P525/1
Chemistry
(Theory)
Paper 1
November
$2^{1/2}$hours

KABOWA HIGH SCHOOL

CHEMISTRY (Theory) Paper one

END OF YEAR EXAM

SENIOR FIVE

2hours: 30 minutes

Instructions

- This paper consists of two sections: A and B. It has six examination items.
- Section A has two compulsory items.
- Section B has two parts; I and II.
- Answer one item from each part.
- Answers to section A and B must be written in the answer booklet(s) provided.
- Answer four items in all. Any additional item(s) answered will not be marked.

SECTION A (Attempt all items in this section)

ITEM ONE

At the **Makerere University Chemistry Research Laboratory**, a group of A-Level Chemistry students participated in an investigation on **colligative properties of solutions**.
They were given samples of:

- **FA1:** Pure benzene (solvent)
- **FA2:** A dilute solution of an unknown polymer in benzene

The supervising researcher explained that, for large molecules such as **polymers**, determining molar mass from **freezing point depression (ΔTf)** or **boiling point elevation (ΔTb)** gives inaccurate results.

Therefore, the group was instructed to use **osmotic pressure measurements** to determine the **molar mass of the polymer graphically**.

Experimental Data Provided

Concentration ($g\ dm^{-3}$)	Osmotic Pressure (atm) at 25 °C
2.00	0.102
4.00	0.204
6.00	0.306
8.00	0.408

(Assume $R = 0.0821\ dm^3\ atm\ K^{-1}\ mol^{-1}$ and $T = 298\ K$.)

TASKS

a) Describe how **osmotic pressure of the polymer solution** can be measured experimentally
b) Using the data provided, **plot a graph** of **osmotic pressure (π)** against **concentration (C)**
c) From the graph, determine the **molar mass (M_r)** of the unknown polymer using the relation:
d) Explain why **osmotic pressure** is a more suitable method for determining the molar mass of **polymers** compared to **freezing point depression** or **boiling point elevation** methods.
e) Discuss how **colligative properties** depend on the **number of solute particles** rather than their chemical nature. Include examples of **electrolytes** and **non-electrolytes** to illustrate your answer.

ITEM 2

An aluminium smelting company in Jinja uses a substance called aluminium fluoride as a flux to lower the melting point of cryolite during aluminium extraction. However, the production unit is facing high energy costs, and the environmental team reports challenges in dissolving waste AlF_3 residues before disposal. The research chemist is tasked to analyse the thermochemical feasibility of both forming and dissolving AlF_3 using available thermodynamic data to determine whether these processes are spontaneous or energy-intensive. Across a certain article the following data was discovered by the researcher:

Type of enthalpy change	Magnitude ($kJ\ mol^{-1}$)
Standard enthalpy of formation of $AlF_3(s)$	−1301
Enthalpy of atomization of aluminium	+314
Bond dissociation energy of fluorine	+158
First, second, and third ionization energies of Al	+577, +1820, and +2740 respectively
First electron affinity of fluorine	−348
Hydration enthalpies aluminium and fluoride ions	−4690 , −364 respectively

The researcher struggles to use this information to construct and interpret an energy cycle diagram, perform calculations, evaluate the feasibility of the key processes and properties that suit aluminium fluoride for use in the process. You have been contacted for help.

Tasks

As a student of chemistry, help the researcher;

a) Analyse the data to construct an energy cycle diagram for the formation of solid substance.
b) Know the lattice energy of substance.
c) Know the enthalpy of solution substance
d) Evaluate whether the dissolution of the substance in water is thermodynamically feasible and spontaneous under standard conditions.

(i) State the properties that make the substance suitable to serve the above purpose

(ii) Suggest the possible impacts and mitigations of the substance to the environment.

SECTION B

Part 1 (Inorganic chemistry) (choose one item)

ITEM 3

At the **Department of Physical Sciences, Kyambogo University**, Advanced Level Chemistry students were invited to participate in a **STEM innovation project** aimed at designing **optical devices** such as **solar panels, sensors, and anti-reflective coatings** using elements from **Period 3** of the periodic table.

Before the design stage, the students needed to understand how **ionisation energy** changes across Period 3 and how this affects **metallic character, conductivity, and optical behaviour** of the elements and their compounds.

The instructor provided experimental data for the **first ionisation energies** of Period 3 elements and tasked the students to:

- Plot a **graph**,
- Analyse the **trend**, and
- Apply the knowledge in selecting **suitable materials for optical or electronic applications.**

Experimental Data

Element	Symbol	Atomic Number (Z)	1st Ionisation Energy (kJ mol^{-1})
Sodium	Na	11	496
Magnesium	Mg	12	738
Aluminium	Al	13	578
Silicon	Si	14	786
Phosphorus	P	15	1012
Sulphur	S	16	1000
Chlorine	Cl	17	1251
Argon	Ar	18	1521

Tasks

Using the data provided:

a) Plot a **graph of ionisation energy** against **atomic number** for Period 3 elements. Label the axes clearly and choose an appropriate scale.
b) Describe the **general trend** of ionisation energy across Period 3.
c) Identify and explain the **irregularities** observed.
d) Explain the observed trend in ionisation energy across Period 3.
e) You are part of a team designing materials for **solar cells and optical sensors**. Using your knowledge of ionisation energy, electric conductivity and bonding across Period 3:

Identify **which elements or compounds** from Period 3 (e.g., Al, Si, MgO, SiO_2) would be **most suitable** for

i. Conductive layers,
ii. Semiconductor layers
iii. Insulating coatings.

f) Justify your selection.

ITEM 4

During a regional chemistry fair, students were challenged to investigate how physical and chemical properties change across **Period 3 (Na → Cl)** in the periodic table.
Your school's chemistry club decided to participate, focusing on how **atomic structure** and **bonding** influence properties such as **melting and boiling,** and **chemical reactivity**.

As the lead student chemist, you are required to prepare a detailed report explaining the **trends in Period 3 elements** and their **oxides** based on the data and reactions provided.

Data Table: Physical Properties of Period 3 Elements

Element	Melting Point (°C)	Boiling Point (°C)
Sodium	98	883
Magnesium	650	1090
Aluminium	660	2519
Silicon	1414	3265

Phosphorus (white)	44	280
Sulphur	115	445
Chlorine	−101	−34

Tasks

(a)Using the data provided, describe and explain the **trend in melting and boiling points** of Period 3 elements.

(b)Describe and write **balanced equations** for the **reactions of Period 3 elements with water such as sodium, sulphur and chlorine**, indicating observations and products formed.

(c)Write **balanced chemical equations** for the reactions of **Period 3**

Oxides such as Sodium oxide, Silicon oxide and Aluminium oxide with:

i. **Water**
ii. **Hydrochloric acid**
iii. **Sodium hydroxide**

(d)Classify each oxide as **basic**, **amphoteric**, or **acidic**.

SECTION B

Part 2 (Organic chemistry) (choose one item)

ITEM 5

A team of Advanced Level Chemistry students from **Mbarara High School** visited **Kampala Industrial Research Centre (KIRC)** to study the **production and application of aromatic compounds** in local industries.
They focused on **nitrobenzene**, **methylbenzene (toluene)**, and **chlorobenzene**, which are widely used in the manufacture of **pharmaceuticals, plastics, dyes, and explosives**.

During the visit, they learned that:

- **Nitrobenzene** is used in making **aniline**, which is a precursor for dyes and drugs.
- **Methylbenzene (toluene)** can be oxidized to **benzoic acid**, an important preservative and intermediate in the synthesis of perfumes.

- **Chlorobenzene** is used to make **pesticides and polymers** such as polyvinyl chloride (PVC).

However, they were not aware of the environmental and health effects of using benzene derivatives.

Tasks

(a) Draw the **structural formulae** of **nitrobenzene**, **methylbenzene**, and **chlorobenzene**.

Using **methylbenzene (toluene)** as a starting material:
(b) (i) Outline the **synthetic route** to **benzoic acid**, indicating all **reagents and conditions** for each step.
(ii)Write **balanced chemical equations** for each reaction involved.

(c) Describe and illustrate the **electrophilic substitution mechanism** for the **nitration of benzene** to form **nitrobenzene**, showing the **generation of the nitronium ion (NO_2^+)** and the **intermediate arenium ion**.

(d) Describe the **halogenation mechanism** of benzene to form **chlorobenzene**, naming the **catalyst used** and explaining its function.

(e)Discuss other **industrial** applications of nitrobenzene

(f)Explain:
(i) The **health risks** associated with prolonged exposure to benzene derivative.
(ii) The **environmental effects** of benzene derivatives on air, water, and soil.
(iii) Suggest **safe handling, storage, and disposal practices** to minimize environmental pollution and health risks.

ITEM 6

At the **National Petroleum Research Centre (NPRC)** in Jinja, a group of Advanced Level Chemistry students participated in a research internship aimed at identifying and comparing hydrocarbons that could serve as **fuel additives and raw materials for polymer industries**.

During one experiment, they encountered two unknown gaseous hydrocarbons:

- **Gas X** with molecular formula $\mathbf{C_4H_6}$
- **Gas Y** with molecular formula $\mathbf{C_4H_8}$

Laboratory tests showed that:

- Gas X **decolourised bromine water** and **underwent partial hydrogenation** in the presence of **Lindlar's catalyst**.
- Gas Y also **decolourised bromine water**, but **did not react with ammoniacal silver nitrate**, and **readily formed polymers**.

The students were challenged to use their knowledge of **organic chemistry** to:

1. Identify the homologous series each gas belongs to,
2. Describe their **possible structures and types of isomerism**,
3. Explain the **reactions and mechanisms** involved, and
4. Discuss their **industrial and daily life applications**.

Tasks

(a) Identify the **homologous series** and functional groups to which **C_4H_6** and **C_4H_8** belong.
(b) Write **all possible structural ,functional group and positional isomers** for each molecular formula. Name each isomer using **IUPAC nomenclature**.

(c) State and illustrate the main **types of isomerism** exhibited by compounds of molecular formulas **C_4H_6** and **C_4H_8.**

(d) (i)Write **balanced equations** for the reactions of **Gas X (C_4H_6)** and **Gas Y (C_4H_8)** with **bromine water**.

(ii)Using **curved arrows, write stepwise electrophilic addition mechanism** of bromine to C4H8.

(iii) Write a **balanced equation** showing **partial hydrogenation of C_4H_6** using **Lindlar's catalyst**.

(e) Discuss **one industrial or daily life applications** of hydrocarbons with formulas **of C_4H_8.**

(f)Construct a **flow diagram** showing interconversions of C4H8 to C4H10O Include the **reagents and conditions** for each step.

HAPPY CHRISTMAS AND PROSPEROUS NEW YEAR

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ITEM ONE

a) A semipermeable membrane that allows only solvent (benzene) molecules to pass is fixed between two compartments.

One compartment contains pure benzene (FA1), the other contains the polymer solution (FA2).

The solution side is connected to a vertical capillary tube.

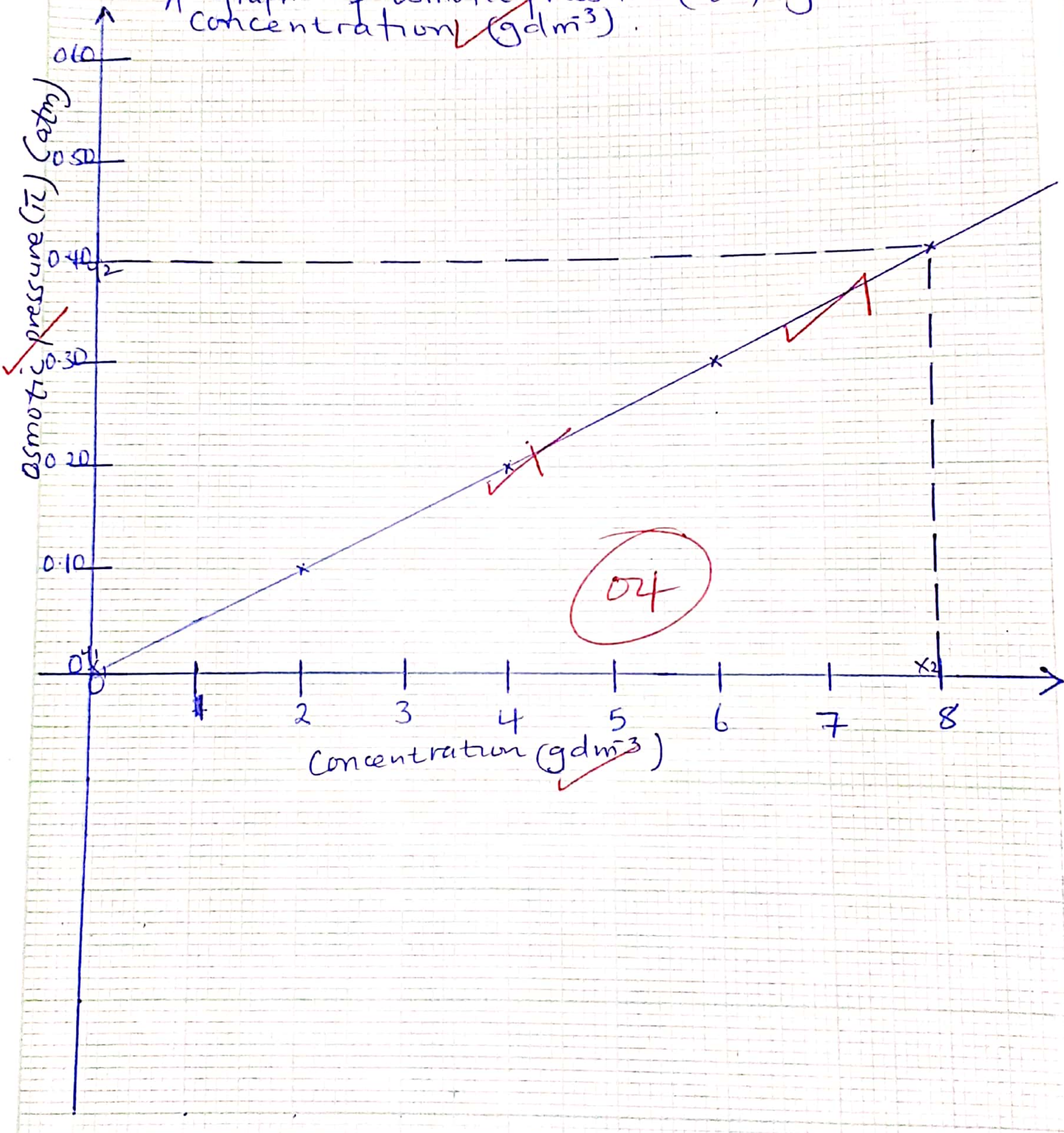
Solvent flows from pure benzene to solution by osmosis. The liquid rises in the capillary tube until the hydrostatic pressure balances the osmotic pressure.

Heigh difference in the capillary is measured or directly read from the pressure gauge in osmometers.

Measurements are done at 298 K or 25°C.

05

1(b) A graph of Osmotic pressure (atm) against Concentration (gdm⁻³).



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b) Graphically done

$$\text{slope} = \frac{\Delta\pi}{\Delta C}$$

$$= \left(\frac{0.408-0}{8-0}\right)$$

$$= 0.051\,\text{atm}\,\text{dm}^3\text{g}^{-1}.$$

02

c) From

$$M = \frac{RT}{\text{slope}} \qquad R = 0.0821\,\text{dm}^3\,\text{atm}\,K^{-1}\text{mol}^{-1}.$$

$$= \frac{0.0821 \times 298\,K}{0.051\,\text{atm}\,\text{dm}^3\text{g}^{-1}}$$

03

$$= 479.68\,\text{g mol}^{-1}. \simeq 480\,\text{g mol}^{-1}.$$

d) Consider

$$\Delta T \propto \frac{m}{Mr}$$

Polymers have very large molecular masses thus ΔT_f and ΔT_b are too small to measure accurately compared to osmotic pressure that gives large reliable values.

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e) Colligative properties depend only on the number of solute particles in solution not their chemical identity.

Consider

Glucose $C_6H_{12}O_6$ with 0.1 Mol particles

NaCl with 0.2 mol particles

$CaCl_2$ with 0.3 mol particles

Implication.

Vi 0.2M Glucose and 0.1M KCl will have same boiling point.

Glucose is a non electrolyte and does not dissociate hence remains as 0.2M

$C_6H_{12}O_6(aq) \longrightarrow C_6H_{12}O_6(aq)$

0.2M   0.2M.

KCl is a strong electrolyte and dissociates to form K^+ and Cl^-

$KCl(aq) \longrightarrow K^+(aq) + Cl^-(aq)$

0.1M   0.1M   0.1M

Total mol particles = 0.2

Same number of particles same colligative effect hence will have same boiling point.

04

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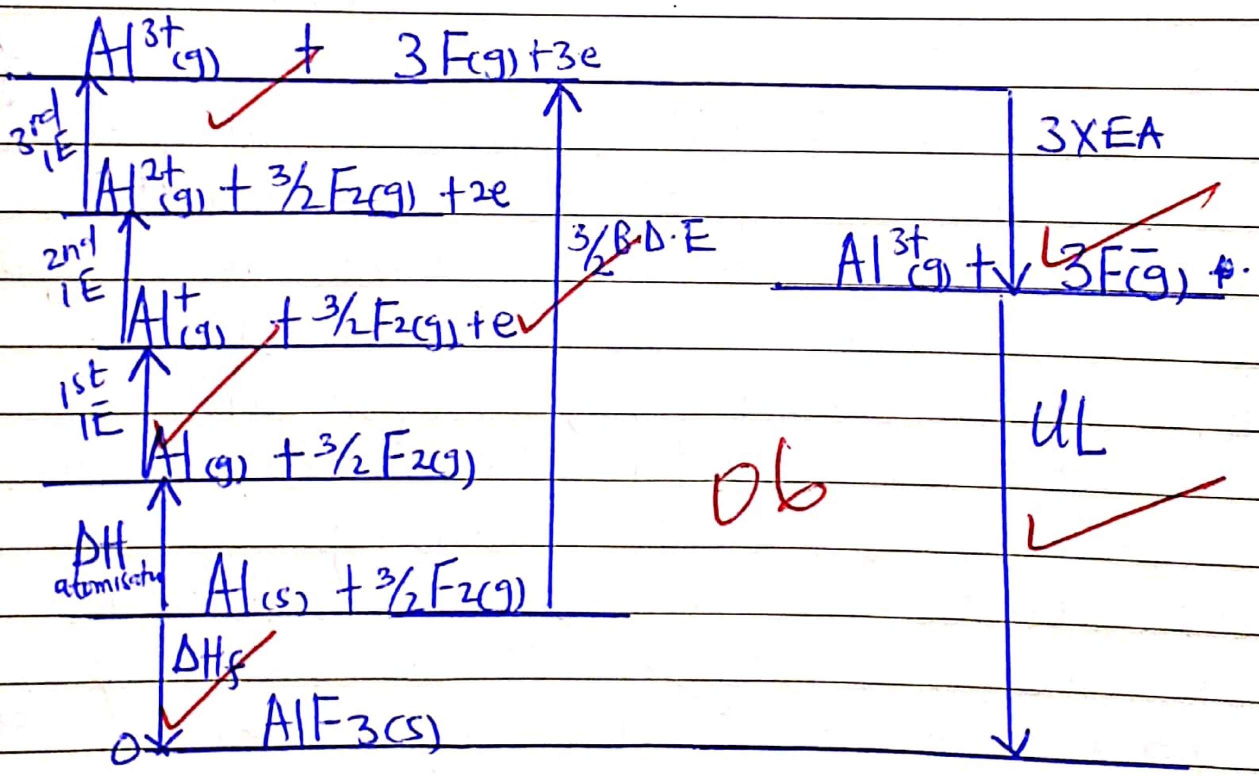
melting point, excellent insulator and protective layer.

ITEM 2

a) Born Haber | Energy level diagram.

Points to emphasize

- Correct physical states



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b) $UL = \Delta H_f - \Delta H_{atomisation\ of\ Al} + 1^{st} IE + 2^{nd} IE + 3^{rd} IE + \frac{3}{2} B.DE + 3 \times EA$

$UL = -1301 - (+314 + 577 + 1820 + 2740 + \frac{3}{2} 158 + 3 \times -348)$

$UL = -5945 \ KJmol^{-1}$. 04

c)

$\Delta H_{solution} = +\text{Lattice energy} + \text{Hydration energy}$.

$\Delta H_{solution} = +5945 + -4690 + (3 \times -364)$

$= +163 \ KJmol^{-1}$. 04

d) Thermodynamically feasible / spontaneous but Kinetically very slow.

(i)

High lattice energy making it stable non volatile at operating temperature.

Ionic, high charge density acting as an excellent fluxing action to break the Al–O bonds in Alumina.

Ability to lower melting point of cryolite dramatically.

Does not contaminate Aluminium during extraction.

(ii) Possibility of fluoride contamination of ground water if leached – Avoid dumping untreated / Neutralise with lime. 02

Very persistent solid waste; mitigation: Convert waste AlF_3 to other useful products like CaF_2

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ITEM 3

a) Graph. (03)

b) First ionisation energy generally increases from Sodium to Argon. However, there are some irregularities between Aluminium and Magnesium, Sulphur and Phosphorus. trend 01

Explanation;

Across the period, nuclear charge increases due to addition of a proton but electrons are added to the same principal shell hence shielding effect almost remains constant. Effective nuclear charge increases hence outermost electrons are held tightly to the nucleus and require higher energy to be removed hence first ionisation energy increases (05)

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c) Irregularities Mg and Al; P and S (01)

d) Mg $[Ne]3s^2$ and Al $[Ne]3s^2 3p^1$

Magnesium has fully filled 3s orbital that is more thermodynamically stable than the $3p^1$ orbital in Aluminium which is neither half filled or fully filled thus Magnesium has a higher value of first ionisation than Aluminium.

Sulphur and Phosphorus. 04

Phosphorus $[Ne]3s^2 3p^3$ and Sulphur $[Ne]3s^2 3p^4$

The $3p^3$ in Phosphorus is thermodynamically stable than the $3p^4$ in Sulphur which is neither half filled nor fully filled thus more energy is required ~~to~~ remove the outermost electron in ~~Magnesium~~ than Phosphorus than in Sulphur.

e) (i) Conductive layers; Aluminium because it is a good metallic conductor and has low ionisation energy

(ii) Semiconductor layers; Silicon because it has moderate ionisation energy with covalent network. (06)

(iii) Insulating / coatings; MgO ~~due~~ to high ionisation energy with strong ionic bonding or SiO_2 with giant covalent structure, high

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ITEM 4

a) Melting points and boiling points increase from Sodium to Aluminium. However; Silicon has an abnormally high value. It decreases generally from Phosphorus to Chlorine However, Sulphur has a higher boiling/ melting point than the rest. (01)

From Sodium to Aluminium;
They all have giant metallic structure which is held together by metallic bonds. The strength of metallic bond depends on the number of electrons contributed during metallic bonding hence Aluminium has the highest boiling / melting point.
Silicon is having an abnormally high melting / boiling point due to giant covalent structure held by strong covalent bonds that require high amounts of heat to be broken.
From Phosphorus to Chlorine,
All are having simple molecular structures holding together by vander waals forces.

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Strength of the vander waals increase with increase in molecular weight. Sulphur has a highest boiling/melting point because of S_8 which gives it stronger vander waals forces. Phosphorus exists as P_4 hence a higher boiling/melting than chlorine that exists as a diatomic Cl_2.

5½

b) $2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$

Sulphur does not react with water under normal conditions.

$Cl_{2(g)} + H_2O_{(l)} \rightleftharpoons HOCl_{(aq)} + HCl_{(aq)}$

c) $2Na_2O_{(s)} + 2H_2O_{(l)} \rightarrow 4NaOH_{(aq)}$.

$Na_2O_{(s)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

Na_2O is basic hence no reaction with Sodium hydroxide.

$SiO_{2(s)} + H_2O_{(l)} \rightarrow H_2SiO_{3(aq)}$.

SiO_2 is an acidic oxide hence no reaction with hydrochloric acid.

$SiO_{2(s)} + 2\bar{O}H_{(aq)} \rightarrow SiO_3^{2-}{}_{(aq)} + H_2O_{(l)}$

Al_2O_3 does not react with water at normal conditions.

$Al_2O_{3(s)} + 6HCl_{(aq)} \rightarrow 2AlCl_{3(aq)} + 3H_2O_{(l)}$.

$3H_2O_{(l)} + Al_2O_{3(s)} + 2\bar{O}H_{(aq)} \rightarrow 2Al(OH)_4^-{}_{(aq)}$ ~~$+ 2H_2O_{(l)}$~~.

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d) Basic Na_2O

Amphoteric Al_2O_3

Acidic SiO_2

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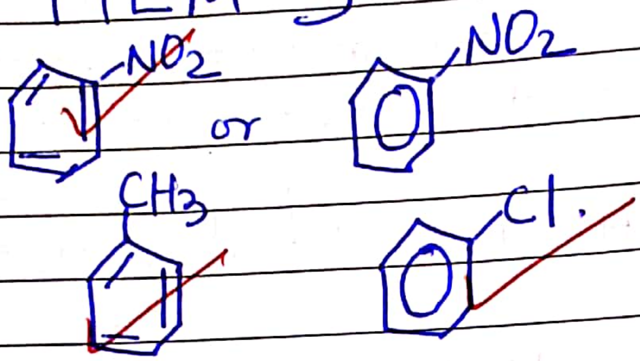
ITEM 5

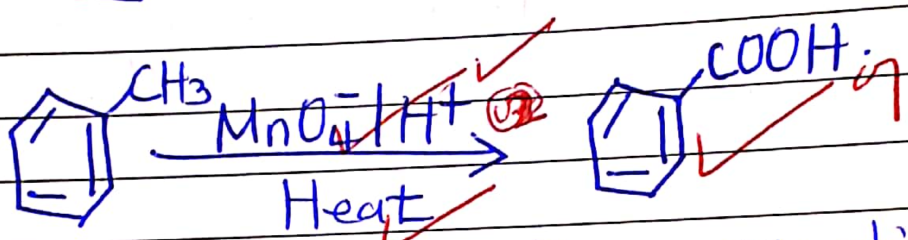
a)



Reject $C_6H_5-NO_2$
$-Cl$
CH_3.

$\boxed{03}$

b)(i)



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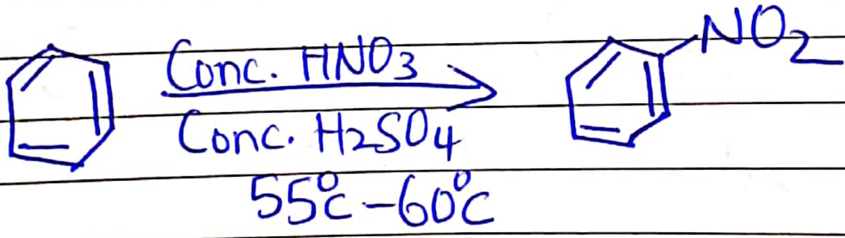
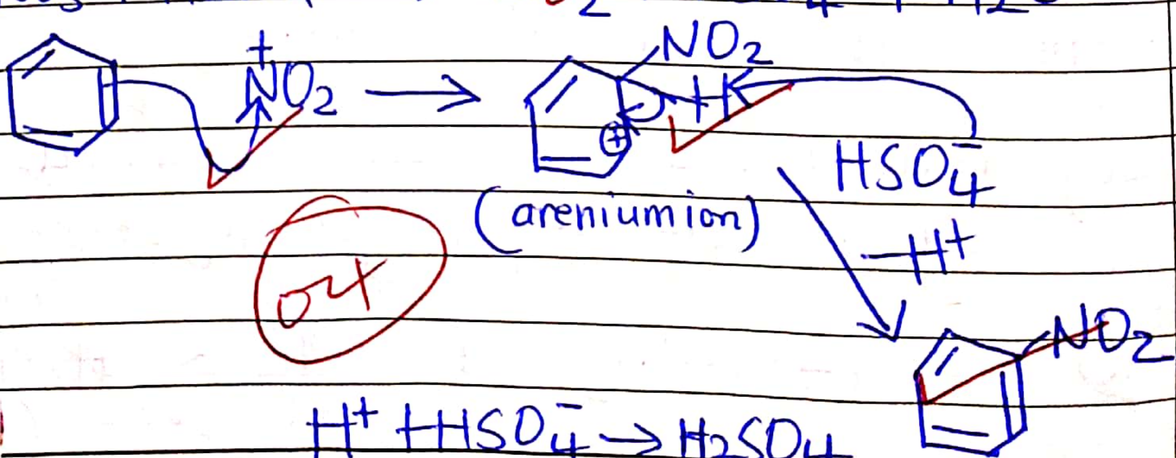
c) Benzene is heated with a nitrating equimolar mixture of conc. HNO_3 and conc. H_2SO_4 at $55°C - 60°C$.



Generation of electrophile.

$HNO_3 + H_2SO_4 \longrightarrow \overset{+}{N}O_2 + HSO_4^- + H_2O$.



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

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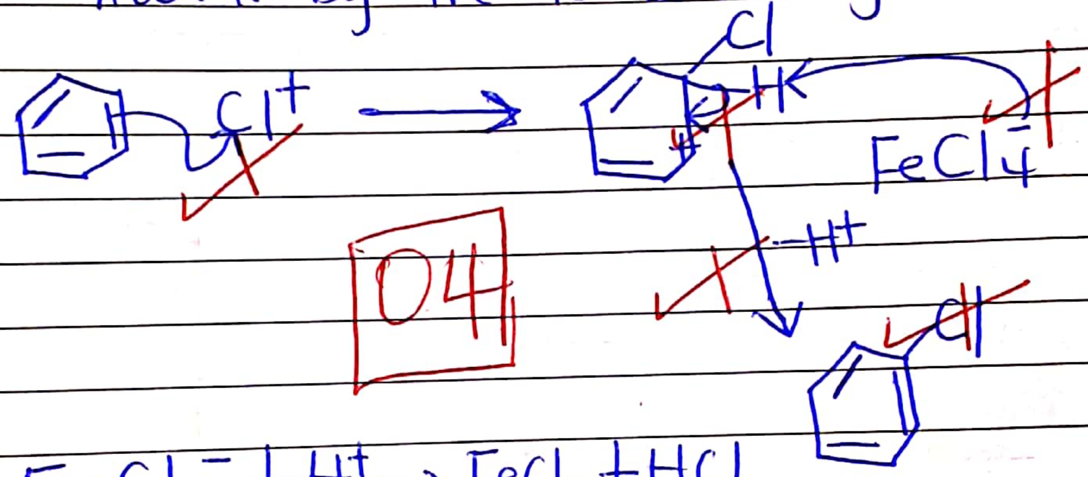
Benzene reacts with chlorine (dry) in presence of Lewis acid catalyst usually $AlCl_3$, $FeCl_3$ (Anhydrous) at a temperature of 30°C–50°C.

Generation of electrophile by the catalyst.

$Cl_2 + FeCl_3 \rightleftharpoons Cl^+ + FeCl_4^-$

Attack by the π electron system.



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$FeCl_4^- + H^+ \rightarrow FeCl_3 + HCl$

e) Making of military explosives upon polynitration.

07

Making of rubber antioxidants to prevent cracking in rubber tyres.

f) Inhalation of benzene causes dizziness, headache

Inhalation of nitrobenzene causes kidney damage and anaemia

03

Nitrobenzene is highly toxic to aquatic life causing death in fish. environment

Wear nitrile/viton gloves when handling benzene

Store flammable liquids in cool, well ventilated plac

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SECTION B Part II (ORGANIC).

ITEM 6

a) C_4H_6; Alkynes

C_4H_8; Alkenes.

Functional groups 04

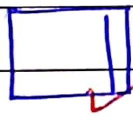
C_4H_6; carbon to carbon triple bond

C_4H_8; carbon to carbon double bond.

b) C_4H_6

$CH_3C \equiv CCH_3$; But-2-yne.

$CH_3CH_2C \equiv CH$; But-1-yne.

Any 3  cyclobutene. 03

$CH_2=CH-CH=CH_2$; Buta-1,3-diene

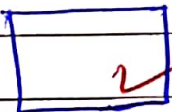
$CH_2=C=CHCH_3$; Buta-1,2-diene.

C_4H_8

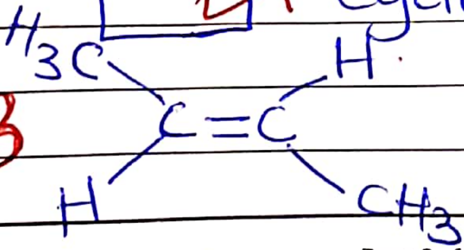
$CH_3CH=CHCH_3$; But-2-ene

$CH_3CH_2CH=CH_2$; But-1-ene

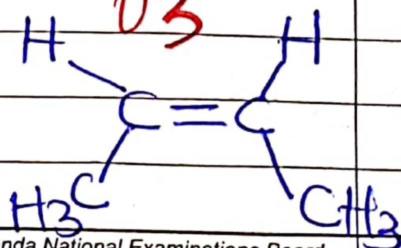
$(CH_3)_2C=CH_2$; 2-methylpropene

 cyclobutane. 03

Any 3



Transbut-2-ene.



Cis but-2-ene

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c) Structural isomerism eg chain isomerism.
Geometric isomerism (Stereoisomerism) eg in Cis and trans but-2-ene.
02

d) (i) $CH_3CH{=}CHCH_3 \xrightarrow{Br_2/H_2O} CH_3CH(OH)CH(Br)CH_3$
(Gas Y)

$CH_3C{\equiv}CCH_3 \xrightarrow{Br_2/H_2O}$

(ii)
$CH_3CH{=}CHCH_3 \xrightarrow{Br_2/CCl_4} CH_3CHBrCHBrCH_3$

$CH_3CH{=}CHCH_3 \longrightarrow CH_3\overset{+}{C}HCHBrCH_3 + Br^-$

$Br^{\delta+}-Br^{\delta-}$

$CH_3\overset{+}{C}HCHBrCH_3 \longrightarrow CH_3CHBrCHBrCH_3$

Br^-

03

(iii) $CH_3C{\equiv}CCH_3 \xrightarrow{H_2/\text{Lindlar's cat.}} CH_3CH{=}CHCH_3$

e) But-1-ene is used in manufacture of low density polyethene bags and films.

$CH_3CH{=}CHCH_3 \xrightarrow[\text{warm}]{H_2O/H^+} CH_3CH(OH)CH_2CH_3$

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UAC