ST ANDREW'S JUNIOR COLLEGE
JC2 PRELIMINARY EXAMINATIONS
HIGHER 2

CANDIDATE NAME	

CLASS	2	2	S		

CHEMISTRY **9729/02**

Paper 2 Structured Questions **30 August 2023**

Candidates answer on the Question Paper. **2 hours**

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work that you hand in.

Write in dark blue or black pen.

You may use a HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the **spaces provided** on the Question Paper.

The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use		
Q1		9
Q2		21
Q3		17
Q4		9
Q5		19
Total		75

1 (a) Table 1.1 lists the number of protons, neutrons and electrons in five different particles. Each particle may be an atom, an anion or a cation.

Table 1.1

particle	number of protons	number of neutrons	number of electrons
A	17	18	17
B	17	20	17
C	17	20	18
D	18	22	18
E	18	22	17
F	19	20	19
G	19	20	18

(i) Use the information in Table 1.1 to identify

- the two particles which are a pair of isotopes of the same element

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- the uncharged particle with no unpaired electrons

____ [2]

(ii) Deduce which particle, **F** or **G** is smaller. Explain your answer. [2]

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(b) Phosphorus pentachloride, PCl_5, is a useful reagent in organic synthesis. It exists in equilibrium with PCl_3 and chlorine gas as shown below:

$$PCl_5\,(g) \rightleftharpoons PCl_3\,(g) + Cl_2\,(g) \qquad \Delta H = +124\ \text{kJ mol}^{-1}$$

At equilibrium, at 200 °C and a total pressure of 5 atm, 40% of PCl_5 is dissociated.

(i) Write an expression for K_p for the above equilibrium. [1]

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(ii) Calculate a value for K_p at 200 °C and state its units. [2]

(iii) Predict and explain the effect of increasing the temperature on the value of K_p. [2]

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[Total: 9]

2 (a) Table 2.1 gives data about some physical properties of the elements potassium, calcium and iron.

Table 2.1

Property	potassium	calcium	iron
relative atomic mass	39.1	40.1	55.8
atomic radius (metallic) / nm	0.243	0.197	0.126
ionic radius (charge) / nm	0.138 (1+)	0.099 (2+)	0.061 (2+)
melting point / K	337	1112	1811
density / g cm^{-3}	0.89	1.54	7.87
electrical conductivity / 10^6 S m^{-1}	0.14	0.298	1.00

(i) Explain why the atomic radius of calcium is less than that of potassium. [2]

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(ii) Use relevant data from Table 2.1 to suggest why the density of calcium is greater than that of potassium. [2]
You may assume that both elements have the same packing arrangement of atoms.

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(iii) Describe the structure and bonding in calcium with the aid of a labelled diagram. [2]

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(b) The high conductivity of iron is a consequence of its electronic configuration.

(i) Complete the electronic configuration of an iron atom and Fe^{2+} ion. [1]

Fe $1s^2$ $2s^2 2p^6$ ________________

Fe^{2+} $1s^2$ $2s^2 2p^6$ ________________

(ii) Despite its high electrical conductivity, iron is rarely used in electrical wires, unlike copper. [1]

Apart from its physical properties, suggest a reason why iron is less preferred than copper in electrical wiring.

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(iii) Iron can form octahedral complexes. In an octahedral complex, the d subshell of a transtion metal ion is split into two energy levels. [1]

On the Cartesian axes in Fig. 2.1, draw a **fully-labelled** diagram of one d orbital at the lower energy level in an octahedral complex.

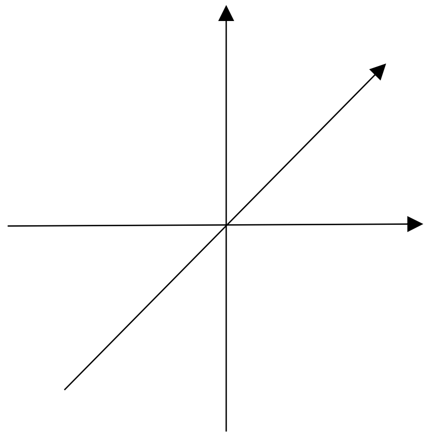

Fig. 2.1

(iv) Describe two ways in which compounds containing Fe^{2+} ions are different from those containing Ca^{2+} ions in terms of their chemical behaviour. [2]

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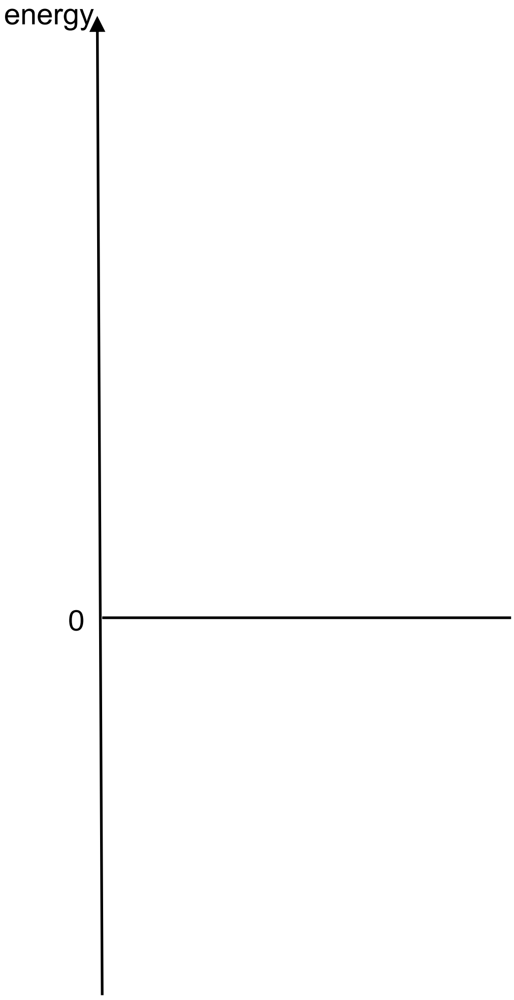
(c) Iron(II) compounds are generally only stable in neutral, non-oxidising conditions.

It is difficult to determine the lattice energy of FeO experimentally.

(i) Use data from the *Data Booklet* and relevant data in Table 2.2 to construct a labelled Born-Haber cycle to determine the enthalpy change of lattice energy of FeO(s). [3]

Table 2.2

	ΔH/kJ mol^{-1}
Enthalpy change of atomisation of Fe(s)	+416
Sum of first and second electron affinity of O(g)	+657
Enthalpy change of formation of FeO(s)	-272



(ii) State and explain how the lattice energy of FeO(s) compares to the lattice energy of CaO(s). [2]

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(iii) Most naturally occurring samples of iron(II) oxide are found as the mineral wüstite.

Wüstite has formula $Fe_{20}O_{\boldsymbol{x}}$. It contains both Fe^{2+} and Fe^{3+} ions.

90% of the iron is present as Fe^{2+} and 10% is present as Fe^{3+}.

Deduce the value of ***x***. [1]

(d) Heating of FeO results in the formation of Fe_3O_4, as shown.

$4FeO \rightarrow Fe + Fe_3O_4$ ------------------------**reaction 1**

Each formula unit of Fe_3O_4 contains one Fe^{2+} and two Fe^{3+} ions.

(i) Deduce the type of reaction in **reaction 1**. Explain your answer. [1]

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(ii) Molten Fe_3O_4 can be electrolysed using inert electrodes to form Fe.

Calculate the maximum mass of iron metal formed when molten Fe_3O_4 is electrolysed for six hours using a current of 50 A.

Assume the one Fe^{2+} and two Fe^{3+} ions are discharged at the same rate. [3]

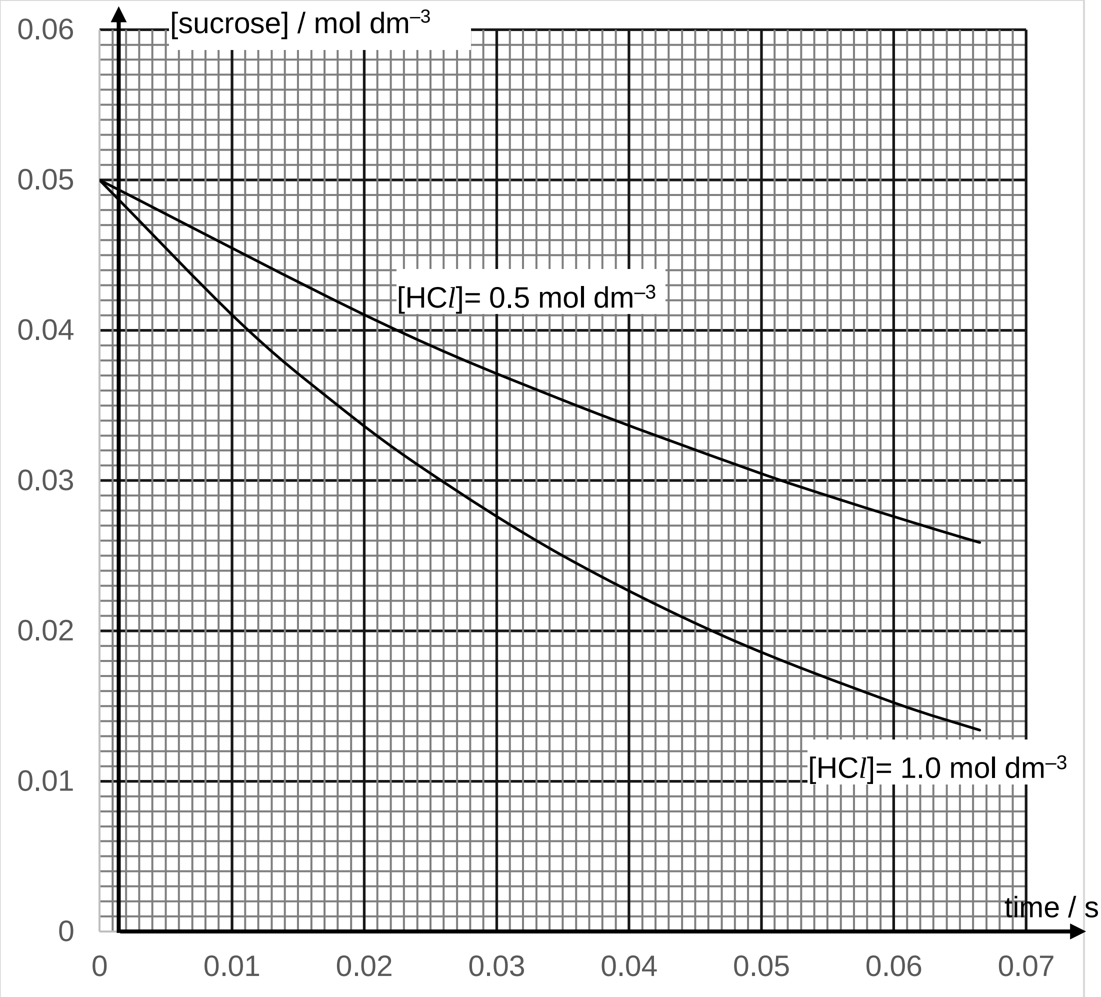
[Total: 21]

3 (a) Sucrose can be hydrolysed in the presence of dilute acids. This reaction can be represented by:

sucrose + water → glucose + fructose

In an investigation of the kinetics of this reaction, sucrose was reacted in two separate experiments with different concentrations of HC*l*.

The following graph was obtained with the initial concentration of sucrose in the reaction mixture = 0.05 mol dm^{-3}. The concentrations cited in the graph indicate the initial concentrations of each reagent in the reaction mixture.



(i) Use the graphs to determine the order of reaction with respect to [sucrose] and [HC*l*]. [3]

(ii) Write the rate equation for the hydrolysis of sucrose. [1]

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(iii) Calculate the rate constant, *k*, for this reaction. [1]

(iv) A third experiment was conducted with the following initial concentrations:

[sucrose] = 0.05 mol dm^{-3} and [HC*l*] = 1.0 x 10^{-6} mol dm^{-3}

Calculate the half-life of this reaction and sketch on the graph how [sucrose] would change with respect to time. [2]

(v) Sucrose in this question is represented by R_1-O-R_2.

Two possible mechanisms have been suggested for the hydrolysis of sucrose, mechanism A and mechanism B.

Mechanism A

$R_1\text{-O-}R_2 + H^+ \rightarrow R_1\text{-O-}R_2H^+$ slow step

$R_1\text{-O-}R_2H^+ + H_2O \rightarrow R_1\text{-OH} + R_2\text{-OH} + H^+$ fast step

Mechanism B

$R_1\text{-O-}R_2 \rightarrow R_1\text{-O}^- + R_2^+$ slow step

$R_2^+ + H_2O \rightarrow H^+ + R_2\text{-OH}$ fast step

$H^+ + R_1\text{-O}^- \rightarrow R_1\text{-OH}$ fast step

Based on your answer in **(a)(ii)**, which is the correct mechanism for the hydrolysis of sucrose? Explain your answer. [2]

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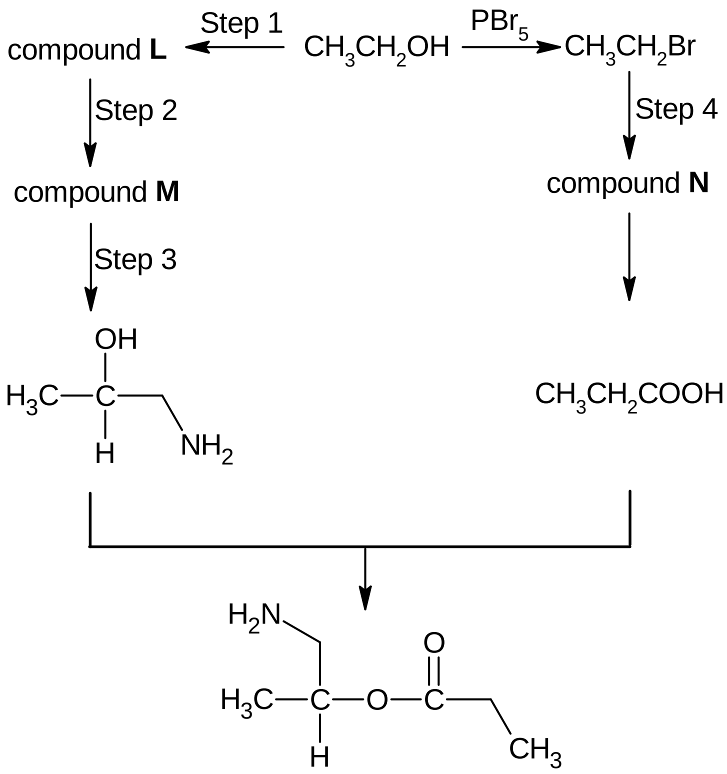
(b) Ethanol is one of the products from the fermentation of sucrose, and can be used to synthesise a variety of chemicals.

Fig. 3.1 shows the synthesis of a compound **K** from ethanol.



compound **K**

Fig. 3.1

(i) Draw the structures of compounds **L**, **M**, and **N**. [3]

Compound **L**	Compound **M**	Compound **N**

(ii) Suggest the reagents and conditions for Steps 1, 2, 3 and 4. [4]

	Reagents and conditions
Step 1	
Step 2	
Step 3	
Step 4	

(iii) Explain why compound **K** is soluble in water. [1]

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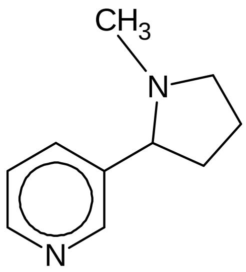
[Total: 17]

4 Nicotine is a stimulant found in the leaves of the tobacco plant. It is a highly addictive substance present in products such as cigarettes, cigars and chewing tobacco.



nicotine

(a) Nicotine has a chiral carbon and can exist as two enantiomers.
Suggest why it is important to ensure the correct enantiomer of nicotine is used in commercial products. [1]

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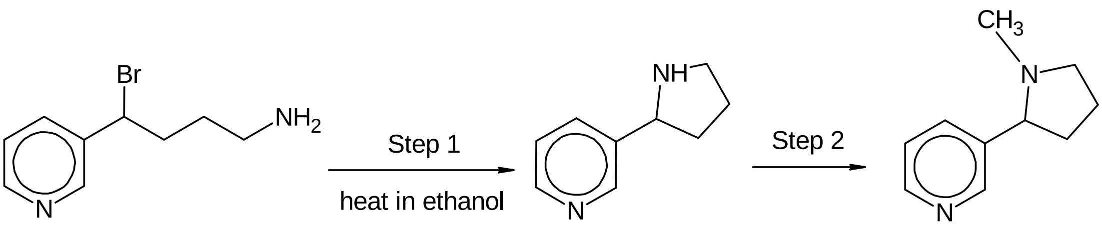
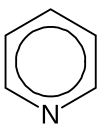
(b) While nicotine occurs naturally in tobacco, it can also be synthetically produced. Fig. 4.1 shows the synthesis of nicotine from an optically active compound **A** ($C_9H_{13}BrN_2$).



compound **A** racemic mixture of intermediate **X** nicotine

Fig. 4.1

(i) Other than pyridine, identify the functional groups in compound **A**.

Structure of pyridine 

[1]

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(ii) Suggest the reagents and conditions required for step 2. [1]

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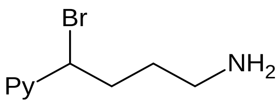
(iii) In step 1, a racemic mixture of products was formed. [3]

Complete Fig. 4.2 to name and suggest a mechanism for this reaction. Show the relevant dipoles, charges, and structure of the intermediate formed. Indicate the movement of electron pairs by using curly arrows, as well as the slow step.

You may represent compound **A** as 

Name of mechanism: …………………………………..

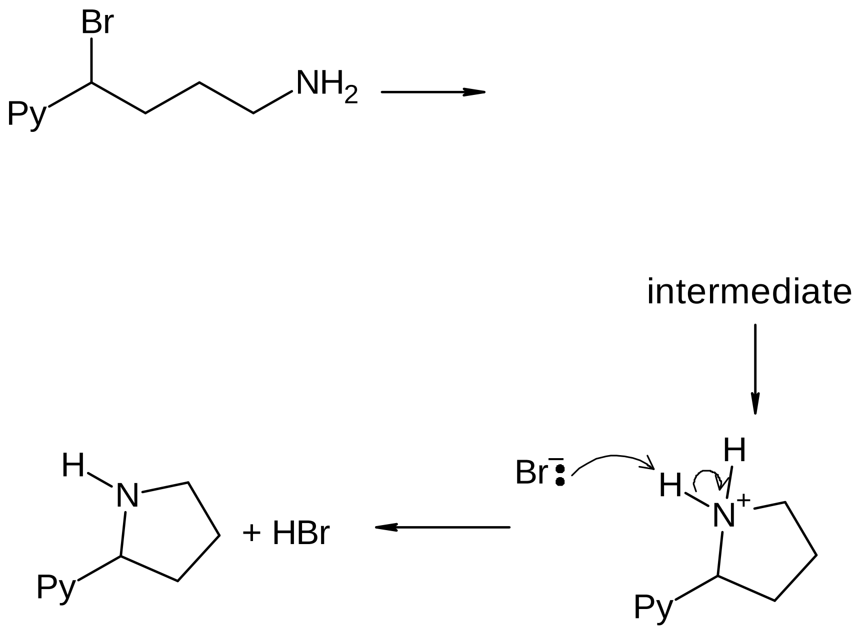
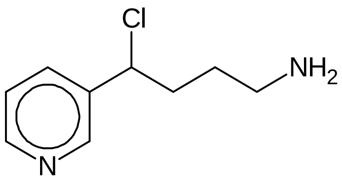


Fig. 4.2

(c) Compound **B** can also be used as the starting material in the reaction scheme in Fig. 4.1 to synthesise nicotine.



compound **B**

Suggest a reason why compound **B** as the starting material to synthesise nicotine is less preferred as compared to compound **A**. [1]

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(d) Carbocations frequently undergo structural changes, called rearrangements, to form more stable ions as shown in Fig. 4.3.

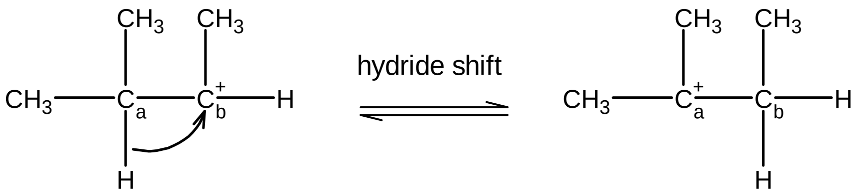
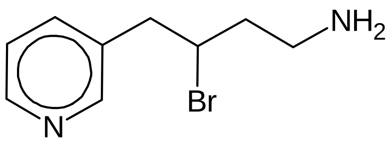


Fig. 4.3

(i) Compound **C** is a constitutional isomer of compound **A** which can also be used as a reactant in Fig. 4.1, forming intermediate compound **X**.



compound **C**

By considering the relative stabilities of the carbocation intermediates, explain why hydride shift would readily occur when compound **C** is used. [1]

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(ii) Compound **C** can undergo the same reaction as compound **A** to form intermediate compound **X**.

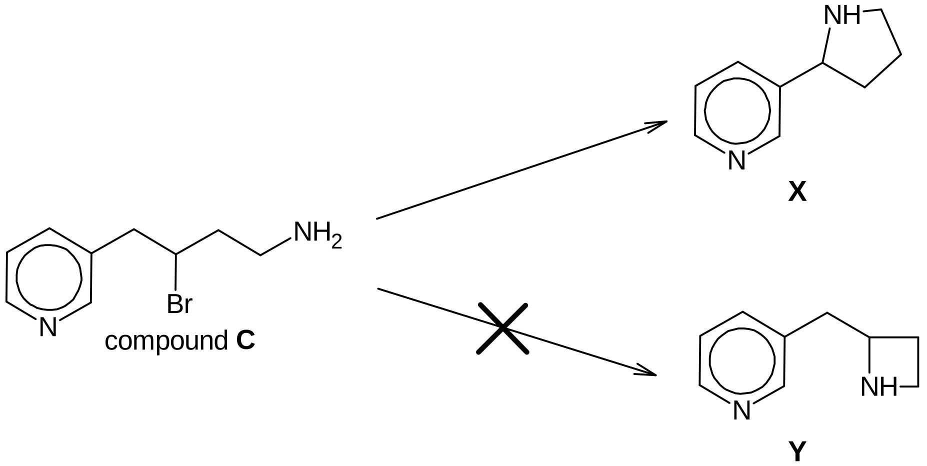

Fig. 4.4

By considering the structures of intermediate compounds **X** and **Y** in Fig. 4.4, suggest why intermediate compound **Y** is not formed. [1]

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[Total: 9]

5 Refrigerants are cooling agents that absorb and release heat in a refrigerator or air-conditioning unit. Common refrigerants are simple covalent molecules such as hydrocarbons like propane, hydroflurocarbons (HFCs) etc, and they exist in both the gaseous and liquid phases in a refrigerator.

(a) State the three basic assumptions of the kinetic theory as applied to an ideal gas. [2]

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(b) The refrigeration cycle in a refrigerator works based on the principles of heat transfer and phase change as it circulates through different components of the system as shown in Fig. 5.1.

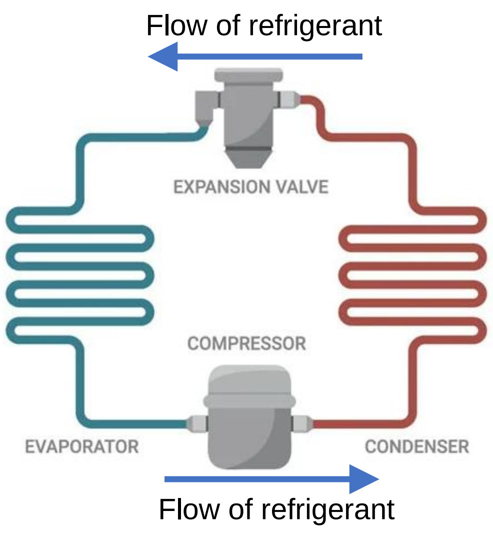

Fig. 5.1

1. At the compressor, the gaseous refrigerant is compressed, increasing the temperature of the refrigerant.
2. The high-pressure, high-temperature refrigerant then flows into the condenser coils located at the back or bottom of the refrigerator and comes into contact with a cooling medium such as air. Heat is released to the surroundings during this process, causing the refrigerant to condense and cool down.
3. The high-pressure liquid refrigerant passes through an expansion valve.
4. The low-pressure, low-temperature refrigerant mixture enters the evaporator coils and reduces the temperature of the contents (e.g. food) of the refrigerator. The refrigerant vaporises after absorbing the heat.
5. The gaseous refrigerant returns to the compressor and the refrigerator cycle repeats.

(i) Describe, in terms of kinetic theory of gases, the change in the behaviour of the gas particles when the refrigerant passes through the compressor. [1]

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(ii) Explain, in terms of kinetic theory of gases, why the gaseous refrigerant is condensed when in contact with the cooling medium at the condenser. [2]

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(iii) Explain, in terms of intermolecular forces, why liquid refrigerants vaporise at the evaporator. [2]

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(iv) Explain why an ideal refrigerant should have a high enthalpy change of vaporisation. [1]

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(c) Table 5.1 shows a list of possible refrigerants. An ideal refrigerant has the following features:

- Low Ozone Depletion Potential
- Low Global Warming Potential
- Non-flammable
- Non-toxic

Table 5.1

Compound	ΔH_{vap}	**Ozone Depletion Potential**	**Global Warming Potential**	**Flammability**	**Toxicity**
Chloroethene, C_2H_3Cl	High	Low	Low	Flammable	High
Dichlorodifluoromethane, CCl_2F_2	High	High	High	Non-flammable	Low
Isobutane, $CH(CH_3)_3$	High	Low	Low	Flammable	Low
Oxygen, O_2	Low	Low	Low	Non-flammable	Low
1,1,1,2 -Tetrafluoroethane, CF_3CH_2F	High	Low	High	Non-flammable	Low
Water, H_2O	High	Low	Low	Non-flammable	Low

(i) Of the list of compounds in Table 5.1, water has the highest melting point of 0 ºC. Explain. [1]

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(ii) Suggest why water is not suitable as a refrigerant for temperatures below 0 °C. [1]

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(iii) Explain why 1,1,1,2-tetrafluoroethane, CF_3CH_2F, has lower ozone depletion potential compared to dichlorodifluoromethane, CCl_2F_2. [1]

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(iv) Which of the compounds in Table 5.1 would you choose as a refrigerant? Explain your choice and suggest how its drawbacks could be mitigated. [2]

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(d) In the past, industrial refrigerators usually are made of common materials such as copper and iron. However, the use of ammonia as the refrigerant has many issues.

(i) Liquid ammonia behaves similarly to water and undergoes auto-ionisation to form ammonium as one of the products. Construct an equation to illustrate this behaviour of liquid ammonia. [1]

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(ii) One of the main issues with the use of ammonia together with iron piping in the refrigerators is the formation and accumulation of hydrogen gas. Suggest the role of iron in the formation of hydrogen gas. [1]

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(iii) A leak of the refrigerant in old refrigerators made in 1800s would often result in a blue solution being found at the collection tray at the bottom of the refrigerator.

Explain, with the aid of the *Data Booklet*, how the blue solution is formed. [2]

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(iv) Ammonia, NH_3, is commonly used in modern industrial refrigeration systems utilising plastic components as it has no effect on the ozone layer.

Suggest, with a reason, why ammonia has zero ozone depletion potential. [1]

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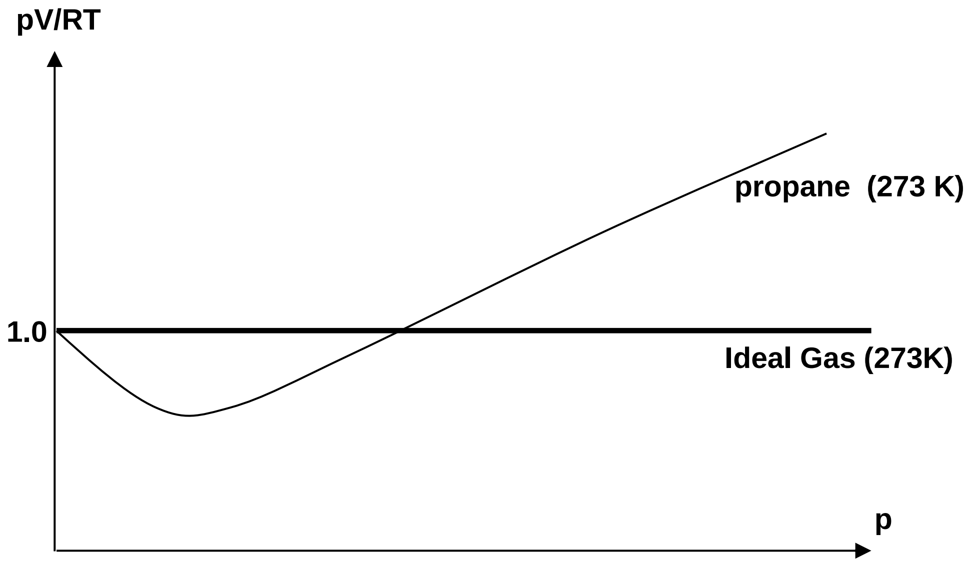
(v) The plots of pV/RT against p for one mole of an ideal gas and one mole of propane at 273 K are given below.

On the same diagram, sketch a curve for the behaviour of 1 mol of ammonia at 273 K. [1]



[Total: 19]

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