2025 JC2 Prelims H2 P2 (Review)

1 In 1932, the American chemist Linus Pauling developed the most common scale of relative electronegativity (EN) values for the elements. The Pauling EN values of elements can be used to predict the chemical properties of compounds. The EN values of four Period 3 elements are given in Table 1.1.

Table 1.1

Element	Sodium	Aluminium	Phosphorus	Chlorine
Pauling EN value	0.93	1.61	2.19	3.16

(a) (i) Explain the difference in the Pauling electronegativity values of Na and C*l*. [2]

Comparing sodium and chlorine, [✓] chlorine has a higher nuclear charge due to larger number of protons, [✓] Screening effect remains approximately constant as electrons are added to the same electronic shell.

[✓] As there is stronger attraction between the nucleus and the bonding electrons in the outer shell, chlorine has higher [✓] electronegativity, resulting in a larger EN value.

2[✓] = [1]

The ionic character of a bond is directly related to the electronegativity difference (ΔEN) between the bonded atoms. Fig. 1.1 shows the plot of percent ionic character against ΔEN for NaC*l*.

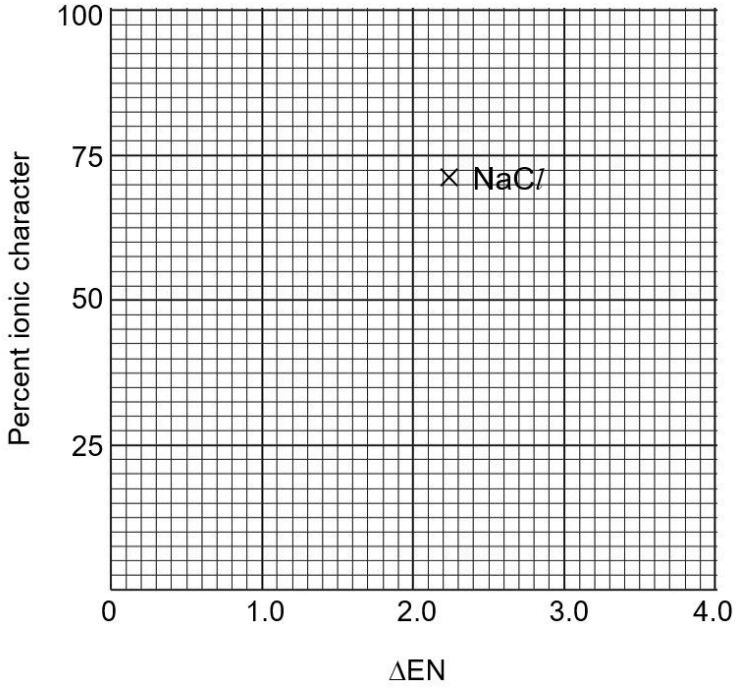


Fig. 1.1

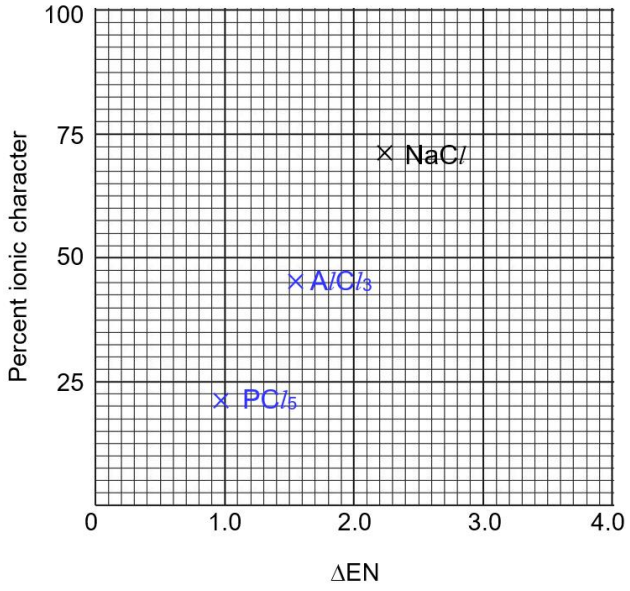
(ii) Using the values in Table 1.1, calculate ΔEN for $AlCl_3$ and PCl_5 respectively. Hence plot the percent ionic character of $AlCl_3$ and PCl_5 on Fig. 1.1. Label your points clearly. [2]

ΔEN for $AlCl_3$ = 3.16 – 1.61 = 1.55 [✓]

ΔEN for PCl_5 = 3.16 – 2.19 = 0.970 [✓]

2[✓] = [1]

[1] Correct relative order for percent ionic character for the three compounds



(iii) Explain the difference in bonding for NaCl and PCl_5 in terms of electronegativity. [2]

[1] Ionic bonds exist in NaCl due to large ΔEN (or large difference in electronegativities) between Na and Cl.

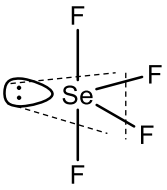
[1] Covalent bonds exist in PCl_5 due to small ΔEN (or small difference in electronegativities) between P and Cl.

(b) (i) The polarity of bonds in covalent molecules is also affected by ΔEN. SeF_4 and BrF_3 are two fluorine-containing molecules. State whether SeF_4 or BrF_3 contains covalent bonds with a higher ionic character. [1]

[1] SeF_4 > BrF_3

(ii) Using VSEPR theory, predict and explain the shape and bond angles of SeF_4. Illustrate the shape of SeF_4 with an appropriate diagram. [3]

There are [✓] 4 bond pairs and 1 lone pair in the valence shell of Se atom. [✓] To minimise repulsion and maximise stability, the shape of SeF_4 is [✓] see-saw.



[✓]

Since [✓] lone pair – bond pair repulsion > bond pair – bond pair repulsion, the [✓] bond angles are 88º and 118º *(accept other bond angles < 90º and < 120º).*

2[✓] = [1]

[Total: 10]

2 PCl_5 is a Period 3 chloride commonly used as a chlorinating agent and catalyst in making organic compounds. Industrial production of PCl_5 involves the reaction of Cl_2 with PCl_3.

Reaction (1) $PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$

(a) Suggest, with an explanation, how the position of equilibrium and the composition of the equilibrium mixture might change when chlorine is added to the equilibrium system. [2]

By Le Chatelier's Principle, the [✓] position of equilibrium will shift right to [✓] decrease the concentration of Cl_2. The equilibrium mixture will contain [✓] more PCl_5, less PCl_3 and [✓] more Cl_2.

2[✓] = [1]

x mol of Cl_2 gas is added to a 2 dm^3 vessel containing an equilibrium system of 0.4 mol of PCl_3, 0.25 mol of Cl_2 gas and 1.2 mol of PCl_5. The new equilibrium amount of PCl_5 is 1.28 mol.

(b) **(i)** Write the K_c expression for reaction (1), giving its units. [1]

[1] $K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]}$, $mol^{-1}dm^3$

(ii) Using the information given above, calculate K_c. [1]

$K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]} = \frac{\left(\frac{1.2}{2}\right)}{\left(\frac{0.4}{2}\right)\left(\frac{0.25}{2}\right)}$ = 24.0 $mol^{-1}dm^3$ [1]

(iii) Hence calculate x, the amount of Cl_2 added. [2]

	$PCl_3(g)$ +	$Cl_2(g)$ ⇌	$PCl_5(g)$
Initial amount /mol	0.4	0.25 + x	1.2
Change in amount /mol	-y	-y	+y
Equilibrium amount /mol	0.4 – y = 0.32	0.25 + x – y = 0.17 + x	1.28

[1] ICE Table Working

y = 1.28 – 1.2 = 0.08

$K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]} = \frac{\left(\frac{1.28}{2}\right)}{\left(\frac{0.32}{2}\right)\left(\frac{0.17+x}{2}\right)}$ = 24

x = 0.163 mol [1]

(c) Period 3 oxides follow a similar trend in bonding as the Period 3 chlorides.

Describe the action of water on the oxides of sodium, aluminium and phosphorus, write equations for any reactions that occur, and suggest the pH of each solution formed. [3]

Na_2O [✓] reacts vigorously with water to give a strongly alkaline solution of NaOH(aq) with a [✓] pH = 13.

[✓] $Na_2O + H_2O \rightarrow 2NaOH$

P_4O_{10} [✓] reacts vigorously with water to give a strongly acidic solution of

$H_3PO_4(aq)$ with a [✓] pH = 2.

[✓] $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$

[✓] Al_2O_3 does not react with water due to its high lattice energy. Hence Al_2O_3 is insoluble in water. [✓] pH = 7

3[✓] = [1]

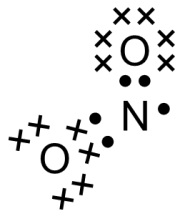
6[✓] = [2]

8[✓] = [3]

[Total: 9]

3 **(a)** Nitrogen exhibits a range of oxidation numbers in its compounds. A few of such species are NO, N_2O, NO_2, N_2 and NH_2OH.

(i) Draw the dot-and-cross diagram for NO_2. [1]



[1]

0.074 g of hydroxylamine, NH_2OH, is dissolved in water. Excess solution of acidified iron(III) salt is added to the dissolved hydroxylamine to form a nitrogen-containing product and iron(II) ions. The iron(II) ions produced requires 44.8 cm^3 of 0.02 mol dm^{-3} acidified potassium manganate(VII) for complete reaction.

The reacting ratio of iron(II) ions and manganate(VII) ions is 5:1.

(ii) Calculate the amount of iron(III) reacted with hydroxylamine. [1]

Amount of manganate used = (44.8/1000) x 0.02 = 0.000896 mol

Amount of iron(II) produced = 0.000896 x 5 = 0.00448 mol

$Fe^{2+} \equiv Fe^{3+}$

Amount of iron(III) reacted with hydroxylamine = 0.00448 mol [1]

(iii) Determine the oxidation state of the nitrogen atom in the nitrogen-containing product. Hence deduce the identity of the nitrogen-containing product. [2]

Amount of hydroxylamine used = 0.074 / 33 = 0.00224 mol

Reduction: $Fe^{3+} + e^- \rightarrow Fe^{2+}$

Hence $2Fe^{3+} \equiv NH_2OH \equiv 2e^-$

Oxidation of 1 NH_2OH loses $2e^-$, so final oxidation state of nitrogen in product = – 1 + 2 = +1 [1 with clear working]

[1 with clear working] N_2O

(iv) Construct a balanced ionic equation for the reaction of NH_2OH with Fe^{3+}. [1]

$Fe^{3+} + e^- \rightarrow Fe^{2+}$ (x4)

$2NH_2OH \rightarrow N_2O + H_2O + 4H^+ + 4e^-$ (x1)

[1] $4Fe^{3+} + 2NH_2OH \rightarrow 4Fe^{2+} + N_2O + H_2O + 4H^+$

(b) Figure 3.1 shows the second ionisation energies of nine consecutive elements **A** to **I** with atomic numbers below 20 in the Periodic Table. Labels **A** to **I** are not the atomic symbols of the elements.

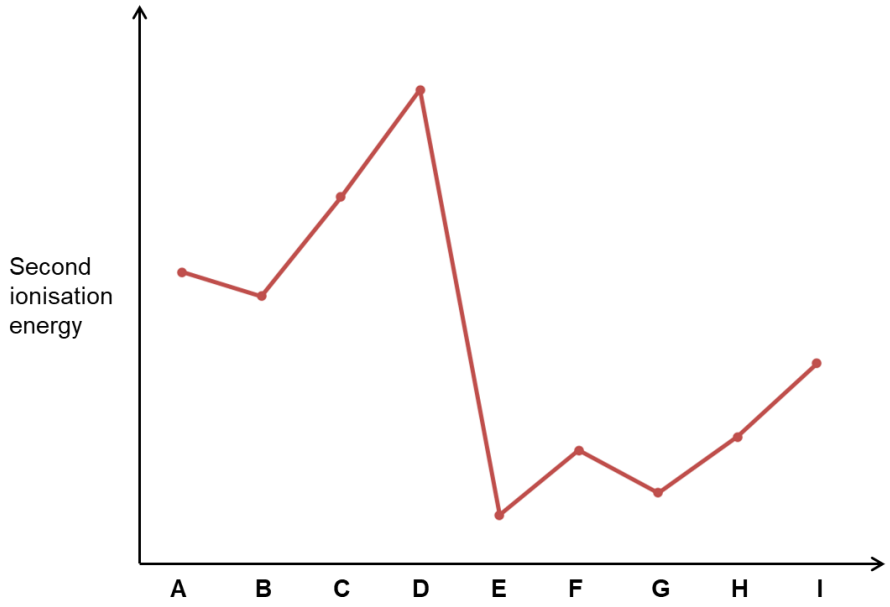


Fig. 3.1

(i) Define the *second ionisation energy* of element **F**. [1]

[1]The second ionisation energy of element F is the minimum energy required to completely remove one mole of electrons from one mole of ground-state gaseous $\mathbf{F}^{+}$ ions to form 1 mole of gaseous $\mathbf{F}^{2+}$ ions.

$\mathbf{F}^{+}(g) \rightarrow \mathbf{F}^{2+}(g) + e^{-}$

(ii) Suggest the identity of **B**. Explain how you arrived at your answer. [2]

[1] Large decrease in 2nd ionisation energy from **D** to **E** implies that the 2nd electron in **E** is removed from the outer electron shell.

E belongs to Group 2 and **B** belongs to group 17.

[1] **B** is fluorine

(iii) Explain the difference in second ionisation energy between element **A** and element **B**. [1]

A: s^2p^4 $\quad$ $\mathbf{A}^{+}$: s^2p^3

B: s^2p^5 $\quad$ $\mathbf{B}^{+}$: s^2p^4

[1] The 2nd electron removed in **B** is a paired electron which experiences interelectronic repulsion, so less energy is needed to remove the paired electron than the unpaired electron removed in **A**.

[Total: 9]

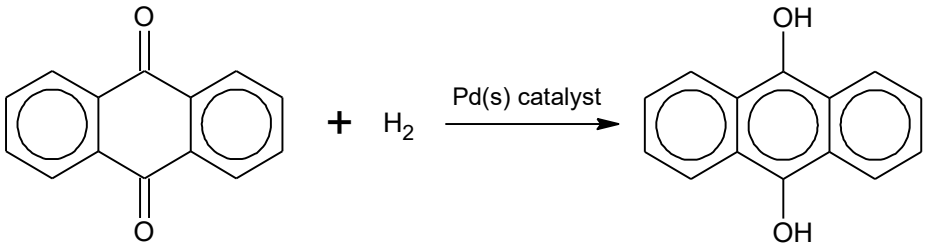
4 Hydrogen peroxide, H_2O_2, finds its applications in a diversity of fields as it is considered an environmentally-friendly oxidising agent.

(a) (i) Suggest why it is environmentally-friendly to use H_2O_2 as an oxidising agent. [1]

[1] The product of reduction of H_2O_2 is water which is clean / non-pollutant / environmentally friendly.

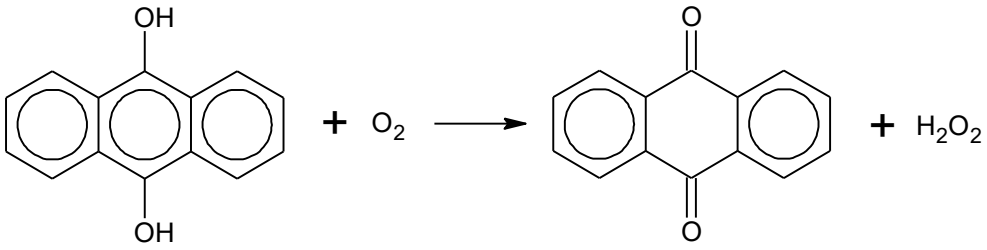
Today, most of the world's hydrogen peroxide is manufactured by the anthraquinone, $C_{14}H_8O_2$ process. This process involves the two steps shown below.

step 1:



Anthraquinone Anthrahydroquinone

step 2:



Anthrahydroquinone Anthraquinone

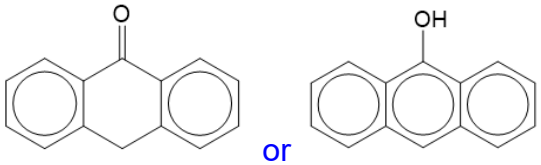
(ii) State the type of reaction in step 1. [1]

[1] Reduction

(iii) In step 1, if Sn is used instead of Pd, compound **P**, $C_{14}H_{10}O$ is obtained. Suggest the structure of **P**. [1]

Analysis: from $C_{14}H_8O_2$ to $C_{14}H_{10}O$, gain of 2 H and loss of 1 O = reduction

[1]

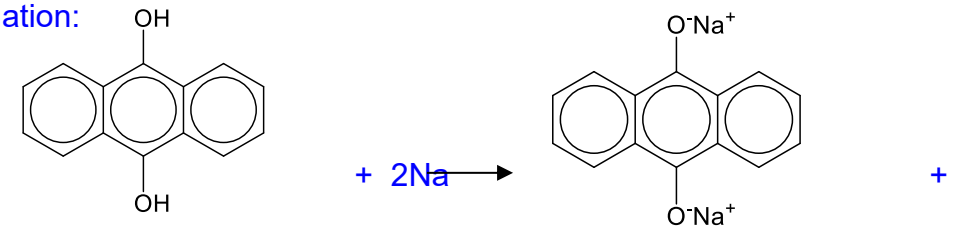


(iv) Describe a chemical test that can be used to distinguish anthraquinone from anthrahydroquinone. State the observations and write a balanced equation for the reaction that occurred. [2]

Add Na metal.	
Anthrahydroquinone	effervescence of hydrogen gas
Anthraquinone	No effervescence
Add Brady's reagent / 2,4-DNPH.	
Anthrahydroquinone	No orange ppt / solid
Anthraquinone	Orange ppt / solid formed

[1] reagent + obs for BOTH cpds

[1] Equation:



H_2 +

Other possible tests: Brady's reagent

At the end of step 2, only anthraquinone and H_2O_2 remain in the reaction mixture. H_2O_2 can be separated out from the reaction mixture by adding water to the reaction mixture.

(b) With reference to the interactions between relevant molecules, explain how the addition of water separates H_2O_2 from the reaction mixture. [2]

[✓] Sufficient energy is released from the formation of [✓] hydrogen bonds between water and H_2O_2 to overcome the [✓] hydrogen bonds between water molecules and hydrogen bonds between H_2O_2 molecules.

[✓] Insufficient energy is released from the formation of [✓] instantaneous dipole-induced dipole interactions between anthraquinone and water to overcome the hydrogen bonds between water molecules.

[✓] H_2O_2 dissolve in water / anthraquinone cannot dissolve in water.

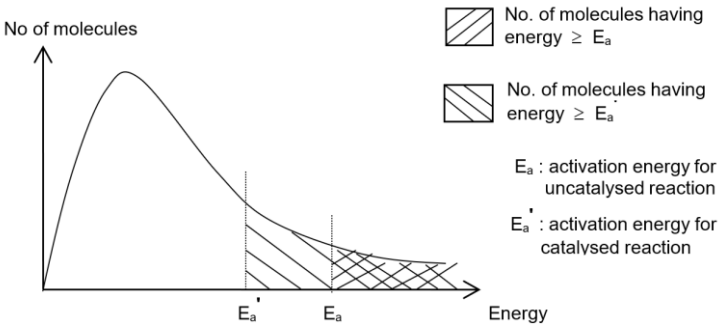
3[✓] = [1]

(c) **(i)** Palladium metal is often used as a heterogeneous catalyst.

Explain what is meant by a *heterogeneous* catalyst. [1]

[1] A catalyst which is not in the same phase / state as the reactants.

(ii) Explain how a ***heterogeneous*** catalyst increases the rate of reaction. Include a sketch of the Maxwell-Boltzmann distribution and use it to illustrate your answer. [4]



[1]

The reactant molecules are [✓] adsorbed unto the surface of the solid catalyst.

Alternative pathway has [✓] lower activation energy due to [✓] higher surface concentration of reactant molecules and [✓] covalent bonds are weakened.

[✓] Number of particles with energy ≥ E_a' / lower activation energy increases. [✓] Frequency of effective collisions increases. [✓] Rate constant increases.

After the reaction, [✓] desorption of product molecules occurs and the molecules eventually [✓] diffuse away from the catalyst surface.

3[✓] = [1]

(d) Nanoparticles are particles with all its dimensions from 1 to 100 nm on the nanoscale. It is observed that the catalytic activity of palladium is vastly increased when the catalyst is finely divided into nanoparticles. These nanoparticles are usually deposited onto the surface of inert metal particles such as gold. This prevents the nanoparticles from being a health hazard.

(i) Explain why catalytic activity is vastly increased when nanoparticles of palladium are used. [1]

[1] Finely dividing the palladium into nanoparticles increases its surface area to volume ratio, providing more active sites for adsorption of reactants.

(ii) Predict how nanoparticles could present a risk to human health. [1]

[1] Due to their small size, nanoparticles can enter human body through pores on skin, breathing/respiratory system, or ingestion (by digestive system).

These particles can travel around the body via the circulatory system, get deposited in body tissues / cells / organs and cause the latter to be damaged / inflamed / develop cancer / cause immune response.

(iii) Explain how the deposition of palladium nanoparticles on gold particles prevents them from being a health hazard. [1]

[1] Gold particles are larger and the deposition of the nanoparticles decreases the chances / prevents them from being inhaled or ingested.

[Total: 15]

5 Copper is a first-row transition metal which has two stable isotopes, ^{63}Cu and ^{65}Cu, that exist naturally in mineral ores.

(a) Explain the trend of first ionisation energy of first-row transition metals. [2]

[✓] Across the period, nuclear charge increases due to increasing number of protons.

[✓] Screening effect increases as electrons are added to the penultimate / second outermost 3d subshell, providing a shield between nucleus and outer 4s electrons.

[✓] The increase in nuclear charge is only slightly more significant than the increase in screening effect.

[✓] Small increase in first IE / relatively invariant

2[✓] = [1]

(b) A sample of mineral ore containing the two isotopes of copper is run in a mass spectrometer to determine their relative amounts. The following mass spectrum is obtained.

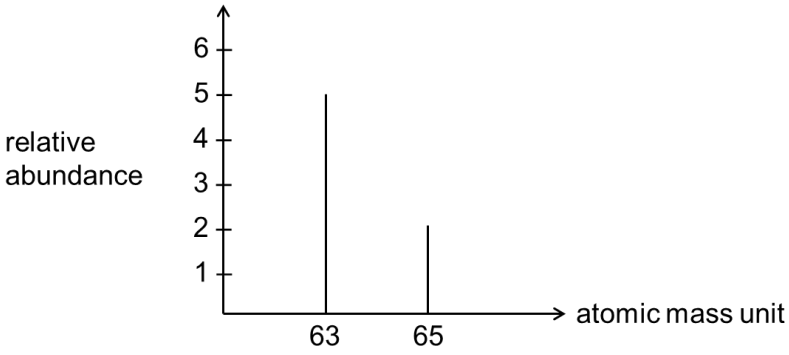


Fig. 5.1

(i) Define the term *isotope*. [1]

[1] Atoms of same element with the same number of protons but different number of neutrons.

(ii) Using Fig. 5.1, determine the relative atomic mass, A_r, of copper. Give your answer to 4 decimal places. [1]

[1] A_r of copper = [5(63)+2(65)]/7 = 63.5714

Chlorine and bromine each has two naturally occuring isotopes. Their relative abundance are shown below.

Table 5.1

Element	Isotope	relative abundance
Chlorine	^{35}Cl	75%
	^{37}Cl	25%
Bromine	^{79}Br	50%
	^{81}Br	50%

The following *incomplete* mass spectrum is obtained from a sample of $BrCl$ where only the abundance for atomic mass unit of 116 is shown.

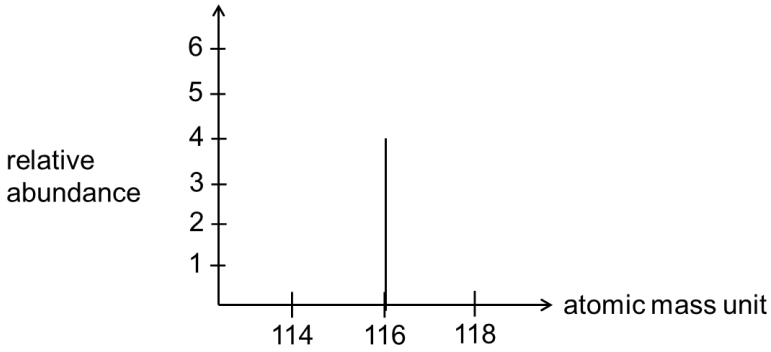


Fig. 5.2

(iii) Identify the species responsible for the atomic mass unit of 114, 116 and 118, taking into consideration the various isotopes. [2]

atomic mass unit of 114 [✓] $^{79}Br^{35}Cl$

atomic mass unit of 116 [✓] $^{79}Br^{37}Cl$ and [✓] $^{81}Br^{35}Cl$

atomic mass unit of 118 [✓] $^{81}Br^{37}Cl$

2[✓] = [1]

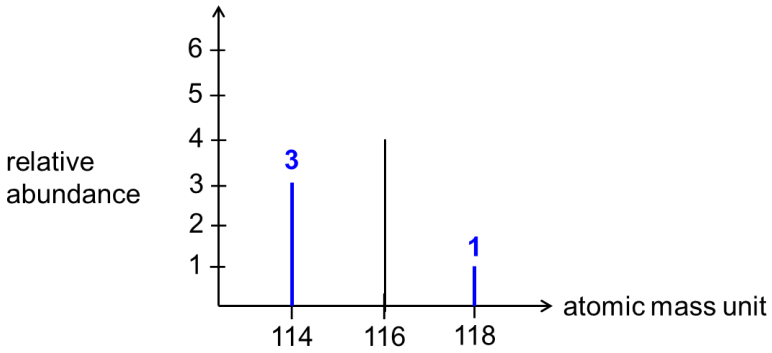
(iv) Hence, calculate the relative abundance of $BrCl$ with atomic mass unit of 114 and 118, and complete Fig 5.2. [2]

Percentage of sample with $^{79}Br^{35}Cl$ = (1/2)(3/4) = 3/8 = 0.375 = 37.5%

Percentage of sample with $^{81}Br^{37}Cl$ = (1/2)(1/4) = 1/8 = 0.125 = 12.5%

Percentage of sample with $^{79}Br^{37}Cl$ and $^{81}Br^{35}Cl$ = (1/2)(1/4) + (1/2)(3/4) = 4/8 = 50%

[1] correct working and answer



[1] correct plots (no ecf)

(c) Most of the world's copper comes from the mining of copper-containing minerals. Two such minerals are bornite, Cu_5FeS_4, and chalcopyrite, Cu_xFeS_y, where x and y are integer values to be determined.

Bornite and chalcopyrite react with concentrated HNO_3 as follows.

$Cu_5FeS_4 + 26HNO_3 \rightarrow Fe(NO_3)_3 + 5Cu(NO_3)_2 + 4S + 13NO_2 + 13H_2O$

$Cu_xFeS_y + (6 + 4x)HNO_3 \rightarrow Fe(NO_3)_3 + xCu(NO_3)_2 + yS + (3 + 2x)NO_2 + (3 + 2x)H_2O$

(i) Explain the role of HNO_3 in the above reactions. [1]

[1] **Oxidising** agent. Oxidation state nitrogen decreases from **+5 in HNO_3** to **+4 in NO_2**.

(ii) When 1 mole each of bornite and chalcopyrite were fully reacted with HNO_3, bornite produced 64.2 g *more* sulfur precipitate and 182 dm^3 *more* nitrogen dioxide than chalcopyrite, at standard temperature and pressure.

Determine the values of x and y. [2]

[1] Sulfur precipitate: $4 - y = \frac{64.2}{32.1}$ $\therefore y = 2$

[1] NO_2 gas: $13 - (3 + 2x) = \frac{182}{22.7}$ $\therefore x = 1$

[Total: 11]

6 Polymers are macromolecules which consist of chains built up from small molecules known as monomers, with at least 100 repeating units. In general, polymers can be made via addition or condensation reactions.

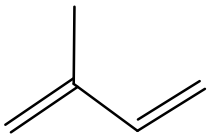
The characteristic properties exhibited by polymers are the result of their unique structure and bonding. Not all polymers are biodegradable, which poses difficulty in recycling them. The monomers and biodegradability of addition and condensation polymers are shown in Table 6.1.

Table 6.1

	addition polymer	condensation polymer
monomers	molecules containing C=C bonds	molecules containing two functional groups
biodegradability of polymer	generally difficult to biodegrade	generally biodegradable

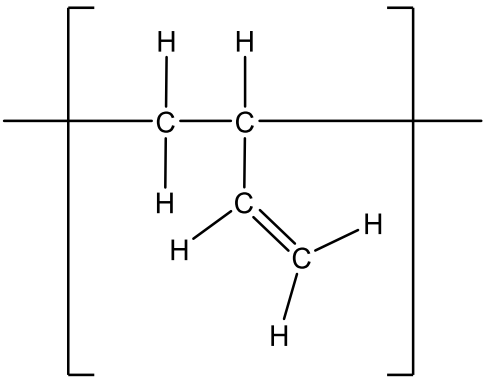
(a) The outer layers of some golf balls are made from a polymer called polyisoprene. The isoprene monomer is a non-cyclic branched hydrocarbon with five carbon atoms. One mole of isoprene reacts with two moles of Br_2 in CCl_4.

Suggest a possible structure of isoprene. [1]



[1]

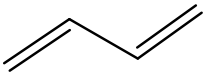
(b) The insides of some golf balls are made from a mixture of three other polymers, **X**, **Y** and **Z**. The repeating unit for polymer **X** is shown.



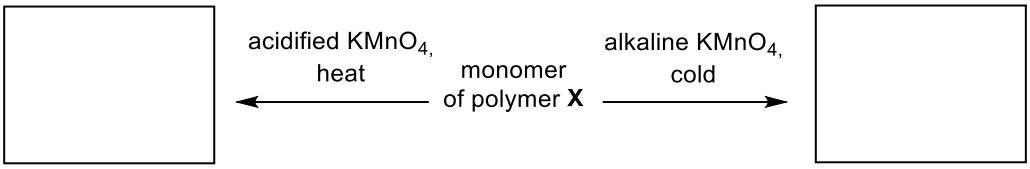
(i) The molecular formula of the monomer of **X** is C_4H_6.

Give the systematic name of the monomer used to make **X**. [1]

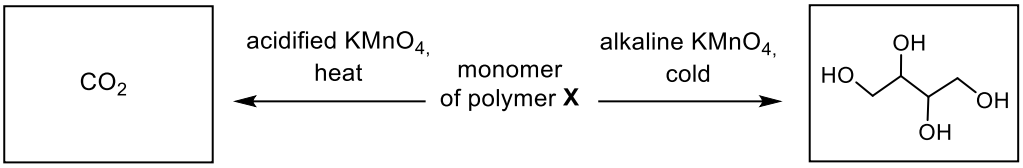
buta-1,3-diene or butadiene [✓]

Structure: 

(ii) Draw the carbon-containing products formed when the monomer undergoes the reactions below.

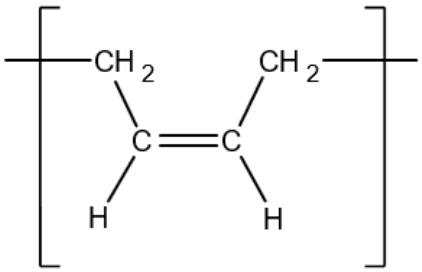


[2]



[1] [1]

(c) **(i)** Polymers **Y** and **Z** are stereoisomers. One of the polymers has a repeating unit with the structure shown.



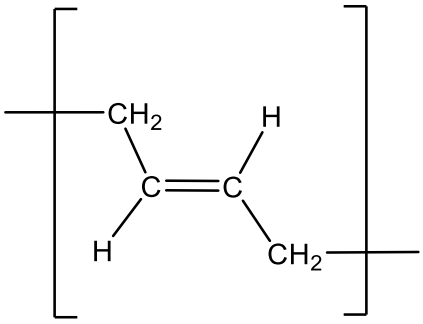
State the type of stereoisomerism and explain why it arises. [2]

Cis-trans isomerism. [1]

There is restricted rotation about the C=C bond and each carbon of the C=C bond is bonded to two different groups. [1]

(ii) Draw the structure of the repeating unit of the other polymer. [1]

repeating unit of the other polymer



Structure of polymer **Y** (trans isomer) [1]

Table 6.2 shows some properties of polymers **Y** and **Z**.

Table 6.2

	polymer **Y**	polymer **Z**
arrangement of polymer chains	crystalline with regular repeating pattern	amorphous with random arrangement
rigidity	high	low
melting point	75 to 135 °C	–25 to 12 °C

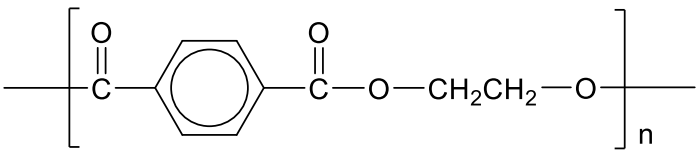
(iii) By referring to the information in Table 6.2, identify whether polymer **Y** or **Z** has the repeating unit in **(c)(i)**. [1]

polymer **Z** (cis isomer) [1]

(d) Golf balls recovered from lakes and ponds can be used again even after being in water for several years. Suggest why these golf balls do not biodegrade. [1]

Carbon-carbon bonds are non-polar / too strong / not attacked by nucleophiles / cannot by hydrolysed. [1] with explanation

(e) Another polymer, poly(ethylene terephthalate), PET, is commonly used to make shirts worn by golfers. The structure of PET is shown below where n is the number of repeating units in the polymer chain. One of the two monomers used to synthesise PET is benzene-1,4-dicarboxylic acid.



PET

Atom economy is a measure of the amount of starting materials which are in the final desired product.

$$\text{percentage atom economy} = \frac{M_r \text{ of the final desired product}}{\text{total } M_r \text{ of all reactants}} \times 100\%$$

(i) Suggest why chemists usually aim to design production methods with a high percentage atom economy. [1]

Reactions with a high percentage atom economy are more efficient and less wasteful/maximises the use of resources/reduce by-products. [1]

(ii) Explain how the percentage atom economy of the reaction to form PET compares with that of polymer **X**. [1]

The percentage atom economy of the reaction to form PET is lower than that to form polymer **X** as H_2O / another molecule is also formed during the condensation while all the monomers are used to form polymer **X**. [1]

(f) Figure 6.1 shows a two-step synthesis of benzene-1,4-dicarboxylic acid from methylbenzene. State the reagents and conditions for each step and draw the structure of the intermediate.

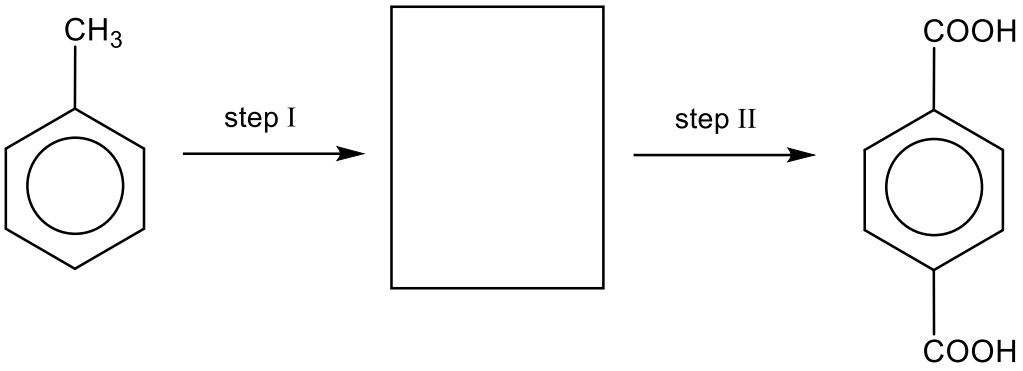


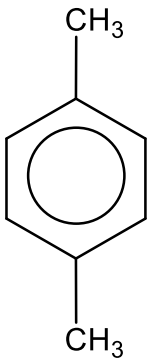
Fig. 6.1

[2]

step I : CH_3Cl, anhydrous $AlCl_3$ [✓] BOD if didn't write 'anhydrous', as long as didn't write aqueous

step II : $KMnO_4(aq)$, $H_2SO_4(aq)$, heat [✓] accept: acidified $KMnO_4$, heat

Intermediate:



[✓]

3[✓] = 2 marks

2[✓] = 1 mark

(g) Benzene-1,2-dicarboxylic acid molecules can also be found in the product mixture in **(f)**.

Table 6.3

	$\Delta H^{\ominus}$ / kJ mol^{-1}
standard enthalpy change of formation of $H_2O(l)$	–286
standard enthalpy change of combustion of benzene-1,2-dicarboxylic acid, $C_6H_4(COOH)_2(s)$	–3220
standard enthalpy change of combustion of benzene-1,4-dicarboxylic acid, $C_6H_4(COOH)_2(s)$	–3190

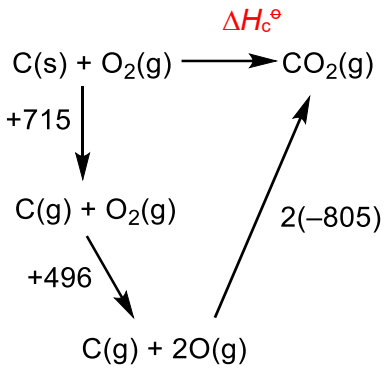
(i) Use relevant data from Table 6.3 to deduce whether benzene-1,2-dicarboxylic acid or benzene-1,4-dicarboxylic acid is more energetically stable under standard conditions. Explain your answer. [1]

Benzene-1,4-dicarboxylic acid is more energetically stable as it has a less exothermic standard enthalpy change of combustion. [1]

Note: Benzene-1,4-dicarboxylic acid is more stable than benzene-1,2-dicarboxylic acid due to less steric repulsion between the –COOH groups as they are further apart.

(ii) The standard enthalpy change of atomisation of carbon is +715 kJ mol^{-1}.

Use this information and the *Data Booklet* to calculate a value for the standard enthalpy change of combustion of carbon. [2]



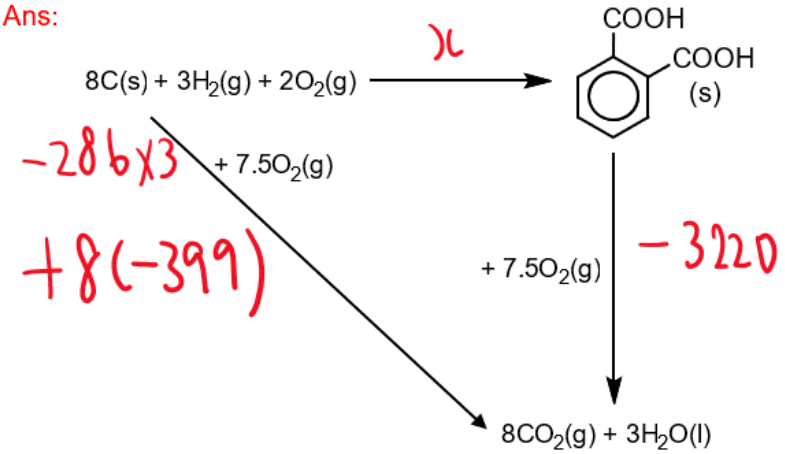
[1] use of standard enthalpy change of atomisation of carbon

$\Delta H_c^{\ominus}$ = 715 + 496 + 2(–805) = – 399 kJ mol^{-1} [1] (no need cycle)

(iii) The standard enthalpy change of formation of benzene-1,2-dicarboxylic acid, **x**, cannot be determined via direct experiment. Using relevant data from Table 6.3 and your answer to **(g)(ii)**, draw an energy cycle to determine a value for **x**. Show your working clearly.

If you were unable to calculate a value for the standard enthalpy change of combustion of carbon in **(g)(ii)**, you should use –450 kJ mol^{-1}. This is **not** the correct answer. [2]

Ans:



x = (–286 x 3) + (–399 x 8) – (–3220)

= – 830 kJ mol^{-1}

[1] Correct cycle (including balanced equations with correct state symbols)

[1] Correct use of values and correct final answer

(h) **(i)** Define the term *standard enthalpy change of neutralisation*. [1]

The *standard enthalpy change of neutralisation*, $\Delta H_n^{\ominus}$, is the enthalpy change when an acid and a base react under infinitely dilute conditions to form one mole of water at 298 K and 1 bar. [1]

The molarity of a buffer is defined as the *total* number of moles of buffering solutes in 1 dm^3 of solution. For example, a 1 dm^3 buffer solution containing 0.3 mol of CH_3COOH and 0.2 mol of CH_3COO^- will have a molarity of 0.5 mol dm^{-3}.

Potassium hydrogen phthalate is a salt that contains the monoanion of benzene-1,2-dicarboxylic acid, HA^-.

(ii) 250 cm^3 of buffer solution at pH 5.0 is prepared by adding 0.1 mol dm^{-3} NaOH(aq) to solid potassium hydrogen phthalate and the resulting solution is made up to 250 cm^3. The molarity of this buffer is 0.1 mol dm^{-3}.

Given that the pK_a of the monoanion of benzene-1,2-dicarboxylic acid, HA^-, is 5.40, calculate the volume of NaOH(aq) required.

After adding NaOH(aq) to solid potassium hydrogen phthalate, the buffer contains A^{2-} and HA^-.

$$5.0 = 5.40 + lg\left(\frac{[A^{2-}]}{[HA^{-}]}\right)$$

$$\frac{[A^{2-}]}{[HA^{-}]} = 0.398 \quad (1)$$

$$[A^{2-}] + [HA^{-}] = 0.1 \quad (2)$$

Solving (1) and (2), $[HA^{-}] = 0.07153$ mol dm^{-3} [1]

$[A^{2-}] = 0.1 - 0.07153 =$ 0.02847 mol dm^{-3}

$HA^{-} + OH^{-} \rightarrow A^{2-} + H_2O$

Amount of NaOH needed = amount of A^{2-} = $0.02847 \times \frac{250}{1000}$ = 0.007118 mol

Volume of NaOH needed = $\frac{0.007118}{0.1} \times 1000$ = 71.2 cm^3 [1]

[Total: 21]