JENN

Training and Consultancy

The path to enlightened education

SUBJECT: SUBJECT NAME

GRADE 12

2026 WINTER CLASSES

TEACHER AND LEARNER CONTENT MANUAL

Topic(s)

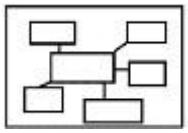
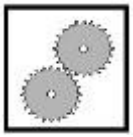
1. Rates of Reaction
2. Chemical Equilibrium
3. Electrochemistry
4. Optical Phenomenon

PHYSICAL SCIENCES PROGRAMME FOR 2025 WINTER CLASSES

PAPER	TOPICS	TOTAL HOURS	END DATE
WEEK 1	PRE- TEST (RATES OF REACTION AND CHEMICAL EQUILIBRIUM)	1HOUR	27/06/2026
CHEMISTRY PAPER 2	RATES OF REACTION	4HOUR	29/06/2026
	CHEMICAL EQUILIBRIUM	5HOURS	01/07/2026
WEEK 2	POST TEST (RATES OF REACTION AND CHEMICAL EQUILIBRIUM)	1HOUR	02/07/2026
CHEMISTRY AND PHYSICS	ELECTROCHEMISTRY	5 HOURS	04/07/2026
	ELECTROCHEMISTRY	4 HOURS	06/07/2026
TOTAL		20 HOURS	

CONTENTS **PAGE**

ICON DESCRIPTION

 MIND MAP	 EXAMINATION GUIDELINE	 CONTENTS	 ACTIVITIES
 BIBLIOGRAPHY	 TERMINOLOGY	 WORKED EXAMPLES	 STEPS

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Topic(s)

RATES OF REACTION

EXAMINATION GUIDELINE

Rate and Extent of Reaction
(This section must be read in conjunction with the CAPS, p. 123–124.)

Rates of reaction and factors affecting rate

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

Rate = $\frac{\Delta C}{\Delta t}$ (Unit: mol·dm^{-3}·s^{-1})

Calculate reaction rate from given data for products:

Rate = $\frac{\Delta C}{\Delta t}$ (Unit: mol·dm^{-3}·s^{-1})

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

- List the factors that affect the rate of chemical reactions, i.e. nature of reacting substances, surface area, concentration (pressure for gases), temperature and the presence of a catalyst.
- Explain in terms of the collision theory how the various factors affect the rate of chemical reactions. The collision theory is a model that explains reaction rate as the result of particles colliding with a certain minimum energy to form products.

Measuring rates of reaction

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

Mechanism of reaction and of catalysis

- Define the term catalyst as a substance that increases the rate of a chemical reaction without itself undergoing a permanent change.
- Explain that a catalyst increases the rate of a reaction by providing an alternative path of lower activation energy. It therefore decreases the net activation energy.
- Interpret Maxwell-Boltzmann curves (number of particles against kinetic energy) to explain the effect of a catalyst, temperature and concentration on reaction rate.

IMPORTANT TERMS AND DEFINITIONS

TERMS AND DEFINITIONS	
Mole	One mole of a substance is the amount of substance having the same number of particles as there are atoms in 12 g carbon-12.
Molar gas volume at STP	The volume of one mole of a gas. (1 mole of any gas occupies 22,4 dm^3 at 0 °C (273 K) and 1 atmosphere (101,3 kPa).
Molar mass	The mass of one mole of a substance. Symbol: M Unit: $g \cdot mol^{-1}$
Avogadro's Law	Under the same conditions of temperature and pressure, the same number of moles of all gases occupy the same volume.
Concentration	The amount of solute per litre/cubic decimeter of solution. n In symbols: $c=\frac{n}{V}$ Unit: $mol \cdot dm^{-3}$ V
Empirical formula	The simplest positive integer ratio of atoms present in a compound.
Percentage yield	Yield is the amount of product obtained from a reaction. percentage yield = $\frac{actual\ mass}{theoretical\ mass}$ × 100
Percentage purity	percentage purity = $\frac{mass\ of\ pure}{mass\ of\ impure} \times 100$
Percentage composition	The percentage of each of the components in a substance. Percentage of component = $\frac{mass\ of\ component}{mass\ of\ all\ components} \times 100$
Limiting reagents	The substance that is totally consumed when the chemical reaction is complete.
Heat of reaction (ΔH)	The energy absorbed or released in a chemical reaction.
Exothermic reactions	Reactions that release energy. (ΔH < 0)
Endothermic reactions	Reactions that absorb energy. (ΔH > 0)
Activation energy	The minimum energy needed for a reaction to take place.
Activated complex	The unstable transition state from reactants to products.
Reaction rate	The change in concentration per unit time
Collision theory	A model that explains reaction rate as the results of particles colliding with minimum energy
Catalyst	A substance that increases the rate of a chemical reaction without itself undergoing a permanent change. (A catalyst increases the rate of a reaction by providing an alternative path of lower activation energy. It therefore decreases the net/total activation energy.)
Factors that affect reaction rate	Nature of reacting substances, surface area, concentration (pressure for gases), temperature and the presence of a catalyst.

Notes

REACTION RATE AND ENERGY IN CHEMICAL REACTIONS

ENERGY IN CHEMICAL REACTIONS

HEAT OF REACTION (ΔH):

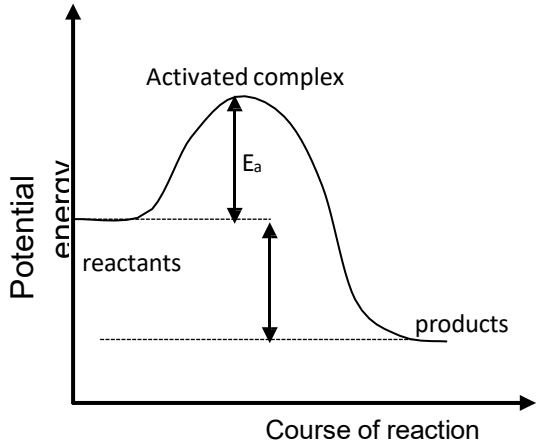
The energy absorbed or released in a chemical reaction.

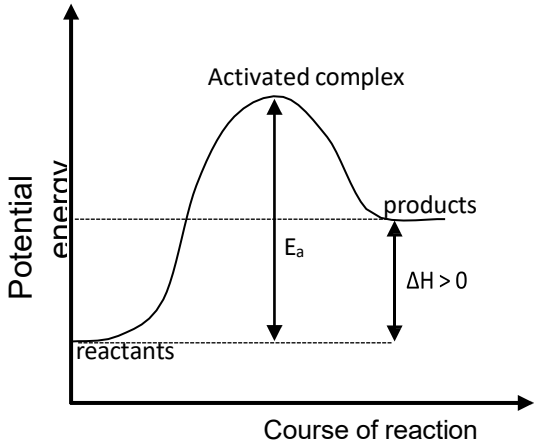
EXOTHERMIC REACTIONS

Reactions that release energy.

ENDOTHERMIC REACTIONS

Reactions that absorb energy.



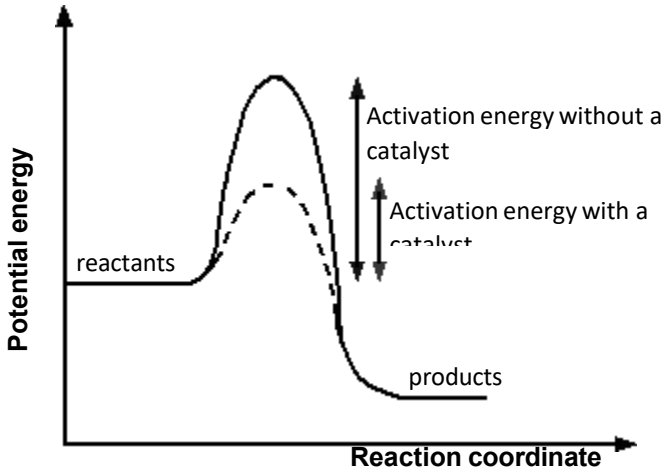


Activation energy

The minimum energy needed for a reaction to take place.

Activated complex

EFFECT OF A CATALYST



Catalyst

Increases reaction rate witout undergoing a permanent change.

Mechanism of catalyst: Increase reaction rate by lowering the total

REACTION RATE

Change in concentration of reactants or products per unit

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**

Calculating rate of reaction

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

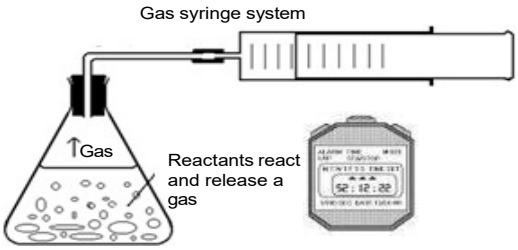
Unit of reaction rate: Any unit of the above quantities per second

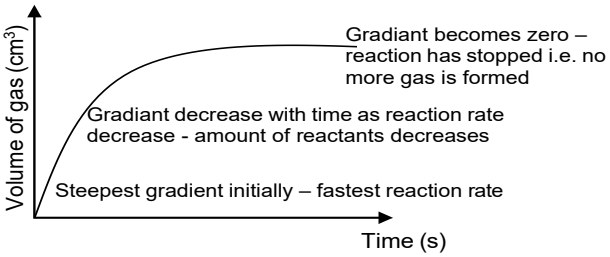
Examples: $mol \cdot dm^{-3} \cdot s^{-1}$ OR $g \cdot s^{-1}$ OR $dm^{-3} \cdot s^{-1}$ OR $mol \cdot s^{-1}$

PRACTICAL SKILLS

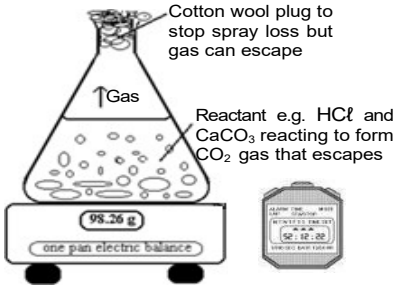
Independent variable	The variable that is changed/manipulated during an investigation e.g. an increase in temperature. (It is the input.)
Dependent variable	The variable that changes due to a change in the independent variable e.g., reaction rate changes due to a change in temperature. (It is the output.)
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.

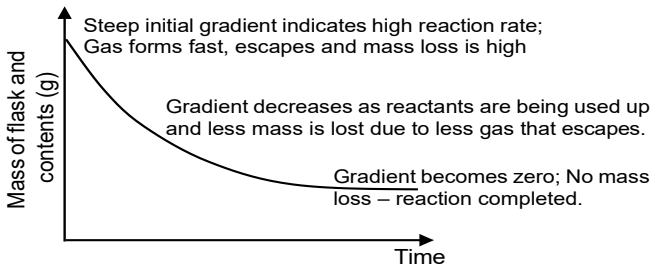
MEASURING VOLUME OF GAS RELEASED PER TIME





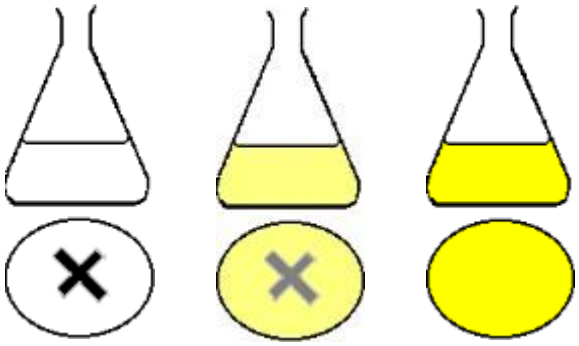
MEASURING LOSS IN MASS OF REACTANTS PER TIME





MEASURING THE TIME FOR THE FORMATION ON AN AMOUNT OF PRECIPITATE

- When sodium thiosulphate ($Na_2S_2O_3$) 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 $Na_2S_2O_3$ and HCℓ), to measure the effect of temperature on rate
  - **Different concentrations** of $Na_2S_2O_3$ at the same temperature to measure the effect of concentration on reaction rate.



Initial — Cross partially visible

Ongoing — Cross invisible

Watch stopped.

THE COLLISION THEORY

The collision theory explains the factors influencing reaction rate.

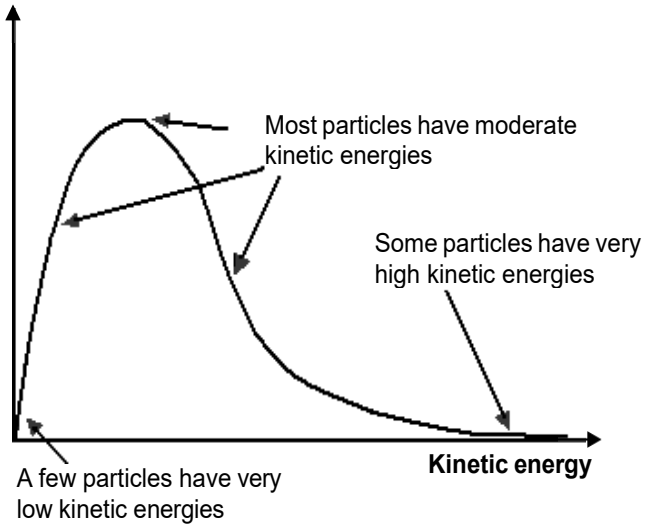
The collision theory states that for a chemical reaction to occur, the reacting particles must collide with one another. The rate of the reaction depends on the frequency of collisions i.e. the number of collisions per unit time. The theory also tells us that reacting particles often collide without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

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

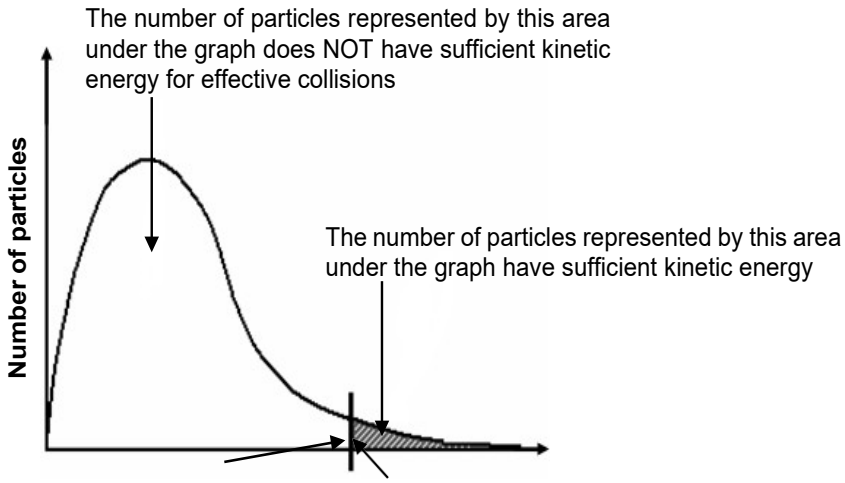
- **Collide with sufficient kinetic energy**
- **Have the correct orientation**

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 **area under the graph** is a measure of the total number of particles, e.g. molecules, present. The **magnitude of the activation energy** is indicated on the Maxwell-Boltzmann distribution curve **as a line at the specific kinetic energy**. Only a few numbers of particles have sufficient kinetic energy i.e. kinetic energy equal to or greater than the activation energy. Most of the particles have insufficient kinetic energy.

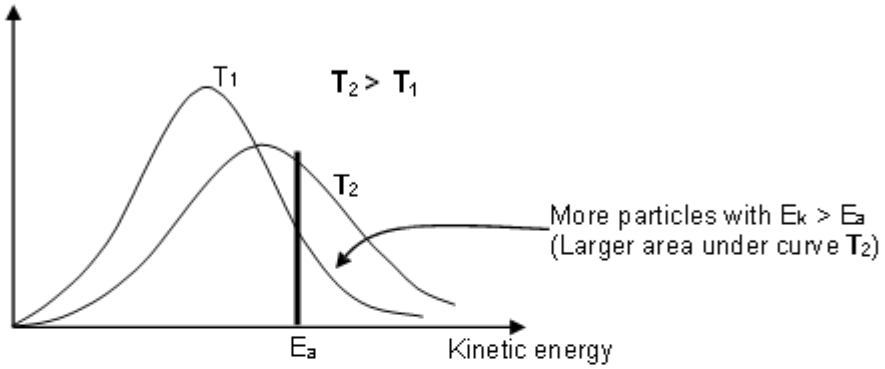


EXPLANATIONS IN TERMS OF THE COLLISION THEORY

EFFECT OF INCREASE IN TEMPERATURE ON REACTION RATE

- **At a higher temperature, the average KINETIC ENERGY of particles INCREASES.**
- More particles have sufficient /enough kinetic energy.
- More effective collisions take place per unit time.
- Reaction rate increases.

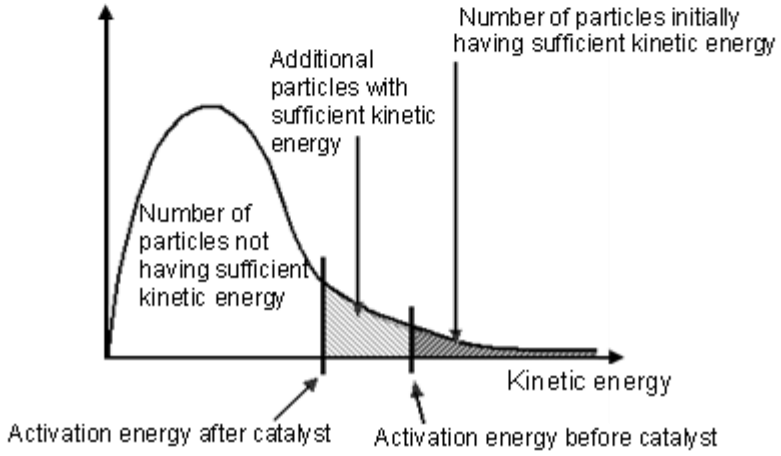
Maxwell-Boltzmann distribution curve/Energy distribution curve



EFFECT OF A CATALYST ON REACTION RATE

- **The catalyst provides a path of LOWER ACTIVATION ENERGY.**
- More particles have sufficient kinetic energy.
- More effective collisions take place per unit time.
- Reaction rate increases.

Maxwell- Boltzmann distribution curve/Energy distribution curve

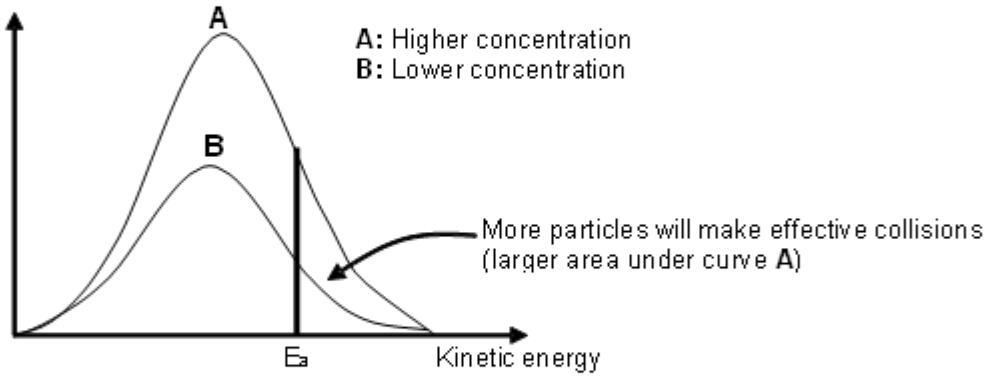


EPLANATIONS IN TERMS OF THE COLLISION THEORY

EFFECT OF INCREASE IN CONCENTRATION ON REACTION RATE

- **At a higher concentration, there are more particles s per unit volume.**
- More particles will have correct orientation./More collisions per unit time.
- More effective collisions take place per unit time.
- Reaction rate increases.

Maxwell-Boltzmann distribution curve/Energy distribution curve



EFFECT OF INCREASE IN SURFACE AREA ON REACTION RATE

- **With a greater surface area/state of division, more particles are exposed per unit volume.**
- More particles will have correct orientation./More collisions per unit time.
- More effective collisions per (unit) time.
- Reaction rate increases.

Maxwell-Boltzmann distribution curve/Energy distribution curve

MULTIPLE CHOICE QUESTIONS

Question 1

A reaction between magnesium and hydrochloric acid was conducted under different conditions:

Experiment	Temperature (°C)	Concentration (mol·dm^{-3})	Surface Area
A	25	1.0	Ribbon
B	35	1.0	Powder
C	25	2.0	Ribbon
D	35	2.0	Powder

Which experiment will have the **fastest reaction rate**?

A. A
B. B
C. C
D. D

Question 2

Consider the reaction:
$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

Experiment	[NO] (mol·dm^{-3})	[O_2] (mol·dm^{-3})	Initial Rate (mol·dm^{-3}·s^{-1})
1	0.1	0.1	0.02
2	0.2	0.1	0.08
3	0.1	0.2	0.02

What is the **order with respect to NO**?

A. 0
B. 1
C. 2
D. 3

Question 3

A catalyst is added to a reaction system. Which statement is **correct**?

A. It increases the activation energy
B. It changes the equilibrium position
C. It provides an alternative reaction pathway
D. It increases the concentration of reactants

Question 4

For a certain reaction:

Time (s)	Concentration of A (mol·dm^{-3})
0	1.00
20	0.75
40	0.50
60	0.25

What is the **average rate of reaction between 20 s and 40 s**?

A. 0.0125 mol·dm^{-3}·s^{-1}
B. 0.025 mol·dm^{-3}·s^{-1}
C. 0.050 mol·dm^{-3}·s^{-1}
D. 0.010 mol·dm^{-3}·s^{-1}

Question 5

The decomposition of hydrogen peroxide is investigated:

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

Experiment	Catalyst Present	Volume of O_2 after 60 s (cm^3)
1	No	20
2	Yes	45

What conclusion can be drawn?

A. Catalyst increases yield
B. Catalyst increases rate of reaction
C. Catalyst is consumed
D. Catalyst shifts equilibrium

.

WORKED EXAMPLES

EXAMPLE 1 (March 2016)

Methanol and hydrochloric acid react according to the following balanced equation:
$CH_3OH(aq) + HCl(aq) \rightarrow CH_3Cl(aq) + H_2O(\ell)$

1.1 State TWO factors that can INCREASE the rate of this reaction. (2)
Answer: Increase temperature. ✓ Increase concentration of acid. ✓ Add a catalyst.

1.2 Define the term reaction rate. (2)
Answer: Change in concentration of products/reactants ✓ per unit time. ✓

1.3 The rate of the reaction between methanol and hydrochloric acid is investigated. The concentration of HCl(aq) was measured at different time intervals. The following results were obtained:

TIME (MINUTES) | HCl CONCENTRATION (mol·dm^{-3})

TIME (MINUTES)	HCℓ CONCENTRATION (mol·dm^{-3})
0	1,90
15	1,45
55	1,10

100	0,85
215	0,60

1.3.1 Calculate the average reaction rate, in $(mol \cdot dm^{-3}) \cdot min^{-1}$ during the first 15 minutes. (3)

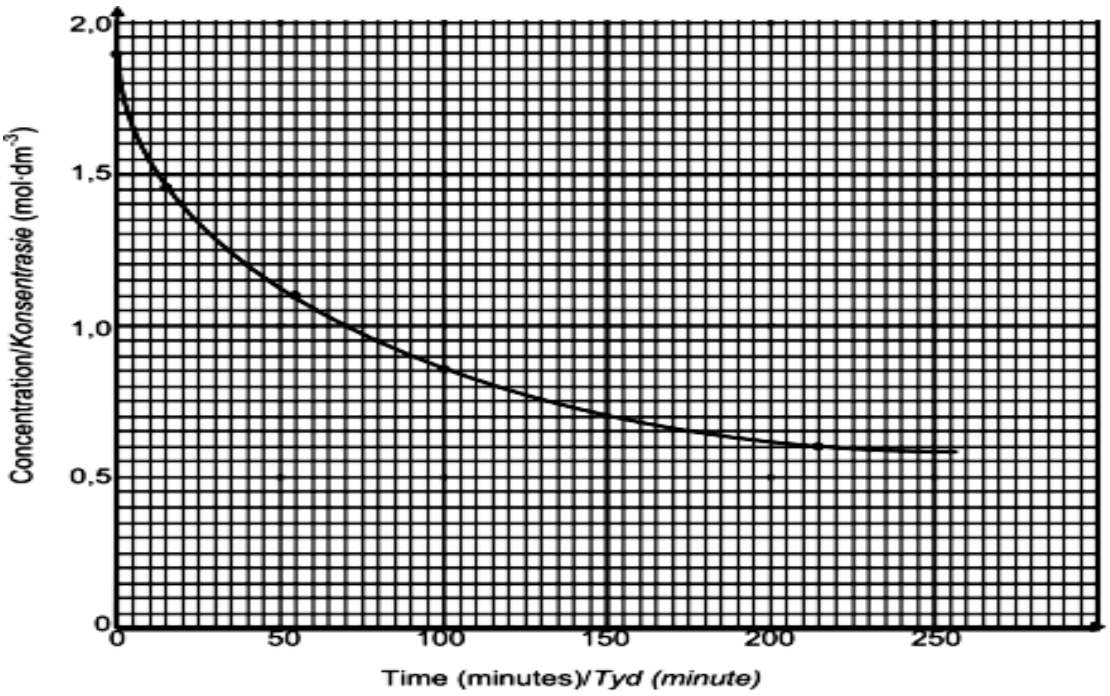
$\Delta c = c(final) - c(initial)$

Answer:
Average rate $= - \Delta c / \Delta t$

$= - (1,45 - 1,90)$ ✓ / $(15 - 0)$ ✓
$= 0,03 (mol \cdot dm^{-3}) \cdot min^{-1}$ ✓

1.3.2 Use the data in the table to draw a graph of concentration versus time on graph paper.
NOTE: The graph is not a straight line. (3)

Answer:



Marking criteria/*Nasienriglyne*	
Four points correctly plotted./*Vier punte korrek gestip.*	✓✓
Curve drawn as shown./*Kurwe getrek soos getoon.*	✓

1.3.3 From the graph, determine the concentration of HCl(aq) at the 40th minute. (1)
Answer: 1,15 to 1,25 $mol \cdot dm^{-3}$ ✓

1.3.4 Use the collision theory to explain why the reaction rate decreases with time. Assume that the temperature remains constant. (3)
Answer:

Concentration of reactants decreases. ✓
Less particles per unit volume. ✓
Less effective collisions per unit time. ✓

1.3.5 Calculate the mass of $CH_3Cl(aq)$ in the flask at the 215th minute. The volume of the reagents remains 60 cm^3 during the reaction. (5)

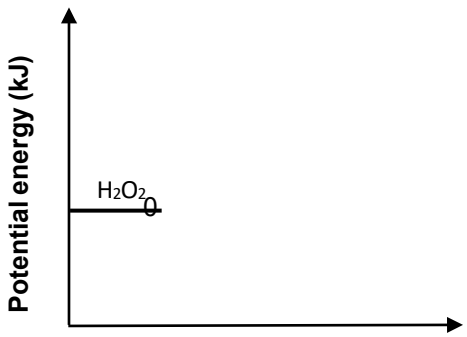
Answer:

OPTION 1/*OPSIE 1*	**OPTION 2/*OPSIE 2***
Mol initially/*begin*: $n(HCl)$ = cV ✓ = (1,9)(60 x 10^{-3}) ✓ = 0,11 mol (0,114) Mol final/*finaal*: $n(HCl)$ = cV = (0,6)(60 x 10^{-3}) = 0,04 mol (0,036) $\Delta n(HCl)$ = 0,04 – 0,011 ✓ = - 0,07 mol (0,078 mol) $\Delta n(HCl)$ = 0,07 mol (0,078) n(formed/*gevorm*) =n(reacted/*reageer*) $n(CH_3Cl)$ = $n(HCl)$ ✓ = 0,07 mol $m(CH_3Cl)$ = nM = (0,07)(50,5) ✓ = 3,54 g ✓ Accept range/*Aanvaar gebied*: 3,54 – 4,0 g	$\Delta c(HCl)$ = 0,6 – 1,9 ✓ = -1,3 = 1,3 mol·dm^{-3} $\Delta n(HCl)$ = ΔcV = (1,3)(60 x 10^{-3}) ✓ = 0,08 mol (0,078) n(formed/*gevorm*) = n(reacted/*reageer*) $n(CH_3Cl)$ = $n(HCl)$ ✓ = 0,08 mol $m(CH_3Cl)$ = nM = (0,08)(50,5) ✓ = 4 g ✓ Accept range/*Aanvaar gebied:* 3,54 – 4,0 g

[19]

EXAMPLE 2 (November 2016)

Hydrogen peroxide, H_2O_2, decomposes to produce water and oxygen according to the following balanced equation:
$2H_2O_2(\ell) \rightarrow 2H_2O(\ell) + O_2(g)$



Course of reaction

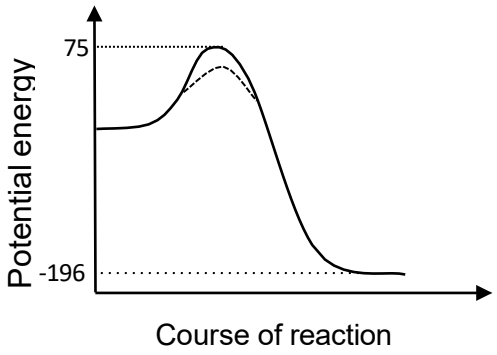
2.1 The activation energy (EA) for this reaction is 75 kJ and the heat of reaction (ΔH) is −196 kJ.

2.1.1 Define the term activation energy. (2)
Answer: The minimum energy needed for a reaction to take place. ✓✓

2.1.2 Redraw the set of axes and complete the potential energy diagram. (3)

Answer:
Marking criteria:
Shape of curve for exothermic reaction. ✓
Energy of activated complex = 75 kJ. ✓
Energy of products = −196 kJ. ✓

Answer:

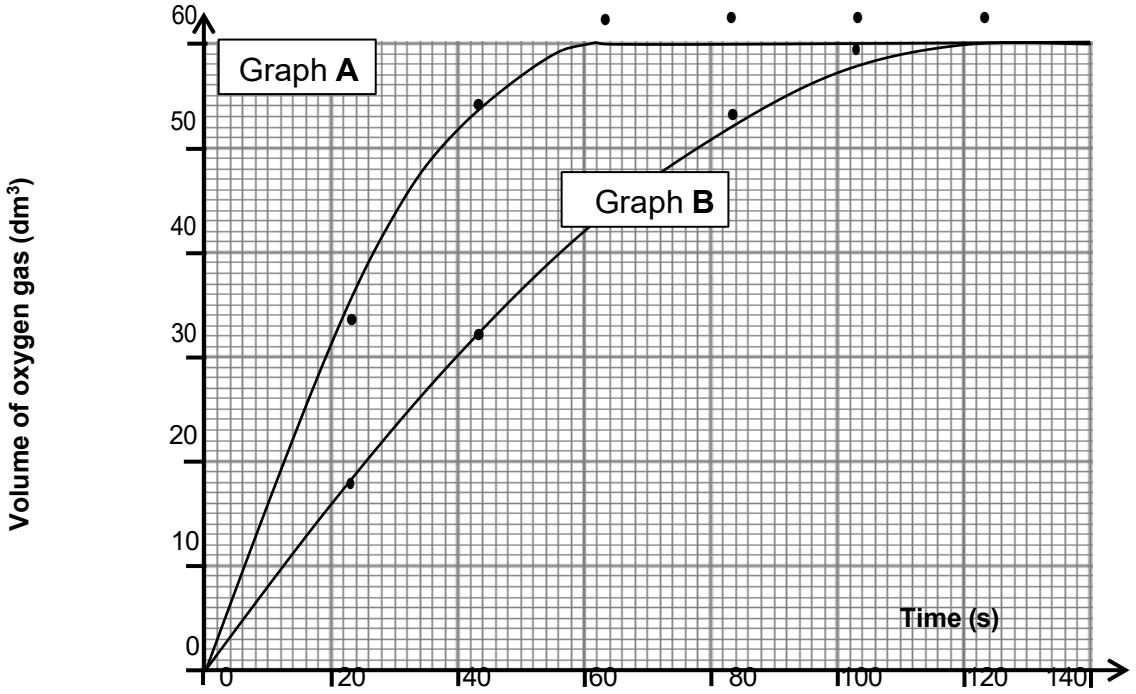


Marking criteria	
Shape of curve for exothermic reaction as shown.	✓
Energy of activated complex shown as 75 kJ in line with the peak.	✓
Energy of products shown as − 196 kJ below the zero.	✓
IF: Wrong shape, e.g. straight line.	0/3

2.1.3 Show effect of manganese dioxide using dotted lines. (2)
Answer:
Dotted curve showing lower activation energy. ✓
Curve starts and ends correctly relative to original. ✓

2.1.4 Use collision theory to explain catalyst effect. (3)
Answer:
Alternative pathway of lower activation energy. ✓
More molecules have sufficient energy. ✓
More effective collisions per unit time. ✓

2.2 Graphs A and B show volume of oxygen vs time.



2.2.1 Calculate average rate between t = 10 s and t = 40 s. (3)

Answer:
Average rate = $\Delta V / \Delta t$

= (52 − 16) ✓ / (40 − 10) ✓
= 1,2 $dm^3 \cdot s^{-1}$ ✓

2.2.2 Calculate mass of hydrogen peroxide used. (4)

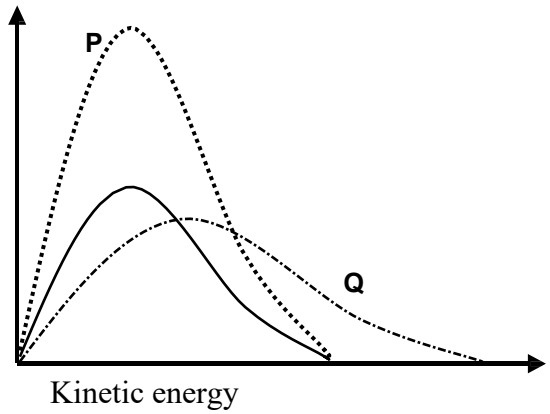
Answer:
$n(O_2) = V / Vm = 60 / 24$ ✓ = 2,5 mol

$n(H_2O_2) = 2n(O_2) = 5$ mol ✓

$m = nM = 5 \times 34$ ✓ = 170 g ✓

2.2.3 Compare mass used for graph B. (1)
Answer: Equal to ✓

h2.3 Energy distribution curves:

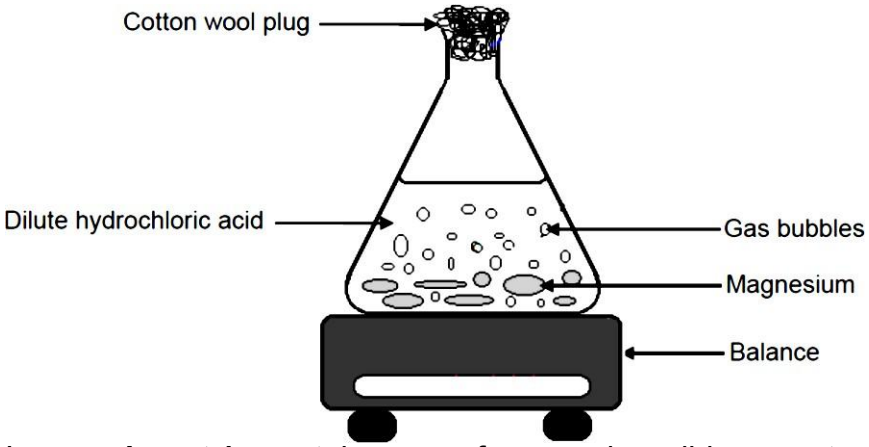


2.3.1 120 °C → Answer: Q ✓ (1)
2.3.2 2 mol at 90 °C → Answer: P ✓ (1)

[20]

EXAMPLE 3 (June 2018)

Reaction:
$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$



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

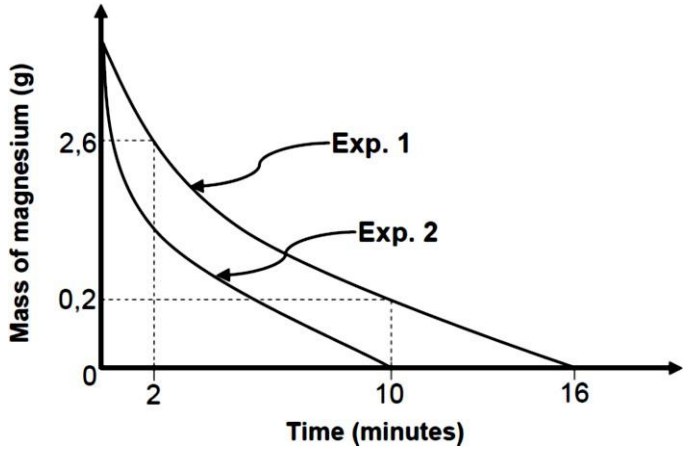
3.1 Define reaction rate. (2)
Answer: Change in concentration of products/reactants per unit time. ✓✓

3.2 Variables:

3.2.1 Independent variable (1)
Answer: Surface area/state of division ✓

3.2.2 Controlled variable (1)
Answer: Mass of magnesium ✓ OR concentration of acid OR temperature

3.3 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).



Calculate :

3.3.1 Volume of hydrogen gas produced (5)

Answer:
$\Delta m(Mg) = 2,6 - 0,2$ ✓ $= 2,4$ g

$n(Mg) = m/M = 2,4 / 24$ ✓ $= 0,1$ mol

$n(H_2) = 0,1$ mol ✓

$V(H_2) = nVm = (0,1)(25)$ ✓ $= 2,5$ dm³ ✓

3.3.2 Initial mass of magnesium (5)

Answer:
Average rate = $\Delta n / \Delta t$

$2,08 \times 10^{-4}$ ✓ $= \Delta n / (10 \times 60)$ ✓

$\Delta n = 0,125$ mol

m = nM = 0,125 × 24 ✓ = 3 g ✓

3.4 Collision theory explanation (3)
Answer:
Larger surface area. ✓
More particles exposed. ✓
More effective collisions per unit time. ✓

[17]

Activities

ACTIVITY 1

The reaction of magnesium carbonate tablets with hydrochloric acid was used to investigate the effect of different factors on the rates of reactions. In each experiment the mass of the tablets was the same and equal volumes of acid were used.

1.1. Write a balanced chemical equation for the reaction between magnesium carbonate and hydrochloric acid. (3)

1.2. Describe an appropriate experimental method to measure the rate of this reaction. Include the appropriate measuring equipment and all quantities that should be measured to determine the rate.
(3)

The results of five experiments are tabulated below.

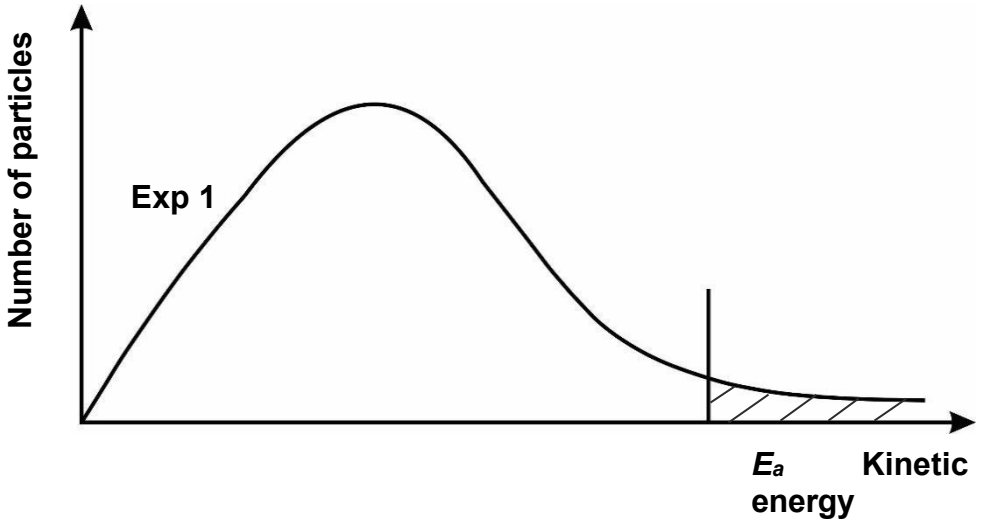
Experiment	Concentration of acid ($mol \cdot dm^{-3}$)	Initial temperature (°C)	Time for reaction to end (s)	
			Whole tablet	Crushed tablet
1	1,0	23	46	
2	1,0	23		40
3	1,5	23	39	
4	2,0	30	31	
5	2,0	26	35	

1.3. Can the results of Experiments **2** and **4** be meaningfully compared? Answer YES or NO. Give a reason. (2)

1.4. What conclusion can be reached when Experiment **4** is compared to Experiment **5**? (2)

1.5 Compare Experiment **1** with Experiment **2**. Explain the results with reference to the collision theory.
(4

2.1 The graph below shows the Maxwell–Boltzmann distribution curve for the reaction mixture in Experiment **1**. The activation energy for the reaction, E_a, is marked.



2.1.1 Define *activation energy*. (2)

2.1.2 What does the shaded area on the graph indicate? (2)

2.1.3 **On the graph above**, draw a new distribution curve for the reaction mixture in Experiment **3**. Label this curve as **Exp3** (2)

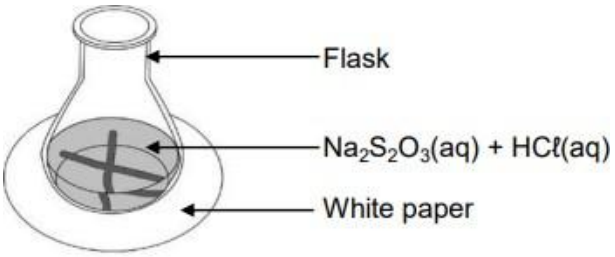
[20]

ACTIVITY 2

The reaction between EXCESS dilute hydrochloric acid and sodium thiosulphate is used to investigate factors that influence reaction rate.

$$Na_2S_2O_3(aq) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + S(s) + H_2O(\ell) + SO_2(g)$$

The concentration of $HC\ell(aq)$ used is 1 mol·dm^{-3}. The same volume of $HC\ell(aq)$ is used in each run. The time taken for the cross on the paper under the flask to become invisible is measured.



RUN	VOLUME $Na_2S_2O_3(aq)$ (cm^3)	VOLUME $H_2O(\ell)$ ADDED (cm^3)	CONCENTRATION $Na_2S_2O_3(aq)$ ($mol \cdot dm^{-3}$)	TIME (s)
1	50	0	0,13	20,4
2	40	10	0,10	26,7
3	30	20	P	33,3

2.1 Define *reaction rate*. (2)
2.2 Write down the independent variable for this investigation. (1)
2.3 Calculate the value of **P** in the table. (3)
2.4 When 0,21 g of sulphur has formed in Run **1**, the cross becomes invisible. Calculate the average reaction rate with respect to sodium thiosulphate, $NaS_2O_3(aq)$, in $g \cdot s^{-1}$. (5)

Another investigation is performed at different temperatures.

2.5 Sketch the Maxwell-Boltzmann distribution curve for the reaction at 20 °C. Label this curve as **A**. On the same set of axes, draw the curve that will be obtained at 35 °C and label it as **B**. (4)
2.6 Explain the effect of temperature on reaction rate in terms of the collision theory. (4)

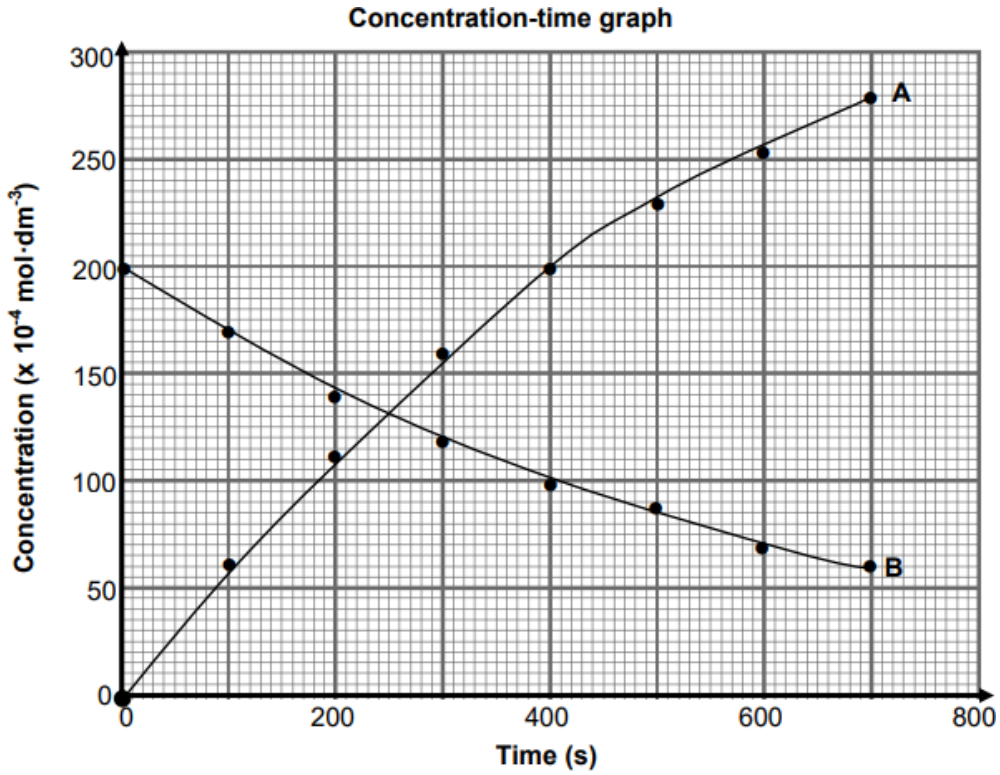
[19]

ACTIVITY 3

Consider the following decomposition reaction that takes place in a sealed 2 dm^3 container:

$2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$

The graph below shows how the concentrations of $N_2O_5(g)$ and $NO_2(g)$ change with time.

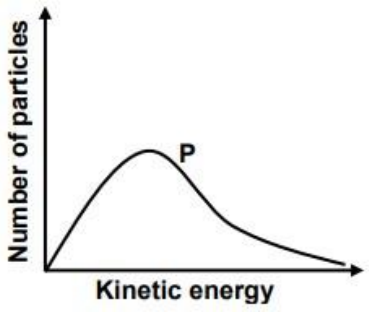


3.4 Refer to the graph above and give a reason why curve A represents the change in the concentration of $NO_2(g)$. (1)

3.5 Consider the statement below:
The rate of decomposition of N2O5(g) is half the rate of formation of NO2(g).
Is this statement TRUE or FALSE? Give a reason for the answer. (2)

3.6 Calculate the:
3.6.1 Mass of NO2(g) present in the container at 400 s (4)
3.6.2 Average rate of production of O2(g) in $mol \cdot dm^{-3} \cdot s^{-1}$ in 700 s (4)

3.7 The Maxwell-Boltzmann distribution curve for the $N_2O_5(g)$ initially present in the container is shown below.



The initial concentration of the N2O5(g) is now INCREASED.

3.7.1 Redraw the distribution curve above in the ANSWER BOOK and label this curve as **P**.
On the same set of axes, sketch the curve that will be obtained for the higher concentration

of $N_2O_5(g)$. Label this curve as **Q**. (2)

3.7.2 Will the rate of decomposition of N2O5(g) at the higher concentration be HIGHER THAN,
LOWER THAN or EQUAL TO the original rate of decomposition? Explain the answer using
the collision theory. (3)

[16]

ACTIVITY 4

Nitrogen monoxide gas may be prepared by adding copper metal to dilute nitric acid. The balanced equation for the redox reaction is given below:

$3Cu(s) + 8HNO_3(aq) \rightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(\ell)$
BLUE

Three different experiments were conducted in which various reaction conditions were changed. The data is tabulated below.

Experiment	**Mass of Cu (g)**	**Volume of HNO_3 (dm^3)**	**[HNO_3] ($mol.dm^{-3}$)**	**State of Cu(s)**
A	2,54	0,10	0,8	Small pellets
B	2,54	0,05	0,8	Large chunks
C	5,08	0,05	1,6	Small pellets

4.1 Using the data from EXPERIMENT A:

4.1.1 Calculate the number of moles of Cu. (3)

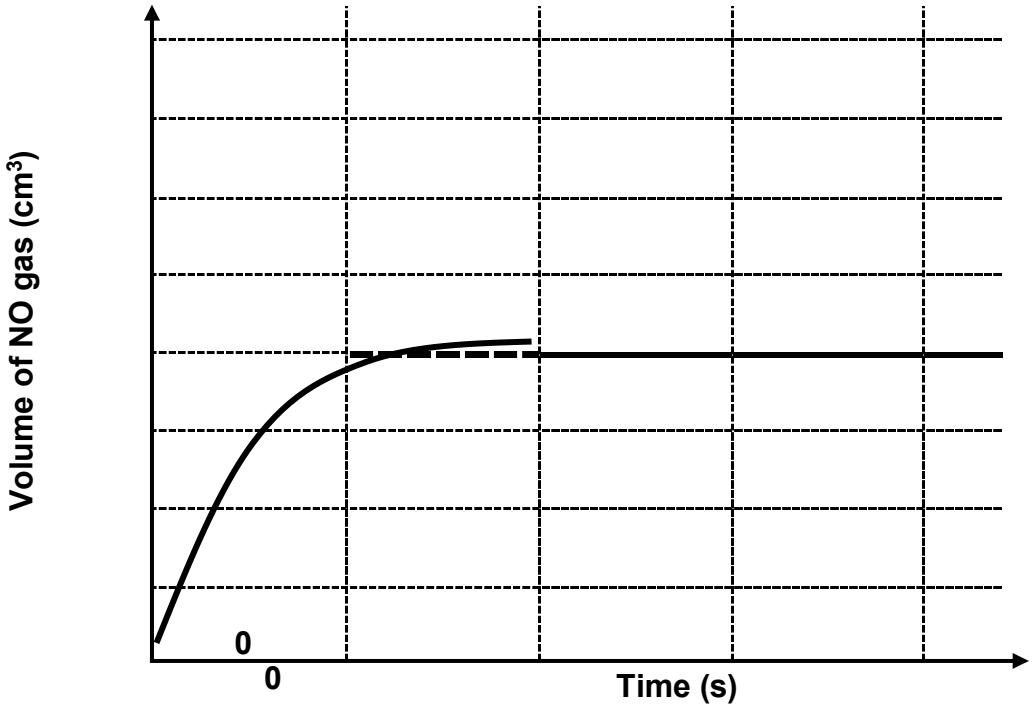
4.1.2 Calculate the number of moles of HNO_3. (3)

4.1.3 Hence, show that copper is in excess. (1)

4.1.4 Assuming that the reaction proceeds to completion, calculate the volume of NO(g) that would be produced at STP. (3)

The NO gas was collected in a gas syringe. The volume of NO gas produced in EXPERIMENT A is plotted against time, as shown in the graph below:

A



4.2 Draw the curves that will be obtained for experiments B and C on the above axes.
LABEL the two new curves clearly. (4)

4.3 Explain how an increase in concentration affects the rate of a reaction in terms of the Collision Theory. (4)

[18]

JENN

Training and Consultancy

The path to enlightened education

SUBJECT: SUBJECT NAME

GRADE 12

2025 WINTER CLASSES

TEACHER AND LEARNER CONTENT MANUAL

Topic(s)

CHEMICAL EQUILIBRIUM

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

Chemical equilibrium and factors affecting equilibrium

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

Equilibrium constant

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

Application of equilibrium principles

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

IMPORTANT TERMS AND DEFINITIONS

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

CHEMICAL EQUILIBRIUM

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

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

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

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

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

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

USEFUL GUIDELINES WHEN APPLYING LE CHATELIER'S PRINCIPLE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ACTIVITY 1 — 10 MARKS 10 MINUTES

MULTIPLE-CHOICE QUESTIONS

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

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

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

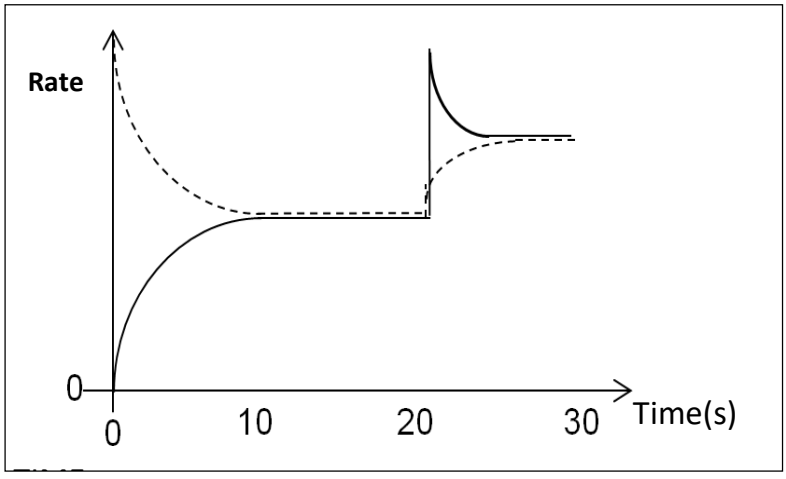
	Yield	Equilibrium constant
A	Increases	Increases
B	Increases	Decreases
C	Decreases	Increases
D	Decreases	Decreases

(2)

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

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

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



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

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

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

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

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

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

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

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

1.5 The following reaction reaches equilibrium in a sealed container:

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

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

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

ACTIVITIES

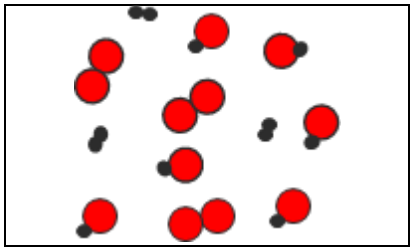
QUESTION 1

The equilibrium reaction between hydrogen gas and iodine gas is investigated at 200 °C. The equation for the reaction is as follows:

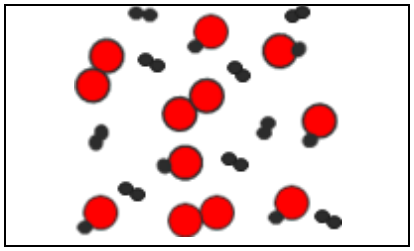
$$H_2(g) + I_2(g) \rightarrow 2HI(g)$$

The number of moles of each substance present in a sealed 2 dm^3 container at various times is represented below. Each molecule represents a mole of that substance.

H ● I ●

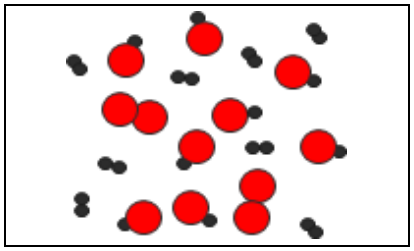


From time t_0 to t_1
At equilibrium:
3 mol H_2
3 mol I_2
6 mol HI



At time t_1

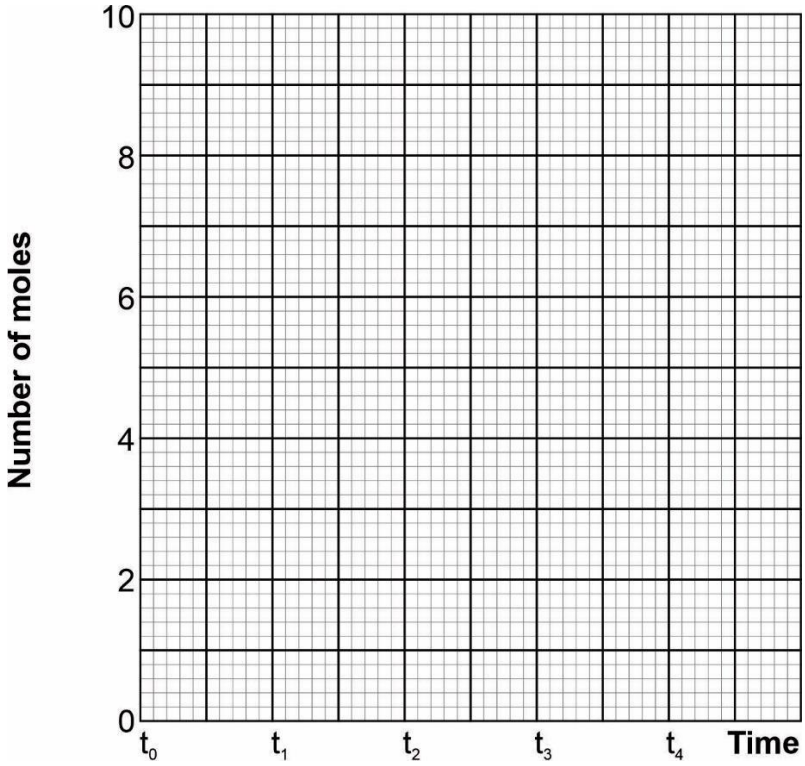
Equilibrium is disturbed.



From time t_2 to t_3
New equilibrium:
8 mol H_2
2 mol I_2
8 mol HI

1. Identify the disturbance that occurred at time t_1. (2)

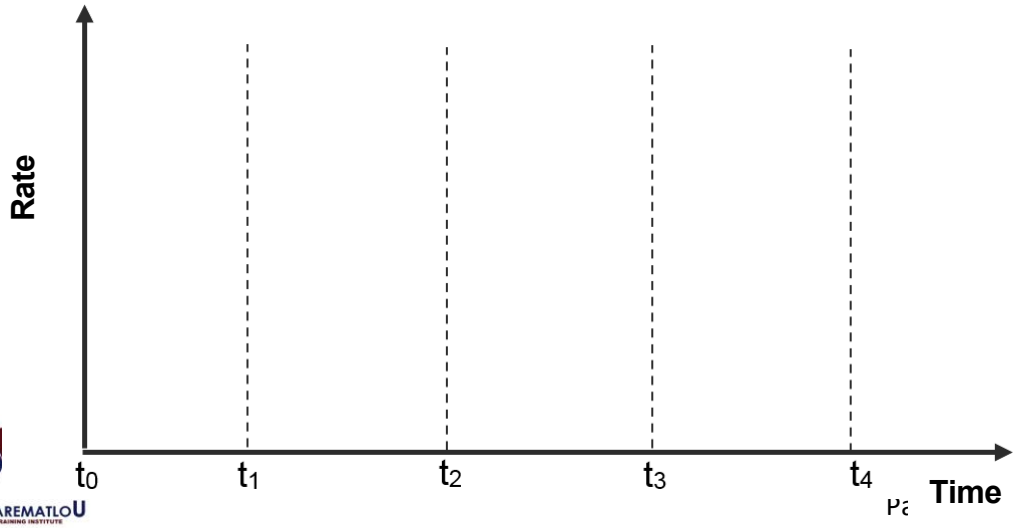
2. Plot the number of moles of H_2, I_2 and HI on the axes below, **from t_0 to t_3 only**. Label each of the three lines clearly. A heading is not required. (6)



3. Explain the change in the number of moles of each substance from time t_1 to time t_2 by applying Le Châtelier's principle. (4)

Calculate K_c before and after the disturbance at t_1 and hence explain why the disturbance could not have been a temperature change. (6)

4. At time t_3, the volume of the container is doubled. Complete the graph **on page 12** (number of moles vs time) from t_3 to t_4 to show any changes that occur as a result of the disturbance at t_3.
(2)
5. On the axes below, sketch the graphs of rate versus time for the forward and reverse reactions, from t_0 to t_4. (5)
   - Use the solid line _____ to represent the forward reaction
   - Use a dashed line - - - - - - - - - - to represent reverse reaction.



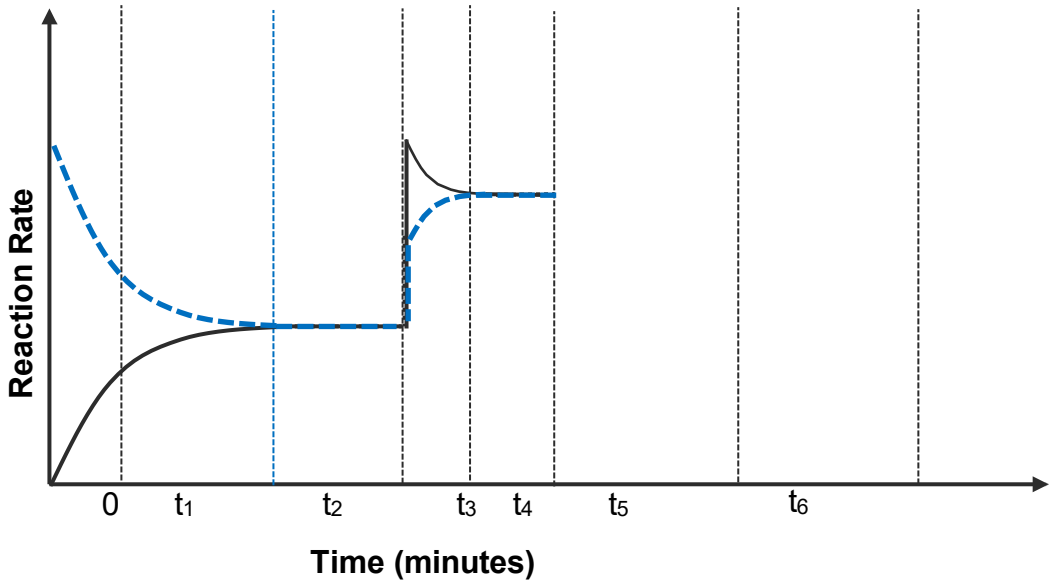
[25]

ACTIVITY 2

Gas AB decomposes according to the following equation:

$$2AB(g) \rightarrow 2A(g) + B_2(g)$$

A certain amount of AB is sealed in a container and allowed to decompose. The graph of the reaction rate vs time is shown below.



2.1 Is the statement below TRUE or FALSE? (2)

'At t_1 the graph indicates that the concentration of AB is greater than the concentrations of A and B_2.'

2.2 What is represented by the dashed line (- - - - - -) one the graph (2)

2.3 Circle the correct word(s) between brackets in the statement below

Between t_2 and t_3, the concentrations of AB, A and B_2 are:

(EQUAL TO EACH OTHER / CONSTANT / CHANGING). (1)

2.4 The **temperature** of the system was **increased** at time t_3.

Is the forward reaction EXOTHERMIC or ENDOTHERMIC?
Explain by applying Le Châtelier's principle. (3)

2.5 At t_5, the volume of the container was increased at constant temperature, resulting in a **decrease** in the **pressure**.

2.5.1 Explain the effect of this change by applying Le Châtelier's principle. (3)

2.5.2 Complete the rate vs time graph on page 10 from t_5 until after equilibrium is re-established at t_6. (3)

2.6 Gas AB was pumped into an evacuated container until the concentration was **X** mol·dm^{-3}. The container was sealed. Once equilibrium was established at 25 °C, the concentration of gas B_2 was 0,025 mol·dm^{-3}.

The reaction equation is re-written below:

$$2AB(g) \rightarrow 2A(g) + B_2(g)$$

2.6.1 Write the equilibrium constant expression, K_c, for the reaction. (2)

The value of K_c for the reaction at 25 °C is 1,56 × 10^{-3}.

2.6.2 Show that the equilibrium concentration of gas AB is 0,2 mol·dm^{-3}. (2)

2.6.3 Hence, calculate **X**, the initial concentration of gas AB in the container. (3)

[21]

ACTIVITY 3

In a 10 dm³ sealed container, 5 mol of $SO_2(g)$ and 2,5 mol of $O_2(g)$ are introduced and heated until equilibrium is established for the reaction:

$$2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$$

At equilibrium, 3 mol of SO_2 remains. The forward reaction is exothermic.

1. Calculate the equilibrium constant Kc for this reaction. (7)

2. The system is at equilibrium when:

- The volume is halved, and
- The temperature is increased.

USING LE CHÂTELIER'S PRINCIPLE and reaction enthalpy, predict and explain:

2.4 The overall direction of the equilibrium shift RIGHT OR LEFT (2)

2.5 Whether the final amount of SO_3 will increase or decrease compared to the original equilibrium. (2)

2.6 Whether the value of K_c will INCREASE, DECREASE OR REMAIN THE SAME

(1)

3 If a catalyst is added after equilibrium is reached, explain its effect on:

- The position of equilibrium
- The time required to reach equilibrium (3)

[15]

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SUBJECT: SUBJECT NAME

GRADE 12

2025 WINTER CLASSES

TEACHER AND LEARNER CONTENT MANUAL

Topic(s)

ELECTROCHEMISTRY

Examination guidelines

Electrochemical Reactions
(This section must be read in conjunction with the CAPS, p. 134–137.)

Galvanic cells

- Define the *galvanic cell* as a cell in which chemical energy is converted to electrical energy.
- Define *oxidation* and *reduction* in terms of electron (e^-) transfer:
- Oxidation is a loss of electrons. Reduction is a gain of electrons.
- Define *oxidation* and *reduction* in terms of oxidation numbers:
  - Oxidation: an increase in oxidation number
  - Reduction: a decrease in oxidation number
- Define an *oxidising agent* and a *reducing agent* in terms of oxidation and reduction:
- Oxidising agent: a substance that is reduced/gains electrons.
- Reducing agent: a substance that is oxidised/loses electrons.
- Define an *anode* and a *cathode* in terms of oxidation and reduction:
- Anode: the electrode where oxidation takes place
- Cathode: the electrode where reduction takes place
- Define an *electrolyte* as a substance of which the aqueous solution contains ions OR a substance that dissolves in water to give a solution that conducts electricity.
- **Relation of current and potential difference to rate and equilibrium**
- State that the potential difference of a galvanic cell (V_{cell}) is related to the extent to which the spontaneous cell reaction has reached equilibrium.
- State and use the qualitative relationship between V_{cell} and the concentration of product ions and reactant ions for the spontaneous reaction, namely V_{cell} decreases as the concentration of product ions increases and the concentration of reactant ions decreases until equilibrium is reached at which the $V_{cell} = 0$ (the cell is 'flat'). (Qualitative only. Nernst equation is NOT required.)
- **Understanding of the processes and redox reactions taking place in galvanic cells** □ Describe the movement of ions in the solutions.
- State the direction of electron flow in the external circuit.
- Write down the half-reactions that occur at the electrodes.
- State the function of the salt bridge.
- Use cell notation or diagrams to represent a galvanic cell.
- When writing cell notation, the following convention should be used:
- The $H_2|H^+$ half-cell is treated just like any other half-cell. o Cell terminals (electrodes) are written on the outside of the cell notation. o Active electrodes:
- reducing agent | oxidised species || oxidising agent | reduced species
- Inert electrodes (usually Pt or C):
- Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt
- Example: Pt | $C\ell^-(aq)$ |$C\ell_2(g)$ || $F_2(g)$ | $F^-(aq)$ | Pt
- Predict the half-cell in which oxidation will take place when two half-cells are connected.

- Predict the half-cell in which reduction will take place when connected to another half-cell.
    - Write down the overall cell reaction by combining two half-reactions.
    - Use the Table of Standard Reduction Potentials to calculate the emf of a standard galvanic cell.
    - Use a positive value of the standard emf as an indication that the reaction is spontaneous under standard conditions.

    - **Standard electrode potentials**
    - Write down the standard conditions under which standard electrode potentials are determined.
    - Describe the standard hydrogen electrode and explain its role as the reference electrode.
    - Explain how standard electrode potentials can be determined using the reference electrode and state the convention regarding positive and negative values.

    - **Electrolytic cells**
    - Define the *electrolytic cell* as a cell in which electrical energy is converted into chemical energy
    - Electrolysis: The chemical process in which electrical energy is converted to chemical energy OR the use of electrical energy to produce a chemical change

    - **Understanding the processes and redox reactions taking place in electrolytic cells** □ Describe the movement of ions in the solution.
    - State the direction of electron flow in the external circuit.
    - Write equations for the half-reactions taking place at the anode and cathode.
    - Write down the overall cell reaction by combining two half-reactions.
    - Describe, using half-reactions and the equation for the overall cell reaction as well as the layout of the particular cell using a schematic diagram, the following electrolytic processes: o The decomposition of copper(II) chloride
    - Electroplating, e.g. the electroplating of an iron spoon with silver/nickel o Refining of metals, e.g. copper
    - The electrolysis of a concentrated solution of sodium chloride

GALVANIC CELLS

TERMS AND DEFINITIONS	
Galvanic cell	A cell in which chemical energy is converted into electrical energy. A galvanic (voltaic) cell has self-sustaining electrode reactions.
Anode	The electrode where oxidation takes place.
Cathode	The electrode where reduction takes place.
Electrolyte	A solution that conducts electricity through the movement of ions.
Salt bridge	The connection between two half-cells needed to ensure electrical neutrality in the cell. OR: A component used in a galvanic cell to complete the circuit.
Electrodes	An electrical conductor used in a galvanic cell to make contact with a non-metallic part of the circuit e.g. the electrolyte.
Cell notation	A short way to represent a galvanic cell. When writing cell notation, the following convention should be used: ○ The $H_2\|H^+$ half-cell is treated just like any other half-cell. ○ Cell terminals (electrodes) are written on the outside of the cell notation. ○ Active electrodes: reducing agent | oxidised species || oxidising agent | reduced species ○ Inert electrodes (usually Pt or C): Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt Example: Pt | $C\ell^-(aq)$ |$C\ell_2(g)$ || $F_2(g)$ | $F^-(aq)$ | Pt
Overall cell reaction	The reaction obtained by combining two half-reactions.
Positive value of the standard emf	The reaction is spontaneous under standard conditions.
Standard conditions for a galvanic cell	Temperature: 25 °C / 298 K Concentration: 1 $mol \cdot dm^{-3}$ Pressure (gases only): 101,3 kPa / 1 atmosphere
Standard hydrogen electrode	The reference electrode used to compile the Table of Standard Reduction Potentials. The hydrogen half-cell was given a standard reduction potential of 0 V. Half-cell notation: Pt | $H_2(g)$ | $H^+(aq)$ Half-reaction: $2H^+ + 2e^- \rightleftharpoons H_2$
Galvanic Cell	A cell in which chemical energy is converted to electrical energy.
Oxidation and reduction	Oxidation is a loss of electrons. Reduction is a gain of electrons.
Oxidation and Reduction in terms of oxidation numbers	Oxidation: an increase in oxidation number Reduction: a decrease in oxidation number
Oxidising agent and Reducing agent	• Oxidising agent: a substance that is reduced/gains electrons. • Reducing agent: a substance that is oxidised/loses electrons.

CONTENT

Electrochemical cells can be divided into two basic groups:

•Electrolytic cells, in which electrical energy is transformed into chemical energy; a constant supply of electrical energy is needed.

•Galvanic cells, in which chemical energy is transformed into electrical energy; spontaneous chemical reactions drive the cell.

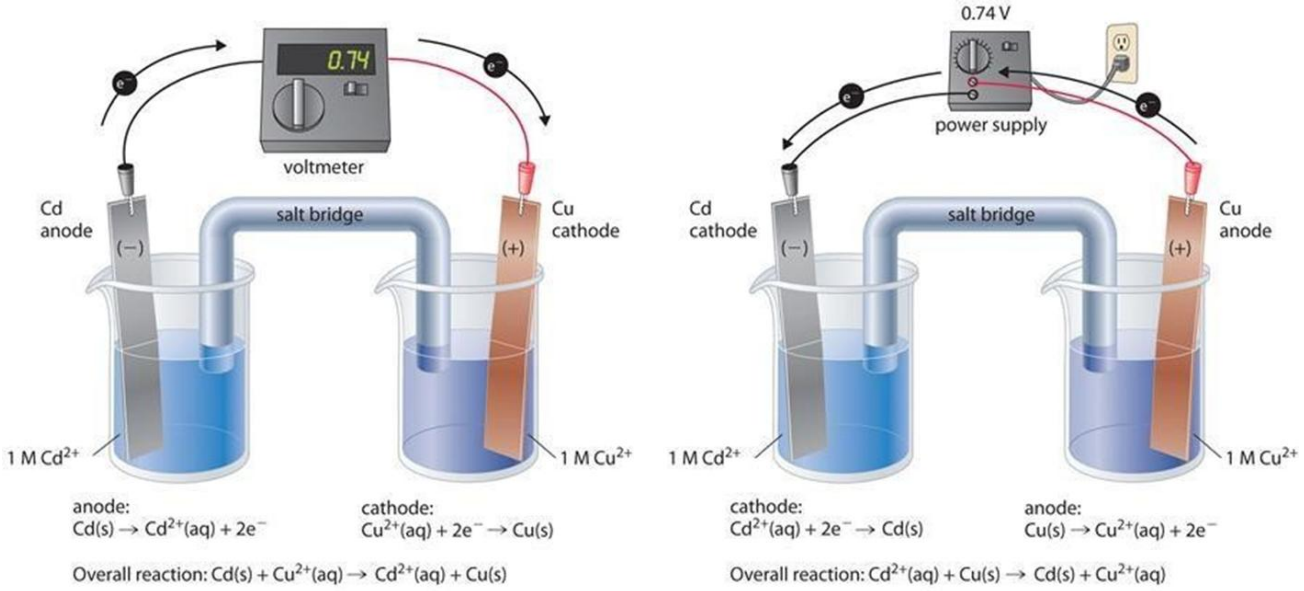
COMPARISON OF GALVANIC AND ELECTROLYTIC CELLS

	Galvanic cell	Electrolytic cell
Basic Principle	A chemical reaction causes charges/electrons to flow	A flowing charge/electron causes a chemical reaction to occur
Energy Conversion	Chemical energy converted to electrical energy	Electrical energy converted to chemical energy
Polarity of electrodes	•**Anode** is negative (-) •**Cathode** is positive (+)	•**Anode** is positive(+) •**Cathode** is negative(-)

	Galvanic cell	Electrolytic cell
Appearance	•No external source of electricity i.e. no battery or cell in circuit •Consists of two half-cells containing different electrodes, each of which is in a solution of its salt. •There must either be a salt bridge or some sort of porous membrane separating the two half-cells to allow for the passage of ions between cells.	•Must have a cell or battery in the external circuit to supply electrical energy. •Consists of two electrodes, either inert (does not take part in the reaction) or active (takes part in the reaction) in the SAME solution (i.e. electrolyte).

	Galvanic cell	Electrolytic cell
Spontaneous/ Non spontaneous	•A **spontaneous** reaction produces electrical energy	•A **Non-Spontaneous** reaction is produced by electrical energy
E^0_{cell}	• E^0 cell = Positive(+)	• E^0 cell = Negative (-)
Uses	Batteries	•Extraction of Aluminium •Purification of metals •Electroplating •Chloro-alkali process

What **DIFFERENCES** can you spot between the two types of cells?

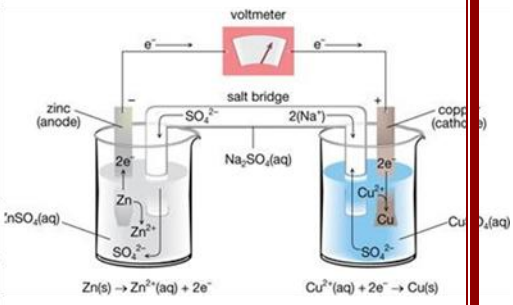


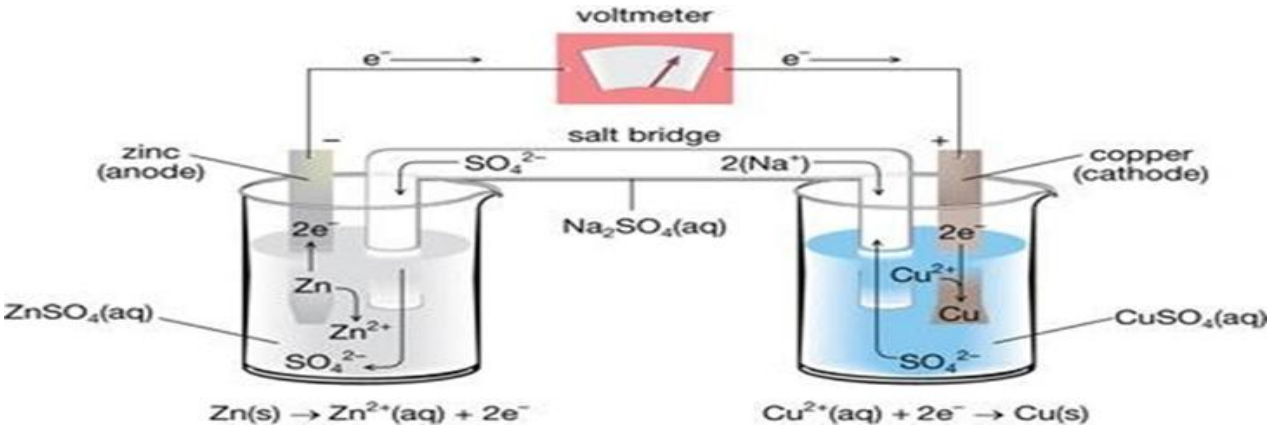
GALVANIC/VOLTAIC CELL

- **It is an electrochemical cell which converts electrical energy into chemical energy.**
- **The reactions in this cell are spontaneous and self-sustained.**
- **The cell is made up of two physically separate half-cells that is the anode half-cell and the cathode half-cell.**
- **Anode -is the electrode where oxidation occurs. It can be inert or reactive.**
- **Cathode is the electrode where reduction occurs.**

- **Each electrolyte is dipped into a corresponding electrolyte e.g Zinc in Zinc sulphate and Copper in Copper(II) sulphate.**
- **When choosing electrolytes, always us a nitrate since all nitrates are soluble.**
- **We are going to analyse galvanic cells operating under standard conditions(not STP) :**
  - **Temperature of 250^{0}C/298K**
  - **Concentration of electrolyte of 1mol.dm^{-3}**
  - **Pressure of 1atm /1,013 x105 pa for gases.**

	ANODE	CATHODE
Identification	- Has a smaller E^θ value.(-076V) -Stronger reducing agent.(Zn)	-Has a larger E^θ value.(+0,34V) -Weaker reducing agent.(Cu)
Type of reaction	Oxidation	Reduction
Half-equation	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$	$Cu^{2+} + 2e^-(aq) \rightarrow Cu(s)$
Observable changes on Electrode	-Mass decreases -It becomes corroded	-mass increases -it becomes thicker
Observable change in electrolyte	-remains colourless	-The intensity of the blue colour decrease. - a reddish brown precipitate is formed

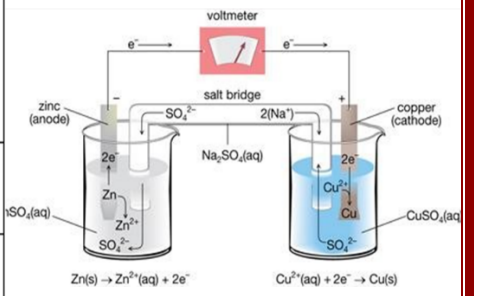




Change in concentration of ions	$[Zn^{2+}]$ increases (product ion)	$[Cu^{2+}]$ decreases. (reactant ion)
Flow of electrons	Generally electrons flow from anode to cathode through the external circuit through the connecting wire(external circuit). In the Zn-Cu cell electrons flow from Zn to Cu	
Accumulation of charge	Positive charge accumulates in the anode(Zn) half-cell due to increase in concentration of cations(Zn^{2+})	Negative charge accumulates in the cathode half-cell due to a decrease in concentration of cations(Cu^{2+})
Flow of ions from salt bridge	Anions migrate from salt bridge to anode half-cell to neutralise the accumulating positive charge.	Anions migrate from salt bridge to cathode half-cell to neutralise the accumulating negative charge.

(The salt bridge completes the circuit and maintains electrical neutrality of electrolytes.)

Net Reaction	$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$
Cell notation	$Zn/Zn^{2+}\ //\ Cu^{2+}/Cu$



4. The emf of the cell/cell potential is calculated as follows :

$$E_{cell} = E^{\theta}_{cathode} - E^{\theta}_{anode}$$
$$= 0,34 - (-076)$$
$$= 1.10V$$

Relation of current and Potential Difference to rate and equilibrium

• The redox reactions in the galvanic cells are REVERSIBLE. However, they have very large Kc values, hence they are usually represented as IRREVERSIBLE
• The galvanic cell has the capacity to deliver current until the reaction
reaches chemical equilibrium or has run to completion.

• According to Le Châtelier's principle, all the factors that favour THE FORWARD reaction INCREASE the voltage of the galvanic cell e.g. Increasing the concentration of the reactants or decreasing the concentration of the products INCREASES voltage

• According to Le Châtelier's principle, all the factors that favour the REVERSE reaction DECREASE the voltage of the galvanic cell e.g. Increasing the concentration of the PRODUCTS or decreasing the concentration of the REACTANTS DECREASES voltage

Consider the net reaction for the Zn-Cu cell

$Zn + Cu^{2+} \leftrightharpoons Zn^{2+} + Cu(s)$

According to Le Chartelier's principle and increase in [Cu^{2+}] favours the forward reaction which is spontaneous thus increasing emf.

• Internal resistance is opposition to the flow of charge through the electrodes and electrolytes in a cell

• Increased surface area of the electrodes increases the rate of the reaction by lowering the internal resistance and increasing the maximum current that the cell can deliver, but does not affect the emf of the cell.

<u>EMF of the Cell</u>

• The EMF of a cell is the maximum potential difference between two half- cells in a galvanic cell.

• If determined under standard conditions, it is referred to as the standard EMF : E°cell

• The standard emf of a cell can be determined from Table 4A (or 4B), by applying one of the following formulae (these are given on exam info sheet)

E^0 cell = E^0 reduction – E^0 oxidation
= E^0 oxidising agent – E^0 reducing agent
= E^0 cathode – E^0 anode

An example: An electrochemical cell is constructed using the following half-reactions:

Pb2+(aq) + 2e- ⇌Pb(s) and Au3+(aq) +3e- ⇌Au(s)

a) Which is the anode and which the cathode?

b) What is the standard cell potential?

Using our simple rule …
Anode – oxidation: Pb (lead)
Cathode – reduction: Au (gold)
E° = E°(cathode) – E°(anode) = + 1,50 – (–0,13) = 1,63 V.
Remember:
When the cell EMF is POSITIVE, the reaction is SPONTANEOUS.
If the EMF is negative, the reaction is non-spontaneous

CELL NOTATION

The following guidelines apply to the writing of the cell notation for cells involving gases:

1. The H_2|H + cell is treated just like any other half-cell.

(Textbooks stating that it always written on the left is INCORRECT.)

2. Cell terminals (electrodes) are written on the outside of the cell notation.
3. Order always:
RA|oxidized species||OA|reduced species.

4. If inert electrodes are used:

Pt|RA|oxidized species||OA|reduced species|Pt.
NB:
(Pt (or C) appears only if an inert electrode is used, as in the stand. H_2|H+ half-cell.) Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt

Correct order Examples:
1. Mg|Mg2+||H+ |H_2 |Pt (Correct)
2. Pt|H_2/H+ ||Cu^{2+} /Cu (Correct)
3. Mg|Mg^{2+} || F_2|F^-|Pt (Correct: order RA, oxidized species, OA, reduced species)
4. Pt|Cℓ- |Cℓ2|| F_2 |F^- |Pt (Correct: order RA, oxidized species, OA, reduced species)

Incorrect Order Examples:
5. Mg|Mg2+||F^- |F_2/Pt (Wrong - order)
6. Pt|$Cℓ_2$|$Cℓ^-$ ||F^-|F_2|Pt (Wrong - order)

Explanation of relative strengths of reducing agents or oxidizing agents

Follow the following steps:
STEP 1: Identify the stronger oxidising agent *(or reducing agent)*.
STEP 2: Identify the species/substance with which it is compared i.e. the weaker oxidising agent *(or reducing agent).*
STEP 3: State the action i.e. which species will be reduced *(or oxidised).* **STEP 4:** State to what species will it be reduced *(or oxidised)*.

EXAMPLE 1:
Can a copper(II) sulphate solution be stored in a zinc container? Explain by referring to the Table of Standard Reduction Potentials.

ANSWER

In terms of relative strength of oxidising agents:
No. ✓
Cu^{2+} is a stronger oxidising agent ✓ than Zn^{2+} ✓ and will oxidise Zn ✓ to Zn^{2+}. ✓

Note: Species on the left of the double arrow in the Table of Standard Reduction Potentials are oxidising agents. Those to the right of the double arrow are reducing agents. When comparing, an oxidising agent should always be compared to another oxidising agent and not with a reducing agent (to the right of the double arrow in the Table of Standard Reduction Potentials).

In terms of relative strengths of reducing agents:
No. ✓
Zn is a stronger reducing agent✓ than Cu ✓ and will reduce Cu^{2+} ✓ to Cu. ✓

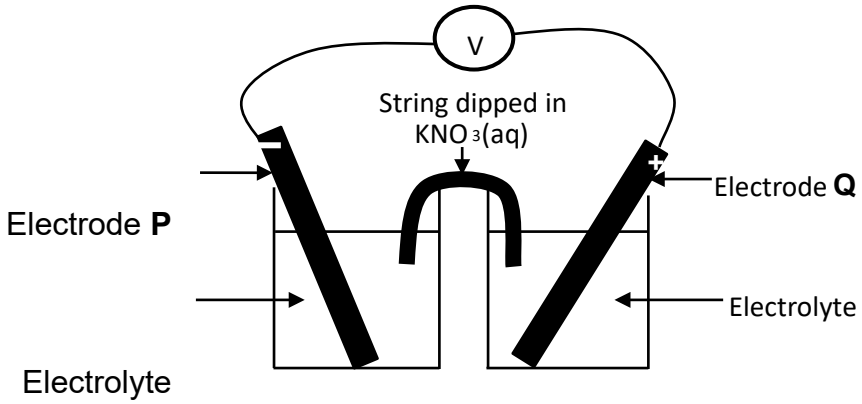
EXAMPLE 2:
It is found that silver does not react with a hydrochloric acid solution. Refer to the relative strengths of reducing agents to explain this observation.

ANSWER
Ag is a weaker reducing agent ✓ than H_2 ✓ and Ag CANNOT reduce H^+ ✓ to H_2. ✓

WORKED EXAMPLES

EXAMPLE 1

Learners set up an electrochemical cell, shown in the simplified diagram below, using magnesium and lead as electrodes. Nitrate solutions are used as electrolytes in both half-cells.



1.1 What type of reaction (NEUTRALISATION, REDOX or PRECIPITATION) takes place in this cell? (1)

Answer: *Redox reaction ✓ (Elecrons are transfered.)*

1.2 Which electrode, **P** or **Q**, is magnesium? Give a reason for the answer. (2)

Answer: *P ✓ Negative electrode. / Mg is a stronger reducing agent/is oxidized/release electrons. ✓*

1.3 Write down the:

1.3.1 Standard conditions under which this cell functions (2)

Answer: *Temperature: 25 °C/298 K ✓*
Concentration: 1 mol·dm^{-3} ✓

1.3.2 Cell notation for this cell (3)

Answer: *Mg(s) | Mg^{2+}(aq) ✓|| ✓ Pb^{2+}(aq) | Pb(s) ✓*

1.3.3 NAME or FORMULA of the oxidising agent in the cell (1)

Answer: *Pb^{2+} / Pb(NO$_3$)$_2$ / lead(II) ions ✓*

1.4 Calculate the initial emf of the cell above under standard conditions (4)

Answer: $E^{\theta}_{cell} = E^{\theta}_{reduction} - E^{\theta}_{oxidation}$ ✓ =
-0,13 ✓+(2,36) ✓ = 2,23 V

1.5 How will the voltmeter reading change if the:
(Write down only INCREASES, DECREASES or REMAINS THE SAME.)

1.5.1 Size of electrode **P** is increased (1)

Answer: *Remains the same ✓*

1.5.2 Initial concentration of the electrolyte in half-cell **B** is increased (1)

Answer: *Increases ✓*

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EXAMPLE 2

2.1 When a piece of sodium metal (Na) is added to water in a test tube, hydrogen gas is released. When phenolphthalein indicator is added to the test tube, the solution turns pink.

2.1.1 Define the term *reduction* in terms of electron transfer. (2)

Answer: *Gain of electrons. ✓✓ (2 or 0)*

2.1.2 Write down the reduction half-reaction. (2)

Answer: *2H$_2$O(ℓ) + 2e$^-$ → H$_2$(g) + 2OH$^-$(aq) ✓✓*

2.1.3 Write down the balanced equation for the reaction that takes place. (3)

Answer: *2Na(s) + 2H$_2$O(ℓ) ✓ → H$_2$(g) + 2OH$^-$(aq) + 2Na$^+$(aq) ✓ Bal ✓*

2.1.4 Give a reason why the solution turns pink. (1)

Answer: *Formation of hydroxide ions/OH$^-$/sodium hydroxide/base/pH > 7 ✓*

When a piece of copper is added to water in a test tube, no reaction Is observed.

2.1.5 Refer to the relative strengths of the REDUCING AGENTS to explain why no reaction is observed. (3)

Answer: *Cu is a weaker reducing agent ✓ than H$_2$ and OH$^-$ ✓ and H$_2$O will not be reduced(to H$_2$ andOH$^-$)* Consider the cell

$Pb(s)/Pb^{2+}(aq)$ || $Fe^{3+}(aq)$, $Fe^{2+}(aq)Pt(s)$

2.1.6 What does the single line (|) in the cell notation above represent? (1)

Answer: *Phase separator* ✓

2.1.7 State the energy conversion that takes place in this cell. (1)

Answer: *Chemical (energy) to electrical (energy)*

2.1.8 Calculate the initial emf of the cell under standard conditions. (4)

Answer: *E cell θ = E^0 reduction – E^0 oxidation* ✓

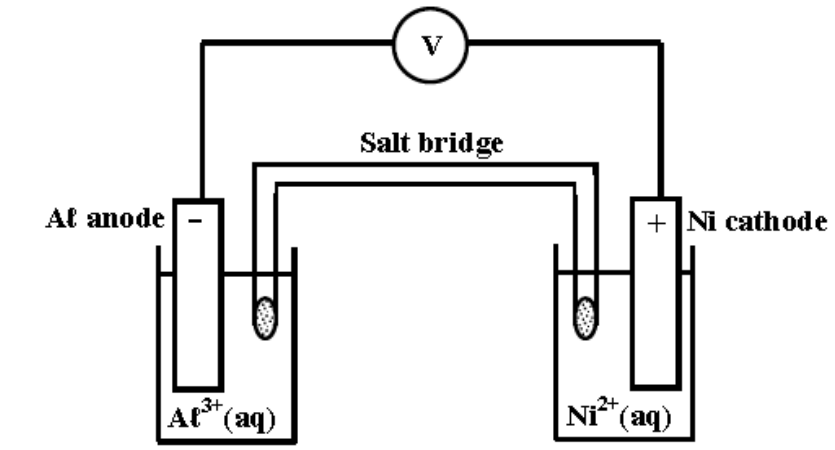
= 0,77 ✓ *- (-0,13)* ✓

E_{cell}^{θ} *= 0,90 V* ✓ **[17]**

GALVANIC CELL ACTIVITIES

ACTIVITY 1

A galvanic cell is set up under standard conditions using Aluminium and Nickel electrodes as shown in the diagram below.



Net cell reaction: $2Aℓ(s) + 3Ni^{2+}(aq) \longrightarrow 2Aℓ^{3+}(aq) + 3Ni(s)$

1.1 State the energy conversion that takes place in this cell. (2)

1.2 Write down the cell notation for this cell. (Standard conditions need not be shown. (3)

1.3 Define:

1.3.1 *Oxidation.* (2)

1.3.2 *Oxidizing agent.* (2)

1.4 Give the symbol of the oxidizing agent in this cell. (1)

1.5 Calculate the initial *emf* of this cell under standard conditions (3)

1.6 State how each of the following changes affect the *emf* of this cell:
(Answer only INCREASES, DECREASES or NO EFFECT.)

1.6.1 A soluble salt containing $A\ell^{3+}$ ions is added to the anode half-cell. (1)

1.6.2 The galvanic cell approaches chemical equilibrium. (1)

1.7 The salt bridge is replaced by one which is wider, shorter and more conductive than that shown in the diagram. State how each of the following will be affected by this change:
(Answer only INCREASES, DECREASES or NO EFFECT.)

1.7.1 The *emf*. (1)

1.7.2 The internal resistance. (1)

1.7.3 The ability of the cell to deliver current. (1)

1.8 After the cell has been operating for a period of time, the gain in mass at the nickel cathode is 1, 77 g.

1.8.1 Calculate the number of moles of Nickel which have been deposited at the cathode. (2)

1.8.2 Calculate the subsequent loss in mass at the Aluminium anode. (3)

1.9 Another cell (cell **P**) is set up under standard conditions.

The following cell notation summarises cell **P**: $Mg/Mg^{2+}// A\ell^{3+} / A\ell$

Write down the balanced equation for the net (overall) reaction that takes place in cell **P.** (3)

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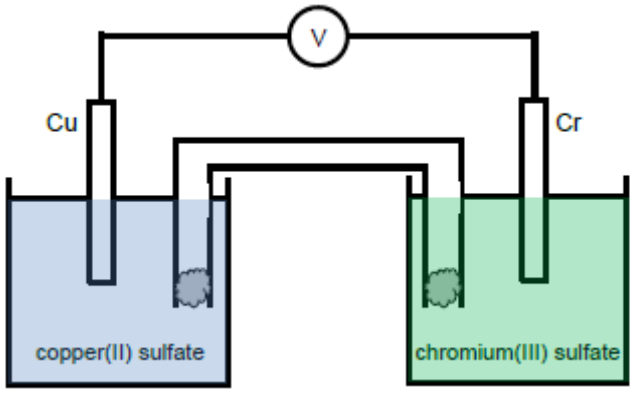
ACTIVITY 2

In the standard cell shown in the diagram below, a copper electrode is placed into a solution of blue copper(II) sulfate, and a chromium electrode is placed into a green chromium(III) sulfate solution. The voltmeter registers a reading.



2.1 Classify this cell as GALVANIC or ELECTROLYTIC. (1)

2.2 Write the formula of chromium(III) sulfate. (1)

2.3 2.3.1 Write the reduction half-reaction. (2)

2.3.2 Identify the anode. (1)

2.3.3 Describe TWO observations that can be made in the chromium half-cell after the cell has delivered current for a significant amount of time. (2)

2.4 Write a chemical equation for the net cell reaction that occurs in this cell. (3)

2.5 2.5.1 Determine the initial reading on the voltmeter. (3)

2.5.2 If the initial concentration of copper(II) sulfate used was greater than 1 mol·dm^{-3}, fully explain the effect that this would have on the initial voltmeter reading. (3)

2.6 2.6.1 Write the chemical formula for a suitable reagent that can be used in the salt bridge.
(1)

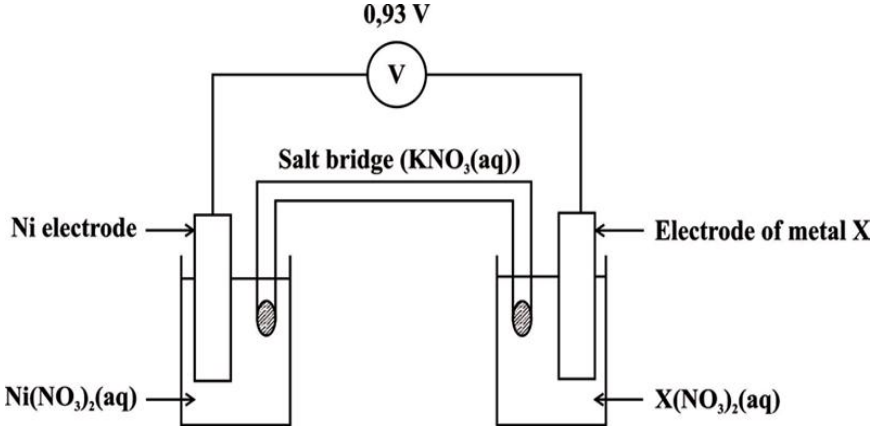
2.6.2 Explain how the salt bridge maintains electrical neutrality in the chromium half-cell. In your answer, refer to the changing ionic conditions as well as the movement of ions. (3)

2.7 Write the cell notation for this cell, including conditions and phase indicators. (5)

[25]

ACTIVITY 3

A galvanic cell is set up under standard conditions using nickel (Ni) and an unknown metalX as electrodes, as shown in the diagram below.The reading on the voltmeter while the cell is operating under standard conditions is 0,93 V. After the cell has been operating for a period of time, it is observed that **the mass of the nickel electrode has increased**.



3.1 Define the term *anode*. (2)

3.2 Which metal (nickel or metal **X**) is the cathode of this galvanic cell? Give a reason for your answer. (2)

3.3 Write down a chemical equation to show the half-reaction taking place at the nickel electrode. (2)

3.3.1.1 Calculate the standard electrode potential (E°) of metal **X** and hence determine the identity of metal. (4)

3.4 Write down the cell notation for this galvanic cell. Standard conditions do not need to be shown. (3)

3.5 The salt bridge used contains a concentrated solution of potassium nitrate. The saltbridge maintains electrical neutrality in the half-cells.

3.5.1 Why is it important that the solution of potassium nitrate is concentrated? (2)

3.5.2 Explain what the expression *'maintain electrical neutrality'* means. (2)

3.5.3 Explain why $\mathbf{K^+}$ ions are more suitable cations than $\mathbf{Fe^{3+}}$ ions for the salt bridge. (Refer to the table of Standard Electrode Potentials.) (3)

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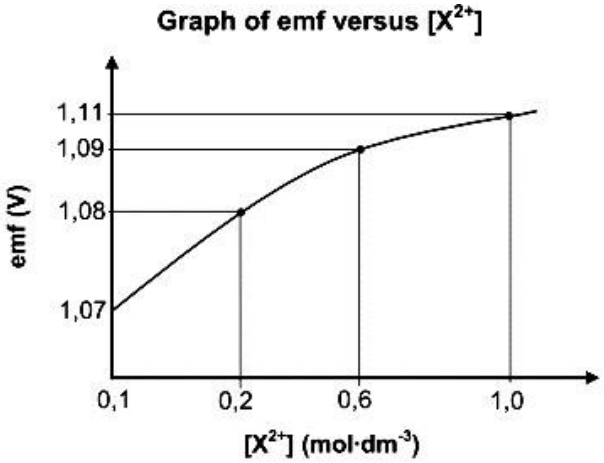
Activity 4

The electrochemical cell represented by the cell notation below is used to investigate the relationship between the concentration of $X^{2+}(aq)$ and the emf of the cell. The concentration of $Zn^{2+}(aq)$ and the temperature are kept at standard conditions.
$Zn(s) \mid Zn^{2+}(aq) \parallel X^{2+}(aq) \mid X(s)$

The graph shows the results obtained.



4.1 For this investigation, write down the:

4.1.1 Dependent variable (1)

4.1.2 Name of an instrument needed to measure the emf of the cell (1)

4.1.3 Name of the component of the cell that ensures electrical neutrality (1)

4.1.4 Values of TWO standard conditions needed to ensure that the standard emf is obtained (2)

4.2 Write down the conclusion that can be drawn from the results. (2)

4.3 Identify electrode **X** with the aid of a calculation. (5)

4.4 Write down the overall (net) cell reaction that takes place when this cell is in operation. (3)

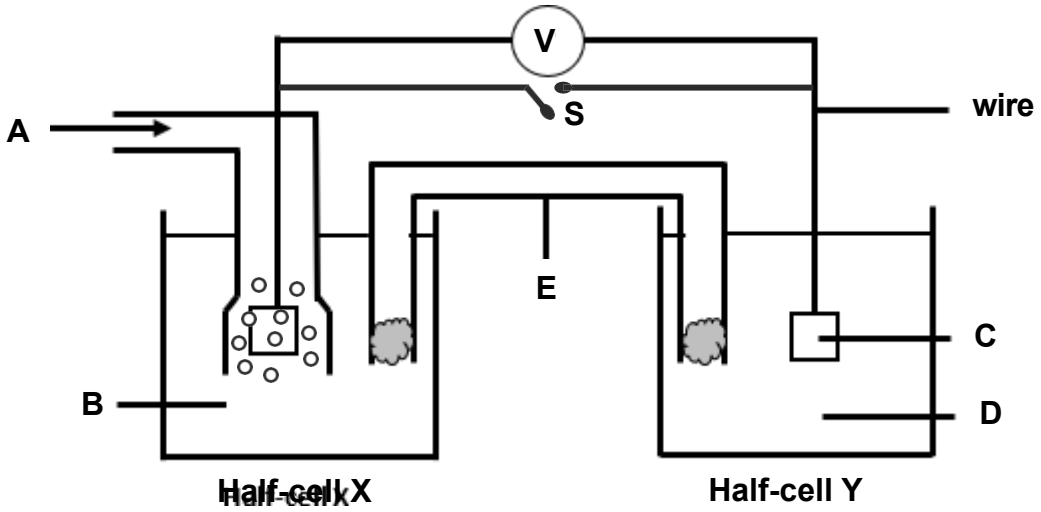
[15]

ACTIVITY 5

Chlorine gas and iron(II) ions react in aqueous solution as follows:

$$C\ell_2 + 2Fe^{2+} \rightarrow 2C\ell^- + 2Fe^{3+}$$

The diagram below shows a galvanic cell used to determine the cell potential $_{cell}$ (E^{θ}) for the above reaction under standard conditions.



5.1 Give the **chemical formulae** of the substances represented by the letters: (**A,B,C,D)** (4)

5.2 Consider the part labelled **E**.

5.2.1 What does **E** represent? (1)

5.2.2 Give the **chemical formula** of a suitable compound that could be dissolved in water to make the solution to fill **E**. (1)

5.2.3 Give two reasons why your choice of compound in Question 6.2.2 is suitable for this purpose. (2)

5.3 Calculate the initial cell potential (E^{θ}_{cell}) for this cell under standard conditions.

(4)

5.4 Identify the reducing agent in this cell. (1)

5.5 Select the correct options between brackets in the statement below.(2)
When switch **S** is closed, electrons will flow from half-cell (**X** to **Y** OR **Y** to **X**) through (THE WIRE OR **E**).

5.5.1 The standard solution of the Fe^{3+} electrolyte is prepared using Fe2(SO4)3. Explain what concentration of Fe2(SO4)3 solution should be prepared. (3)

5.6 Iron(III) hydroxide is far less soluble than iron(II) hydroxide. Make use of this fact and Le Châtelier's principle to explain how the emf of the cell will be affected if some NaOH is added to the Fe^{2+}/Fe^{3+}halfcell. (4)

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Training and Consultancy

The path to enlightened education

SUBJECT: SUBJECT NAME

GRADE 12

2026 WINTER CLASSES

TEACHER AND LEARNER CONTENT MANUAL

Topic(s)

Optical Phenomenon

Examination guidelines

Optical Phenomena and Properties of Materials
(This section must be read in conjunction with the CAPS, p. 132–133.)

Photo-electric effect

- Describe the *photoelectric effect* as the process whereby electrons are ejected from a metal surface when light of suitable frequency is incident on that surface.
- State the significance of the photoelectric effect.
- Define *threshold frequency*, f_o, as the minimum frequency of light needed to emit electrons from a certain metal surface.
- Define *work function*, W_o, as the minimum energy that an electron in the metal needs to be emitted from the metal surface.
- Perform calculations using the photoelectric equation:

  $E = W_o + E_{k(max)}$, where $E = hf$ and $W_o = hf_o$ and $E_{k(max)} = \frac{1}{2} mv_{max}^2$

- Explain the effect of intensity and frequency on the photoelectric effect.
- State that the photoelectric effect demonstrates the particle nature of light.

Emission and absorption spectra

- Explain the *formation of atomic spectra* by referring to energy transition.
- Explain the difference between *atomic absorption* and *emission spectra*.

  An atomic absorption spectrum is formed when certain frequencies of electromagnetic radiation passing through a substance is absorbed.

  For example, when light passes through a cold gas, atoms in the gas absorb characteristic frequencies of the light and the spectrum observed is a continuous spectrum with dark lines where characteristic frequencies of light were removed. The frequencies of the absorption lines are unique to the type of atoms in the gas.

  An atomic emission spectrum is formed when certain frequencies of electromagnetic radiation are emitted due to an atom making a transition from a higher energy state to a lower energy state.

  For example, atoms in a hot gas emit light at characteristic frequencies. The spectrum observed is a line spectrum with only a few coloured lines of frequencies unique to the type of atom that is producing the emission lines.

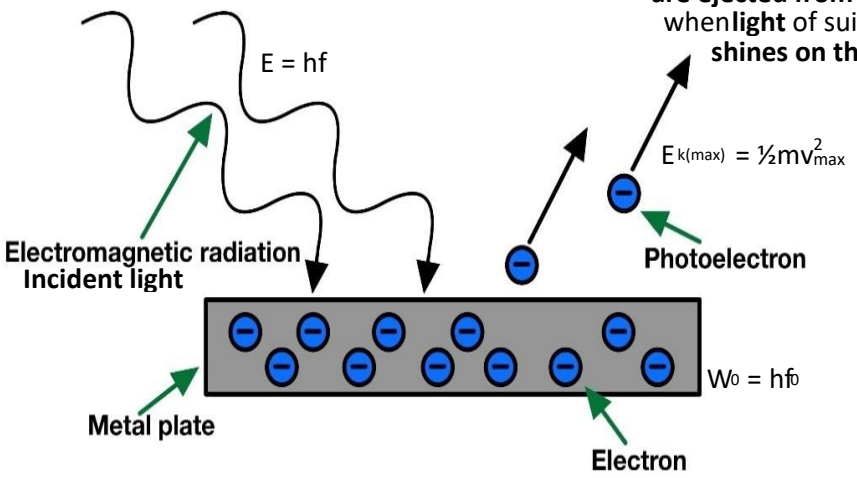
IMPORTANT TERMS AND DEFINITIONS

TERMS AND DEFINITIONS	
Dual nature	Double nature – light behaves like waves when in propagation and like particles when interacting with matter.
Photo-electric effect	The process whereby electrons are ejected from a metal surface when light of suitable frequency is incident on /shines on the surface.
Threshold frequency (f_o)	The minimum frequency of light needed to emit electrons from a certain metal surface.
Work function (W_o)	The minimum energy that an electron in the metal needs to be emitted from the metal surface.
Photo-electric equation	$E = W_o + K_{max}$, where $E = hf$ and $W_o = hf_o$ and $K_{max} = ½mv^2_{max}$
Spectrum	A band of colours with different wavelengths observed when light is dispersed by a prism. The rainbow is an example of a continuous spectrum.
Atomic absorption spectrum	Formed when certain frequencies of electromagnetic radiation that passes through a medium, e.g. a cold gas, is absorbed.
Atomic emission spectrum	Formed when certain frequencies of electromagnetic radiation are emitted due to an atom's electrons making a transition from a high-energy state to a lower energy state.

CONTENT

OPTICAL PHENOMENA AND PROPERTIES OF MATERIALS

Photo -electric effect — The process **whereby electrons are ejected from a metal surface** when **light** of suitable frequency **shines on the surface**.



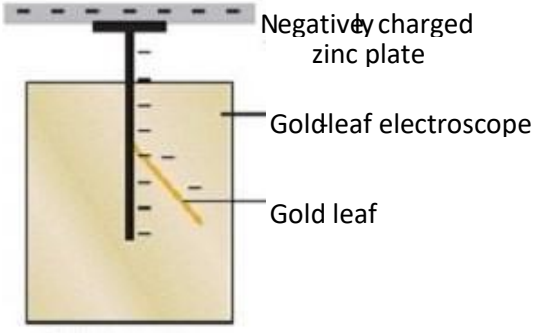
Each incident light photon has energy — **E = hf**
The metal needs energy (work function) to release an electron: — **$W_0 = hf_0$**
A photoelectron moves away at kinetic energy: — **$E_{k(max)} = ½mv^2_{max}$**

$E_{k(max)} = hf - W_0$ OR $hf = W_0 + E_{k(max)}$

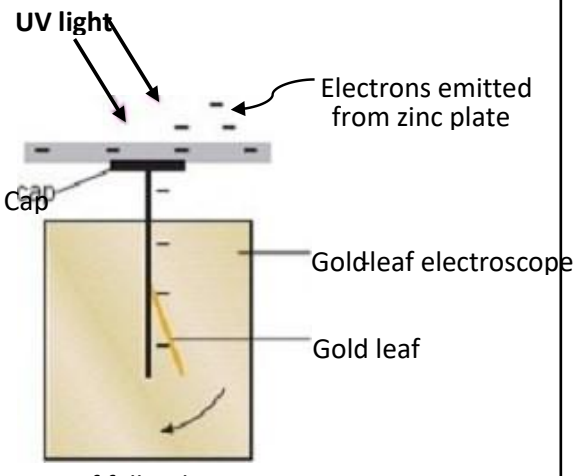
h: Planck's constant $6{,}63 \times 10^{-34}$ J·s
f: Frequency of incident light in hertz (Hz)
W_0: Work function of the metal in joule (J)
$E_{k(max)}$: Maximum kinetic energy of photoelectrons in joule (J)

Demonstration of the photoelectric effect

- A zinc plate is placed on the cap of an electroscope.
- The electroscope and zinc plate are negatively charged.
- UV light is shone on the zinc plate.



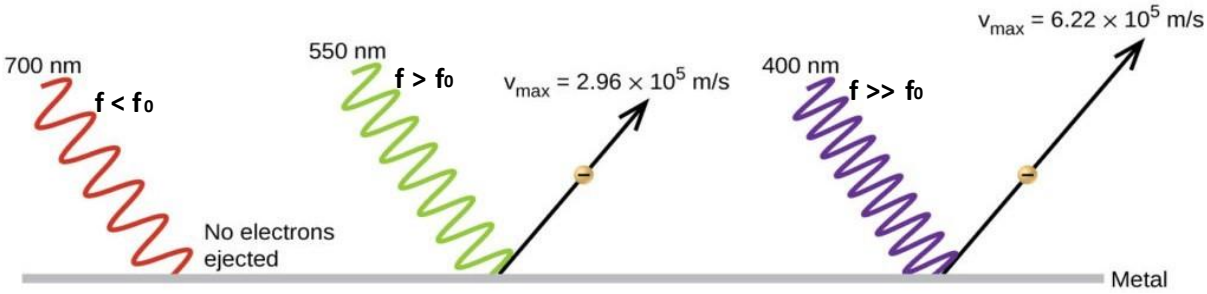
Initial position of gold leaf



Leaf falls when UV light is incident

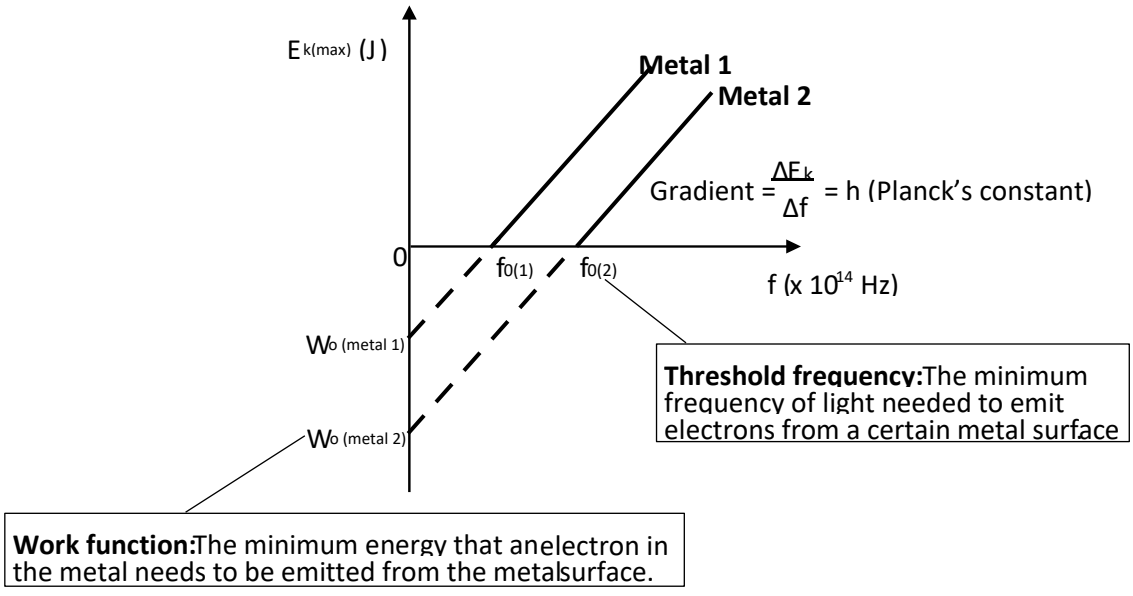
FACTORS INFLUENCING THE PHOTO - ELECTRIC EFFECT

Effect of FREQUENCY OF LIGHT on the photo -electric effect

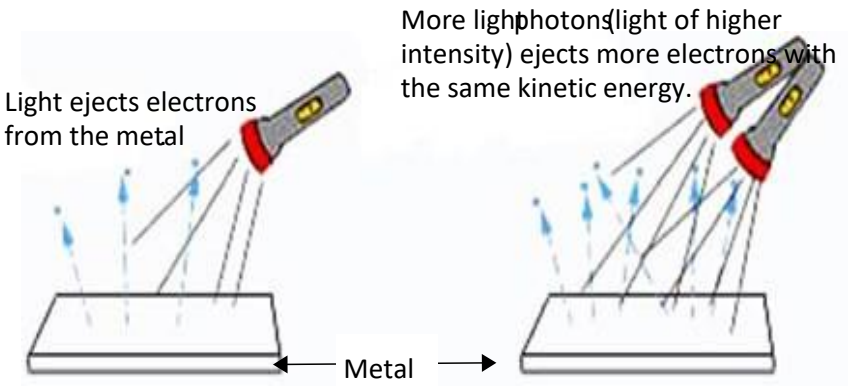


- The frequency of incident light determines whether electrons will be emitted or not.
- A metal has a minimum frequency needed to release electrons from the surface of the metal. It is called the **threshold frequency** f_0.
- If the frequency of the incident light is smaller than the threshold frequency for the metal, no electrons will be emitted.
- If the frequency of the incident light is equal to the threshold frequency for the metal, electrons will be emitted with zero kinetic energy.
- If the frequency of the incident light is greater than the threshold frequency for the metal, electrons will be emitted with a certain kinetic energy i.e. $E_{k(max)} = \frac{1}{2} v_{max}^2 = hf - hf_0$.
- **Work function** of a metal, $W_0 = hf_0$, is the minimum energy that an electron in the metal needs to be emitted from the metal surface

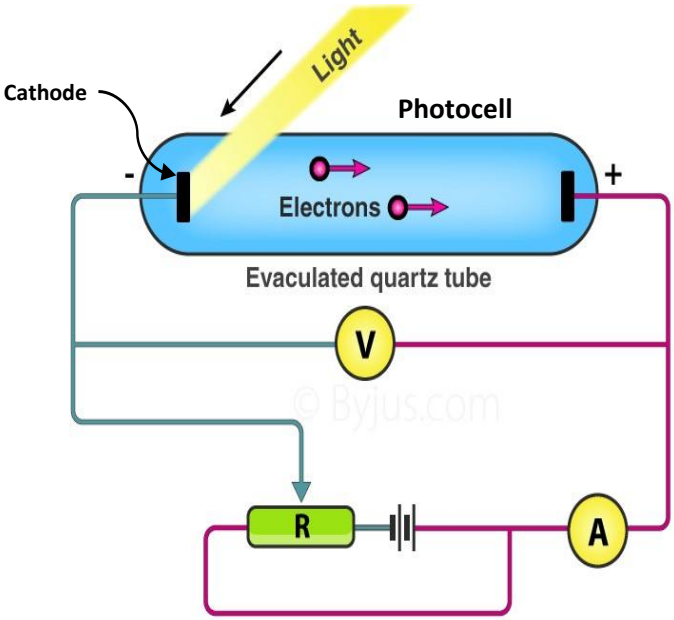
Graph of E_{kmax} versus frequency



Effect of INTENSITY OF LIGHT on the photo-electric effect

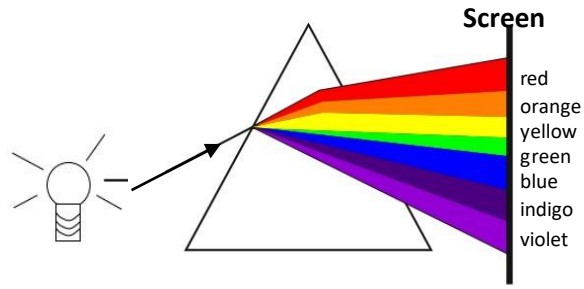


If the frequency of incident light is high enough to emit electrons from a metal surface, a **higher intensity** of this light will **emit more electrons per unit time with the same kinetic energy** .



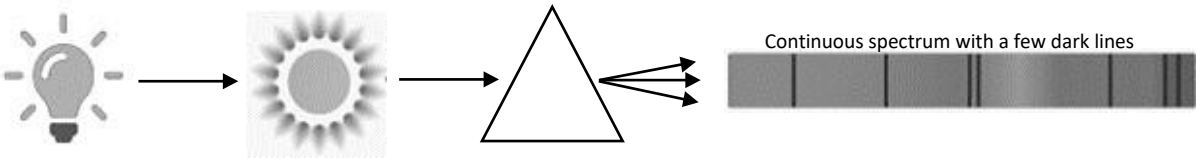
- Incident light emits electrons from the cathode
- The photoelectrons are then attracted by the positive anode and a current flow in the circuit.
- The ammeter registers a reading.
- If light of higher intensity is used, the ammeter will register a higher reading because more photons strike the metal cathode per unt time and therefore more electrons are emitted from the cathode per unit time.

Absorption and Emission Spectra



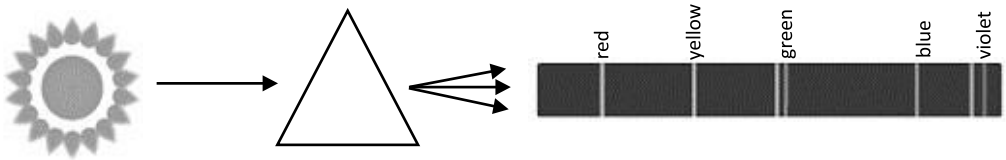
White light **Prism** **Continuous Spectrum**

A **Continuous Spectrum** contains all the wavelengths of visible light. Many electron transitions between energy levels are possible and all wavelengths of light are radiated.



Hot matter **Cold gas** **Prism** **Line Absorption Spectrum on screen**

An **Absorption Spectrum** shows the spectrum of electromagnetic waves that passed through a substance with a few dark lines due to the absorption of specific wavelengths when electrons in atoms of the substance make transitions from lower to higher energy levels.



Hot gas **Prism** **Line Emission Spectrum on screen**

An **Emission Spectrum** shows the spectrum of electromagnetic waves emitted by a hot substance with only a few bright lines due to the emission of specific wavelengths when electrons in atoms of the substance make transitions from higher to lower energy levels.

WORKED EXAMPLES

MULTIPLE CHOICE QUESTIONS

QUESTION 1 (2 marks)

Which ONE of the following correctly describes the **photoelectric effect**?

A. Emission of electrons when a metal is heated
B. Emission of electrons when light of sufficient frequency strikes a metal
C. Reflection of light from a metal surface
D. Absorption of light without emission of particles

Answer: B (2 marks)
✓ Electrons are emitted when light with sufficient frequency strikes a metal

---

QUESTION 2 (2 marks)

Which factor determines the **maximum kinetic energy** of emitted electrons?

A. Intensity of the incident light
B. Frequency of the incident light
C. Distance from the light source
D. Surface area of the metal

Answer: B (2 marks)
✓ $K_{max} = hf - W_0 \rightarrow$ depends on frequency

QUESTION 3 (2 marks)

What happens when the frequency of incident light is **below the threshold frequency**?

A. Electrons are emitted with low kinetic energy
B. No electrons are emitted
C. Electrons are emitted after a delay
D. Intensity increases automatically

Answer: B (2 marks)
✓ No emission occurs below threshold frequency

QUESTION 4 (2 marks)

The work function of a metal is defined as:

A. Maximum kinetic energy of emitted electrons
B. Minimum energy required to remove an electron from a metal
C. Total energy of incident light
D. Energy lost during reflection

Answer: B (2 marks)
✓ Work function = minimum energy needed to eject electrons

QUESTION 5 (2 marks)

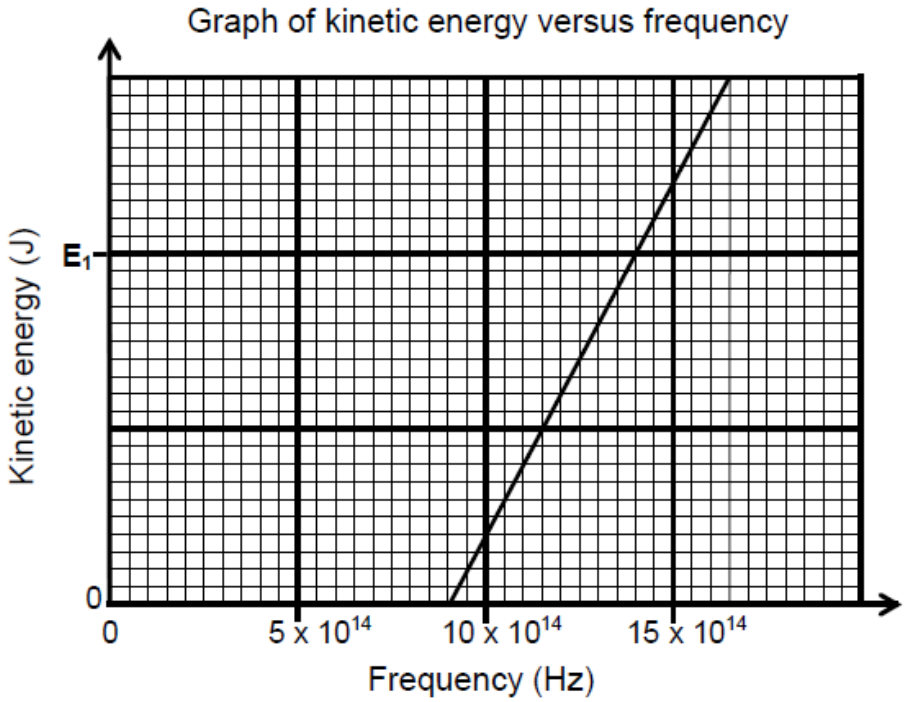
If the intensity of incident light increases while frequency remains constant (above threshold), what happens?

A. Maximum kinetic energy increases
B. Number of emitted electrons increases
C. Work function increases
D. Threshold frequency increases

Answer: B (2 marks)
✓ More photons → more electrons emitted
✓ Energy per electron unchanged

QUESTION 1

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



1.1 For this investigation, write down the following:

1.1.1 Dependent variable (1)

1.1.2 Independent variable (1)

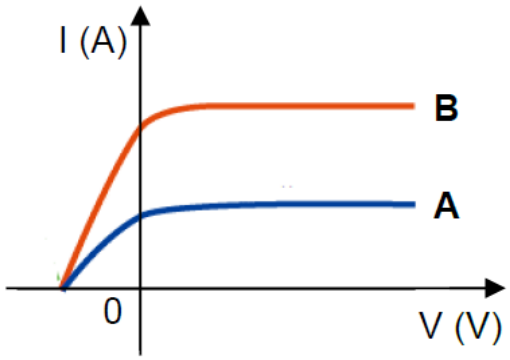
1.1.3 Controlled variable (1)

1.2 Define the term *threshold frequency*. (2)

1.3 Use the graph to obtain the threshold frequency of the metal used as cathode in the photocell. (1)

1.4 Calculate the kinetic energy at E_1 shown on the graph. (4)

To determine the effect of the intensity of a radiation on the photo-electric current, radiations of the same frequency with different intensities is incident on the sodium plate. The following graphs of current (I) versus potential difference (V) were obtained.



1.5 Which ONE of the curves corresponds to a radiation of greater intensity?

Explain the answer.

(3)

1.6 How does the maximum kinetic energy of the ejected electrons by radiation **A** compare to the maximum kinetic energy of the ejected electrons by radiation **B**.

Choose from GREATER THAN, SMALLER THAN or EQUAL TO. (1)

[14]

QUESTION 1 [SOLUTIONS]

1.1 1.1.1 Kinetic energy✓ (1)

1.1.2 Frequency ✓ (1)

1.1.3 (Type of) metal ✓ (1)

1.2 The minimum frequency needed to emit electrons ✓from (the surface of) a metal. ✓ ✓ (2)

1.3 9×10^{14} Hz ✓ (1)

1.4 $E = W_0 + E_k$ ✓

$hf = hf_0 + E_k$

$(6{,}63 \times 10^{-34})(14 \times 10^{14})$ ✓ $= (6{,}63 \times 10^{-34})(9 \times 10^{14})$ ✓ $+ E_k$

$\therefore E_k = 3{,}32 \times 10^{-19}$ J ✓ $(3{,}31 \times 10^{-19}$ J) (4)

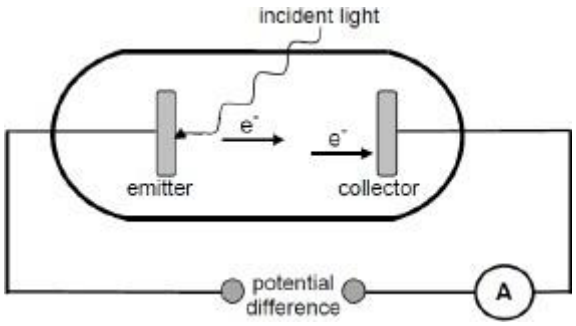
1.5 **B**. ✓
As the intensity of light increases the number of photons per second increase. ✓

Since each photon releases one electron, the number of ejected electrons per second increases. ✓This causes the current /ammeter reading to increase. (3)

1.6 Equal to✓ **[14]**

QUESTION 2

2. The apparatus below is used to demonstrate the photoelectric effect using sodium metal.



The longest wavelength that will cause electrons to be ejected from a sodium metal surface when light is shone on the metal is 583 nm.

2.1.1 Define *threshold frequency*. (2)

2.1.2 Calculate the threshold frequency for sodium metal. (3)

2.1.3 Hence, calculate the work function of sodium metal. (3)

A low intensity light of wavelength of 450 nm is incident on the sodium.

2.1.4 Calculate the kinetic energy of the ejected electrons. (4)

A higher intensity light, also of wavelength 450 nm, replaces the low intensity light.

2.1.5 What will the effect be of the higher intensity light on

2.5.2.1 The kinetic energy of the ejected electrons? (1)

2.5.2 The number of ejected electrons? (1)

Diagram 1 below shows some of the possible energy emissions as excited electrons in a hot gas fall to lower energy levels. (Level n = 4 has the highest energy.)

Diagram 2 below shows the line emission spectrum produced. The white lines indicate the wavelengths at which light was observed

Diagram 1

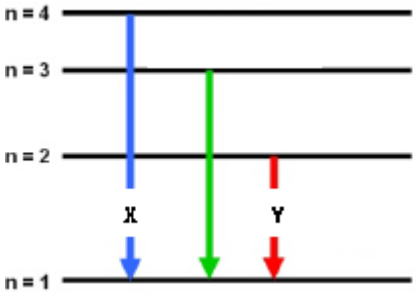


Diagram 2

2.2.1 Which of the emissions, **X** or **Y** (diagram 1) is most likely to Correspond to spectral line **A** in diagram 2?

Explain your answer. (3)

2.2.2 Write down ONE important use of line emission spectra (1)

[18]

Question 2 [Answers]

2.1.1 **Threshold frequency** is the minimum frequency of light needed to eject electrons from a metal (surface) **OR** **Threshold frequency** is the minimum frequency of incident radiation at which electrons will be emitted from a particular metal(surface). (2)

2.1.2 $c = f\lambda$ √

$3 \times 10^8 = f_o \ (583 \times 10^{-9})$√

$f_o = (5{,}15 \times 10^{14}$ Hz √ (3)

2.1.3 $W_o = hf_o$ √

$W_o = (6{,}6 \times 10^{-34})\ (5{,}15 \times 10^{14})$ √

$W_o = 3{,}40 \times 10^{-19}$ J √ (3)

2.1.4 $E = \frac{hc}{\lambda} = W_o + E_{kmax}$ √

$= \frac{(6{,}6 \times 10^{-34})(3 \times 10^8)}{450 \times 10^{-9}}$ ✓ $= 3{,}40 \times 10^{-19} + E_{kmax}$ ✓

$E_{kmax} = 1 \times 10^{-19}$ J √ (4)

2.1.5.1 Higher intensity has no effect □ (1)

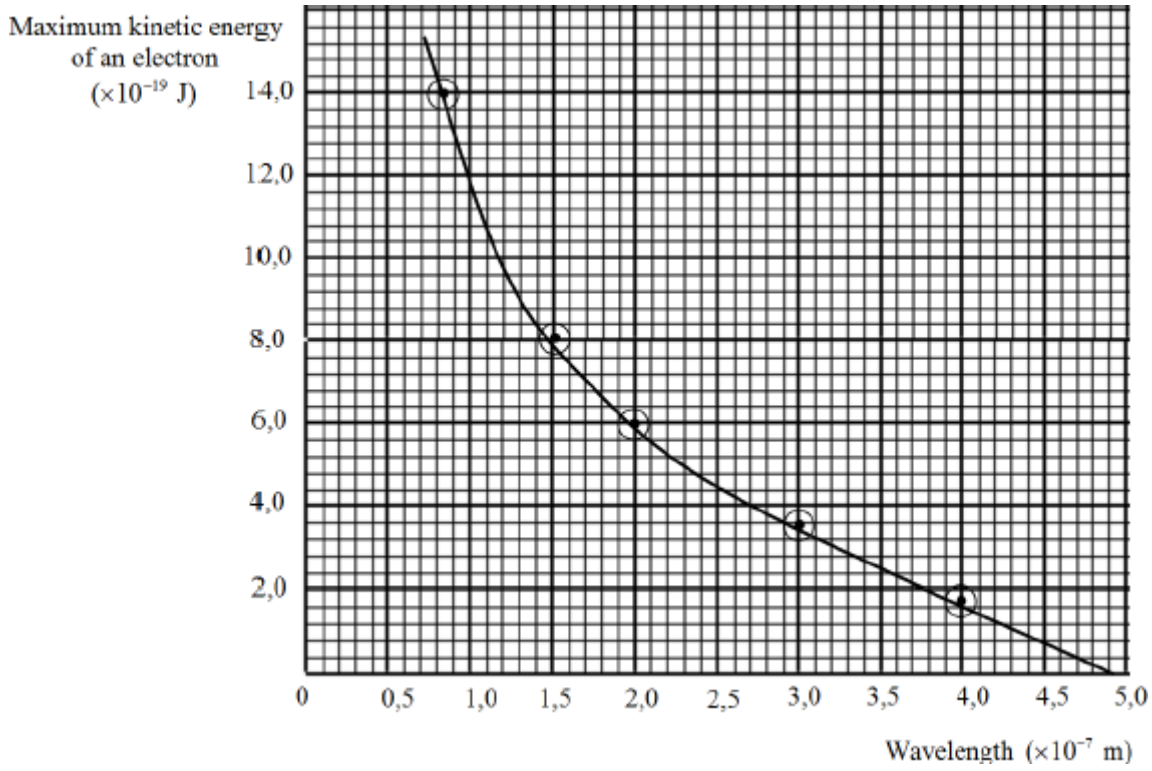
Higher intensity increases the number of ejected electrons□ (1)

2.2.1 **Emission X**✓ corresponds to spectral line A. The **energy** of the Photon emitted is **greatest** in emission X✓∴ wavelength is shortest, (3)

2.2.2 To identify unknown elements□ (Each element has its own characteristic line spectrum). (1)

ACTIVITY 1

The graph below shows how the maximum kinetic energy of an electron emitted from the metal cathode of a photoelectric cell varies with the wavelength of the incident radiation.



1.1 Use the graph to determine the maximum kinetic energy of the electron emitted when the wavelength of the incident radiation is $1{,}0 \times 10^{-7}$ m. (1)

1.2 Describe the relationship shown in the graph. (2)

1.3 Use your knowledge of the photoelectric effect to EXPLAIN the relationship shown in the graph. Support your answer with reference to relevant formulae. (2)

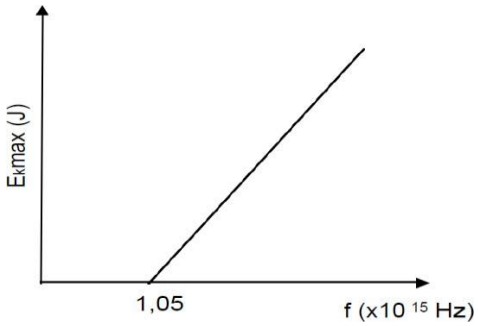
1.4 Use the graph to calculate the threshold frequency of the light needed to emit electrons from the metal cathode of the photovoltaic cell. (3)

1.5 Calculate the work function of the metal used for the cathode of the photovoltaic cell. (3)

ACTIVITY 2

A Physics student measures the maximum kinetic energy of photoelectrons emitted from the surface of metal **X**, using different frequencies of the incident radiation. The student uses his data to plot the graph shown below.

Graph showing the relationship between the maximum kinetic energy of photoelectrons and the frequency of incident radiation for metal X.



The following table shows the work function of a variety of metals:

Metal	Work Function (J)
Sodium	$3{,}82 \times 10^{-19}$
Zinc	$6{,}97 \times 10^{-19}$
Copper	$7{,}52 \times 10^{-19}$
Platinum	$1{,}02 \times 10^{-18}$
Calcium	$4{,}78 \times 10^{-19}$

2.1 Define *work function*. (2)

2.2 State the independent variable in this experiment. (1)

2.3 Show that the gradient of the graph has units N·m·s. (2)

2.4 Use information from the graph and the table above to determine the

identity of metal **X**. (5)

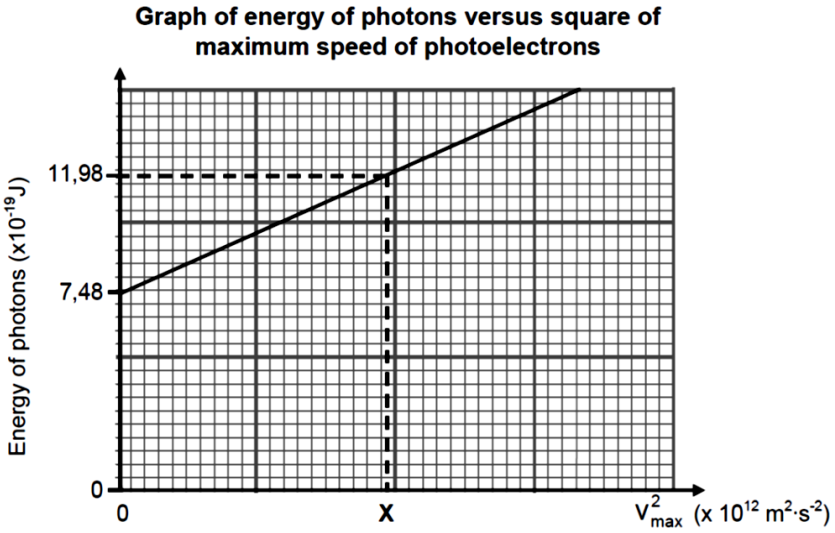
2.5 The wavelength of blue light is given as 475 nm. When this blue light is shone onto a certain metal surface, the maximum velocity of emitted electrons is $2{,}77 \times 10^5$ $m \cdot s^{-1}$. Determine which metal from the table above is being used. (6)

[16]

Activity 3

During an experiment, light of different frequencies is radiated onto a silver cathode of a photocell and the corresponding maximum speed of the ejected photoelectrons are measured.

A graph of the energy of the incident photons versus the square of the maximum speed of the ejected photoelectrons is shown below.



3.1 Define the term *photoelectric effect*. (2)

Use the graph to answer the following questions.

3.2 Write down the value of the work function of silver. Use a relevant equation to justify the answer. (3)

3.3 Which physical quantity can be determined from the gradient of the graph? (1)

3.4 Calculate the value of **X** as shown on the graph. (5)

The experiment above is now repeated using light of higher intensity.

3.5 How will EACH of the following be affected?

Choose from INCREASES, DECREASES or REMAINS THE SAME.

3.5.1 The gradient of the graph (1)

3.5.2 The number of photoelectrons emitted per unit time (1)

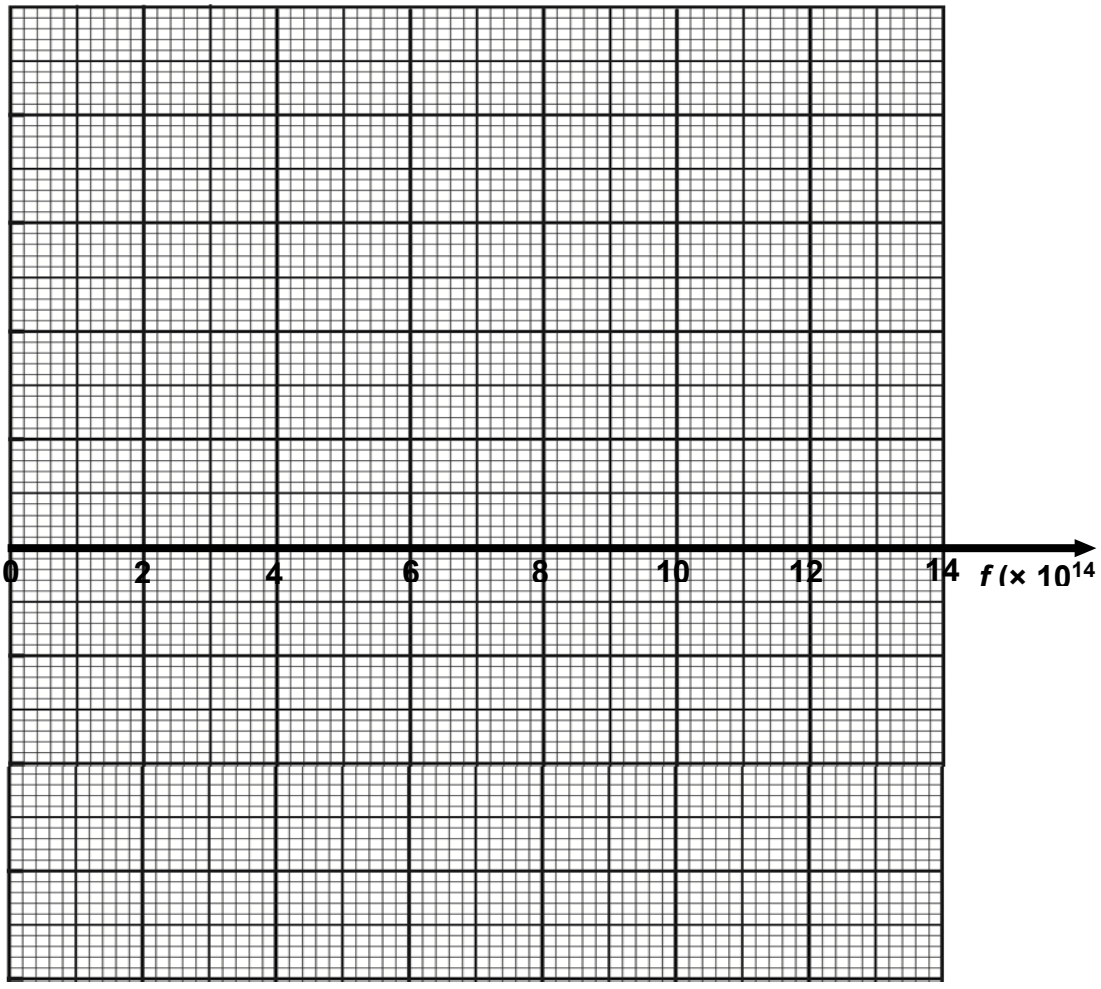
[13]

ACTIVITY 4

Light of increasing frequency is shone onto a caesium surface and the maximum kinetic energy of the electrons ejected from the surface is recorded in the table below.

f ($\times 10^{14}$ Hz)	$E_{K(max)}$ ($\times 10^{-19}$ J)
5,6	0,3
6,2	0,8
7,8	1,7
8,4	2,3
10,0	3,4
11,4	4,2

4.1 Plot a graph of the maximum kinetic energy of the ejected electrons (on *y*-axis) vs the frequency of incident light (on *x*-axis) on the graph paper below. (6)



4.1 Define *threshold frequency*. (2)

4.2 Determine the threshold frequency of caesium using the graph drawn in Question 9.1. (2)

4.3 Determine the gradient of the graph that you plotted in Question 9.1. Include a unit with your gradient. (4)

4.4 Use the photoelectric effect equation and your answer to Question 9.4 to calculate Planck's constant. (2)

4.5 State what quantity can be determined from the y-intercept of the graph plotted in Question 9.1. (2)

[18]

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