

**CHEMISTRY
PAPER II**

Question 1

a. Methylpropane ($\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_3$), is saturated hydrocarbon commonly used in the petrochemical industry.

i. State fully what is meant by a saturated hydrocarbon.

[1]

ii. Give the empirical formula of methylpropane.

[1]

iii. Methylpropane reacts with chlorine, Cl_2 , in the presence of ultraviolet light, forming two isomers of $\text{C}_4\text{H}_9\text{Cl}$.

Draw the skeletal formulae of these two isomers.

[2]

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iv. Name the mechanism of the reaction in (a) (iii).

[1]

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- v. Methylpropane is an alkane. Alkanes are generally unreactive.
Explain why alkanes are generally unreactive towards polar reagents such as acids and alkalis.

[2]

- b. Organic compounds can undergo different types of chemical reaction. Table 1.1 shows three reactions involving organic compounds.

Table 1.1

Reaction	Equation
I	$\text{CH}_3\text{CH}=\text{CHCH}_3 + \text{Br}_2 \rightarrow \text{CH}_3\text{CHBr}-\text{CHBrCH}_3$
II	$\text{CH}_3\text{CH}_2\text{Cl} + \text{NaOH} \rightarrow \text{CH}_3\text{CH}_2\text{OH} + \text{NaCl}$
III	$\text{CH}_3\text{CH}_2\text{Cl} + \text{NaOH} \rightarrow \text{CH}_2=\text{CH}_2 + \text{NaCl} + \text{H}_2\text{O}$

- i. The organic reactant in reaction I is but-2-ene.
Explain the origin of geometrical isomerism in but-2-ene.

[2]

- ii. Identify the chiral centres in the product of reaction I.

[1]

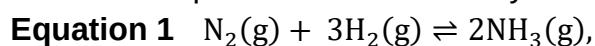
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- iii. State one difference in the conditions used in reactions II and III.
Explain why different products are formed in these reactions.

[2]

Question 2

- a. In the Haber process, ammonia gas is synthesized from its constituent elements as shown in equation 1. An iron catalyst is used in this process.



- i. State Le Chatelier's principle.

[1]

- ii. Write the equilibrium constant expression (K_p) for the synthesis of ammonia shown in Equation 1.

[1]

- b. In an industrial reactor at a temperature of 400 °C, the equilibrium partial pressures of nitrogen and hydrogen are 2.50×10^6 Pa and 7.50×10^6 Pa respectively. Given that $K_p = 4.32 \times 10^{-15} \text{ Pa}^{-2}$

- i. At this temperature, calculate the equilibrium partial pressure of ammonia.

[2]

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- ii. The forward reaction in Equation 1 is exothermic. A student suggests that increasing the temperature would increase the rate of reaction and therefore increase the yield. Use Le Chatelier's principle to explain this. [1]

- c. $\text{NH}_3(\text{g})$ dissolves in water to form an alkaline solution. In this solution, $\text{NH}_3(\text{aq})$ is in equilibrium with its conjugate acid. Identify the conjugate acid of NH_3 . [1]

- d. $\text{NH}_3(\text{aq})$ reacts with dilute nitric acid to form a salt.

- i. Write an equation for this reaction. Include state symbols. [1]

- ii. In an experiment, 23.40 cm^3 of $\text{NH}_3(\text{aq})$ reacted exactly with 25.00 cm^3 of $0.025 \text{ mol dm}^{-3}$ dilute nitric acid. Calculate the pH value of dilute nitric acid solution. [1]

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- iii. Determine the concentration of $\text{NH}_3(\text{aq})$ in d(ii). [2]

Question 3

a. Transition elements play an important role in biochemistry and industrial synthesis due to their ability to form complex ions and act as catalysts.

i. State the full electronic configuration of the copper (II) ion, Cu^{2+} . [1]

ii. Explain why transition metal complexes are typically coloured. Your answer should refer to d-orbital splitting and electronic transitions. [2]

b. Figure 3.1 shows a series of ligand substitution reactions starting from the hexaaquacopper(II) complex.

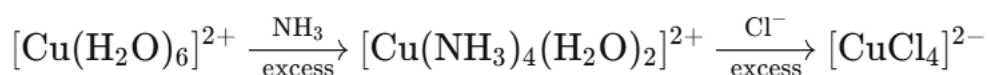


Figure 3.1

i. Identify the ligand in the final complex, $[\text{CuCl}_4]^{2-}$. [1]

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ii. State the shape of $[\text{CuCl}_4]^{2-}$. [1]

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iii. Complete Table 3.1 to show the colours of the three complexes in Figure 3.1. [2]

Table 3.1

Complex	Colour
$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$	
$[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$	
$[\text{CuCl}_4]^{2-}$	

- c. The complex $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ is heated gently, forming a precipitate of $\text{Cu}(\text{OH})_2$. This precipitate is then added to concentrated hydrochloric acid, forming the complex $[\text{CuCl}_4]^{2-}$.

Construct a balanced equation for the overall reaction starting from $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ and ending with $[\text{CuCl}_4]^{2-}$.

[2]

- d. Platinum forms square-planar complexes. The complex $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ exists as two isomers.

- i. Draw the structures of the two isomers of $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$.

[2]

- ii. By comparison with a similar type of isomerism in organic chemistry, suggest the name of this type of isomerism.

[1]

- e. Copper forms two series of compounds, one containing copper (II) ions and the other containing copper (I) ions.

Explain why Copper (II) salts are usually coloured and Copper (I) salts are usually white or colourless?

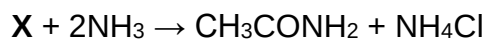
[2]

Question 4

- a. Amines, amides, and amino acids are all types of molecules that contain nitrogen atoms.

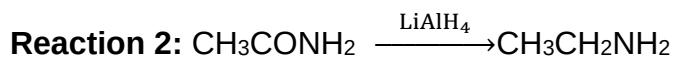
The reaction below shows the synthesis of ethanamide at room temperature.

X is the starting material in the reaction.



- i. Suggest the possible molecular formula of **X**. [1]

- ii. Ethanamide reacts with LiAlH_4 as shown in Reaction 2.



- State the role of LiAlH_4 in Reaction 2. [1]

- iii. The product of Reaction 2, $\text{CH}_3\text{CH}_2\text{NH}_2$, reacts with ethanoyl chloride to form a secondary amide.

Draw the structure of this secondary amide.

[1]

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- b. Figure. 4.1 shows the general representation of an amino acid.

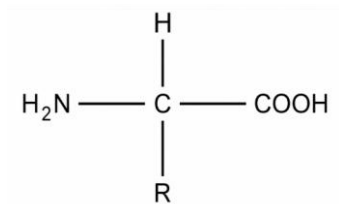


Figure. 4.1

- i. Determine the systematic name of the amino acid in Figure 4.1 where R = CH₃.

[1]

- ii. The amino acid in Figure 4.1, where R = CH₃, reacts with dilute HCl (aq). Draw the structure of the organic product formed by this reaction.

[1]

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- iii. Construct an equation for the reaction the amino acid in Figure 4.1, where R = CH₃, with dilute NaOH(aq).

[1]

- iv. Two molecules of the amino acid in Figure 4.1, where $R = CH_3$, react together to form a dipeptide.

Draw the structure of this dipeptide.

[2]

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- c. A pharmaceutical company wants to synthesize ethylamine to use in various products.

- i. Describe how ethylamine can be prepared from a halogenoalkane.

[1]

- ii. State the necessary reagents and conditions.

[1]

- iii. Construct a balanced equation for the reaction.

[1]

Question 5

- a. A group of students investigates different solutions to determine how solute-solvent interactions affect the physical properties of the solution.

i. Define the term colligative property.

[1]

- ii. An aqueous solution contains volatile component A and a volatile solvent B. At 298 K, the vapour pressure of pure A is 120 kPa and the vapour pressure of pure B is 80 kPa. Calculate the total vapour pressure of an ideal mixture where the mole fraction of A is 0.40.

[2]

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- b. Solution **C** is prepared by dissolving 4.50 g of a non-volatile, non-electrolyte solid solute in 125.00 g of pure water. The boiling point of the solution is measured to be 100.31 °C.

i. Calculate the boiling point elevation, ΔT_b , of C.

[1]

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- ii. Determine the molality of solution C.
Use the boiling point elevation constant for water, $K_b = 0.512 \text{ K kg mol}^{-1}$. [2]

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- iii. Calculate the molar mass of the solute. [1]

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- c. The same mass of solute (4.50 g) is dissolved in the same mass of water (125.00 g). However, the solute is now an electrolyte that dissociates into 2 ions per formula unit.

- i. State the expected effect of this on the boiling point of the solution compared to solution C. [1]

- ii. Explain your answer to (c) (i). [1]

Question 6

- a. Mass spectrometry and proton (^1H) NMR are useful techniques for analysing molecules.

A student analyses compound **P**, $\text{C}_2\text{H}_6\text{O}$, using mass spectrometry.

Figure 6.1 shows the mass spectrum obtained for **P**.

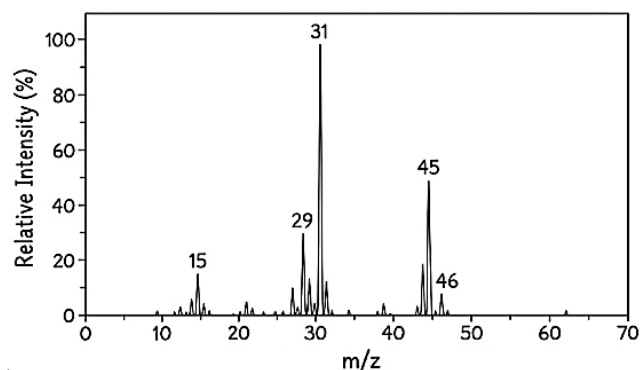


Figure 6.1

- i. Write the $\frac{m}{e}$ value of the molecular ion (M^+) peak of Compounds **P**. [1]

- ii. Identify the fragment ions responsible for the peaks at $\frac{m}{e} = 29$ and at $\frac{m}{e} = 31$. [2]

- iii. The $[\text{M}+1]^+$ peak in the spectrum in Figure 6.1 is very small.
Give the $\frac{m}{e}$ value of the $[\text{M}+1]^+$ peak. Identify the isotope responsible for this signal. [1]

- iv. Compound P has two possible structural isomers. Deduce the structure of the isomer that would give the mass spectrum in Figure 6.1. Explain your answer using the fragment ions identified in (a) (ii).

[2]

- b. A student analyses compound **Q**, $C_4H_8O_2$, using both mass spectrometry and proton (^1H) NMR spectroscopy. The spectra are shown in Figure 6.2 and Figure 6.3.

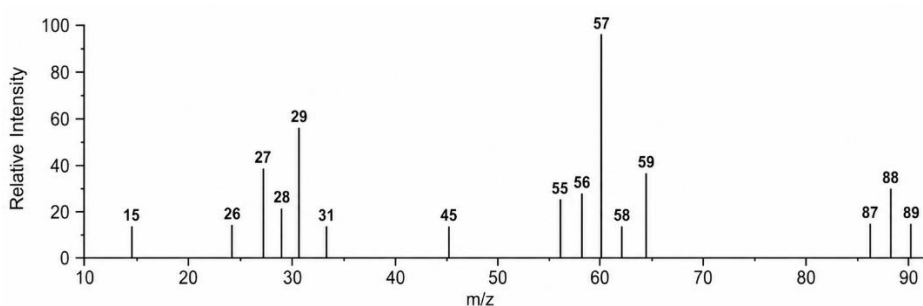


Figure 6.2

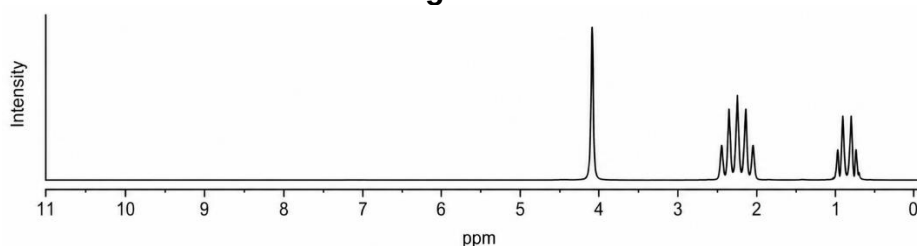


Figure 6.3

- i. Deduce the structure of **Q** using the information given to you in Figure 6.2 and in Figure 6.3. Explain your answer fully.

[4]

- ii. State the number of signals that would be present in the ^{13}C NMR spectrum of Q. Explain your answer. [1]

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- iii. State the purpose of using tetramethylsilane (TMS) as a standard in NMR spectroscopy. [1]

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- iv. Explain why the solvent used for obtaining the ^1H NMR spectrum must be deuterated (e.g., CDCl_3). [1]

The Periodic Table of Elements

Group																															
1	2	Key												13	14	15	16	17	18												
		atomic number atomic symbol name relative atomic mass												1 H hydrogen 1.0						2 He helium 4.0											
3	4													5	6	7	8	9													
Li lithium 6.9	Be beryllium 9.0													B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0													
Na sodium 23.0	Mg magnesium 24.3													Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5													
11	12													13	14	15	16	17	18												
K potassium 39.1	Ca calcium 40.1													Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9													
37	38													49	50	51	52	53	54												
Rb rubidium 85.5	Sr strontium 87.6													In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xeron 131.3												
55	56													81	82	83	84	85	86												
Cs caesium 132.9	Ba barium 137.3													Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —												
87	88													113	114	115	116	117	118												
Fr francium —	Ra radium —													Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganesson —												
lanthanoids		57	La lanthanum 138.9	58	Ce cerium 140.1	59	Pr praseodymium 140.9	60	Nd neodymium 144.4	61	Pm promethium —	62	Sm samarium 150.4	63	Eu europium 152.0	64	Gd gadolinium 157.3	65	Tb terbium 158.9	66	Dy dysprosium 162.5	67	Ho holmium 164.9	68	Er erbium 167.3	69	Tm thulium 168.9	70	Yb ytterbium 173.1	71	Lu lutetium 175.0
actinoids		89	Ac actinium —	90	Th thorium 232.0	91	Pa protactinium 231.0	92	U uranium 238.0	93	Np neptunium —	94	Pu plutonium —	95	Am americium —	96	Cm curium —	97	Bk berkelium —	98	Cf californium —	99	Es einsteinium —	100	Fm fermium —	101	Md mendelevium —	102	No nobelium —	103	Lr lawrencium —

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