A Level

Article: 232

TOPICAL WORKBOOK

9701

CHEMISTRY

PAPER-2

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A Level

Article No. 232

Chemistry 9701

Paper-2

Topical Workbook with Mark Schemes
2007-2020

- Questions order new to old
- References of repeated questions added
- Mark schemes included
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UNIT 1

Atoms, Molecules and Stoichiometry

A-Level
Chemistry Paper 2
Topical Workbook

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Unit 1: Atoms, Molecules and Stoichiometry

1. M/J 17/P22/Q1/b

(a) Boron occurs naturally as a mixture of two stable isotopes, ^{10}B and ^{11}B. The relative isotopic masses and percentage abundances are shown.

isotope	relative isotopic mass	abundance / %
^{10}B	10.0129	19.78
^{11}B	to be calculated	80.22

(i) Define the term *relative isotopic mass*.

.....

..... **[2]**

(ii) Calculate the relative isotopic mass of ^{11}B.

Give your answer to **six** significant figures. Show your working.

[2

2. M/J 17/P21/Q1/a

Combustion data can be used to calculate the empirical formula, molecular formula and relativ molecular mass of many organic compounds.

(a) Define the term *relative molecular mass.*

.....

.....

.....

..... **[**

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3. M/J 16/P23/Q1

An experiment was carried out to determine the percentage of iron in a sample of iron wire.

(a) A 3.35 g piece of the wire was reacted with dilute sulfuric acid, in the absence of air, so that all of the iron atoms were converted to iron(II) ions. The resulting solution was made up to 250 cm^3.

(i) Write a balanced equation for the reaction between the iron in the wire and the sulfuric acid.

..... **[1]**

A 25.0 cm^3 sample of this solution was acidified and titrated with 0.0250 $mol\,dm^{-3}$ potassium dichromate(VI). 32.0 cm^3 of the potassium dichromate(VI) solution was required for complete reaction with the iron(II) ions in the sample.

The relevant half-equations are shown.

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$$

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

(ii) Use the half-equations to write an equation for the reaction between the iron(II) ions and the acidified dichromate(VI) ions.

..... **[1]**

(iii) Calculate the amount, in moles, of dichromate(VI) ions used in the titration.

amount = ... mol **[1]**

(iv) Calculate the amount, in moles, of iron(II) ions in the 25.0 cm^3 sample of solution.

amount = ... mol **[1]**

(v) Calculate the amount, in moles, of iron in the 3.35 g piece of wire.

amount = ... mol **[1]**

(vi) Calculate the mass of iron in the 3.35 g piece of wire.

mass = ... g **[1]**

(vii) Calculate the percentage of iron in the iron wire.

percentage = ... % **[1]**

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(b) Some electronegativity values are shown.

element	electronegativity
aluminium	1.5
chlorine	3.0
iron	1.8

(i) Use the data to suggest the nature of the bonding in iron(III) chloride. Explain your answer.

.....

.....

..... **[2]**

(ii) Suggest an equation for the reaction between iron(III) chloride and water.

..... **[1]**

[10]

4. M/J 16/P22/Q3

Acidified potassium dichromate(VI) can oxidise ethanedioic acid, $H_2C_2O_4$.
The relevant half-equations are shown.

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$$

$$H_2C_2O_4 \rightarrow 2CO_2 + 2H^+ + 2e^-$$

(a) State the overall equation for the reaction between acidified dichromate(VI) ions and ethanedioic acid.

..... **[2]**

(b) In an experiment a 0.242 g sample of hydrated ethanedioic acid, $H_2C_2O_4.\boldsymbol{x}H_2O$, was reacted with a 0.0200 mol dm^{-3} solution of acidified potassium dichromate(VI).

32.0 cm^3 of the acidified potassium dichromate(VI) solution was required for complete oxidation of the ethanedioic acid.

(i) Calculate the amount, in moles, of dichromate(VI) ions used to react with the sample of ethanedioic acid.

amount = ... mol **[1]**

(ii) Calculate the amount, in moles, of ethanedioic acid in the sample.

amount = ... mol **[1]**

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(iii) Calculate the relative molecular mass, M_r, of the hydrated ethanedioic acid.

M_r = ... **[1]**

(iv) Calculate the value of ***x*** in $H_2C_2O_4.xH_2O$.

x = ... **[1]**

[6]

5. M/J 16/P22/Q1/c

(a) A sample of oxygen exists as a mixture of three isotopes. Information about two of these isotopes is given in the table.

mass number	16	17
abundance	99.76%	0.04%

(i) Calculate the abundance of the third isotope.

abundance = ... % **[1]**

(ii) The relative atomic mass of this sample of oxygen is 16.0044.

Calculate the mass number of the third isotope. You **must** show your working.

mass number = ... **[2]**

6. M/J 16/P21/Q1/d

(a) A sample of strontium exists as a mixture of four isotopes. Information about three of these isotopes is given in the table.

mass number	86	87	88
abundance	9.86%	7.00%	82.58%

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(i) Calculate the abundance of the fourth isotope.

abundance = ... % **[1]**

(ii) The relative atomic mass of this sample of strontium is 87.71.
Calculate the mass number of the fourth isotope.

mass number = ... **[2]**

7. MAR 16/P22/Q2

Spathose is an iron ore that contains iron(II) carbonate, $FeCO_3$. The percentage of iron(II) carbonate in spathose can be determined by titration with acidified potassium dichromate(VI) solution using a suitable indicator.

The ionic equation is shown below.

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6Fe^{2+}(aq) \rightarrow 2Cr^{3+}(aq) + 6Fe^{3+}(aq) + 7H_2O(l)$$

(a) A 5.00 g sample of spathose was reacted with excess concentrated hydrochloric acid and then filtered.
The filtrate was made up to 250 cm^3 in a volumetric flask with distilled water.

A 25.0 cm^3 sample of the standard solution required 27.30 cm^3 of 0.0200 mol dm^{-3} dichromate(VI) solution for complete reaction.

(i) Calculate the amount, in moles, of dichromate(VI) ions used in the titration.

amount = ... mol **[1]**

(ii) Use your answer to **(i)** to calculate the amount, in moles, of Fe^{2+} present in the 25.0 cm^3 sample.

amount = ... mol **[1]**

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(iii) Use your answer to **(ii)** to calculate the amount, in moles, of Fe^{2+} present in the 250 cm^3 volumetric flask.

amount = ... mol **[1]**

(iv) Use your answer to **(iii)** to calculate the mass of iron(II) carbonate present in the sample of spathose.

mass = ... g **[2]**

(v) Calculate the percentage of iron(II) carbonate in the sample of spathose.

percentage of iron(II) carbonate = ... % **[1]**

(b) Iron ores containing iron(III) compounds can be analysed using a similar method.

A standard solution of an aqueous iron(III) compound is reacted with aqueous tin(II) chloride. Aqueous tin(IV) chloride and aqueous iron(II) chloride are the products of this reaction.

(i) Write an **ionic** equation for this reaction. Do not include state symbols.

..... **[2]**

(ii) Any excess tin(II) chloride can be removed by reaction with $HgCl_2(aq)$. A white precipitate of Hg_2Cl_2 is produced.

Complete the equation for this reaction.

.....(.....) + ...$HgCl_2(aq)$ → $SnCl_4$(.....) + Hg_2Cl_2(.....) **[2]**

[10]

8. M/J 15/P22/Q2/e

(a) The sulfur dioxide content of wine is most commonly measured by the Ripper Method which involves titration with iodine in the presence of starch as an indicator.

$$SO_2(aq) + I_2(aq) + 2H_2O(l) \rightarrow 2I^-(aq) + SO_4^{2-}(aq) + 4H^+(aq)$$

A 50.0 cm^3 sample of wine required 12.35 cm^3 of 0.010 $mol\,dm^{-3}$ $I_2(aq)$ for complete reaction with the SO_2.

(i) How many moles of SO_2 are present in 50.0 cm^3 of wine?

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moles of SO_2 in 50.0 cm^3 = ... **[1]**

(ii) How many moles of SO_2 are present in 1 dm^3 of wine?

moles of SO_2 in 1 dm^3 = ... **[1]**

(iii) How many milligrams, mg, of SO_2 are present in 1 dm^3 of wine? Give your answer to **three** significant figures. (1 g = 1000 mg)

mass of SO_2 in 1 dm^3 = ... mg **[1]**

9. M/J 15/P22/Q1/a,b

(a) Chemists recognise that atoms are made of three types of particle.
Complete the following table with their names and properties.

name of particle	relative mass	relative charge
		+1
	1/1836	

[3]

(b) Most elements exist naturally as a mixture of isotopes, each with their own relative isotopic mass. The mass spectrum of an element reveals the abundances of these isotopes, which can be used to calculate the relative atomic mass of the element.

Magnesium has three stable isotopes. Information about two of these isotopes is given.

isotope	relative isotopic mass	percentage abundance
^{24}Mg	24.0	79.0
^{26}Mg	26.0	11.0

(i) Define the term *relative isotopic mass*.

.....

.....

..... **[2]**

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(ii) The relative atomic mass of magnesium is 24.3.

Calculate the percentage abundance and hence the relative isotopic mass of the third isotope of magnesium. Give your answer to **three** significant figures

percentage abundance = ...

isotopic mass = ...

[3]

10. M/J 15/P22/Q1/c(ii)

(a) (i) An investigation of the reaction between magnesium oxide and hydrogen chloride gas showed that an intermediate product was formed with the composition by mass Mg, 31.65%; O, 20.84%; H, 1.31% and C*l*, 46.20%.

Calculate the empirical formula of this intermediate compound.

empirical formula ..... **[2]**

11. M/J 15/P21/Q1/a,b

(a) Chemists recognise that atoms are made of three types of particle.

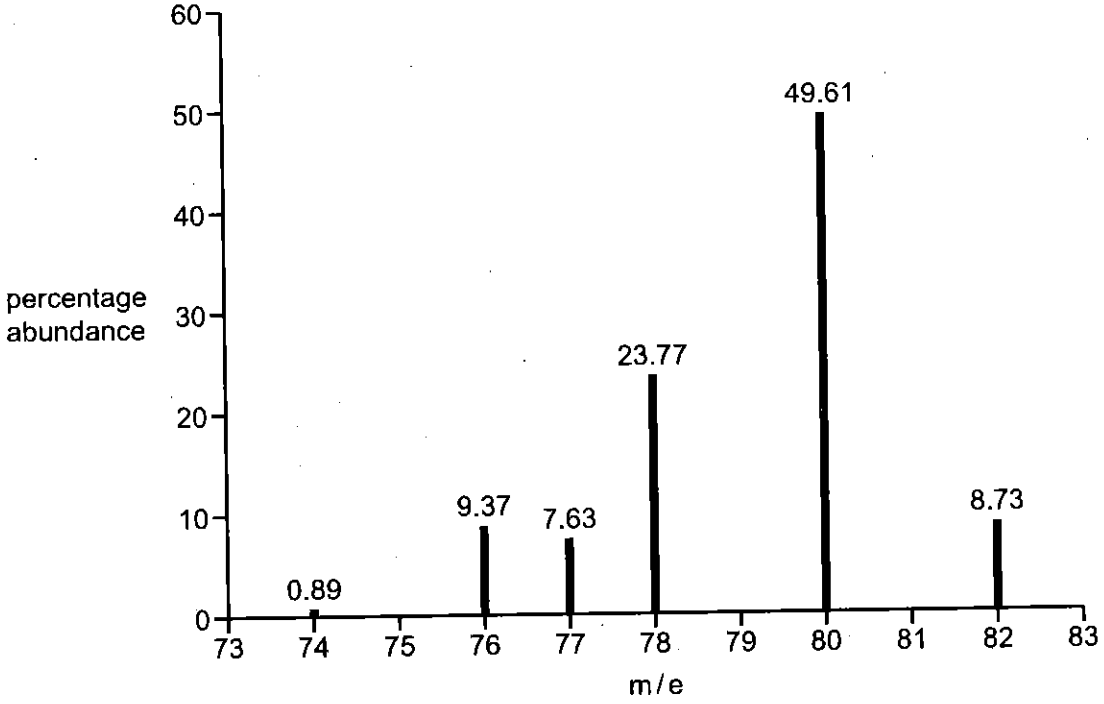
Complete the following table with their names and properties.

name of particle	relative mass	relative charge
		0
	1/1836	

[3]

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(b) The relative atomic mass of an element can be determined using data from its mass spectrum. The mass spectrum of element **X** is shown, with the percentage abundance of each isotope labelled.



(i) Define the terms *relative atomic mass* and *isotope*.

relative atomic mass .....

.....

.....

isotope .....

..... **[3]**

(ii) Use the data in the mass spectrum to calculate the relative atomic mass, A_r, of **X**. Give your answer to **two** decimal places and suggest the identity of **X**.

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A_r of **X** .....

identity of **X** .....

[2]

12. M/J 15/P21/Q1/c(i)

(a) The element tellurium, Te, reacts with chlorine to form a single solid product, with a relative formula mass of 270. The product contains 52.6% chlorine by mass.

(i) Calculate the molecular formula of this chloride.

molecular formula ..... **[3]**

13. O/N 14/P22/Q1/b(ii & iii),c

(a) A sample of strontium, atomic number 38, gave the mass spectrum shown. The percentage abundances are given above each peak.

(i) Explain why there are four different peaks in the mass spectrum of strontium.

.....

..... **[1]**

(ii) Calculate the atomic mass, A_r, of this sample of strontium.
Give your answer to **three** significant figures.

A_r ..... **[2]**

(b) A compound of barium, **A**, is used in fireworks as an oxidising agent and to produce a green colour.

(i) Explain, in terms of electron transfer, what is meant by the term *oxidising agent*.

.....

..... **[1]**

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(ii) **A** has the following percentage composition by mass: Ba, 45.1; C*l*, 23.4; O, 31.5.
Calculate the empirical formula of **A**.

empirical formula of **A** ..... **[3]**

14. M/J 14/P23/Q2

A sample of a hydrated double salt, $Cu(NH_4)_x(SO_4)_2.6H_2O$, was boiled with an excess of sodium hydroxide. Ammonia was given off.

The ammonia produced was absorbed in 40.0 cm^3 of 0.400 mol dm^{-3} hydrochloric acid. The resulting solution required 25 cm^3 of 0.12 mol dm^{-3} sodium hydroxide to neutralise the excess acid.

(a) Write the ionic equation for the reaction between ammonium ions and hydroxide ions.

..... **[1]**

(b) (i) Calculate the amount, in moles, of hydrochloric acid in 40.0 cm^3 of 0.400 mol dm^{-3} solution.

[1]

(ii) Calculate the amount, in moles, of sodium hydroxide needed to neutralise the excess acid. This will be equal to the amount of hydrochloric acid left in excess.

[1]

(iii) Calculate the amount, in moles, of hydrochloric acid that reacted with ammonia.

[1]

(iv) Calculate the amount, in moles, of ammonium ions in the sample of the double salt.

[1]

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(v) The sample contained 0.413 g of copper. Use this information and your answer to **(iv)** to calculate the value of x in $Cu(NH_4)_x(SO_4)_2.6H_2O$.

[2]

(vi) Calculate the M_r of $Cu(NH_4)_x(SO_4)_2.6H_2O$.

[1]

[8]

15. M/J 14/P22/Q1/a,b,c

(a) Explain what is meant by the term *nucleon number*.

.....

..... **[1]**

(b) Bromine exists naturally as a mixture of two stable isotopes, ^{79}Br and ^{81}Br, with relative isotopic masses of 78.92 and 80.92 respectively.

(i) Define the term *relative isotopic mass*.

.....

.....

..... **[2]**

(ii) Using the relative atomic mass of bromine, 79.90, calculate the relative isotopic abundances of ^{79}Br and ^{81}Br.

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[3]

(c) Bromine reacts with the element **A** to form a compound with empirical formula ABr_3. The percentage composition by mass of ABr_3 is **A**, 4.31; Br, 95.69.

Calculate the relative atomic mass, A_r, of **A**.
Give your answer to **three** significant figures.

A_r of **A** = ... **[3]**

16. M/J 14/P22/Q2

A 6.30 g sample of hydrated ethanedioic acid, $H_2C_2O_4.xH_2O$, was dissolved in water and the solution made up to 250 cm^3.

A 25.0 cm^3 sample of this solution was acidified and titrated with 0.100 mol dm^{-3} potassium manganate(VII) solution. 20.0 cm^3 of this potassium manganate(VII) solution was required to react fully with the ethanedioate ions, $C_2O_4^{2-}$, present in the sample.

(a) The MnO_4^- ions in the potassium manganate(VII) *oxidise* the ethanedioate ions.

(i) Explain, in terms of electron transfer, the meaning of the term *oxidise* in the sentence above.

.....

..... **[1]**

(ii) Complete and balance the ionic equation for the reaction between the manganate(VII) ions and the ethanedioate ions.

$2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) + ...H^+(aq) \rightarrow .....(aq) + 10CO_2(aq) + ...H_2O(l)$ **[3]**

(b) (i) Calculate the number of moles of manganate(VII) used in the titration.

[1]

(ii) Use the equation in **(a)(ii)** and your answer to **(b)(i)** to calculate the number of moles of $C_2O_4^{2-}$ present in the 25.0 cm^3 sample of solution used.

[1]

(iii) Calculate the number of moles of $H_2C_2O_4.xH_2O$ in 6.30 g of the compound.

[1]

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(iv) Calculate the relative formula mass of $H_2C_2O_4.xH_2O$.

[1]

(v) The relative formula mass of anhydrous ethanedioic acid, $H_2C_2O_4$, is 90.
Calculate the value of x in $H_2C_2O_4.xH_2O$.

[1]
[9]

17. M/J 14/P21/Q1/c

(a) Another element, **Z**, in the same period of the Periodic Table as **A**, reacts with chlorine to form a compound with empirical formula ZCl_2. The percentage composition by mass of ZCl_2 is **Z**, 31.13; *Cl*, 68.87.

(i) Define the term *relative atomic mass*.

.....

.....

..... [2]

(ii) Calculate the relative atomic mass, A_r, of **Z**.
Give your answer to **three** significant figures.

A_r of **Z** = ... [2]

18. M/J 14/P21/Q2/a(ii),b

The commonest form of iron(II) sulfate is the heptahydrate, $FeSO_4.7H_2O$. On heating at 90 °C this loses **some** of its water of crystallisation to form a different hydrated form of iron(II) sulfate, $FeSO_4.xH_2O$.

3.40 g of $FeSO_4.xH_2O$ was dissolved in water to form 250 cm^3 of solution.

A 25.0 cm^3 sample of this solution was acidified and titrated with 0.0200 mol dm^{-3} potassium manganate(VII).

In this titration 20.0 cm^3 of this potassium manganate(VII) solution was required to react fully with the Fe^{2+} ions present in the sample.

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(a) The MnO_4^- ions in the potassium manganate(VII) *oxidise* the Fe^{2+} ions in the acidified solution.

(i) Complete and balance the ionic equation for the reaction between the manganate(VII) ions and the iron(II) ions.

$MnO_4^-(aq) + 5Fe^{2+}(aq) + ...H^+(aq) \rightarrow .....(aq) + 5Fe^{3+}(aq) + ...H_2O(l)$

[3]

(b) (i) Calculate the number of moles of manganate(VII) used in the titration.

[1]

(ii) Use the equation in **(a)(ii)** and your answer to **(b)(i)** to calculate the number of moles of Fe^{2+} present in the 25.0 cm^3 sample of solution used.

[1]

(iii) Calculate the number of moles of $FeSO_4.xH_2O$ in 3.40 g of the compound.

[1]

(iv) Calculate the relative formula mass of $FeSO_4.xH_2O$.

[1]

(v) The relative formula mass of anhydrous iron(II) sulfate, $FeSO_4$, is 151.8.
Calculate the value of x in $FeSO_4.xH_2O$.

[1]
[9]

19. M/J 13/P22/Q2/a

Chile saltpetre is a mineral found in Chile and Peru, and which mainly consists of sodium nitrate, $NaNO_3$. The mineral is purified to concentrate the $NaNO_3$ which is used as a fertiliser and in some fireworks.

In order to find the purity of a sample of sodium nitrate, the compound is heated in NaOH(aq) with Devarda's alloy which contains aluminium. This reduces the sodium nitrate to ammonia which is boiled off and then dissolved in acid.

$3NaNO_3(aq) + 8Al(s) + 5NaOH(aq) + 18H_2O(l) \rightarrow 3NH_3(g) + 8NaAl(OH)_4(aq)$

The ammonia gas produced is dissolved in an excess of H_2SO_4 of known concentration.

$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$

The amount of unreacted H_2SO_4 is then determined by back-titration with NaOH of known concentration.

$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$

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(a) A 1.64 g sample of impure $NaNO_3$ was reacted with an excess of Devarda's alloy. The NH_3 produced was dissolved in 25.0 cm^3 of 1.00 mol dm^{-3} H_2SO_4. When all of the NH_3 had dissolved, the resulting solution was titrated with NaOH(aq). For neutralisation, 16.2 cm^3 of 2.00 mol dm^{-3} NaOH were required.

(i) Calculate the amount, in moles, of H_2SO_4 present in the 25.0 cm^3 of 1.00 mol dm^{-3} H_2SO_4.

(ii) Calculate the amount, in moles, of NaOH present in 16.2 cm^3 of 2.00 mol dm^{-3} NaOH.

(iii) Use your answer to **(ii)** to calculate the amount, in moles, of H_2SO_4 that reacted with 16.2 cm^3 of 2.00 mol dm^{-3} NaOH.

(iv) Use your answers to **(i)** and **(iii)** to calculate the amount, in moles, of H_2SO_4 that reacted with the NH_3.

(v) Use your answer to **(iv)** to calculate the amount, in moles, of NH_3 that reacted with the H_2SO_4.

(vi) Use your answer to **(v)** to calculate the amount, in moles, of $NaNO_3$ that reacted with the Devarda's alloy.

(vii) Hence calculate the mass of $NaNO_3$ that reacted.

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(viii) Use your answer to **(vii)** to calculate the percentage by mass of $NaNO_3$ present in the impure sample.
Write your answer to a suitable number of significant figures.

[9]

20. M/J 13/P21/Q1/a

A sample of a fertiliser was known to contain ammonium sulfate, $(NH_4)_2SO_4$, and sand only.

A 2.96 g sample of the solid fertiliser was heated with 40.0 cm^3 of NaOH(aq), an excess, and all of the ammonia produced was boiled away.

After cooling, the remaining NaOH(aq) was exactly neutralised by 29.5 cm^3 of 2.00 mol dm^{-3} HC*l*.

In a separate experiment, 40.0 cm^3 of the original NaOH(aq) was exactly neutralised by 39.2 cm^3 of the 2.00 mol dm^{-3} HC*l*.

(a) (i) Write balanced equations for the following reactions.

NaOH with HC*l*

.....

$(NH_4)_2SO_4$ with NaOH

.....

(ii) Calculate the amount, in moles, of NaOH present in the 40.0 cm^3 of the original NaOH(aq) that was neutralised by 39.2 cm^3 of 2.00 mol dm^{-3} HC*l*.

(iii) Calculate the amount, in moles, of NaOH present in the 40.0 cm^3 of NaOH(aq) that remained after boiling the $(NH_4)_2SO_4$.

(iv) Use your answers to **(ii)** and **(iii)** to calculate the amount, in moles, of NaOH that reacted with the $(NH_4)_2SO_4$.

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(v) Use your answers to **(i)** and **(iv)** to calculate the amount, in moles, of $(NH_4)_2SO_4$ that reacted with the NaOH.

(vi) Hence calculate the mass of $(NH_4)_2SO_4$ that reacted.

(vii) Use your answer to **(vi)** to calculate the percentage, by mass, of $(NH_4)_2SO_4$ present in the fertiliser.
Write your answer to a suitable number of significant figures.

[9]

21. O/N 12/P22/Q1/a,b

Zinc is an essential trace element which is necessary for the healthy growth of animals and plants. Zinc deficiency in humans can be easily treated by using zinc salts as dietary supplements.

(a) One salt which is used as a dietary supplement is a hydrated zinc sulfate, $ZnSO_4.xH_2O$, which is a colourless crystalline solid.

Crystals of zinc sulfate may be prepared in a school or college laboratory by reacting dilute sulfuric acid with a suitable compound of zinc.

Give the formulae of **two** simple compounds of zinc that could **each** react with dilute sulfuric acid to produce zinc sulfate.

..... and ..... **[2]**

(b) A simple experiment to determine the value of x in the formula $ZnSO_4.xH_2O$ is to heat it carefully to drive off the water.

$$ZnSO_4.xH_2O(s) \rightarrow ZnSO_4(s) + xH_2O(g)$$

A student placed a sample of the hydrated zinc sulfate in a weighed boiling tube and reweighed it. He then heated the tube for a short time, cooled it and reweighed it when cool. This process was repeated four times. The final results are shown below.

mass of empty tube / g	mass of tube + hydrated salt / g	mass of tube + salt after fourth heating / g
74.25	77.97	76.34

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(i) Why was the boiling tube heated, cooled and reweighed four times?

.....

.....

(ii) Calculate the amount, **in moles**, of the anhydrous salt produced.

(iii) Calculate the amount, **in moles**, of water driven off by heating.

(iv) Use your results to **(ii)** and **(iii)** to calculate the value of x in $ZnSO_4.xH_2O$.

[7]

22. M/J 12/P23/Q2

Washing soda is hydrated sodium carbonate, $Na_2CO_3.xH_2O$.

A student wished to determine the value of x by carrying out a titration with the following results.

> 5.13 g of washing soda crystals were dissolved in water and the solution was made up to 250 cm^3 in a standard volumetric flask.
>
> 25.0 cm^3 of this solution reacted exactly with 35.8 cm^3 of 0.100 mol dm^{-3} hydrochloric acid and carbon dioxide was produced.

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(a) (i) Write a balanced equation for the reaction between Na_2CO_3 and HC*l*.

.....

(ii) Calculate the amount, in moles, of HCl in the 35.8 cm^3 of solution used in the titration.

(iii) Use your answers to **(i)** and **(ii)** to calculate the amount, in moles, of Na_2CO_3 in the 25.0 cm^3 of solution used in the titration.

(iv) Use your answer to **(iii)** to calculate the amount, in moles, of Na_2CO_3 in the 250 cm^3 of solution in the standard volumetric flask.

(v) Hence calculate the mass of Na_2CO_3 present in 5.13 g of washing soda crystals.

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[6]

(b) Use your calculations in **(a)** to determine the value of x in $Na_2CO_3.xH_2O$.

[2]

[8]

23. M/J 12/P21/Q2

Ammonium sulfate, $(NH_4)_2SO_4$, is widely used as a fertiliser.

In order to determine its percentage purity, a sample of ammonium sulfate fertiliser was analysed by reacting a known amount with an excess of NaOH(aq) and then titrating the unreacted NaOH with dilute HC*l*.

(a) Ammonium sulfate reacts with NaOH in a 1 : 2 ratio.
Complete and balance the equation for this reaction.

$$(NH_4)_2SO_4 + 2NaOH \rightarrow .....NH_3 + ... + ...$$ **[2]**

(b) A 5.00 g sample of a fertiliser containing $(NH_4)_2SO_4$ was warmed with 50.0 cm^3 (an excess) of 2.00 mol dm^{-3} NaOH.

When all of the ammonia had been driven off, the solution was cooled.

The remaining NaOH was then titrated with 1.00 mol dm^{-3} HC*l* and 31.2 cm^3 were required for neutralisation.

(i) Write a balanced equation for the reaction between NaOH and HC*l*.

.....

(ii) Calculate the amount, in moles, of HC*l* in 31.2 cm^3 of 1.00 mol dm^{-3} HC*l*.

(iii) Calculate the amount, in moles, of NaOH in 50.0 cm^3 of 2.00 mol dm^{-3} NaOH.

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(iv) Use your answers to **(i)**, **(ii)** and **(iii)** to calculate the amount, in moles, of NaOH used up in the reaction with $(NH_4)_2SO_4$.

(v) Use your answer to **(iv)** and the equation in **(a)** to calculate the amount, in moles, of $(NH_4)_2SO_4$ that reacted with NaOH.

(vi) Use your answer to **(v)** to calculate the mass of $(NH_4)_2SO_4$ that reacted with NaOH.

(vii) Hence, calculate the percentage purity of the ammonium sulfate fertiliser.

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[7]

[9]

24. O/N 11/P23/Q2/a

When 0.42 g of a gaseous hydrocarbon **A** is slowly passed over a large quantity of heated copper(II) oxide, CuO, **A** is completely oxidised.

The products are collected and it is found that 1.32 g of CO_2 and 0.54 g of H_2O are formed. Copper is the only other product of the reaction.

(a) **(i)** Calculate the mass of carbon present in 1.32 g of CO_2.

Use this value to calculate the amount, in moles, of carbon atoms present in 0.42 g of **A**.

(ii) Calculate the mass of hydrogen present in 0.54 g of H_2O.

Use this value to calculate the amount, in moles, of hydrogen atoms present in 0.42 g of **A**.

(iii) It is thought that **A** is an alkene rather than an alkane.
Use your answers to **(i)** and **(ii)** to deduce whether this is correct.
Explain your answer.

.....

..... **[5]**

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25. O/N 11/P23/Q1

Sulfur, S, and polonium, Po, are both elements in Group VI of the Periodic Table.
Sulfur has three isotopes.

(a) Explain the meaning of the term *isotope*.

.....

.....

..... **[2]**

(b) A sample of sulfur has the following isotopic composition by mass.

isotope mass	32	33	34
% by mass	95.00	0.77	4.23

Calculate the relative atomic mass, A_r, of sulfur to **two** decimal places.

A_r = ... **[2]**

(c) Isotopes of polonium, proton number 84, are produced by the radioactive decay of several elements including thorium, Th, proton number 90.

The isotope ^{213}Po is produced from the thorium isotope ^{232}Th.

Complete the table below to show the atomic structures of the isotopes ^{213}Po and ^{232}Th.

	number of		
isotope	protons	neutrons	electrons
^{213}Po			
^{232}Th			

[3]

Radiochemical reactions, such as nuclear fission and radioactive decay of isotopes, can be represented by equations in which the nucleon (mass) numbers must balance and the proton numbers must also balance.

For example, the nuclear fission of uranium-235, $^{235}_{92}U$, by collision with a neutron, $^{1}_{0}n$, produces strontium-90, xenon-143 and three neutrons.

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{90}_{38}Sr + {}^{143}_{54}Xe + 3\,{}^{1}_{0}n$$

In this equation, the nucleon (mass) numbers balance because: 235 + 1 = 90 + 143 + (3x1).

The proton numbers also balance because: 92 + 0 = 38 + 54 + (3x0).

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(d) In the first stage of the radioactive decay of $^{232}_{90}Th$, the products are an isotope of element *E* and an alpha-particle, $^{4}_{2}He$.

(i) By considering nucleon and proton numbers only, construct a balanced equation for the formation of the isotope of *E* in this reaction.

$$^{232}_{90}Th \rightarrow \text{.....} + {}^{4}_{2}He$$

Show clearly the nucleon number and proton number of the isotope of *E*.

nucleon number of the isotope of *E* .....

proton number of the isotope of *E* .....

(ii) Hence state the symbol of the element *E*.

.....

[3]

[10]

26. O/N 11/P22/Q1/a

Compound **A** is an organic compound which contains carbon, hydrogen and oxygen.

When 0.240 g of the vapour of **A** is slowly passed over a large quantity of heated copper(II) oxide, CuO, the organic compound **A** is completely oxidised to carbon dioxide and water. Copper is the only other product of the reaction.

The products are collected and it is found that 0.352 g of CO_2 and 0.144 g of H_2O are formed.

(a) In this section, give your answers to <u>three</u> decimal places.

(i) Calculate the mass of carbon present in 0.352 g of CO_2.

Use this value to calculate the amount, in moles, of carbon atoms present in 0.240 g of **A**.

(ii) Calculate the mass of hydrogen present in 0.144 g of H_2O.

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Use this value to calculate the amount, in moles, of hydrogen atoms present in 0.240 g of **A**.

(iii) Use your answers to calculate the mass of oxygen present in 0.240 g of **A**.

Use this value to calculate the amount, in moles, of oxygen atoms present in 0.240 g of **A**.

[6]

27. M/J 11/P23/Q1

Methanoic acid, HCO_2H, was formerly known as formic acid because it is present in the sting of ants and the Latin name for ant is *formica*. It was first isolated in 1671 by John Ray who collected a large number of dead ants and extracted the acid from them by distillation.

In this question, you should give all numerical answers to <u>two</u> significant figures.

At room temperature, pure methanoic acid is a liquid which is completely soluble in water.

When we are stung by a 'typical' ant a solution of methanoic acid, **A**, is injected into our skin.

Solution **A** contains 50% by volume of pure methanoic acid.

A 'typical' ant contains 7.5×10^{-6} dm^3 of solution **A**.

(a) (i) Calculate the volume, in cm^3, of solution **A** in one ant.

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volume = ... cm^3

(ii) Use your answer to **(i)** to calculate the volume, in cm^3, of pure methanoic acid in one ant.

volume = ... cm^3

(iii) Use your answer to **(ii)** to calculate how many ants would have to be distilled to produce 1 dm^3 of pure methanoic acid.

number = ... **[3]**

When we are stung by an ant, the amount of solution **A** injected is 80% of the total amount of solution **A** present in one ant.

The density of pure methanoic acid is 1.2 $g\,cm^{-3}$.

(b) (i) Calculate the volume, in cm^3, of **pure** methanoic acid injected in one ant sting.

volume = ... cm^3

(ii) Use your answer to **(i)** to calculate the mass of methanoic acid present in one ant sting.

mass = ... g **[3]**

Bees also sting us by using methanoic acid. One simple treatment for ant or bee stings is to use sodium hydrogencarbonate, $NaHCO_3$.

(c) (i) Construct a balanced equation for the reaction between methanoic acid and sodium hydrogencarbonate.

.....

(ii) In a typical bee sting, the mass of methanoic acid injected is 5.4×10^{-3} g. Calculate the mass of $NaHCO_3$ needed to neutralise one bee sting.

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mass = ... g **[3]**

[9]

28. O/N 10/P23/Q1

The element magnesium, Mg, proton number 12, is a metal which is used in many alloys which are strong and light.

Magnesium has several naturally occurring isotopes.

(a) What is meant by the term *isotope*?

.....

.....

..... [2]

(b) Complete the table below for two of the isotopes of magnesium.

isotope	number of protons	number of neutrons	number of electrons
^{24}Mg			
^{26}Mg			

[2]

A sample of magnesium had the following isotopic composition:
^{24}Mg, 78.60%; ^{25}Mg, 10.11%; ^{26}Mg, 11.29%.

(c) Calculate the relative atomic mass, A_r, of magnesium in the sample.
Express your answer to an appropriate number of significant figures.

[2]

Antimony, Sb, proton number 51, is another element which is used in alloys.

Magnesium and antimony each react when heated separately in chlorine.

(d) Construct a balanced equation for the reaction between magnesium and chlorine.

..... [1]

When a 2.45 g sample of antimony was heated in chlorine under suitable conditions, 4.57 g of a chloride **A** were formed.

(e) **(i)** Calculate the amount, in moles, of antimony atoms that reacted.

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(ii) Calculate the amount, in moles, of chlorine atoms that reacted.

(iii) Use your answers to **(i)** and **(ii)** to determine the empirical formula of **A**.

(iv) The empirical and molecular formulae of **A** are the same.
Construct a balanced equation for the reaction between antimony and chlorine.

..... **[5]**

(f) The chloride **A** melts at 73.4 °C while magnesium chloride melts at 714 °C.

(i) What type of bonding is present in magnesium chloride?

.....

(ii) Suggest what type of bonding is present in **A**.

..... **[2]**

[14]

29. O/N 10/P22/Q1

In 1814, Sir Humphrey Davy and Michael Faraday collected samples of a flammable gas, **A**, from the ground near Florence in Italy.
They analysed **A** which they found to be a hydrocarbon. Further experiments were then carried out to determine the molecular formula of **A**.

(a) What is meant by the term *molecular formula*?

.....

.....

.....**[2]**

Davy and Faraday deduced the formula of **A** by exploding it with an excess of oxygen and analysing the products of combustion.

(b) Complete and balance the following equation for the complete combustion of a hydrocarbon with the formula C_xH_y.

$$C_xH_y + \left(x + \frac{y}{4}\right)O_2 \rightarrow \text{.....} + \text{.....}$$

[2]

(c) When 10 cm^3 of **A** was mixed at room temperature with 50 cm^3 of oxygen (an excess) and exploded, 40 cm^3 of gas remained after cooling the apparatus to room temperature and pressure.
When this 40 cm^3 of gas was shaken with an excess of aqueous potassium hydroxide, KOH, 30 cm^3 of gas still remained.

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(i) What is the identity of the $30\,cm^3$ of gas that remained at the end of the experiment?

.....

(ii) The combustion of **A** produced a gas that reacted with the KOH(aq).
What is the identity of this gas?

.....

(iii) What volume of the gas you have identified in **(ii)** was produced by the combustion of **A**?

.....cm^3

(iv) What volume of oxygen was used up in the combustion of **A**?

.....cm^3 **[4]**

(d) Use your equation in **(b)** and your results from **(c)(iii)** and **(c)(iv)** to calculate the molecular formula of **A**.
Show all of your working.

[3]
[11]

30. M/J 10/P22/Q4/a

An organic compound, **E**, has the following composition by mass:
C, 48.7%; H, 8.1%; O, 43.2%.

(a) Calculate the empirical formula of **E**.

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[2]

31. O/N 09/P21/Q1/b

A sample of magnesium has the following isotopic composition by mass.

isotope mass	24	25	26
% by mass	78.60	10.11	11.29

(a) Calculate the relative atomic mass, A_r, of magnesium to **four** significant figures.

A_r = ... **[2]**

32. M/J 09/P22/Q1/d

Titanium also reacts with chlorine.

(a) When an excess of chlorine was reacted with 0.72 g of titanium, 2.85 g of a chloride **A** was formed.

(i) Calculate the amount, in moles, of titanium used.

(ii) Calculate the amount, in moles, of chlorine atoms that reacted.

(iii) Hence, determine the empirical formula of **A**.

(iv) Construct a balanced equation for the reaction between titanium and chlorine.

..... **[4]**

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33. O/N 08/P2/Q1

Most submarines travel under water using electrical power from batteries. The German engineer Helmut Walter designed a diesel engine that could be used to propel a submarine beneath the surface of the sea. Instead of taking air from above the surface of the sea, Walter's engine used hydrogen peroxide, H_2O_2, to provide oxygen for a conventional diesel engine.

Hydrogen peroxide may be catalytically decomposed to give water and oxygen.

(a) (i) What is meant by the term *catalyst*?

.....

.....

(ii) Construct a balanced equation for the decomposition of H_2O_2.

..... **[3]**

Diesel fuel may be considered to consist of the hydrocarbon $C_{15}H_{32}$ which reacts completely with oxygen according to the following equation.

$$C_{15}H_{32} + 23O_2 \rightarrow 15CO_2 + 16H_2O$$

(b) (i) To which homologous series does $C_{15}H_{32}$ belong?

.....

(ii) Use the equation above and your answer to **(a)(ii)** to calculate the amount, in moles, of H_2O_2, that will provide sufficient oxygen for the complete oxidation of one mole of $C_{15}H_{32}$.

amount of H_2O_2 = ... mol **[3]**

A submarine equipped with a Walter engine used 212 tonnes of diesel fuel during an underwater voyage. The submarine also carried concentrated aqueous H_2O_2.
[1 tonne = 10^6 g]

(c) (i) Calculate the amount, in moles, of diesel fuel used during the underwater voyage.

amount of diesel fuel = ... mol

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(ii) Use your answers to **(b)(ii)** and **(c)(i)** to calculate the mass, in tonnes, of hydrogen peroxide used during the underwater voyage.

mass of H_2O_2 = ... tonnes **[4]**

(d) The exhaust products of the Walter engine were passed into the sea.
What would happen to them?

..... **[1]**

[11]

34. O/N 07/P2/Q3/c

(a) Sulphur and chlorine can be reacted together to form disulphur dichloride, S_2Cl_2.

Disulphur dichloride, S_2Cl_2, is decomposed by water forming sulphur and a mixture of hydrochloric acid and sulphurous acid.

When 2.7g of S_2Cl_2 is reacted with an excess of water, 0.96g of sulphur, S, is produced.

(i) What is the amount, in moles, of S_2Cl_2 present in 2.7g?

(ii) What is the amount, in moles, of S produced from 1.0mol of S_2Cl_2?

(iii) Construct a balanced equation for the reaction of S_2Cl_2 with water.

..... **[4]**

35. M/J 06/P2/Q1

Mohr's salt is a pale green crystalline solid which is soluble in water. Mohr's salt is a 'double salt' which contains

two cations, one of which is Fe^{2+},

one anion which is SO_4^{2-},

and water of crystallisation.

(a) The identity of the second cation was determined by the following test.
Solid Mohr's salt was heated with solid sodium hydroxide and a colourless gas was evolved. The gas readily dissolved in water giving an alkaline solution.

(i) What is the gas?

.....

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(ii) What is the formula of the second cation identified by this test?

.....

(iii) In this test, a grey/green solid residue was also formed.
Suggest a name **or** formula for this solid.

..... **[3]**

(b) The identity of the anion present in Mohr's salt was confirmed by adding dilute hydrochloric acid followed by aqueous barium chloride to an aqueous solution of Mohr's salt. A white precipitate was formed.
Suggest the identity of the white precipitate.

.....**[1]**

(c) When a double salt such as Mohr's salt is made, the two individual salts are mixed together in a 1:1 molar ratio, dissolved in water and the solution crystallised.

(i) Give the formula of **each** of the two salts that would be mixed to make the double salt, Mohr's salt.

salt 1 .....

salt 2 .....

(ii) Calculate the relative formula mass of **each** of the salts present in Mohr's salt.
salt 1

relative formula mass of salt 1 .....

salt 2

relative formula mass of salt 2 .....

(iii) The crystals of the double salt contain water of crystallisation.
The relative formula mass of Mohr's salt is 392. Use your answers to (ii) to calculate the number of moles of water of crystallisation present in one mole of Mohr's salt.

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[6]

[10]

36. M/J 05/P2/Q2/d(iii)

Hydrogen sulphide burns with a blue flame in an excess of oxygen to form sulphur dioxide and water.

(a) (i) What volume of oxygen, measured at room temperature and pressure, is required for the complete combustion of 8.65 g of H_2S? Give your answer to two decimal places.

[5]

37. M/J 05/P2/Q1

Iron and cobalt are adjacent elements in the Periodic Table. Iron has three main naturally occurring isotopes, cobalt has one.

(a) Explain the meaning of the term *isotope*.

.....

.....

..... [2]

(b) The most common isotope of iron is ^{56}Fe; the only naturally occurring isotope of cobalt is ^{59}Co.

Use the *Data Booklet* to complete the table below to show the atomic structure of ^{56}Fe and of ^{59}Co.

	number of		
isotope	protons	neutrons	electrons
^{56}Fe			
^{59}Co			

[3]

(c) A sample of iron has the following isotopic composition by mass.

isotope mass	54	56	57
% by mass	5.84	91.68	2.17

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(i) Define the term *relative atomic mass.*

.....

.....

.....

.....

(ii) By using the data above, calculate the relative atomic mass of iron to **three** significant figures.

[5]

[10]

38. M/J 04/P2/Q3/c

(a) 1.20 dm^3 of ammonia gas were dissolved in water to form 200 cm^3 of aqueous alkali at room temperature and pressure.

(i) Use the *Data Booklet* to calculate how many moles of $NH_3(g)$ were dissolved.

(ii) Write the equation for the neutralisation of aqueous ammonia by dilute sulphuric acid.

.....

(iii) Calculate the volume of 0.50 mol dm^{-3} sulphuric acid that is required to neutralise the 200 cm^3 of aqueous ammonia.

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[3]

39. M/J 04/P2/Q2/c

(a) The salt sodium phosphate, Na_3PO_4, is a water-softening agent.

(i) Write the equation for the complete neutralisation of phosphoric acid with aqueous sodium hydroxide.

.....

Sodium phosphate was prepared from 50.0 cm^3 of 0.500 mol dm^{-3} H_3PO_4 and an excess of aqueous sodium hydroxide.

(ii) How many moles of H_3PO_4 were used?

(iii) Use your equation in **(c)(i)** to calculate how many moles of sodium hydroxide are required.

[3]

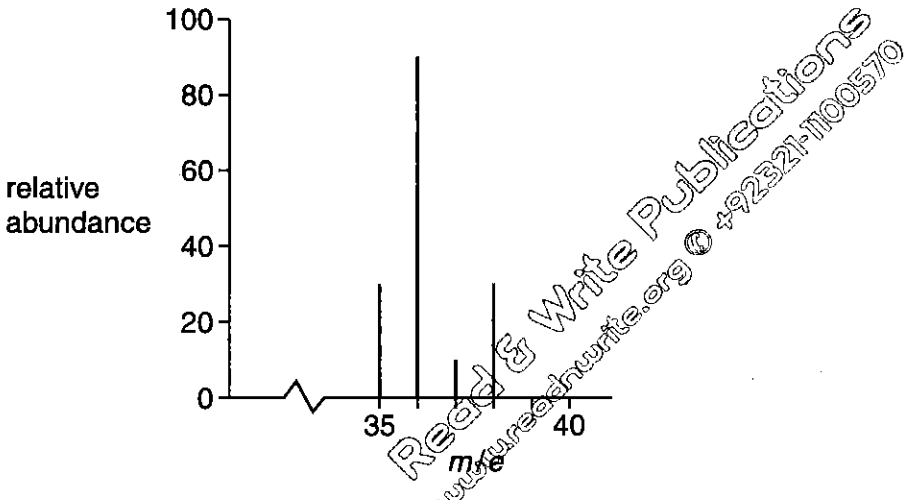
40. M/J 03/P2/Q1

(a) Define *an isotope* in terms of its sub-atomic particles.

.....

..... [1]

(b) In a mass spectrometer some hydrogen chloride molecules will split into atoms. The mass spectrum of HCl is given. Chlorine has two isotopes. The hydrogen involved here is the isotope ^1_1H only.



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(i) What particle is responsible for the peak at mass 35? .....

(ii) What particle is responsible for the peak at mass 38? ..... [2]

(c) Use the relative heights of the peaks to determine the proportions of the two isotopes of chlorine. Explain simply how you obtained your answer.

[2]

(d) Use your answer to **(c)** to explain why chlorine has a relative atomic mass of 35.5.

[1]

[6]

41. O/N 02/P2/Q3/d

(a) Antimony, Sb, has been known for about 6000 years. It is present in many ancient forms of bronze, but now its main use is to strengthen lead alloys.

Antimony is produced in a two-stage process from stibnite, a sulphide ore, Sb_2S_3.

The ore is first roasted in oxygen to form the oxide.

$$2Sb_2S_3 + \ldots\ldots\ldots\ldots O_2 \longrightarrow Sb_4O_6 + \ldots\ldots\ldots\ldots SO_2$$

(i) Balance the above equation.

The oxide is then reduced with carbon.

$$Sb_4O_6 + 3C \longrightarrow 4Sb + 3CO_2$$

(ii) What is the oxidation number of antimony in Sb_4O_6?

.....

(iii) Calculate the volume of carbon dioxide, measured at room temperature and pressure, that would be produced by the processing of 10 moles of Sb_2S_3.

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[4]

42. M/J 02/P2/Q6/c

(a) Another CFC contains the following elements by mass. The value of its M_r is 135.

C, 17.8%; H, 1.5%; Cl, 52.6%; F, 28.1%

Use these data to determine the molecular formula of the CFC.

[3]

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Answers Section

1. M/J 17/P22/Q1/b

(a) (i) EITHER **2**

mass of an atom / isotope 1

relative / compared to 1/12 (the mass) of (an atom of) C-12 OR

on a scale in which a C-12 (atom / isotope) has (a mass of exactly) 12 (units) 1

OR

mass of one mol (of atoms) of an isotope

relative / compared to 1/12 (the mass) of 1 mol of C-12 OR

on a scale in which one mol C-12 (atom / isotope) has a mass of (exactly) 12 g

(ii) $\frac{(10.0129 \times 19.78) + (80.22x)}{100} = 10.8$ **1**

x = 10.9941 **1**

2. M/J 17/P21/Q1/a

(a) The mass of a molecule **1**

OR the (weighted) average / (weighted) mean mass of the molecules

Relative / compared to $\frac{1}{12}$ (the mass) of an atom of carbon–12 **1**

OR on a scale in which a carbon–12 atom / isotope has a mass of (exactly) 12 (units)

3. M/J 16/P23/Q1

(a) (i) $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$ [1] [1]

(ii) $Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$ [1] [1]

(iii) $(0.025 \times 32.0/1000 =) 8 \times 10^{-4}$ [1] [1]

(iv) $(8 \times 10^{-4} \times 6 =) 4.8 \times 10^{-3}$ [1] [1]

(v) $(4.8 \times 10^{-3} \times 250/25.0 =) 4.8 \times 10^{-2}$ [1] [1]

(vi) $(4.8 \times 10^{-2} \times 55.8 =)$ 2.68 / 2.678 [1] [1]

(vii) (2.68/3.35=) 80% [1] [1]

(b) (i) covalent [1] [2]

small(er) difference in electronegativity between Fe and Cl (than between Al and Cl) [1]

(ii) $FeCl_3 + 6H_2O \rightarrow [Fe(H_2O)_6]^{3+} 3Cl^-$ OR [1] [1]

$FeCl_3 + 6H_2O \rightarrow [Fe(H_2O)_6OH]^{2+} + H^+ + 3Cl^-$ **[10]**

4. M/J 16/P22/Q3

(a) $Cr_2O_7^{2-} + 8H^+ + 3H_2C_2O_4 \rightarrow 2Cr^{3+} + 6CO_2 + 7H_2O$

M1 = species [1]

M2 = balancing [1] [2]

(b) (i) $(0.02 \times 32.0/1000 =) 6.40 \times 10^{-4}$ [1] [1]

(ii) $(6.4 \times 10^{-4} \times 3 =) 1.92 \times 10^{-3}$ [1] [1]

(iii) $(0.242 / 1.92 \times 10^{-3} =) 126(.0)$ [1] [1]

(iv) (126 – 90 = 36; 36 / 18 = 2 hence) x = 2 [1] [1]

[6]

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5. M/J 16/P22/Q1/c

(a) (i) (100 – 99.76 – 0.04=) 0.2 [1] [1]

(ii) $\frac{0.2x + (99.76 \times 16) + (0.04 \times 17)}{100} = 16.0044$ [1]

$x = 18$ [1] **[2]**

6. M/J 16/P21/Q1/d

(a) (i) 0.56(%) [1] [1]

(ii) $\frac{(A \times 0.56) + (86 \times 9.86) + (87 \times 7.00) + (88 \times 82.58)}{100} = 87.71$ [1] **[2]**

$A = 84$ [1]

7. MAR 16/P22/Q2

(a) (i) $\frac{27.30}{1000} \times 0.020 = \mathbf{5.46 \times 10^{-4}}$ (mol) [1] **[1]**

(ii) **(i)** $\times 6 = \mathbf{3.28 \times 10^{-3}}$ (mol) [1] **[1]**

(iii) **(ii)** $\times \frac{250}{25.00} = \mathbf{3.28 \times 10^{-2}}$ (mol) [1] **[1]**

(iv) M_r of $FeCO_3$ = 55.8 + 12.0 + 3(16.0) = **115.8** [1] **[2]**

(iii) $\times M_r(FeCO_3)$ = **3.79**g [1]

(v) $\frac{\textbf{(iv)}}{5.00} \times 100\% =$ **75.9%** [1] **[1]**

(b) (i) $2Fe^{3+} + Sn^{2+} \rightarrow 2Fe^{2+} + Sn^{4+}$

species [1] **[2]**

balancing [1]

(ii) $\mathbf{SnCl_2(aq)} + \mathbf{2}HgCl_2(aq) \rightarrow SnCl_4(\mathbf{aq}) + Hg_2Cl_2(\mathbf{s})$

$SnCl_2$ AND 2 [1] **[2]**

state symbols [1]

[10]

8. M/J 15/P22/Q2/e

(a) (i) $12.35 \times 0.01 / 1000 = 1.235 \times 10^{-4}$ [1] [1]

(ii) $1.235 \times 10^{-4} \times 1000/50 = 2.47 \times 10^{-3}$ [1] [1]

(iii) $2.47 \times 10^{-3} \times 64.1 = 0.158327\,g = 158$ (3 sf only) [1] [1]

9. M/J 15/P22/Q1/a,b

(a)

name of particle	relative mass	relative charge
proton	1	+1
electron	1/1836	–1
neutron	1	0

[1] [1] [1] **[3]**

(b) (i) Mass of an atom(s) [1]

relative to 1/ 12th(the mass) of (an atom of) carbon-12

OR [1] **[2]**

relative to carbon-12 which is (exactly) 12

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(ii) % of third isotope = 10 [1]

$$\frac{(24\times 79)+(26\times 11.0)+10x}{100}=24.3$$ [1]

10x = 248

x = 24.8 (3s.f.) [1] **[3]**

10. M/J 15/P22/Q1/c(ii)

(a) (i)

Mg	O	H	Cl	
31.65	20.84	1.31	46.2	[1]
24.3	16	1	35.5	
1.30	1.30	1.31	1.30	= 1:1:1:1

MgOHCl [1] **[2]**

11. M/J 15/P21/Q1/a,b

(a)

sub-atomic particle	relative mass	relative charge	
neutron	**1**	0	[1]
electron	1/1836	**–1**	[1]
proton	**1**	**+1**	[1] [3]

(b) (i) RAM = mean/ average mass of the isotopes/an atom(s) [1]
relative to 1/12 the mass of an atom of ^{12}C/ on a scale where an atom of ^{12}C is (exactly) 12 (units) [1]

isotope = atoms with the same number of protons / atomic number/ proton number with different mass numbers / numbers of neutrons / nucleon number [1] **[3]**

(ii) $$\frac{(0.89\times 74)+(9.37\times 76)+(7.63\times 77)+(23.77\times 78)+(49.61\times 80)+(8.73\times 82)}{100}$$ [1]

= 79.04 (2 d.p.) **AND** Se [1] **[2]**

12. M/J 15/P21/Q1/c(i)

(a) (i)

Te	Cl	
47.4	52.6	[1]
128	35.5	
0.370	1.48	
0.370	0.370	
1	4	so EF = $TeCl_4$ [1]

Empirical Formula Mass = 270 so MF = $TeCl_4$ [1] **[3]**

13. O/N 14/P22/Q1/b(ii & iii),c

(a) (i) four isotopes owtte 1 **[1]**

(ii) $$\frac{(84\times 0.56)+(86\times 9.86)+(87\times 7)+(88\times 82.58)}{100}$$ 1

= 87.7 (must be 3 sig figs) 1 **[2]**

(b) (i) (a species that) gains/takes electron(s) 1 **[1]**

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(ii)

Ba	Cl	O
45.1 / 137	23.4 / 35.5	31.5 / 16
0.329 / 0.329	0.659 / 0.329	1.969 / 0.329
1.00	2.00	5.98 / 6

1

1

emp form = $BaCl_2O_6$ 1 **[3]**

14. M/J 14/P23/Q2

(a) $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$ (1) [1]

(b) (i) Initial acid = $40 \times 0.4 / 1000 = 0.016$ (mol) (1) [1]

(ii) $\frac{25 \times 0.12}{1000} = 3.0 \times 10^{-3}$ (mol) (of OH^- used) (1) [1]

(iii) excess acid = $OH^- = 0.003$ (1)
acid reacted = $0.016 - 0.003 = 0.013$ (mol) [1]

(iv) $NH_4^+ : H^+ = 1:1$ so = 0.013 (mol NH_4^+) (1) [1]

(v) amount of Cu = mass/M_r = $0.413 / 63.5 = 6.5 \times 10^{-3}$ (mol) (1)
so $Cu:NH_4 = 0.0065:0.013 = 1:2$ so x = 2 (1) [2]

(vi) $M_r = 399.7$ (1) [1]

[8]

15. M/J 14/P22/Q1/a,b,c

(a) The (total) number of protons and neutrons (in the nucleus of an atom) 1 **1**

(b) (i) Mass of an atom(s) or isotope 1

relative to $\frac{1}{12}$ (the mass) of (an atom of) carbon–12 1

OR

relative to carbon–12 which is (exactly) 12 (units) **2**

allow a correct expression

(ii)

^{79}Br	^{81}Br	
$78.92x$	$80.92(100-x)$	where x = % abundance of ^{79}Br

so $\frac{78.92x + 80.92(100-x)}{100} = 79.9$ 1

$x = 51$ 1

hence $^{79}Br : {}^{81}Br = 51:49$ 1 **3**

(c)

A	Br	
$\frac{4.31}{A_r}$	$\frac{95.69}{79.9}$	$= 1:3$

So $\frac{95.69/79.9}{4.31/A_r} = 3$ 1

$A_r = \frac{3 \times 4.31 \times 79.9}{95.69} = 10.796 = 10.8$ to 3 s.f. 1

3 sig figs 1 **3**

allow alternative correct methods

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16. M/J 14/P22/Q2

(a) (i) (The $C_2O_4^{2-}$ ions) lose electrons owtte / ora

(ii) $2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) + \mathbf{16}H^+(aq) \rightarrow \mathbf{2Mn^{2+}}(aq) + 10CO_2(aq) + \mathbf{8}H_2O(l)$ 1+1+1 **3**

(b) (i) $\frac{20.0 \times 0.100}{1000} = 2(.00) \times 10^{-3}$ (mol) 1 **1**

(ii) $MnO_4^- : C_2O_4^{2-} = 2 : 5$
so amount of $C_2O_4^{2-} = (5/2) \times 2.00 \times 10^{-3} = 5(.00) \times 10^{-3}$ (mol) 1 **1**
ecf from **(b)(i)**

(iii) $5.00 \times 10^{-3} \times 250/25 = 0.05(0)$ (mol) 1 **1**
ecf from **(b)(ii)**

(iv) amount = mass/M_r so M_r = mass/amount = 6.30/ 0.05 = 126 1 **1**
ecf from **(b)(iii)**

(v) 126 – 90 = 36
36/18 = 2.00
$x = 2$ 1 **1**
Ecf from **(b)(iv)** if suitable

9

17. M/J 14/P21/Q1/c

(a) (i) (Weighted) mean / average mass of an atom(s) (of an element) 1
Relative to 1 / 12th of (the mass of an atom of) carbon-12 **OR** 1 **2**
relative to carbon-12 which is (exactly) 12 (units)
allow as an expression

(ii) $\frac{\mathbf{Z}}{\frac{31.13}{A_r}} \quad \frac{Cl}{\frac{68.87}{35.5}} = 1:2$

So $\frac{68.87/35.5}{31.13/A_r} = 2$ 1

$A_r = \frac{2 \times 31.13 \times 35.5}{68.87} = 32.0923 = 32.1$ to 3s.f. 1

Allow alternative correct methods **2**

18. M/J 14/P21/Q2/a(ii),b

(a) (i) $MnO_4^-(aq) + 5Fe^{2+}(aq) + \mathbf{8}H^+(aq) \rightarrow \mathbf{Mn^{2+}}(aq) + 5Fe^{3+}(aq) + \mathbf{4}H_2O(l)$ 1+1+1 **3**

(b) (i) $\frac{20.0 \times 0.020}{1000} = 4(.00) \times 10^{-4}$ (mol) 1 **1**

(ii) $MnO_4^- : Fe^{2+} = 1 : 5$ 1 **1**
so amount of $Fe^{2+} = 5 \times 4.00 \times 10^{-4} = 2(.00) \times 10^{-3}$ (mol)
ecf from **(b)(i)**

(iii) $2.00 \times 10^{-3} \times 250/25 = 0.02(00)$ (mol) 1 **1**
ecf from **(b)(ii)**

(iv) 3.40/0.02 = 170 1 **1**
ecf from (b)(iii)

(v) 170 151.8 = 18.2 1 **1**
18.2/18 = 1.01
x = 1
ecf from (b)(iv) if appropriate

9

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19. M/J 13/P22/Q2/a

(a) (i) $n(H_2SO_4) = \frac{25.0 \times 1.00}{1000} = 0.025$ mol (1)

(ii) $n(NaOH) = \frac{16.2 \times 2.00}{1000} = 0.0324$ mol (1)

(iii) $n(H_2SO_4)$ reacting with NaOH $= \frac{0.0324}{2} = 0.0162$ mol (1)

(iv) $n(H_2SO_4)$ reacting with NH_3 = 0.025 - 0.0162 = 0.0088 mol (1)

(v) $n(NH_3)$ reacting with H_2SO_4 = 2 x 0.0088 = 0.0176 mol (1)

(vi) $n(NaNO_3)$ reacting = $n(NH_3)$ produced = 0.0176 mol (1)

(vii) mass of $NaNO_3$ that reacted = 0.0176 x 85 = 1.496 g (1)

(viii) % of $NaNO_3 = \frac{1.496 \times 100}{1.64} = 91.2195122 = 91.2$

give one mark for the correct expression (1)
give one mark for answer given as 91.2 – i.e to 3 sig. fig. (1)
allow ecf where appropriate

[9]

20. M/J 13/P21/Q1/a

(a) (i) $NaOH + HCl \rightarrow NaCl + H_2O$ (1)

$(NH_4)_2SO_4 + 2NaOH \rightarrow 2NH_3 + Na_2SO_4 + 2H_2O$ (1) **[1]**

allow ionic equations in each case

(ii) $n(NaOH) = n(HCl) = \frac{39.2 \times 2.00}{1000} = 0.0784$ (1) **[1]**

(iii) $n(NaOH) = n(HCl) = \frac{29.5 \times 2.00}{1000} = 0.059$ (1) **[1]**

(iv) $n(NaOH) = 0.0784 - 0.059 = 0.0194$ (1) **[1]**

(v) $n[(NH_4)_2SO_4] = \frac{0.0194}{2} = 9.7 \times 10^{-3}$ (1)

(vi) mass of $(NH_4)_2SO_4 = 9.7 \times 10^{-3} \times 132.1 = 1.2814$ g (1)

(vii) % of $(NH_4)_2SO_4 = \frac{1.2814 \times 100}{2.96} = 43.30405405 = 43.3$

give one mark for the correct expression (1) **[1]**
give one mark for answer given as 43.3 – i.e. to 3 sig. fig. (1)
allow ecf where appropriate **[9]**

21. O/N 12/P22/Q1/a,b

(a) $ZnCO_3$ $Zn(OH)_2$ ZnO
not Zn **or** other compounds of Zn (any 2) **[2]**

(b) (i) to ensure all of the water of crystallisation had been driven off **or** to be at constant mass (1)

(ii) mass of $ZnSO_4$ = 76.34 – 74.25 = 2.09 g (1)

M_r $ZnSO_4$ = 65.4 + 32.1 + (4 × 16.0) = 161.5

allow use of Zn = 65 and/or S = 32 to give values between 161 and 161.5 (1)

$n(ZnSO_4) = \frac{2.09}{161.5} = 0.01294 = 1.29 \times 10^{-2}$

$ZnSO_4$ = 161 gives 1.30×10^{-2} (1)

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(iii) mass of H_2O driven off = 77.97 – 76.34 = 1.63 g (1)

$n(H_2O) = \frac{1.63}{18} = 0.0905 = 9.1 \times 10^{-2}$ (1)

(iv) 1.29×10^{-2} mol $ZnSO_4$ are combined with 9.1×10^{-2} mol H_2O

1 mol $ZnSO_4$ is combined with $\frac{9.1 \times 10^{-2}}{1.29 \times 10^{-2}}$

= 7.054 ≡ 7 mol H_2O

answer must be expressed as a whole number

allow ecf on candidate's answers to **(b)(ii)** and **(b)(iii)** (1) **[7]**

22. M/J 12/P23/Q2

(a) (i) $Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$ (1)

(ii) $n(HCl) = \frac{35.8}{1000} \times 0.100 = 3.58 \times 10^{-3}$ (1)

(iii) $n(Na_2CO_3) = \frac{35.8}{2} \times 10^{-3} = 1.79 \times 10^{-3}$ mol in 25.0 cm^3 (1)

(iv) $n(Na_2CO_3) = 1.79 \times 10^{-3} \times 10 = 1.79 \times 10^{-2}$ mol in 250 cm^3 (1)

(v) mass of $Na_2CO_3 = 1.79 \times 10^{-2} \times 106 = 1.90$g

M_r of $Na_2CO_3 = 106$ (1)

mass of Na_2CO_3 = 1.90 g (1) **[6]**

(b) $n(H_2O)$ in 5.13 g of washing soda $= \frac{5.13 - 1.90}{18} = 1.79 \times 10^{-1}$ mol (1)

$n(Na_2CO_3)$ in 5.13 g of washing soda = 1.79×10^{-2} mol

$n(H_2O) : n(Na_2CO_3) = 10 : 1$ (1)

or

1.90 g Na_2CO_3 are combined with 3.23.g H_2O

106 g Na_2CO_3 are combined with $\frac{3.23 \times 106}{1.90} = 180.2$ g H_2 (1)

this is 10 mol of H_2O (1)

or

1.79×10^{-2} mol $Na_2CO_3.xH_2O$ ≡ 5.13 g of washing soda

1 mol $Na_2CO_3.xH_2O \equiv \frac{5.13}{1.79 \times 10^{-2}} = 286.6$ g (1)

$Na_2CO_3 = 106$ and $H_2O = 18$ hence $x = 10$ (1) **[2]**

[8]

23. M/J 12/P21/Q2

(a) $(NH_4)_2SO_4 + 2NaOH \rightarrow \mathbf{2NH_3 + Na_2SO_4 + 2H_2O}$

correct products (1)

correctly balanced equation (1) **[2]**

(b) (i) $NaOH + HCl \rightarrow NaCl + H_2O$ (1)

(ii) $n(HCl) = \frac{31.2}{1000} \times 1.00 = 0.0312 = 0.03$ (1)

(iii) $n(NaOH) = \frac{50.0}{1000} \times 2.00 = 0.10$ (1)

(iv) n(NaOH) used up = 0.10 – 0.0312 = 0.0688 = 0.07 (1)

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(v) $n[(NH_4)_2SO_4] = \frac{0.0688}{2} = 0.0344 = 0.03$ (1)

(vi) mass of $(NH_4)_2SO_4 = 0.0344 \times 132 = 4.5408 = 4.54$ (1)

(vii) percentage purity $= \frac{4.5408 \times 100}{5.00} = 90.816 = 90.8$ (1) **[7]**

[9]

24. O/N 11/P23/Q2/a

(a) (i) mass of C $= \frac{12 \times 1.32}{44} = 0.36$g (1)

$n(C) = \frac{0.36}{12} = 0.03$ (1)

(ii) mass of H $= \frac{2 \times 0.54}{18} = 0.06$ g (1)

$n(H) = \frac{0.06}{1} = 0.06$ (1)

(iii) yes **because** 0.03 mol of C are combined with 0.06 mol of H **or**
C : H ratio is 1 : 2 **or**
empirical formula is CH_2 (1) **[5]**

25. O/N 11/P23/Q1

(a) same proton number/atomic number (1)
different mass number/nucleon number (1) **[2]**

(b) $A_r = \frac{(32 \times 95.00) + (33 \times 0.77) + (34 \times 4.23)}{100}$ (1)

$= \frac{3040 + 25.41 + 143.82}{100} = \frac{3209.23}{100}$

which gives $A_r = 32.09$ (1) **[2]**

(c)

	number of		
isotopes	protons	neutrons	electrons
^{213}Po	84	129	84
^{232}Th	90	142	90

allow **one mark** for each correct column
if there are no 'column' marks,
allow **maximum one mark** for a correct row (3 × 1) **[3]**

(d) (i) nucleon no. is 228 (1)
proton no. is 88 (1)

(ii) Ra **not** radium (1) **[3]**

[10]

26. O/N 11/P22/Q1/a

(a) (i) mass of C $= \frac{12 \times 0.352}{44} = 0.096$g (1)

$n(C) = \frac{0.096}{12} = 0.008$ (1)

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(ii) mass of H = $\frac{2 \times 0.144}{18}$ = 0.016g (1)

n(H) = $\frac{0.016}{1}$ = 0.016 (1)

(iii) mass of oxygen = 0.240 – (0.096 + 0.016) = 0.128g (1)

n(O) = $\frac{0.128}{16}$ = 0.008 (1)

allow ecf at any stage **[6]**

27. M/J 11/P23/Q1

Throughout this question, deduct **one mark only** for sig. fig. error.

(a) (i) the volume of solution **A** present in one 'typical ant' is
$7.5 \times 10^{-6} \times 1000 = 7.5 \times 10^{-3}$ cm^3 (1)

(ii) the volume of pure methanoic acid in one 'typical ant' is
$7.5 \times 10^{-3} \times \frac{50}{100} = 3.75 \times 10^{-3}$ gives 3.8×10^{-3} cm^3

allow ecf on **(i)** (1)

(iii) no. of ants = $\frac{1000}{3.8 \times 10^{-3}}$ = 263157.8947 gives 2.6×10^5

use of 3.75×10^{-3} gives 266666.6667 = 2.7×10^5 (1) **[3]**

(b) (i) the volume of solution **A**, in one ant bite is
$\frac{80}{100} \times 7.5 \times 10^{-3} = 6.0 \times 10^{-3}$ cm^3

allow ecf on **(a)(i)** (1)

the volume of pure methanoic acid in one bite is
$\frac{50}{100} \times 6.0 \times 10^{-3} = 3.0 \times 10^{-3}$ cm^3

allow ecf on first part of **(b)(i)** (1)

(ii) the mass of methanoic acid in one bite is
$3.0 \times 10^{-3} \times 1.2 = 3.6 \times 10^{-3}$ g

allow ecf on **(b)(i)** (1) **[3]**

(c) (i) $HCO_2H + NaHCO_3 \rightarrow HCO_2Na + H_2O + CO_2$ (1)

(ii) 46 g $HCO_2H \equiv$ 84 g $NaHCO_3$ (1)

5.4×10^{-3} g $HCO_2H \equiv \frac{84 \times 5.4 \times 10^{-3}}{46}$ g $NaHCO_3$

$= 9.860869565 \times 10^{-3}$

$= 9.9 \times 10^{-3}$ g $NaHCO_3$ (1) **[3]**

[9]

28. O/N 10/P23/Q1

(a) atoms of the same element / with same proton (atomic) number / same number of protons (1)
different numbers of neutrons / nucleon number / mass number (1) **[2]**

(b)

isotope	no. of protons	no. of neutrons	no. of electrons
^{24}Mg	12	12	12
^{26}Mg	12	14	12

each correct row (1) **[2]**

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(c) $A_r = \frac{24 \times 78.60 + 25 \times 10.11 + 26 \times 11.29}{100}$ (1)

$= \frac{1886.40 + 252.75 + 293.54}{100}$

gives 24.33 to 4 sig fig (same as data in question)

do not credit wrong number of sig figs **or** incorrect rounding up/down **(1)** **[2]**

(d) $Mg + Cl_2 \rightarrow MgCl_2$ (1) **[1]**

(e) **(i)** $n(Sb) = \frac{2.45}{122} = 0.020$ (1)

(ii) mass of Cl in **A** = 4.57 – 2.45 = 2.12 g (1)

$n(Cl) = \frac{4.57 \quad 2.45}{35.5} = \frac{2.12}{35.5} = 0.06$

allow ecf as appropriate (1)

(iii) Sb : Cl = 0.02 : 0.06 = 1:3

empirical formula of **A** is $SbCl_3$ (1)

(iv) $2Sb + 3Cl_2 \rightarrow 2SbCl_3$ (1) **[5]**

(f) **(i)** ionic (1)

(ii) covalent (1)

not van der Waals' forces **[2]**

[14]

29. O/N 10/P22/Q1

(a) the actual number of atoms of each element present (1)

in one molecule of a compound (1) **[2]**

(b) $C_xH_y + \left(x + \frac{y}{4}\right)O_2 \longrightarrow xCO_2 + \frac{y}{2}H_2O$

xCO_2 (1)

$\frac{y}{2}H_2O$ (1) **[2]**

(c) **(i)** oxygen/O_2 (1)

(ii) carbon dioxide/CO_2 (1)

(iii) 10 cm^3 (1)

(iv) 20 cm^3 (1) **[4]**

(d) $C_xH_y + \left(x + \frac{y}{4}\right)O_2 \longrightarrow xCO_2 + \frac{y}{2}H_2O$

10 cm^3 20 cm^3 10 cm^3

1 mol of C_xH_y gives 1 mol of CO_2

whence $x = 1$ (1)

1 mol of C_xH_y reacts with 2 mol of O_2

whence $\left(x + \frac{y}{4}\right) = 2$

and $y = 4$ (1)

molecular formula is CH_4 (1) **[3]**

[11]

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30. M/J 10/P22/Q4/a

(a) C : H : O $= \frac{48.7}{12} : \frac{8.1}{1} : \frac{43.2}{16}$ (1)

$= 4.06 : 8.1 : 2.70$

$= 1.5 : 3 : 1$

$= 3 : 6 : 2$

empirical formula is $C_3H_6O_2$ (1) **[2]**

31. O/N 09/P21/Q1/b

(a) $A_r = \frac{(24 \times 78.60) + (25 \times 10.11) + (26 \times 11.29)}{100}$ (1)

$= \frac{1886.4 + 252.75 + 293.54}{100} = \frac{2432.69}{100}$

which gives $A_r = 24.33$ (1)

penalise (–1) for misuse of significant figures **[2]**

32. M/J 09/P22/Q1/d

(a) **(i)** $n(Ti) = \frac{0.72}{47.9} = 0.015$ (1)

(ii) $n(Cl) = \frac{(2.85 - 0.72)}{35.5} = 0.06$ (1)

(iii) $0.015 : 0.06 = 1:4$

empirical formula of **A** is $TiCl_4$

Allow ecf on answers to **(i)** and/or **(ii)**. (1)

(iv) $Ti + 2Cl_2 \rightarrow TiCl_4$ (1)

Allow ecf on answers to **(iii)** **[4]**

33. O/N 08/P2/Q1

(a) **(i)** substance that speeds up a chemical reaction (1)
by lowering E_a
or by providing an alternative reaction pathway
or without being used up in the process (1)

(ii) $2H_2O_2 \rightarrow 2H_2O + O_2$ (1) **[3]**

(b) **(i)** alkanes **or** paraffins (1)

(ii) $2H_2O_2 : O_2$ and $C_{15}H_{32} : 23O_2$ (1)
whence $C_{15}H_{32} : 46H_2O_2$ (1)
allow e.c.f. on **(a)(ii)** **[3]**

(c) **(i)** $C_{15}H_{32} = 212$ (1)

$n(C_{15}H_{32}) = \frac{212 \times 10^6}{212} = 1 \times 10^6$ mol

allow e.c.f. on wrong M_r of $C_{15}H_{32}$ (1)

(ii) $n(H_2O_2)$ required $= 46 \times 10^6$ mol (1)
mass of $H_2O_2 = 34 \times 46 \times 10^6$ g $= 1564$ tonnes
final answer must be in tonnes (1)
allow e.c.f. on **(b)(ii)** and **(c)(i)** **[4]**

(d) they would dissolve (1) **[1]**

[11]

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34. O/N 07/P2/Q3/c

(a) (i) $S_2Cl_2 = (2 \times 32.1) + (2 \times 35.5) = 135.2$

$n(S_2Cl_2) = \frac{2.7}{135.2} = 0.0199 = 0.02$ (1)

0.02 mol $S_2Cl_2 \rightarrow \frac{0.96}{32.1} = 0.03$ mol S

1.0 mol $S_2Cl_2 \rightarrow \frac{0.03 \times 1.0}{0.02} = 1.5$ mol S (1)

(iii) $2S_2Cl_2 + 3H_2O \rightarrow 3S + H_2SO_3 + 4HCl$

correct products (1)

balanced equation (1) **[4]**

35. M/J 06/P2/Q1

(a) (i) ammonia/NH_3 (1)

(ii) NH_4^+ (1)

(iii) iron(II) hydroxide/$Fe(OH)_2$ (1) **[3]**

(b) barium sulphate/$BaSO_4$ (1) **[1]**

(c) (i) $FeSO_4$ (1)

$(NH_4)_2SO_4$ (1)

(ii) $FeSO_4 = 151.9$ (allow 151.8 to 152) (1)

$(NH_4)_2SO_4 = 132.1$ (allow 132) (1)

(iii) $xH_2O = 392 - (132.1 + 151.9) = 108$ (1)

$x = \frac{108}{18} = 6$ (1)

allow e.c.f. on candidate's sulphate in **(c)(i)**

e.c.f. answer must be a whole number **[6]**

[10]

36. M/J 05/P2/Q2/d(iii)

(a) (i) $2H_2S + 3O_2 \rightarrow 2H_2O + 2SO_2$ (1)

from -2 **(1)** to +4 (1)

allow e.c.f. on equation

(ii) 68.2g H_2S react with 3 x 24 dm^3 O_2 (1)

8.65g H_2S react with $\frac{3 \times 24 \times 8.65}{68.2} = 9.13\ dm^3$ (1)

allow 9.16 dm^3 if $H_2S = 68$ is used

allow e.c.f on **(d)(i)** **[5]**

37. M/J 05/P2/Q1

(a) same proton no./atomic no./no. of protons (1)

different mass no./nucleon no./no. of neutrons (1) **[2]**

(b)

	number of		
isotope	protons	neutrons	electrons
^{56}Fe	**26**	**30**	**26**
^{59}Co	**27**	**32**	**27**
	(1)	**(1)**	**(1)**

give one mark for each correct column

allow **(1)** if no column is correct but one row is correct **[3]**

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(c) (i) weighted mean/average mass
of an atom (not element) (1)
compared with ^{12}C (1)
one atom of ^{12}C has a mass of exactly 12 (1)
[relative to $^1/_{12}^{th}$ the mass of a ^{12}C atom would get 2]

or
mass of 1 mol of atoms (1)
compared with ^{12}C (1)
1 mol of ^{12}C has a mass of 12 g (1)

(ii) $A_r = \frac{54 \times 5.84 + 56 \times 91.68 + 57 \times 2.17}{100}$ (1)

$= \frac{5573.13}{100} = 55.7$ to 3 sf (1)

allow 55.9 if A_r is calculated using 99.69 instead of 100 **[5]**

[10]

38. M/J 04/P2/Q3/c

(a) (i) (1.2) / (2.4) = 1/20 or 0.05 moles **[1]**

(ii) $2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$ or equivalent **[1]**

(iii) 0.025 mols of H_2SO_4 are required
Vol. of 0.50 mol dm^{-3} H_2SO_4 required = (0.025 x 1000) / 0.5 = $50cm^3$ **[1]**

39. M/J 04/P2/Q2/c

(a) (i) $3NaOH + H_3PO_4 \longrightarrow Na_3PO_4 + 3H_2O$ **[1]**

(ii) (50 x 0.5) / 1000 = 0.025 (moles) **[1]**

(iii) conseq. on **(i)** 3 x .025 = 0.075 (moles) **[1]**

40. M/J 03/P2/Q1

(a) Atoms which have the same number of protons (or same element) but different numbers of neutrons (1) **[1]**

(b) (i) ^{35}Cl (1)
(ii) $H^{37}Cl$ (1) **[2]**

(c) H Cl line at 36 has rel. abundance of 90 (1)
38 30
These show ^{35}Cl and ^{37}Cl in ratio 3:1 (1)
[or use of 35 and 37] **[2]**

(d) Mean of the two isotopes $\frac{3 \times 35 + 1 \times 37}{4} = 35.5$ (1) **[1]**

[6]

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41. O/N 02/P2/Q3/d

(a) (i) $2Sb_2S_3 + 9O_2 \longrightarrow Sb_4O_6 + 6SO_2$ (1)

(ii) +3 or 3 NOT 3+ (1)

(iii) 2 mols Sb_2S_3 give $3CO_2$
∴ 10 mols Sb_2S_3 give 15 mol CO_2 (1)
$15 \times 24 = 0 dm^3 = 360 dm^3$ (1) **[4]**

42. M/J 02/P2/Q6/c

(a)

C	H	Cl	F
17.8	1.5	52.6	28.1
12	1	35.5	19
= 1.48	= 1.5	1.48	= 1.48

∴ CHClF (1) mass = 67.5 (1) ≠ mol of 135

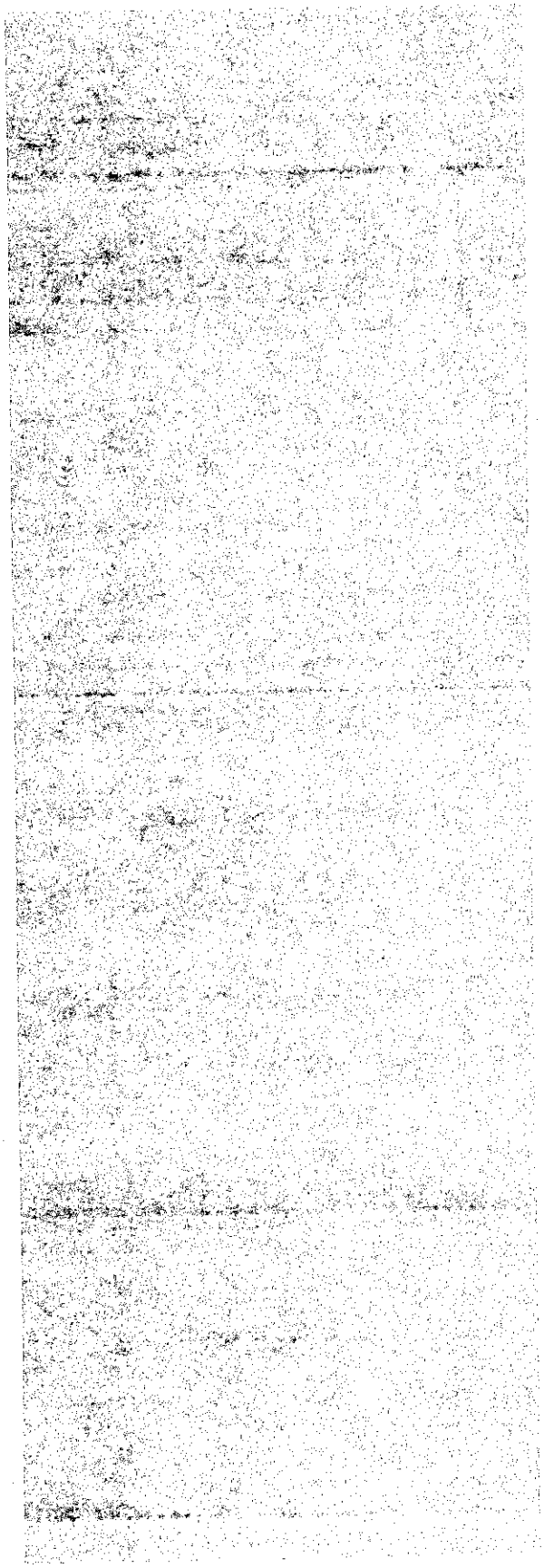
∴ Molecular formula is $C_2H_2Cl_2F_2$ (1) 3

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UNIT 2

Atomic Structure

A-Level
Chemistry Paper 2
Topical Workbook



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Unit 2: Atomic Structure

1. M/J 16/P22/Q1/a,b

(a) Complete the table to show the composition and identity of some atoms and ions.

name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge
boron	10	5	.....	.....	.....	0
nitrogen	.....	.....	.....	8	10	.....
.....	208	82	82	.....	80	.....
.....	.....	.....	3	3	.....	+1

[4]

(b) The fifth to eighth ionisation energies of three elements in the third period of the Periodic Table are given. The symbols used for reference are **not** the actual symbols of the elements.

	ionisation energies, kJ mol^{-1}			
	fifth	sixth	seventh	eighth
X	7012	8496	27107	31671
Y	6542	9362	11018	33606
Z	7238	8781	11996	13842

(i) State and explain the group number of element **Y**.

group number .....

explanation .....

.....

[1]

(ii) State and explain the general trend in **first** ionisation energies across the third period.

.....

.....

..... **[2]**

(iii) Complete the electronic configuration of element **X**.

$1s^2$ ..... **[1]**

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2. M/J 16/P21/Q1/a,b

(a) Complete the table to show the composition and identity of some atoms and ions.

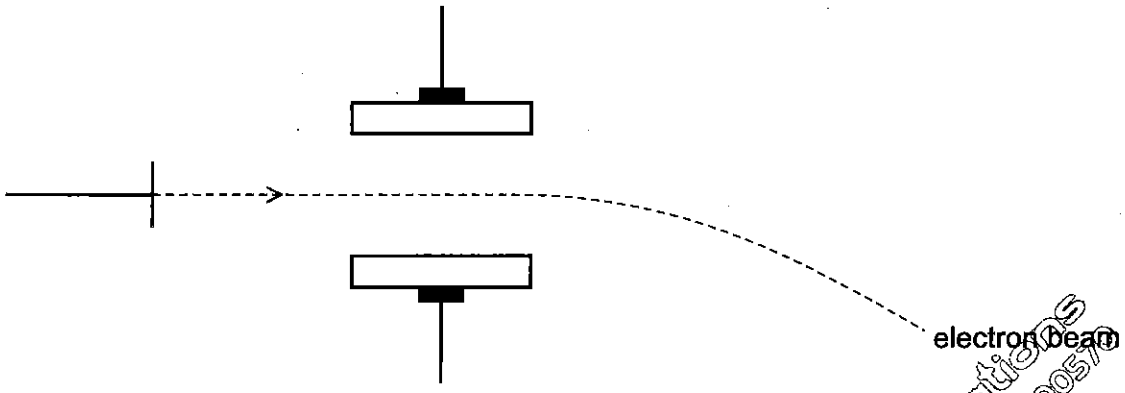
name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge
lithium	6	3	.....	.....	.....	+1
oxygen	.....	.....	.....	9	10	.....
.....	54	26	26	.....	24	.....
.....	.....	.....	17	18	.....	0

[4]

(b) Beams of protons, neutrons and electrons behave differently in an electric field due to their differing properties.

The diagram shows the path of a beam of electrons in an electric field.

Add and label lines to represent the paths of beams of protons and neutrons in the same field.



[3]

3. O/N 14/P22/Q1/a,b(i),c(i)

(a) Successive ionisation energies for the elements magnesium to barium are given in the table.

element	1st ionisation energy / kJ mol^{-1}	2nd ionisation energy / kJ mol^{-1}	3rd ionisation energy / kJ mol^{-1}
Mg	736	1450	7740
Ca	590	1150	4940
Sr	548	1060	4120
Ba	502	966	3390

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(i) Explain why the first ionisation energies decrease down the group.

.....

.....

.....

..... **[3]**

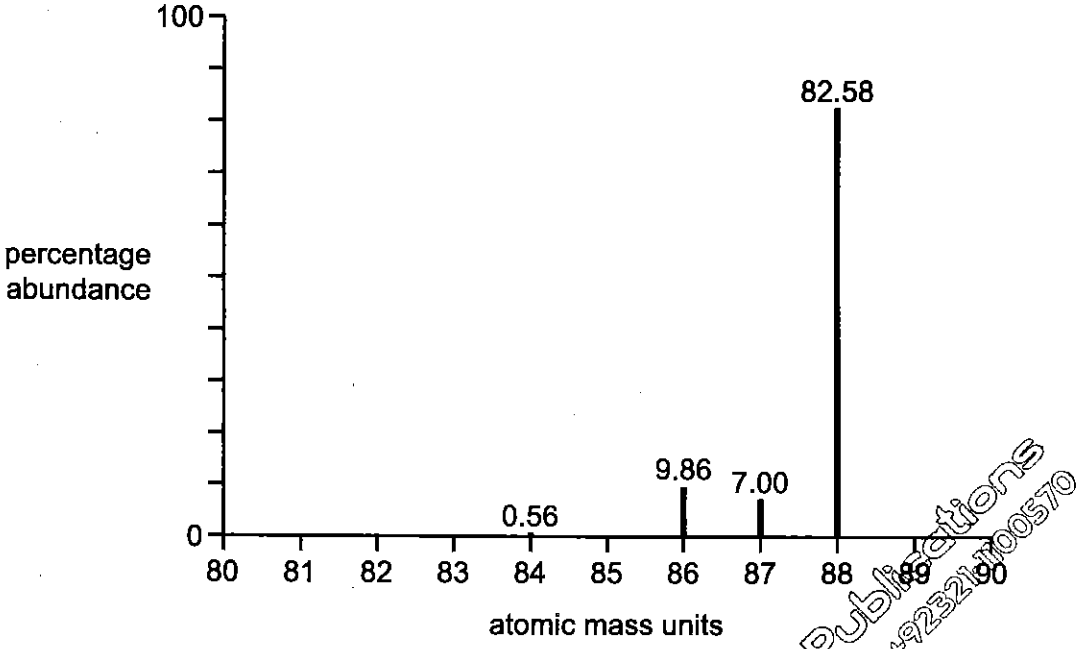
(ii) Explain why, for each element, there is a large increase between the 2nd and 3rd ionisation energies.

.....

.....

..... **[2]**

(b) A sample of strontium, atomic number 38, gave the mass spectrum shown. The percentage abundances are given above each peak.



(i) Complete the full electronic configuration of strontium.

$1s^2\ 2s^2\ 2p^6$ ..... **[1]**

(c) A compound of barium, **A**, is used in fireworks as an oxidising agent and to produce a green colour.

(i) Explain, in terms of electron transfer, what is meant by the term *oxidising agent*.

.....

..... **[1]**

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4. M/J 14/P21/Q1/a,b

(a) Explain what is meant by the term *ionisation energy*.

.....

.....

..... **[3]**

(b) The first seven ionisation energies of an element, **A**, in kJ mol^{-1}, are

1012 1903 2912 4957 6274 21 269 25 398.

(i) State the group of the Periodic Table to which **A** is most likely to belong. Explain your answer.

.....

.....

.....

..... **[2]**

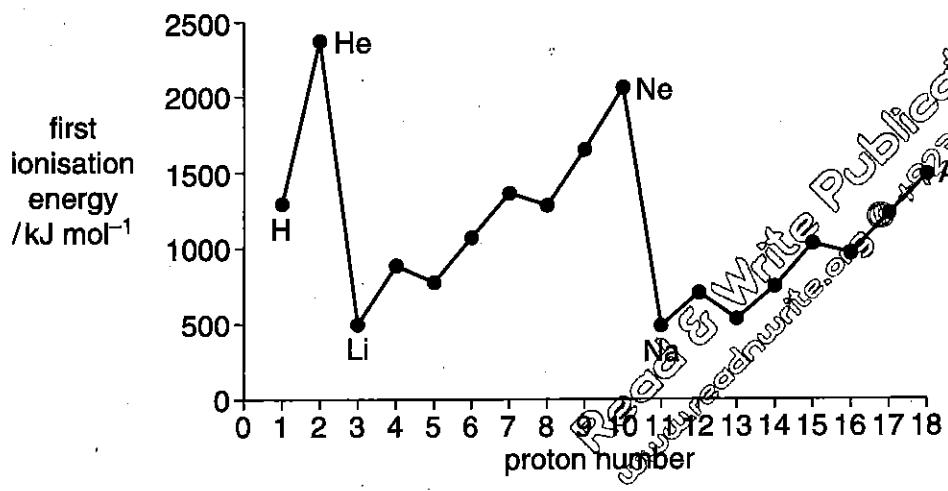
(ii) Complete the electronic configuration of the element in Period 2 that is in the same group as **A**.

$1s^2$ ..... **[1]**

5. O/N 11/P23/Q3/a,b

The Periodic Table we currently use is derived directly from that proposed in 1869 by Mendeleev who had noticed patterns in the physical and chemical properties of the elements he had studied.

The diagram below shows the first ionisation energies of the first 18 elements of the Periodic Table.



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(a) Give the equation, including state symbols, for the first ionisation energy of carbon.

..... **[2]**

(b) **(i)** Explain why sodium has a lower first ionisation energy than magnesium.

.....

.....

(ii) Explain why magnesium has a higher first ionisation energy than aluminium.

.....

.....

(iii) Explain why helium, He, and neon, Ne, occupy the two highest positions on the diagram.

.....

.....

(iv) Explain why the first ionisation energy of argon, Ar, is lower than that of neon, which is lower than that of helium.

.....

.....

..... **[8]**

6. O/N 11/P23/Q1/a,c,d

Sulfur, S, and polonium, Po, are both elements in Group VI of the Periodic Table.

Sulfur has three isotopes.

(a) Explain the meaning of the term *isotope*.

.....

.....

..... **[2]**

(b) Isotopes of polonium, proton number 84, are produced by the radioactive decay of several elements including thorium, Th, proton number 90.

The isotope ^{213}Po is produced from the thorium isotope ^{232}Th.

Complete the table below to show the atomic structures of the isotopes ^{213}Po and ^{232}Th.

	number of		
isotope	protons	neutrons	electrons
^{213}Po			
^{232}Th			

[3]

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Radiochemical reactions, such as nuclear fission and radioactive decay of isotopes, can be represented by equations in which the nucleon (mass) numbers must balance and the proton numbers must also balance.

For example, the nuclear fission of uranium-235, $^{235}_{92}U$, by collision with a neutron, $^{1}_{0}n$, produces strontium-90, xenon-143 and three neutrons.

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{90}_{38}Sr + {}^{143}_{54}Xe + 3\,{}^{1}_{0}n$$

In this equation, the nucleon (mass) numbers balance because: 235 + 1 = 90 + 143 + (3x1).

The proton numbers also balance because: 92 + 0 = 38 + 54 + (3x0).

(c) In the first stage of the radioactive decay of $^{232}_{90}Th$, the products are an isotope of element *E* and an alpha-particle, $^{4}_{2}He$.

(i) By considering nucleon and proton numbers only, construct a balanced equation for the formation of the isotope of *E* in this reaction.

$$^{232}_{90}Th \rightarrow \text{.....} + {}^{4}_{2}He$$

Show clearly the nucleon number and proton number of the isotope of *E*.

nucleon number of the isotope of *E* .....

proton number of the isotope of *E* .....

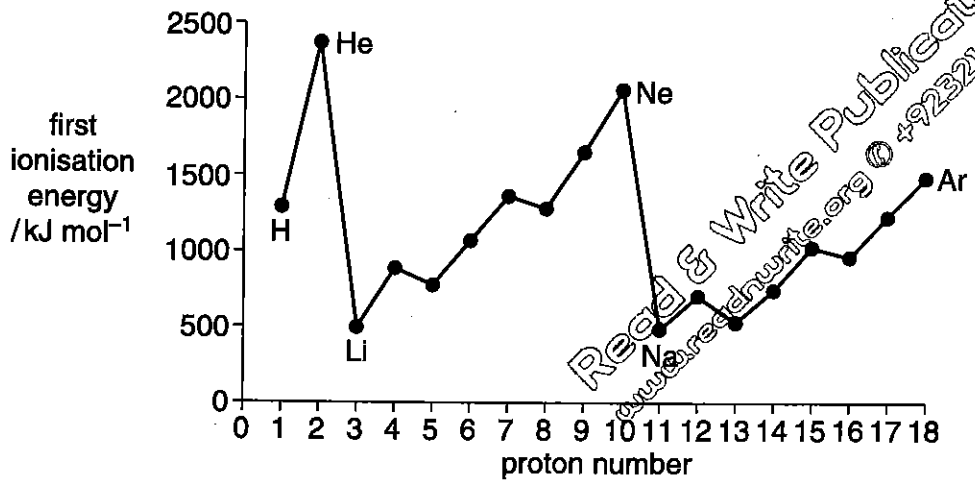
(ii) Hence state the symbol of the element *E*.

..... **[3]**

7. O/N 11/P21/Q2/a,b,c

The Periodic Table we currently use is derived directly from that proposed in 1869 by Mendeleev who had noticed patterns in the physical and chemical properties of the elements he had studied.

The diagram below shows the first ionisation energies of the first 18 elements of the Periodic Table.



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(a) Give the equation, including state symbols, for the first ionisation energy of sulfur.

..... [2]

(b) Explain why there is a **general** increase in first ionisation energies across the Period from sodium to argon.

.....

.....

.....

..... [3]

(c) **(i)** Explain why the first ionisation energy of magnesium is greater than that of aluminium.

.....

.....

.....

(ii) Explain why the first ionisation energy of phosphorus is greater than that of sulfur.

.....

.....

..... [4]

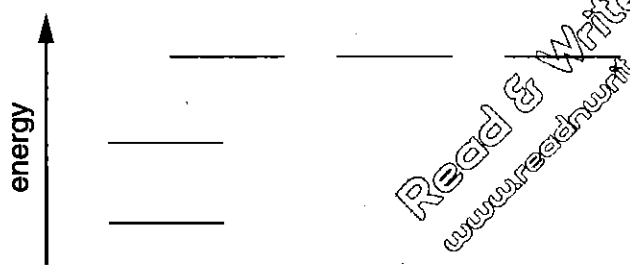
8. M/J 10/P22/Q1

In the 19th and 20th centuries, experimental results showed scientists that atoms consist of a positive, heavy nucleus which is surrounded by electrons.

Then in the 20th century, theoretical scientists explained how electrons are arranged in orbitals around atoms.

(a) The diagram below represents the energy levels of the orbitals present in atoms of the second period (Li to Ne).

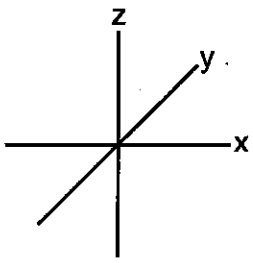
(i) Label the energy levels to indicate the principal quantum number and the type of orbital at each energy level.

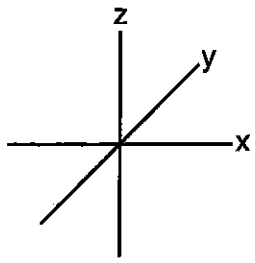


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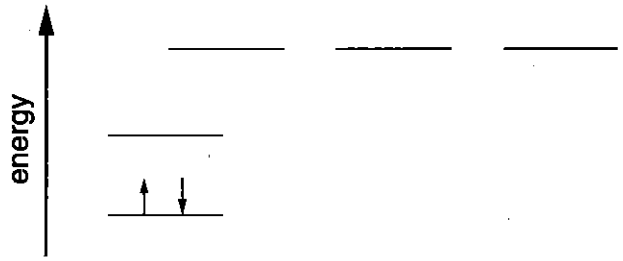
(ii) On the axes below, draw a sketch diagram of **one** of each **different type (shape)** of orbital that is occupied by the electrons in a second-period element.

Label each type.

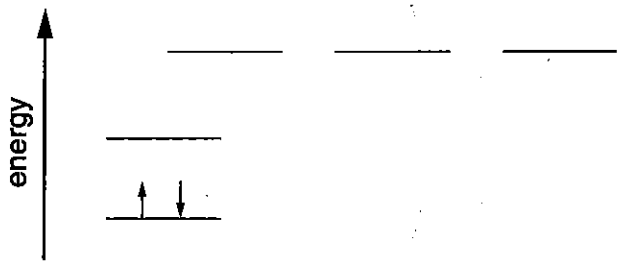




(iii) Complete the electronic configurations of nitrogen atoms and oxygen atoms on the energy level diagrams below.
Use arrows to represent electrons.



nitrogen



oxygen

[6]

(b) (i) Use the *Data Booklet* to state the value of the first ionisation energy of nitrogen and of oxygen.

N ..... kJ mol^{-1} O ..... kJ mol^{-1}

(ii) Explain, with reference to your answer to **(a)(iii)**, the relative values of these two ionisation energies.

.....

.....

.....

[3]

[9]

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9. O/N 09/P21/Q1/a,c

Magnesium, Mg, and radium, Ra, are elements in Group II of the Periodic Table.

Magnesium has three isotopes.

(a) Explain the meaning of the term *isotope.*

.....

.....

..... **[2]**

Radium, proton number 88, and uranium, proton number 92, are radioactive elements.

The isotope ^{226}Ra is produced by the radioactive decay of the uranium isotope ^{238}U.

(b) Complete the table below to show the atomic structures of the isotopes ^{226}Ra and ^{238}U.

	number of		
isotopes	protons	neutrons	electrons
^{226}Ra			
^{238}U			

[3]

10. M/J 09/P22/Q1/a

Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, *Al*, is in the third period of the Periodic Table; copper and titanium are both transition elements.

(a) Complete the electronic configuration of aluminium and of titanium, proton number 22.

Al	$1s^2$
Ti	$1s^2$

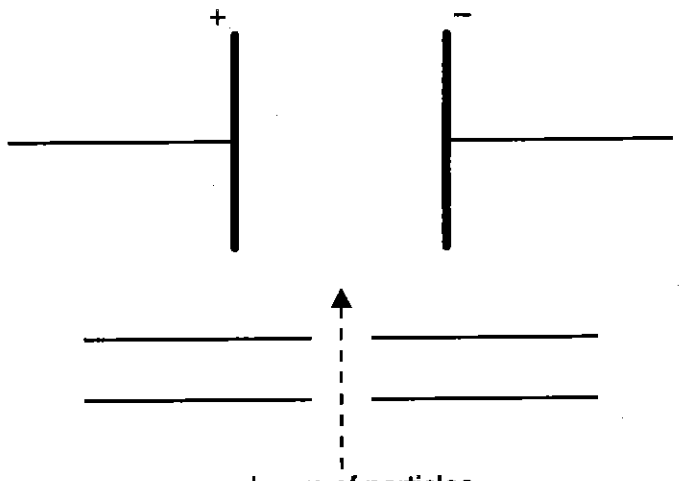
[1]

11. O/N 06/P2/Q1

In the 19th and 20th centuries, scientists established the atomic theory and showed that three sub-atomic particles, electron, neutron and proton, exist. The masses and charges of these three particles were subsequently determined.

When separate beams of electrons, neutrons or protons are passed through an electric field in the apparatus below, they behave differently.

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(a) **(i)** Which of these three particles will be deflected the most by the electric field?

.....

(ii) In which direction will this particle be deflected?

.....

(iii) Explain your answer.

.....

.....

[4]

(b) **(i)** Define the term *proton number*.

.....

.....

(ii) Why is the proton number of an atom of an element usually different from the nucleon number of an atom of the element?

.....

.....

[2]

(c) Protons and neutrons have been used in nuclear reactions which result in the formation of artificial elements. In such processes, protons or neutrons are accelerated to high speeds and then fired like 'bullets' at the nucleus of an atom of an element.

Suggest why neutrons are more effective than protons as 'nuclear bullets'.

.....

..... **[2]**

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(d) In some cases, when neutrons are fired at atoms of an element, the neutrons become part of the nucleus of those atoms.

What effect does the presence of an extra neutron have on the chemical properties of the new atoms formed? Explain your answer.

.....

.....

..... [2]

[10]

12. O/N 05/P2/Q1

The first six ionisation energies of an element **X** are given below.

ionisation energy / kJ mol^{-1}					
first	second	third	fourth	fifth	sixth
950	1800	2700	4800	6000	12300

(a) Define the term *first ionisation energy*.

.....

.....

.....

..... [3]

(b) Write an equation, with state symbols, for the **second** ionisation energy of element **X**.

..... [2]

(c) Use the data given above to deduce in which Group of the Periodic Table element **X** is placed. Explain your answer.

Group .....

explanation .....

.....

.....

..... [3]

The first ionisation energies (I.E.) for the elements of Group IV are given below.

element	C	Si	Ge	Sn	Pb
1st I.E. / kJ mol^{-1}	1090	786	762	707	716

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(d) Explain the trend shown by these values in terms of the atomic structure of the elements.

.....

.....

.....

.....

..... **[4]**

[12]

13. M/J 05/P2/Q2/e-ii

Hydrogen sulphide is a weak diprotic (dibasic) acid. Its solution in water contains HS^- and a few S^{2-} ions.

(a) Write an equation, with state symbols, for the **first** ionisation of H_2S when it dissolves in water.

..... **[3]**

14. M/J 02/P2/Q1

Sir James Jeans, who was a great populariser of science, once described an atom of carbon as being like six bees buzzing around a space the size of a football stadium.

(a) **(i)** Suggest what were represented by the six bees in this description.

.....

(ii) Explain (in terms of an atom of carbon) what stopped the bees from flying away from the space of the football stadium.

.....

.....

(iii) What is missing from Jeans' description when applied to an atom of carbon?

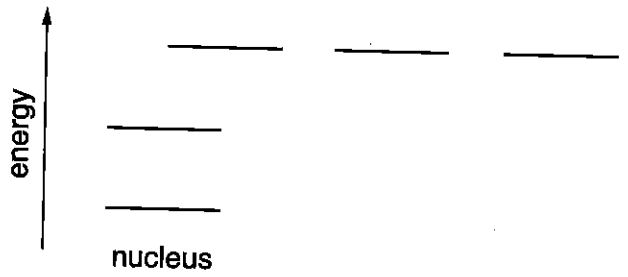
.....

..... **[3]**

(b) The diagram below represents the energy levels of the orbitals in atoms of the second period, lithium to neon.

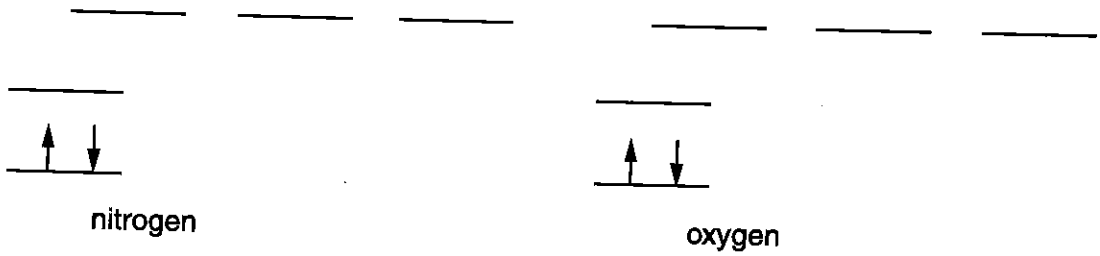
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(i) Label the energy levels to indicate the principal quantum number and the type of orbital at each energy level.



(ii) In the space below, sketch the shapes of the two types of orbital.

(iii) Complete the electron configurations of nitrogen and oxygen on the energy level diagrams below, using arrows to represent electrons.



(iv) Explain, with reference to your answer to **(iii)**, the relative values of the first ionisation energies of nitrogen and oxygen. The values are given in the *Data Booklet* and should be quoted in your answer.

.....

.....

.....

.....

[6]

(c) **(i)** State the formulae of the negatively charged ions formed by these elements in simple binary compounds (nitrides and oxides).

.....

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(ii) Why do nitrogen and oxygen form negative ions, but not positive ions, in simple binary compounds?

.....

.....

.....

[2]

[11]

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Answers Section

1. M/J 16/P22/Q1/a,b

(a)

name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge		
boron	10	5	5	5	5	0	[1]	
nitrogen	15	7	7	8	10	–3	[1]	
lead	208	82	82	126	80	+2	[1]	
lithium	6	3	3	3	2	+1	[1]	[4]

(b) (i) Group 17/VII/7

AND

big (owtte) increase/big difference/big gap/big jump/jump in increase/jump in difference after 7th IE [1] [1]

(ii) increases across period due to increasing attraction (of nucleus for electrons) [1]

due to increasing nuclear charge/atomic/proton number AND constant/similar shielding/same (outer) shell/energy level [1] [2]

(iii) $1s^2 2s^2 2p^6 3s^2 3p^4$ [1] [1]

2. M/J 16/P21/Q1/a,b

(a)

name of element	nucleon no.	atomic no.	no. of protons	no. of neutrons	no. of electrons	overall charge		
lithium	6	3	3	3	2	+1	[1]	
oxygen	17	8	8	9	10	–2	[1]	[4]
iron	54	26	26	28	24	+2	[1]	
chlorine	35	17	17	18	17	0	[1]	

(b) line straight on labelled 'neutrons' [1]
line (curving) up labelled 'protons' [1] [3]
proton line clearly shows less (overall) deflection than electron curve [1]

3. O/N 14/P22/Q1/a,b(i),c(i)

(a) (i) increasing **distance** of (outer) electron(s) from nucleus
OR increasing distance of outer/valence shell from nucleus 1

increased **shielding**/screening (from inner shells) 1

reduces **attraction** 1 [3]

(ii) (3^{rd} electron for each in) inner/lower energy level/**shell**/closer to nucleus (than first two)/less shielding 1

(large) increase in nuclear attraction 1 [2]

(b) (i) $(1s^2\ 2s^2\ 2p^6)\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 5s^2$ 1 [1]

(c) (i) (a species that) gains/takes electron(s) 1 [1]

4. M/J 14/P21/Q1/a,b

(a) The amount of energy required/energy change/enthalpy change when one electron is removed 1
from each atom/(cat)ion in one mol 1
of gaseous atoms/(cat)ions 1
OR energy change when 1 mole of electrons is removed from one mole of gaseous atoms/ions
$X(g) \rightarrow X^+(g) + e^-$ gains 2 marks 3

(b) (i) Group V/5/15 1

Big difference between fifth and sixth ionisation energies 1 2

(ii) $1s^2\ 2s^2\ 2p^3$ 1 1
ecf from **(b)(i)** if period 2

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5. O/N 11/P23/Q3/a,b

(a) $C(g) \rightarrow C^+(g) + e^-$ (1)
correct equation
correct state symbols (1) [2]

(b) (i) Na and Mg
Mg has greater nuclear charge/more protons than Na (1)

in both atoms, the 3s electrons are in the same orbital/ same energy level/same shell (1)

(ii) Mg and Al
in Al outermost electron is in 3p rather than 3s (1)

3p electron is at higher energy **or** is further away/is more shielded from nucleus (1)

(iii) He and Ne
both He and Ne have the highest nuclear charges in their Period (1)

(iv) He, Ne, and Ar
going down the group,

valence/outer shell electrons are farther from the nucleus (1)

there is greater shielding (1)

attraction between valence electrons and nucleus is less **or** effective nuclear charge is less (1) [8]

6. O/N 11/P23/Q1/a,c,d

(a) same proton number/atomic number (1)
different mass number/nucleon number (1) [2]

(b)

	number of		
isotopes	protons	neutrons	electrons
^{213}Po	84	129	84
^{232}Th	90	142	90

allow **one mark** for each correct column
if there are no 'column' marks,
allow **maximum one mark** for a correct row (3 × 1) [3]

(c) (i) nucleon no. is 228 (1)
proton no. is 88 (1)

(ii) Ra **not** radium (1) [3]

7. O/N 11/P21/Q2/a,b,c

(a) $S(g) \rightarrow S^+(g) + e^-$ (1)
correct equation
correct state symbols (1) [2]

(b) from Na to Ar,
electrons are added to the same shell/have same shielding (1)
electrons are subject to increasing nuclear charge/proton number (1)
electrons are closer to the nucleus **or** atom gets smaller (1) [3]

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(c) (i) Mg and Al

in Mg outermost electron is in 3s **and**
in Al outermost electron is in 3p (1)

3p electron is at higher energy **or**
is further away from the nucleus **or**
is more shielded from the nucleus (1)

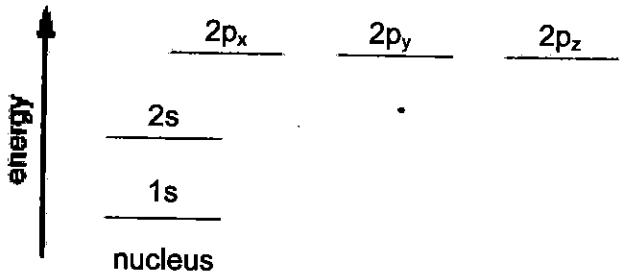
(ii) S and P

for S one 3p orbital has paired electrons **and**
for P 3p sub-shell is singly filled (1)

paired electrons repel (1) [4]

8. M/J 10/P22/Q1

(a) (i)



correct 1s and 2s (1)
correct $2p_x$, $2p_y$ and $2p_z$ (1)

(ii)

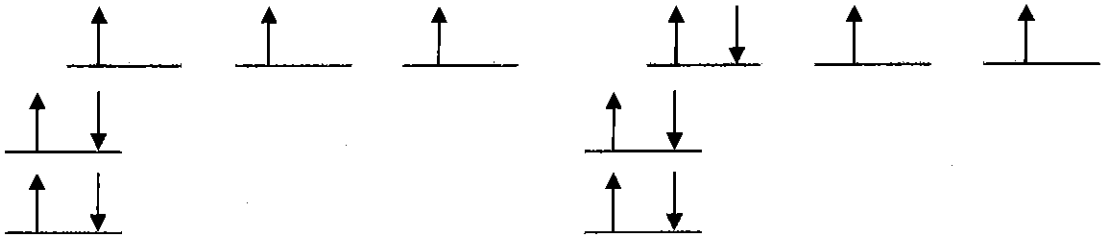
spherical s orbital (1)

double lobed p orbital along one axis (1)

both orbitals correctly labelled (1)

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(iii)



nitrogen oxygen

both correct (1) [6]

(b) (i) N 1400 kJ mol^{-1} O 1310 kJ mol^{-1} **both** (1)

(ii) N is all singly filled 2p orbitals **or** O has one filled/paired 2p orbital (1)
these paired 2p electrons in the O atom repel one another (1) [3]

[9]

9. O/N 09/P21/Q1/a,c

(a) same proton number/atomic number (1)
different mass number/nucleon number (1) [2]

(b)

isotopes	number of		
	protons	neutrons	electrons
^{226}Ra	88	138	88
^{238}U	92	146	92

allow **one mark** for each correct column (3 × 1)
if there are no correct columns,
allow **maximum one mark** for a correct row [3]

10. M/J 09/P22/Q1/a

(a) Al $1s^2\ 2s^2 2p^6\ 3s^2 3p^1$ (1)

Ti $1s^2\ 2s^2 2p^6\ 3s^2\ 3p^6\ 3d^2\ 4s^2$ **or**

$1s^2\ 2s^2 2p^6\ 3s^2\ 3p^6\ 4s^2 3d^2$ penalise any error (1) [2]

11. O/N 06/P2/Q1

(a) (i) electron (1)

(ii) towards the positive pole (1)

(iii) electron has negative charge (1)

electron has very small mass (1)

(b) (i) the number of protons in the nucleus of an atom (1)

(ii) the nucleus usually contain protons and neutrons (1)

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(c) neutrons are uncharged (1)

and are not repelled by protons in the nuclei of atoms (1)

(d) no change (1)

new atom/isotope formed has the same electronic configuration as the original element (1)

12. O/N 05/P2/Q1

(a) Energy required to remove one electron from each atom (1)

in one mole of (1)

gaseous atoms of an element (1)

(*'Energy change when one mole of gaseous atoms loses one mole of electrons'* would score all three marks.) **[3]**

(b) $X^+(g) \rightarrow X^{2+}(g) + e^-$ equation (1)

state symbols (1) **[2]**

(c) Group 5 (1)

sharp rise in successive ionisation energies between 5th and 6th IEs (1)

indicating change to a different shell/energy level **or** outer shell contains 5 electrons (1) **[3]**

(d) down the Group

atomic radii increase/ outer electrons are increasingly further away (1)

electrons are added to new shells/more shells (1)

more shielding (1)

despite increase in nuclear charge (1) **[4]**

[12]

13. M/J 05/P2/Q2/e-ii (i,ii)

(a) $H_2S(g) + H_2O(l) \rightarrow H_3O^+(aq) + HS^-(aq)$

or

$H_2S(g) + aq \rightarrow H^+(aq) + HS^-(aq)$

or

$H_2S(aq) \rightarrow H^+(aq) + HS^-(aq)$

equation **(1)** state symbols **(1)** **[3]**

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14. M/J 02/P2/Q1

(a)(i) The six electrons of carbon. /some reference to charge.

(ii) The electrostatic attraction from the oppositely charged particles. [3]

(iii) The nucleus (give credit if answered in (ii)).

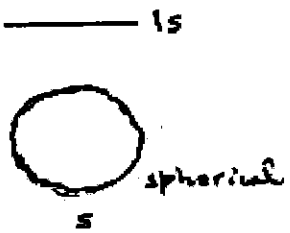
(b) (i) $2p_x$ $2p_y$ $2p_z$ (1)

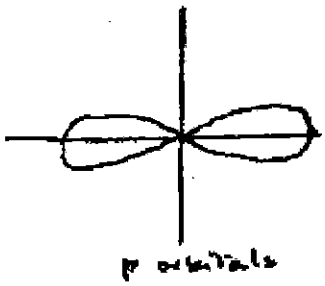
2s

1s

n = 1, 2, 3 (1) [2]

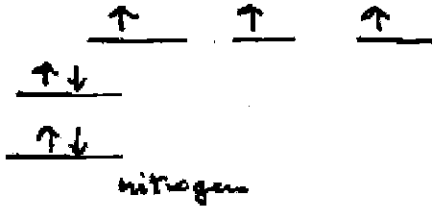
(ii)

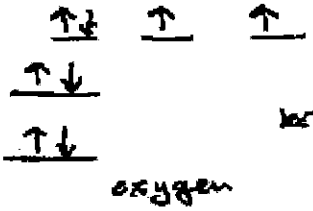




both [1]

(iii)





both (1) [1]

(iv) Ion IE. N is 1402 O is 1310 OR N > O (1)

explanation in Terms of electron repulsion within doubly occupied p orbital half-filled

OR symmetry of two p orbitals of single occupancy (1) [2]

NOT 3 electrons are notable

(c)(i) N^{3-} and O^{2-} both (1) [2]

(ii) These anions have complete octet / inert gas configuration

OR I.E values too large for stability of cations (1) [1]

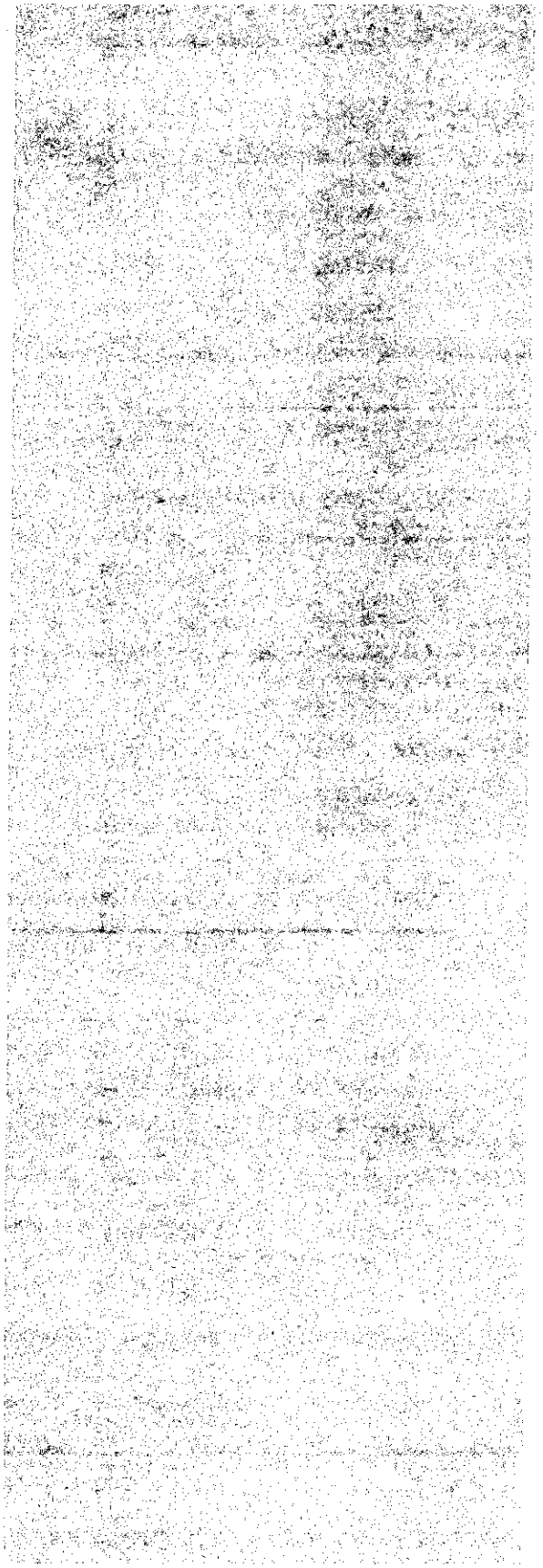
Not electronegative.

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UNIT 3

Chemical Bonding

A-Level
Chemistry Paper 2
Topical Workbook



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Unit 3: Chemical Bonding

1. M/J 17/P21/Q4/a,(ii),(iii)

(a) (i) Explain how sp^2 and sp^3 hybridisation can occur in carbon atoms.

sp^2 hybridisation .....

.....

sp^3 hybridisation .....

..... **[2]**

(ii) State the bond angles normally associated with each type of hybridisation in carbon atoms.

sp^2 .....

sp^3 ..... **[2]**

2. M/J 17/P21/Q2/a,b

Structure and bonding can be used to explain many of the properties of substances.

(a) Copper, ice, silicon(IV) oxide, iodine and sodium chloride are all crystalline solids.

Complete the table with:

- the name of a type of bonding found in each crystalline solid,
- the type of lattice structure for each crystalline solid.

crystalline solid	type of bonding	type of lattice structure
copper		
ice		
silicon(IV) oxide		
iodine		
sodium chloride		

[5]

(b) (i) Name the strongest type of intermolecular force in ice.

..... **[1]**

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(ii) Draw a fully labelled diagram of two water molecules in ice, showing the force in **(i)** and how it forms.

[3]

3. MAR 17/P22/Q2/a,(i)(ii)

(a) (i) Explain the meaning of the term *bond polarity*.

.....

.....

..... **[1]**

(ii) Suggest why the boiling point of HF is **much** higher than the boiling points of the other hydrogen halides.

.....

.....

.....

.....

..... **[2]**

4. M/J 16/P23/Q2/d

(a) (i) Draw a dot-and-cross diagram of the ammonium ion. Show the outer electrons only.
Use the following code for your electrons.
- electrons from nitrogen
× electrons from hydrogen

[2]

(ii) State the shape of an ammonium ion and give the H–N–H bond angle.

shape .....

bond angle .....

[2]

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5. MAR 16/P22/Q3/a

Over one million tonnes of hydrogen cyanide, HCN, are produced each year using the Andrussow process. The overall equation for the reaction is shown.

$$CH_4(g) + NH_3(g) + 1\tfrac{1}{2}O_2(g) \rightleftharpoons HCN(g) + 3H_2O(g)$$

(a) (i) Draw a dot-and-cross diagram to represent the bonding in a molecule of ammonia, NH_3, and state the shape of the molecule.

shape of molecule .....

[3]

(ii) A molecule of hydrogen cyanide, HCN, is shown.

$$H—C\equiv N$$

The bonding between the carbon and nitrogen atoms consists of one sigma (σ) bond and two pi (π) bonds.

Sketch the shape of the sigma bond and one of the pi bonds in the space below.
Show clearly the position of the atomic nuclei in each diagram.

sigma (σ)

pi (π)

[2]

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6. O/N 14/P21/Q2/O/N 14/P22/Q2/c

(a) (i) Sulfur dioxide and sulfur trioxide both contain only S=O double bonds. Draw labelled diagrams to show the shapes of these two molecules.

SO_2 SO_3

[2]

(ii) For your diagrams in **(i)**, name the shapes and suggest the bond angles.

SO_2 shape ..... SO_3 shape .....

SO_2 bond angle ..... SO_3 bond angle .....

[2]

7. M/J 14/P21/Q1/e

(a) Sulfur reacts with fluorine to form SF_6. State the shape and bond angle of SF_6.

shape of SF_6 .....

bond angle of SF_6 .....

[2]

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8. O/N 13/P23/Q1

Ammonia, NH_3, and methane, CH_4, are the hydrides of elements which are next to one another in the Periodic Table.

(a) In the boxes below, draw the 'dot-and-cross' diagram of a molecule of **each** of these compounds. Show outer electrons only.
State the shape of **each** molecule.

NH_3	CH_4
shape	shape

[3]

(b) Ammonia is polar whereas methane is non-polar. The physical properties of the two compounds are different.

(i) Explain, using ammonia as the example, the meaning of the term *bond polarity*.

.....

.....

.....

(ii) Explain why the ammonia molecule is polar.

.....

.....

(iii) State **one** physical property of ammonia which is caused by its polarity.

.....

..... **[4]**

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(c) When ammonia gas is mixed with hydrogen chloride, white, solid ammonium chloride is formed.

State **each type** of bond that is present in one formula unit of ammonium chloride and how many of each type are present.
You may draw diagrams.

.....

.....

.....

.....

..... **[3]**

9. O/N 13/P21/Q5/O/N 13/P22/Q5,e

(a) The boiling points of methane, ethane, propane, and butane are given below.

compound	CH_4	CH_3CH_3	$CH_3CH_2CH_3$	$CH_3(CH_2)_2CH_3$
boiling point/K	112	185	231	273

(i) Suggest an explanation for the increase in boiling points from methane to butane.

.....

.....

.....

(ii) The isomer of butane, 2-methylpropane, $(CH_3)_3CH$, has a boiling point of 261 K.
Suggest an explanation for the difference between this value and that for butane in the table above.

.....

.....

..... **[4]**

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10. O/N 13/P21/Q1, O/N 13/P22/Q1/a,b

Valence Shell Electron Pair Repulsion theory (VSEPR) is a model of electron-pair repulsion (including lone pairs) that can be used to deduce the shapes of, and bond angles in, simple molecules.

(a) Complete the table below by using simple hydrogen-containing compounds. One example has been included.

number of bond pairs	number of lone pairs	shape of molecule	formula of a molecule with this shape
3	0	trigonal planar	BH_3
4	0		
3	1		
2	2		

[3]

(b) Tellurium, Te, proton number 52, is used in photovoltaic cells.

When fluorine gas is passed over tellurium at 150 °C, the colourless gas TeF_6 is formed.

(i) Draw a 'dot-and-cross' diagram of the TeF_6 molecule, showing outer electrons only.

(ii) What will be the shape of the TeF_6 molecule?

.....

(iii) What is the F–Te–F bond angle in TeF_6?

.....

11. M/J 13/P23/Q1/a,b **[3]**

Carbon disulfide, CS_2, is a volatile, flammable liquid which is produced in small quantities in volcanoes.

(a) The sequence of atoms in the CS_2 molecule is sulfur to carbon to sulfur.

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(i) Draw a 'dot-and-cross' diagram of the carbon disulfide molecule.
Show outer electrons only.

(ii) Suggest the shape of the molecule and state the bond angle.

shape .....

bond angle .....

[3]

(b) Carbon disulfide is readily combusted to give CO_2 and SO_2.

(i) Construct a balanced equation for the complete combustion of CS_2.

.....

(ii) Define the term *standard enthalpy change of combustion*, ΔH_c^e.

.....

.....

.....

[3]

12. M/J 13/P22/Q3/a(ii)

This question refers to the elements in the section of the Periodic Table shown below.

		H							He
Li	Be					B	C	N	O	F	Ne
Na	Mg					Al	Si	P	S	Cl	Ar
K	Ca	..... transition elements				Ga	Ge	As	Se	Br	Kr

(a) (i) An element whose molecules contain π bonding.

.....

13. M/J 13/P22/Q3/c

(a) Chlorine reacts with both bromine and iodine to form BrCl and ICl respectively.
The melting points of chlorine and the two chlorides are shown in the table.

substance	Cl_2	BrCl	ICl
m.p./°C	–101	–66	24

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(i) Showing outer electrons only draw a 'dot-and-cross' diagram of the bonding in ICl.

(ii) Suggest why the melting points increase from Cl_2 to ICl.

.....

.....

.....

(iii) Suggest which of these three molecules has the largest permanent dipole.
Explain your answer.

.....

.....

.....

[5]

14. M/J 13/P21/Q3/c

(a) Fluorine reacts with other elements in Group VII to form a number of different compounds.
Two such compounds and their boiling points are given in the table.

compound	ClF_3	BrF_3
boiling point / °C	12	127

(i) The two molecules have similar electronic configurations.
Showing outer electrons only, draw a 'dot-and-cross' diagram of the bonding in ClF_3.

(ii) The two molecules have the same shape.
Suggest why the boiling points are significantly different.

.....

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.....

.....

[4]

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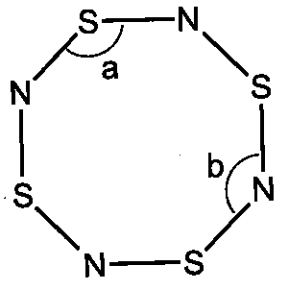
15. O/N 12/P21/Q3/c

(a) Ammonia is a weak base which forms salts containing the ammonium ion.
Describe, with the aid of an equation, the formation and structure of the ammonium ion.
You should use displayed formulae in your answer.

[3]

16. M/J 12/P22/Q1/c

(a) Sulfur forms the compound S_4N_4 with nitrogen. The structure of S_4N_4 is shown below.
Assume all bonds shown are single bonds.



(i) Determine the number of lone pairs of electrons around a nitrogen atom and a sulfur atom in S_4N_4.

nitrogen atom .....

sulfur atom .....

(ii) Which bond angle, a or b, in the S_4N_4 molecule will be smaller? Explain your answer.

.....

.....

[2]

17. M/J 12/P21/Q1/f

(a) Another sulfur compound which is present in the Earth's atmosphere is carbonyl sulfide, OCS. The sequence of atoms in the molecule is oxygen-carbon-sulfur and the molecule is **not** cyclic.

(i) Draw a 'dot-and-cross' diagram of the OCS molecule.
Show outer electrons only.

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(ii) Suggest a value for the O–C–S bond angle.

.....

[2]

18. M/J 11/P23/Q2/e,f

(a) Ethane, CH_3CH_3, and fluoromethane, CH_3F are *iso*-electronic, that is they have the same total number of electrons in their molecules.

Calculate the **total** number of electrons in one molecule of CH_3F.

[1]

(b) The boiling points of these two compounds are given below.

compound	bp/K
CH_3CH_3	184.5
CH_3F	194.7

Suggest explanations for the following.

(i) the close similarity of the boiling points of the two compounds

.....

.....

(ii) the slightly higher boiling point of CH_3F

.....

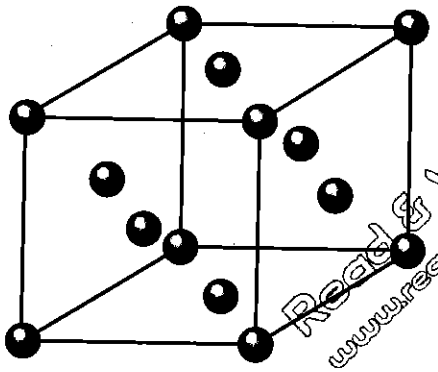
.....

[2]

19. M/J 10/P22/Q2

Copper, proton number 29, and argon, proton number 18, are elements which have different physical and chemical properties.

In the solid state, each element has the same face-centred cubic crystal structure which is shown below.



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The particles present in such a crystal may be atoms, molecules, anions or cations. In the diagram above, the particles present are represented by ●.

(a) Which types of particle are present in the copper and argon crystals? In each case, give their formula.

element	particle	formula
copper		
argon		

[2]

At room temperature, copper is a solid while argon is a gas.

(b) Explain these observations in terms of the forces present in **each** solid structure.

.....

.....

.....

.....

.....

..... **[4]**

Although copper is a relatively unreactive element, when it is heated to a high temperature in an excess of chlorine, copper(II) chloride is formed.

When a mixture of argon and chlorine is heated to a high temperature, no reaction occurs.

(c) (i) How does chlorine behave in its reaction with copper?

.....

(ii) Suggest a reason for the lack of a reaction between argon and chlorine.

.....

..... **[2]**

The melting points of the noble gases neon to xenon are given below.

	Ne	Ar	Kr	Xe
melting point/K	25	84	116	161

(d) Explain why there is an increase in melting point from neon to xenon.

.....

.....

..... **[2]**

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20. M/J 10/P21/Q3/b,c

(a) (i) Give the formula of the oxide of the most electronegative element.

.....

(ii) Several of these elements form more than one acidic oxide.
Give the formulae of **two** such oxides formed by the **same** element.

..... and .....

[3]

The formulae and melting points of the fluorides of the elements in Period 3, Na to Cl, are given in the table.

formula of fluoride	NaF	MgF_2	AlF_3	SiF_4	PF_5	SF_6	ClF_5
m.p./K	1268	990	1017	183	189	223	170

(b) (i) Suggest the formulae of **two** fluorides that could possibly be ionic.

.....

(ii) What is the shape of the SF_6 molecule?

.....

(iii) In the sequence of fluorides above, the oxidation number of the elements increases from NaF to SF_6 and then falls at ClF_5.
Attempts to make ClF_7 have failed but IF_7 has been prepared.
Suggest an explanation for the existence of IF_7 and for the non-existence of ClF_7.

.....

.....

.....

[4]

21. M/J 10/P21/Q1/a,b,c

Elements and compounds which have small molecules usually exist as gases or liquids.

(a) Chlorine, Cl_2, is a gas at room temperature whereas bromine, Br_2, is a liquid under the same conditions.
Explain these observations.

.....

.....

..... [2]

(b) The gases nitrogen, N_2, and carbon monoxide, CO, are isoelectronic, that is they have the same number of electrons in their molecules.
Suggest why N_2 has a lower boiling point than CO.

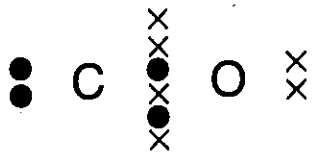
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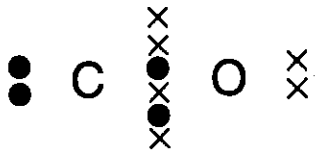
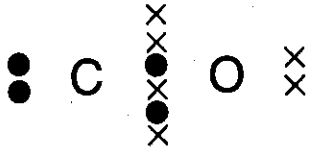
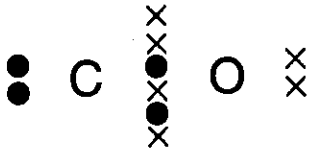
..... [2]

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(c) A 'dot-and-cross' diagram of a CO molecule is shown below. Only electrons from outer shells are represented.



In the table below, there are three copies of this structure.
On the structures, draw a circle round a pair of electrons that is associated with **each** of the following.

(i) a co-ordinate bond	**(ii)** a covalent bond	**(iii)** a lone pair
		

[3]

22. O/N 09/P22/Q2/b,d

Sodium hydride, NaH, is a colourless crystalline solid which melts at 800 °C and has the same crystal structure as sodium chloride which has a melting point of 808 °C. When molten sodium chloride is electrolysed using graphite electrodes, a shiny deposit, **D**, forms on the cathode and a greenish-yellow gas is evolved from the anode. When molten sodium hydride is electrolysed, under suitable conditions using graphite electrodes, the same shiny deposit **D** is formed on the cathode and a colourless gas, **G**, is evolved from the anode.

(a) (i) Describe with the aid of a diagram the bonding in a sodium chloride crystal.

(ii) Suggest the type of bonding that is present in sodium hydride.

.....

(iii) What is the oxidation number of hydrogen in sodium hydride?

.....

(iv) Draw a 'dot-and-cross' diagram for sodium hydride. Show outer electrons only.

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(v) The metals magnesium and aluminium form hydrides with formulae MgH_2 and AlH_3. The non-metals phosphorus and sulfur form hydrides with formulae PH_3 and H_2S.
By considering their positions in the Periodic Table, suggest oxidation numbers for these four elements in their hydrides.

compound	MgH_2	AlH_3	PH_3	H_2S
oxidation number of element in the hydride				

[8]

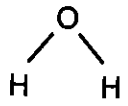
At room temperature, the chlorides of silicon, phosphorus and sulfur are all low melting point solids or low boiling point liquids that can be seen to react with water.

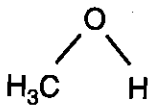
(b) (i) Suggest what type of bonding is present in sulfur dichloride, SCl_2.

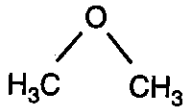
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23. M/J 08/P2/Q1

The structural formulae of water, methanol and methoxymethane, CH_3OCH_3, are given below.







(a) (i) How many lone pairs of electrons are there around the oxygen atom in methoxymethane?

.....

(ii) Suggest the size of the C–O–C bond angle in methoxymethane.

.....

[2]

The physical properties of a covalent compound, such as its melting point, boiling point, vapour pressure, or solubility, are related to the strength of attractive forces between the molecules of that compound.

These relatively weak attractive forces are called intermolecular forces. They differ in their strength and include the following.

A interactions involving permanent dipoles

B interactions involving temporary or induced dipoles

C hydrogen bonds

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(b) By using the letters **A**, **B**, or **C**, state the **strongest** intermolecular force present in **each** of the following compounds.
For each compound, write the answer on the dotted line.

ethanal	CH_3CHO	.....
ethanol	CH_3CH_2OH	.....
methoxymethane	CH_3OCH_3	.....
2-methylpropane	$(CH_3)_2CHCH_3$	.....

[4]

(c) Methanol and water are completely soluble in each other.

(i) Which intermolecular force exists between methanol molecules and water molecules that makes these two liquids soluble in each other?

.....

(ii) Draw a diagram that clearly shows this intermolecular force. Your diagram should show any lone pairs or dipoles present on either molecule that you consider to be important.

[4]

(d) When equal volumes of ethoxyethane, $C_2H_5OC_2H_5$, and water are mixed, shaken, and then allowed to stand, two layers are formed.

Suggest why ethoxyethane does not fully dissolve in water. Explain your answer.

.....

.....

.....

..... **[2]**

24. O/N 07/P2/Q2/e

(a) When solid aluminium chloride is heated above 451 K, a vapour is formed which has $M_r = 267$.
When this vapour is heated above 1100 K, the vapour has $M_r = 133.5$.

(i) What are the molecular formulae of these two forms of aluminium chloride?

at 460 K ..... at 1180 K .....

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(ii) Draw a 'dot-and-cross' diagram of the form of aluminium chloride that exists at the **higher** temperature.

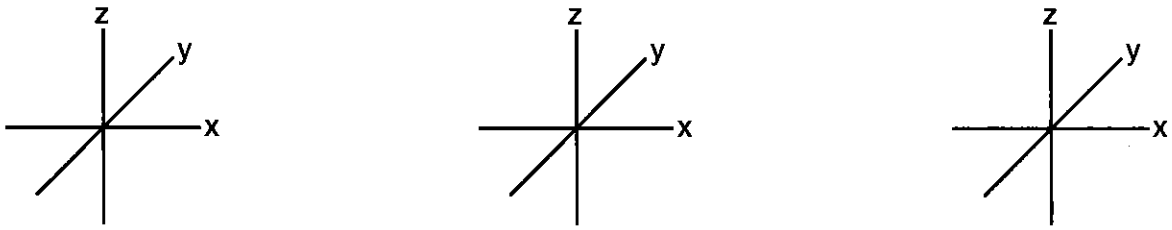
(iii) Draw a displayed formula of the form of aluminium chloride that exists at the **lower** temperature. Indicate clearly the different types of bonds present.

[5]

25. O/N 07/P2/Q1/a,b,c,d

This question is about the bonding of covalent compounds.

(a) On the axes below, sketch the shapes of a 1s, a 2s, and a $2p_x$ orbital.



1s 2s $2p_x$

[3]

(b) Covalent bonding occurs when two atoms share a pair of electrons. Covalent bonding may also be described in terms of orbital overlap with the formation of σ bonds.

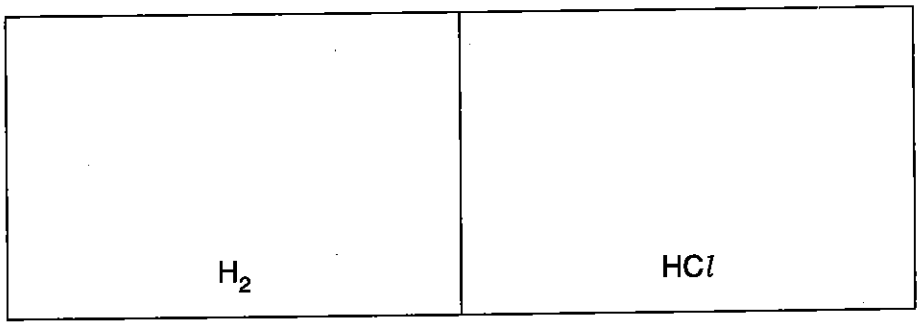
(i) How are the two atoms in a covalent bond held together? In your answer, state which particles are attracted to one another and the nature of the force of attraction.

.....

.....

(ii) Draw sketches to show orbital overlap that produces the σ bonding in the H_2 **and** HCl molecules.

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[4]

(c) The bond in the HCl molecule is said to be 'polar'.

(i) What is meant by the term *bond polarity*?

.....

(ii) Explain why the HCl molecule is polar.

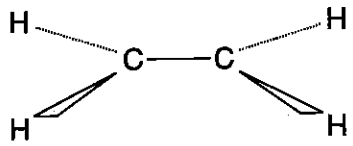
.....

.....

[2]

(d) The bonding in ethene may be described as a mixture of σ and π bonding.

Each carbon atom in ethene forms three σ bonds as shown below.



On the diagram, sketch the π bond that is also present in ethene. [1]

26. O/N 07/P2/Q1/a,b

Ethene, C_2H_4, and hydrazine, N_2H_4, are hydrides of elements which are adjacent in the Periodic Table. Data about ethene and hydrazine are given in the table below.

	C_2H_4	N_2H_4
melting point/°C	–169	+2
boiling point/°C	–104	+114
solubility in water	insoluble	high
solubility in ethanol	high	high

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(a) Ethene and hydrazine have a similar arrangement of atoms but differently shaped molecules.

(i) What is the H-C-H bond angle in ethene?

.....

(ii) Draw a 'dot-and-cross' diagram for hydrazine.

(iii) What is the H-N-H bond angle in hydrazine?

..... **[4]**

(b) The melting and boiling points of hydrazine are much higher than those of ethene. Suggest reasons for these differences in terms of the intermolecular forces **each** compound possesses.

.....

.....

.....

.....

..... **[3]**

27. O/N 05/P2/Q2/a,b

Carbon disulphide, CS_2, is a volatile, stinking liquid which is used to manufacture viscose rayon and cellophane.

(a) The carbon atom is in the centre of the CS_2 molecule.

Draw a 'dot-and-cross' diagram of the carbon disulphide molecule.

Show outer electrons only.

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[2]

(b) Suggest the shape of the molecule and give its bond angle.

shape .....

bond angle ..... **[2]**

28. M/J 05/P2/Q2/c

(a) (i) Draw a 'dot-and-cross' diagram to show the structure of the H_2S molecule.

(ii) Predict the shape of the H_2S molecule.

.....

(iii) Oxygen and sulphur are both in Group VI of the Periodic Table.

Suggest why the melting and boiling points of water, H_2O, are much higher than those of H_2S.

.....

.....

..... **[4]**

29. M/J 04/P2/Q3/d

(a) In the boxes below, draw diagrams to show the shapes of an ammonia molecule and an ammonium ion. Clearly show the bond angles on your diagrams.

ammonia	ammonium ion

[4]

30. O/N 02/P2/Q3/a

(a) Showing outer electrons only, draw a dot-and-cross electron diagram for magnesium oxide, MgO.

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[1]

31. M/J 02/P2/Q2/c

(a) Ethanol is miscible with water because of hydrogen bonding between molecules of ethanol and water. Draw a diagram, including dipoles, to show the hydrogen bonding between a molecule of ethanol and a molecule of water.

[2]

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Answers Section

1. M/J 17/P21/Q4/a,(ii),(iii)

(a) (i) sp^2 overlap of (2)s with two (2)p (atomic) orbitals 1

sp^3 overlap of (2)s with all three (2)p (atomic) orbitals 1

(ii) $sp^2 = 116° - 124°$ 1

$sp^3 = 106° - 112°$ 1

2. M/J 17/P21/Q2/a,b

(a)

substance	type of bonding	type of lattice structure
copper	metallic	giant/metallic
ice	covalent OR hydrogen(-bonding) / H(–bonding)	hydrogen-bonded / simple / molecular
silicon(IV) oxide	covalent	giant (molecular) / macromolecular
iodine	covalent	simple / molecular
sodium chloride	ionic	giant / ionic

1 1 1 1 1

(b) (i) hydrogen bonding 1

(ii) H-bond between O and H of different molecules 1

minimum **three** partial charges (in a row) over **two** H_2O molecules, i.e.:

either $^{\delta-}O—H^{\delta+} - - - -\ ^{\delta-}O$

or $H^{\delta+} - - - -\ ^{\delta-}O—H^{\delta+}$

lone pair of electrons on O of H-bond, in line with H-bond 1

3. MAR 17/P22/Q2/a,(i)(ii)

(a) (i) bond in which the centres of positive and negative charges do not coincide 1

OR electron distribution is asymmetric / unequal

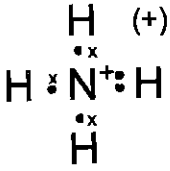
OR two (bonded) atoms are partially charged

(ii) HF has the strongest (permanent) dipole–dipole / van der Waals' (forces) / HF has hydrogen bonding 1

requires more energy to overcome (than weaker (permanent) dipole–dipole/ van der Waals' forces between other hydrogen halides) 1

4. M/J 16/P23/Q2/d

(a) (i)



[1+1] [2]

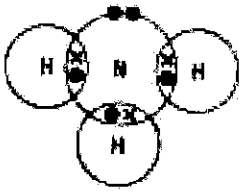
(ii) shape = tetrahedral [1]

angle = 109°–109.5° [1] [2]

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5. MAR 16/P22/Q3/a

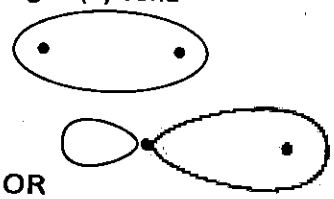
(a) (i)



[3]

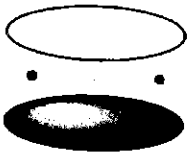
three bonding pairs
lone pair AND octet [1]
shape = (trigonal) pyramidal [1]

(ii) sigma(σ) bond [1]



OR

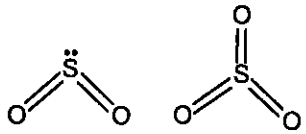
pi(π) bond [2]



[1]

6. O/N 14/P22/Q2/c, O/N 14/P21/Q2/c

(a) (i)



M1 SO_2 correct M2 SO_3 correct 1+1

[2]

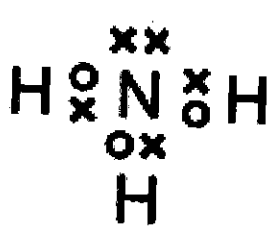
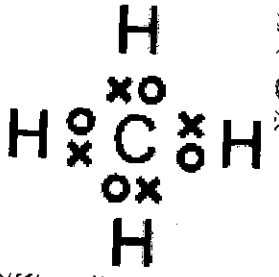
(ii) 115–120° bent / non-linear 1
120° trigonal planar 1 [2]

7. M/J 14/P21/Q1/e

(a) shape of SF_6 = Octahedral 1
bond angle = 90° 1 2

8. O/N 13/P23/Q1

(a)

NH_3	CH_4
	
pyramidal	tetrahedral

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both 'dot-and-cross' diagrams correct (1)
NH_3 is pyramidal **or** trigonal pyramidal (1)
CH_4 is tetrahedral (1) [3]

(b) (i) nitrogen and hydrogen have different electronegativities **(1)**
N–H bond has a dipole **or**
$N^{\delta-}—H^{\delta+}$ **or**
bonding pair is unequally shared **(1)**

(ii) molecule is not symmetrical **or**
dipoles do not cancel out **(1)**

(iii) NH_3 has higher boiling point than expected from M_r value **or**
has higher boiling point than methane
or NH_3 is soluble in water **(1) [4]**

(c) three covalent N–H bonds **(1)**
one co-ordinate (dative covalent) N–H bond **(1)**
one ionic bond between NH_4^+ and Cl^- **(1) [3]**

9. O/N 13/P21/Q5/O/N 13/P22/Q5,e

(a) (i) from methane to butane
there are more electrons in the molecule **(1)**
therefore greater/stronger van der Waals' forces **(1)**

(ii) straight chain molecules can pack more closely **(1)**
therefore stronger van der Waals' forces **(1)**
or reverse argument **[4]**

10. O/N 13/P21/Q1, O/N 13/P22/Q1/a,b

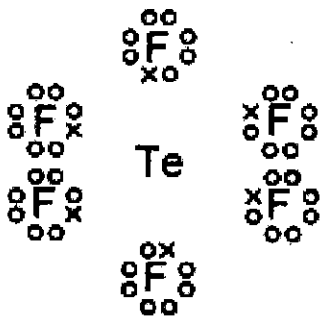
(a)

number of bond pairs	number of lone pairs	shape of molecule	formula of a molecule with this shape
3	0	trigonal planar	BH_3
4	0	tetrahedral	CH_4 allow other Group IV hydrides
3	1	pyramidal **or** trigonal pyramidal	NH_3 allow other Group V hydrides
2	2	non-linear **or** bent **or** V-shaped	H_2O allow other Group VI hydrides

1 mark for each correct row **(3 × 1) [3]**

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(b) (i)



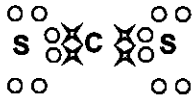
(1)

(ii) octahedral **or** square-based bipyramid (1)

(iii) 90° (1) **[3]**

11. M/J 13/P23/Q1/a,b

(a) (i)



S atom has 6 **and C** atom has 4 electrons (1)

S=C double bonds (4 electrons) clearly shown (1)

(ii) linear **and** 180° (1) **[3]**

(b) (i) $CS_2 + 3O_2 \rightarrow CO_2 + 2SO_2$ (1)

(ii) enthalpy change when 1 mol of a substance is burnt in an excess of oxygen/air **or** is completely combusted under standard conditions (1) (1) **[3]**

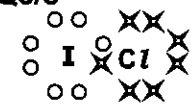
12. M/J 13/P22/Q3/a(ii)

(a) penalise (-1) the use of names of elements or formulae of compounds

(i) O **or** N **or** C (1)

13. M/J 13/P22/Q3/c

(a) (i)



(1)

(ii) intermolecular forces/van der Waals' forces are stronger or greater in IC*l* (1)

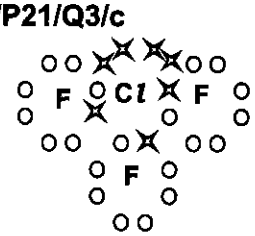
IC*l* has most electrons **or** has the largest permanent dipole (1)

(iii) IC*l* (1)

greatest difference in electronegativity is between I and C*l* (1) **[5]**

14. M/J 13/P21/Q3/c

(a) (i)



3 bonding pairs **and**

2 lone pairs around C*l* atom (1)

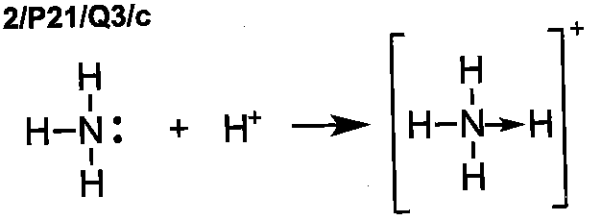
3 lone pairs on **each** of the F atoms (1)

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(ii) **either**
referring to van der Waals' forces in BrF_3
van der Waals' **or** (1)
intermolecular forces are greater/stronger (1)
because there are more electrons in BrF_3 than in ClF_3
OR referring to permanent dipoles (1)
permanent dipole **or** intermolecular forces are stronger/greater in BrF_3
because BrF_3 has a larger permanent dipole than ClF_3
OR because difference in electronegativity is larger between Br and F than (1)
between Cl and F
part **(ii)** has a maximum of 2 marks (max 2) **[4]**

15. O/N 12/P21/Q3/c

(a)



correct displayed eqn., (1)
with positive charge clearly shown (1)
lone pair on NH_3 (1)
co-ordinate / dative bond clearly shown **[3]**

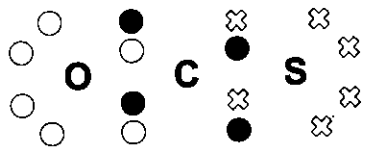
16. M/J 12/P22/Q1/c

(a) **(i)** around the N atom there is only one lone pair
around the S atom there are two lone pairs **both (1)**

(ii) angle (a) **or** sulfur – **no mark for this**
because two lone pairs repel more than one lone pair **or**
lone pair-lone pair repulsions are stronger
than lone pair-bond pair repulsions **(1) [2]**

17. M/J 12/P21/Q1/f

(a) **(i)**



(1)

(ii) 180° (1) **[2]**

18. M/J 11/P23/Q2/e,f

(a) 18 (1) **[1]**

(b) **(i)** both have very similar/same van der Waals' forces (1)

(ii) CH_3F has permanent dipole (1) **[2]**

19. M/J 10/P22/Q2

(a)

element	particle	formula
copper	cation	Cu^{2+} allow Cu^{+}
argon	atom **or** molecule	Ar

one mark for each correct row **or** column (2 × 1) **[2]**

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(b) **Cu** cations held in 'sea' of delocalised electrons (1)
by strong metallic bonds (1)
Ar van der Waals' forces between molecules (1)
which are weak (1)

(c) **(i)** oxidising agent **or** electron acceptor (1)
Ar has very high first I.E
or E_a for reaction is very high
or Ar has full valency shell/complete octet (1) **[4]**

(d) from Ne to Xe more electrons in atom (1)
hence more induced dipoles/van der Waals' forces (1) **[2]**

20. M/J 10/P21/Q3/b,c **[2]**

(a) Accept only formulae.
(i) F_2O (1)
(ii) SO_2 **and** SO_3
or P_2O_3/P_4O_6 **and** P_2O_5/P_4O_{10}
or any two from N_2O_3, NO_2/N_2O_4, N_2O_5
or any two from Cl_2O, ClO_2, ClO_3, Cl_2O_7 (1+1) **[3]**

(b) **(i)** NaF, MgF_2, AlF_3 – any two (1)
(ii) octahedral (1)
(iii) I atom is larger than Cl atom (1)
(iv) cannot pack 7 F atoms around Cl atom
or can pack 7 F atoms around I atom (1) **[4]**

21. M/J 10/P21/Q1/a,b,c

(a) fewer electrons in Cl_2 than in Br_2 (1)
smaller van der Waals' forces in Cl_2 **or** stronger van der Waals' forces in Br_2 (1) **[2]**

(b) CO has a permanent dipole **or** N_2 does not (1)
permanent dipole-permanent dipole interactions are stronger than those from induced dipoles (1) **[2]**

(c) **(i)** a co-ordinate bond (1)

(ii) a covalent bond (1)

or

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(iii) a lone pair (1)

or

penalise any groups of 3 or 4 electrons that are circled **[3]**

22. O/N 09/P22/Q2/b,d

(a) **(i)** with strong ionic bonding **(1)**

(ii) ionic **(1)**

(iii) –1 **(1)**

(iv) 

correct numbers of electrons **(1)**
correct charges **(1)**

(v)

compound	MgH_2	AlH_3	PH_3	H_2S
oxidation number of element in the hydride	+2	+3	–3	–2

correct oxidation nos. for MgH_2 **and** AlH_3 **(1)**
correct oxidation nos. for PH_3 **and** H_2S **(1)** **[8]**

(b) **(i)** covalent **(1)**

23. M/J 08/P2/Q1

(a) **(i)** 2 (1)

(ii) between 104° and 105° (1) **[2]**

(b)

ethanal	CH_3CHO	**A** (1)
ethanol	CH_3CH_2OH	**C** (1)
methoxymethane	CH_3OCH_3	**A** (1)
2-methylpropane	$(CH_3)_2CHCH_3$	**B** (1)

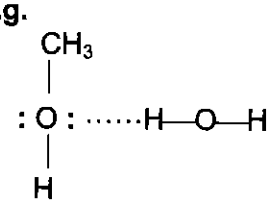
[4]

(c) **(i)** hydrogen bonds (1)

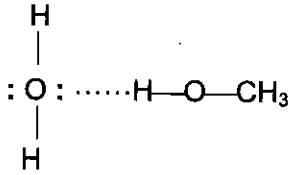
(ii) correct dipole on an -O—H bond (1)
hydrogen bond shown between the lone pair of an O and a H atom in an –OH group (1)
lone pair on O atom of CH_3OH **or** H_2O clearly shown **in the hydrogen bond** (1)

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e.g.



or



[4]

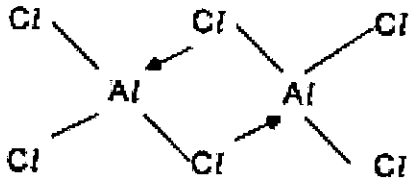
(d) hydrogen bonds exist between H_2O molecules (1)
hydrogen bonds cannot form
between $C_2H_5OC_2H_5$ molecules (1) **[2]**

24. O/N 07/P2/Q2/e

(a) **(i)** 460 K Al_2Cl_6 **(1)**
1150 K $AlCl_3$ **(1)**

(ii) correct **dot-and-cross** diagram for $AlCl_3$ **(1)**

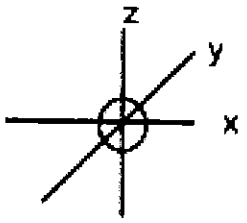
(iii) correct displayed structure for Al_2Cl_6 **(1)**
two correct co-ordinate bonds **(1)**



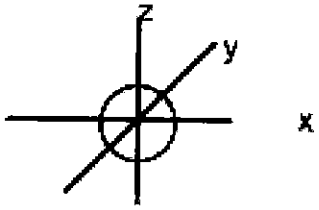
[5]

25. O/N 07/P2/Q1/a,b,c,d

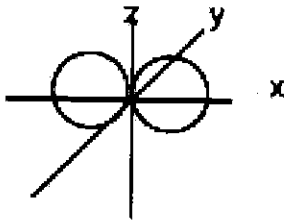
(a)



1s
spherical (1)



2s
larger spherical (1)



$2p_x$

double lobes along the *x*-axis (1) **[3]**

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(b) **(i)** attraction between bonding electrons and nuclei **(1)**
attraction is electrostatic **(1)**

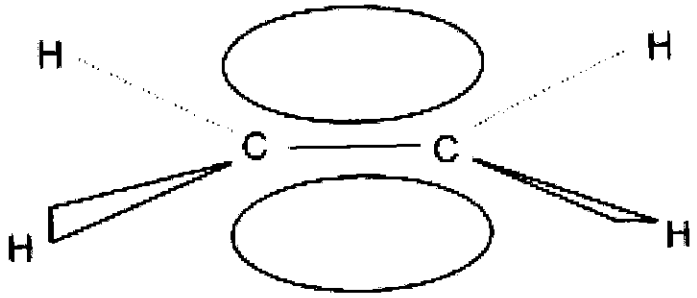
(ii) H_2 s-s **overlap** clearly shown
must **not** be normal dot/cross diagram **(1)**

HCl s-p **overlap** clearly shown
overlap must involve s and p orbitals **(1)** **[4]**

(c) **(i)** bonding electrons are unequally shared **or**
the molecule has a dipole/δ+ and δ- ends to molecule **(1)**

(ii) the H and Cl atoms have different electronegativities
or chlorine is more electronegative than hydrogen **(1)** **[2]**

(d)

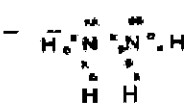


allow two 'sausages' above **and** below the C-C axis
or two p orbitals **overlapping** sideways
to form one (localised) π bond over two carbon atoms **(1)** **(1)**

26. M/J 07/P2/Q1/a,b

(a) **(i)** between 117° and 120° **[1]**

(ii)



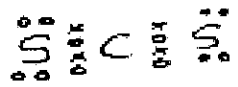
14 electrons must be shown **[1]**
single N-N bond **[1]**
lone pair on each N atom **[1]**

(iii) between 107° and 109° **[1]** **[4]**

(b) ethene – van der Waals' forces **[1]**
hydrazine – hydrogen bonds **[1]**
hydrogen bonds are stronger
or van der Waals' forces are weaker **[1]** **[3]**

27. O/N 05/P2/Q2/a,b

(a)



sulphur atom has 6 /carbon atom has 4 electrons **(1)**
S=C double bonds (4 electrons) clearly shown **(1)** **[2]**

(b) linear **(1)**
180° **(1)** **[2]**

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28. M/J 05/P2/Q2/c

(a) (i)

$H^{x}{}_{o}\overset{oo}{\underset{oo}{S}}{}_{o}{}^{x}H$ **(1)**

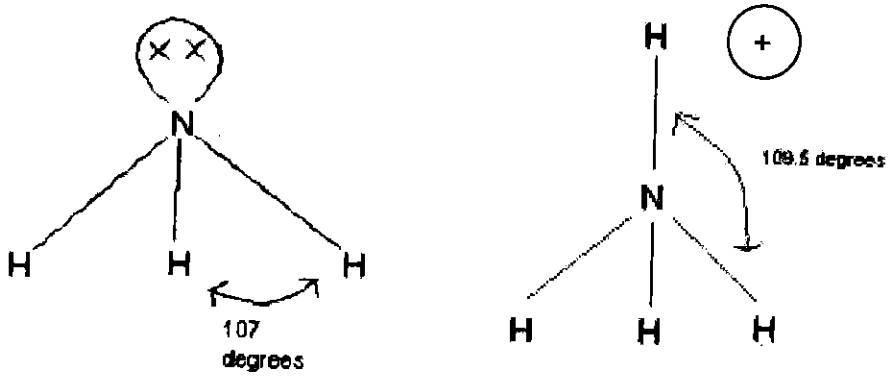
(ii) non-linear/bent/V-shaped **(1)**

(iii) H_2O has hydrogen bonds/H_2S does not or
H_2S has van der Waals' forces only
hydrogen bonds are stronger
than van der Waals' forces or
H_2S has weaker intermolecular bonds
than H_2O **(1)**

(1) [4

29. M/J 04/P2/Q3/d

(a)



1 mark for each diagram, 1 mark for each correct bond angle
If not 3-dimensional diagram – 1 penalty.

30. O/N 02/P2/Q3/a

3 (a) $\left[\times\underset{\times}{\overset{\times\times}{Mg}}\times\right]^{2+}$ $\left[:\ddot{O}:\right]^{2-}$ (1)

[1] [4]

31. M/J 02/P2/Q2/c

(c) $C_2H_5-\overset{\delta-}{O}-\overset{\delta+}{H}\cdots\overset{\delta-}{O}-H$ H bond

dipole (1)
H bond (1)

or $C_2H_5-O^{\delta-}\cdots H^{\delta+}-O^{\delta-}-H$

2

[Total 5]

* Some energy reference required.

UNIT 4

States of Matter

A-Level
Chemistry Paper 2
Topical Workbook

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Unit 4: States of Matter

1. M/J 17/P21/Q1/b(v)
Combustion data can be used to calculate the empirical formula, molecular formula and relative molecular mass of many organic compounds.

(a) **T** is an alcohol, C_xH_yO. A gaseous sample of **T** occupied a volume of 20 cm^3 at 120 °C and 100 kPa.

The sample was completely burned in 200 cm^3 of oxygen (an excess). The final volume, measured under the same conditions as the gaseous sample, was 250 cm^3.

Under these conditions, all water present is vaporised. Removal of the water vapour from the gaseous mixture decreased the volume to 170 cm^3.

Treating the remaining gaseous mixture with concentrated alkali, to absorb carbon dioxide, decreased the volume to 110 cm^3.

The equation for the complete combustion of **T** can be represented as shown.

$$C_xH_yO + zO_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

(i) Use the general gas equation to calculate the mass of **T** present in the original 20 cm^3 gaseous sample, which was measured at 120 °C and 100 kPa.

Give your answer to **three** significant figures. Show your working.

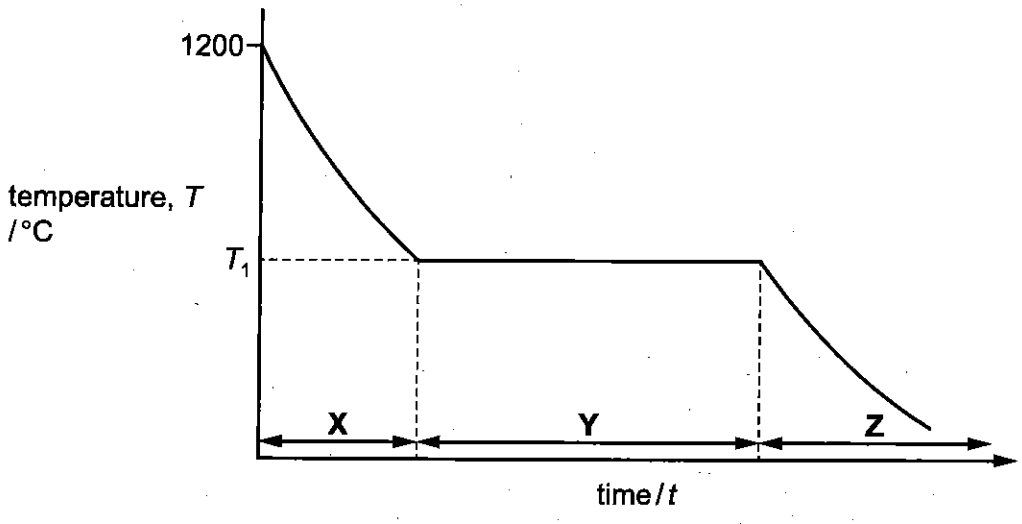
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mass = ... g **[3]**

2. M/J 17/P21/Q2/c

Structure and bonding can be used to explain many of the properties of substances.

(a) The graph represents how the temperature of a sample of copper (melting point 1085 °C) changes as it is gradually cooled from 1200 °C.



(i) Identify the state(s) of matter present during each stage of the process shown in the graph.

X .....

Y .....

Z .....

[2]

(ii) State what is happening to the energy and movement of the particles in the copper during stage **X**.

.....

.....

..... [2]

(iii) Explain why the temperature stays constant at T_1 during stage **Y**.

.....

.....

.....

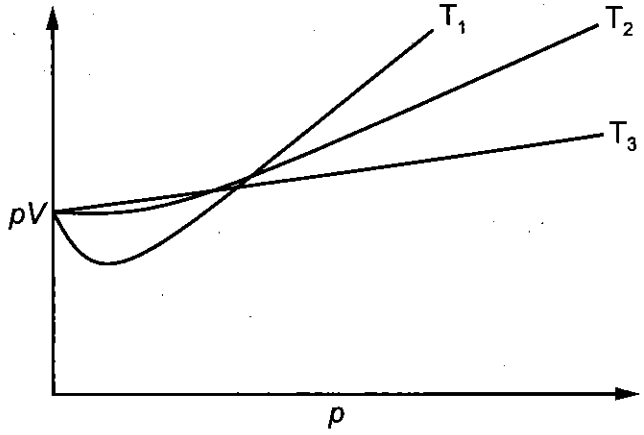
..... [2]

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3. M/J 15/P21/Q2/a,b

The relationship $pV = nRT$ can be derived from the laws of mechanics by assuming ideal behaviour for gases.

(a) The graph represents the relationship between pV and p for a real gas at three different temperatures, T_1, T_2 and T_3.



(i) Draw **one** line on the graph to show what the relationship should be for the same amount of an **ideal** gas. [1]

(ii) State and explain, with reference to the graph, which of T_1, T_2 or T_3 is the lowest temperature.

.....

..... [1]

(iii) Explain your answer to **(ii)** with reference to intermolecular forces.

.....

..... [1]

(iv) State and explain the effect of pressure on the extent to which a gas deviates from ideal behaviour.

.....

.....

.....

..... [2]

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(b) A flask with a volume of 100 cm^3 was first weighed with air filling the flask, and then with another gas, **Y**, filling the flask. The results, measured at 26 °C and 1.00×10^5 Pa, are shown.

Mass of flask containing air = 47.930 g

Mass of flask containing **Y** = 47.989 g

Density of air = 0.00118 g cm^{-3}

Calculate the relative molecular mass, M_r, of **Y**.

M_r of **Y** = ... [4]

4. M/J 11/P21/Q1/d,e

Bicycles may be carried on commercial airliners. When carried on airliners, bicycles are placed in the luggage hold. This is a part of the aircraft which, in flight, will have different temperatures and air pressures from those at sea level.

This question concerns the change in pressure in an inflated bicycle tyre from when it is at sea level to when it is in the hold of an airliner in flight.

(a) At sea level and a temperature of 20 °C an inflated bicycle tyre contains 710 cm^3 of air at an internal pressure of 6×10^5 Pa.

Use the general gas equation $PV = nRT$ to calculate the amount, in moles, of air in the tyre at sea level.

2

(b) The same bicycle, with its tyres inflated at sea level as described in **(d)** above, is placed in the luggage hold of an airliner. At a height of 10 000 m, the temperature in the luggage hold is 5 °C and the air pressure is 2.8×10^4 Pa.

Assuming the volume of the tyre does not change, use your answer to **(d)** to calculate the pressure inside the tyre at a height of 10 000 m.

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2

5. M/J 11/P23/Q2/a,b,c,d

The kinetic theory of gases is used to explain the large scale (macroscopic) properties of gases by considering how individual molecules behave.

(a) State **two** basic assumptions of the kinetic theory as applied to an ideal gas.

(i) .....

.....

(ii) .....

..... **[2]**

(b) State **two** conditions under which the behaviour of a real gas approaches that of an ideal gas.

(i) .....

(ii) ..... **[2]**

(c) Place the following gases in decreasing order of ideal behaviour.

ammonia, neon, nitrogen

most ideal ..... **least ideal**

Explain your answer.

.....

..... **[3]**

(d) By using the kinetic-molecular model, explain why a liquid eventually becomes a gas as the temperature is increased.

.....

.....

.....

..... **[2]**

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6. O/N 09/P22/Q1

The elements carbon and silicon are both in Group IV of the Periodic Table.
Carbon is the second most abundant element by mass in the human body and silicon is the second most common element in the Earth's crust.

Carbon and silicon each form an oxide of general formula XO_2.
At room temperature, CO_2 is a gas while SiO_2 is a solid with a high melting point.

(a) Briefly explain, in terms of the chemical bonds and intermolecular forces present in **each** compound, why CO_2 is a gas and SiO_2 is a solid at room temperature.

.....

.....

.....

..... **[3]**

(b) Draw a simple diagram to show the structure of SiO_2. Your diagram should contain at least **two** silicon atoms **and** show clearly how many bonds each atom forms.

[2]

CO_2 does not behave as an ideal gas.

(c) (i) State the basic assumptions of the kinetic theory as applied to an ideal gas.

.....

.....

.....

.....

.....

.....

(ii) Suggest **one** reason why CO_2 does not behave as an ideal gas.

.....

[5]

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Carbon exists in a number of forms, one of which is a conductor of electricity and one of which is a non-conductor of electricity. Silicon is the main component of most semi-conductors.

(d) Graphite is the form of carbon that is a conductor of electricity. Give a simple explanation for this property.

.....

..... **[1]**

When carbon and silicon(IV) oxide are heated together at about 2000 °C, silicon carbide, SiC, is formed. Silicon carbide is a hard material which is widely used as an abrasive and in ceramics.

(e) **(i)** Construct an equation for the reaction of carbon and silicon(IV) oxide.

.....

(ii) SiC has a similar structure to one of the common forms of carbon. Which form is this? Give a reason for your answer.

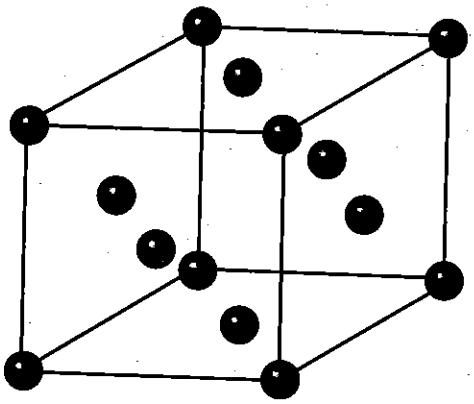
form .....

reason .....

[2]

7. O/N 06/P2/Q2

Copper and iodine are both solids which have different physical and chemical properties. Each element has the same face-centred crystal structure which is shown below.



The particles present in such a crystal may be atoms, molecules, anions or cations. In the diagram above, the particles present are represented by ● .

(a) Which type of particles are present in the iodine crystal? Give their formula.

particle.....

formula..... **[2]**

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(b) When separate samples of copper or iodine are heated to 50 °C, the copper remains as a solid while the iodine turns into a vapour.

(i) Explain, in terms of the forces present in the solid structure, why copper remains a solid at 50 °C.

.....

.....

.....

(ii) Explain, in terms of the forces present in the solid structure, why iodine turns into a vapour when heated to 50°C.

.....

.....

.....

[4]

(c) **(i)** Although copper is a relatively unreactive metal, when it is heated to a high temperature in an excess of chlorine, copper(II) chloride is formed.

How does chlorine behave in this reaction?

.....

(ii) When a mixture of copper and iodine is heated to a high temperature, no reaction occurs.

Suggest a reason for this difference.

.....

.....

[2]

8. M/J 06/P2/Q2/a,b,c,

The unsaturated hydrocarbon ethyne (acetylene), C_2H_2, is widely used in 'oxy-acetylene torches' for cutting and welding metals. In the torch, ethyne is burned in oxygen to produce a flame with a temperature of 3400 K.

(a) Ethyne is a linear molecule with a triple bond, C≡C, between the two carbon atoms.

Draw a 'dot-and-cross' diagram of an ethyne molecule.

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[1]

(b) When used for cutting or welding, ethyne is transported in cylinders which contain the gas under pressure. A typical cylinder has a volume of 76 dm^3 and contains ethyne gas at 1515 kPa pressure at a temperature of 25 °C.

Use the general gas equation, $pV = nRT$, to calculate the amount, in moles, of ethyne in this cylinder.

[2]

(c) In some countries, ethyne is manufactured from calcium carbide, CaC_2, which is produced by heating quicklime and coke together at 2300 K.

$$CaO + 3C \rightarrow CaC_2 + CO$$

When water is added to the CaC_2, calcium hydroxide, $Ca(OH)_2$, and ethyne, C_2H_2, are produced.

(i) Construct a balanced equation for the formation of ethyne from calcium carbide.

.....

(ii) Use this equation and your answer to part **(b)** to calculate the mass of CaC_2 which will react with an excess of water to produce enough ethyne to fill 100 cylinders of the gas.

[3]

9. M/J 04/P2/Q1/a,b,c,

(a) State **two** assumptions of ideal gas behaviour.

(i) .....

.....

(ii) .....

..... **[2]**

Use of the *Data Booklet* is relevant in (b) and (c).

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(b) The ideal gas equation is $pV = nRT$. Explain as fully as you can the meaning of the following terms, and give the units for each to correspond with the value of R given in the *Data Booklet*.

(i) p .....

.....

(ii) V .....

.....

(iii) T .....

..... **[6]**

(c) **(i)** When an evacuated glass bulb of volume 63.8 cm^3 is filled with a gas at 24 °C and 99.5 kPa, the mass increases by 0.103 g. Deduce whether the gas is ammonia, nitrogen or argon.

(ii) Explain why ammonia is the most likely of these three gases to deviate from ideal gas behaviour.

.....

.....

.....

.....

..... **[5]**

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10. M/J 03/P2/Q2,

This question is about the physical chemistry of gases, with particular emphasis on the inert gas argon. Argon exists in the atmosphere as single atoms.

(a) State **two** of the assumptions of the kinetic theory as applied to an inert gas.

(i) .....

.....

(ii) .....

.....

[2]

(b) How many atoms of argon are present in **one** mole of the gas?

..... **[1]**

(c) You are to calculate the percentage of the volume occupied by the atoms themselves in one mole of argon at room temperature and pressure.

(i) Use the *Data Booklet* to calculate the volume of one atom of argon.
[volume = $\frac{4}{3}\pi r^3$ $\pi = 3.14$]

(ii) Use your answer to **(c)(i)** to calculate the volume of one mole of argon atoms.

(iii) State the volume occupied by one mole of argon (assume it to behave as an ideal gas) at room temperature and pressure.

.....

(iv) What percentage of this volume is occupied by the atoms themselves?

(v) Explain how your answer to **(c)(iv)** justifies one of your assumptions in **(a)**.

.....

.....

[5]

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(d) Argon is used to fill electric light bulbs. These have a fine filament of a metal wire, usually tungsten, which glows white hot from its electrical resistance to the current.

Suggest why argon, rather than air, is used to fill electric light bulbs.

.....

.....

.....

..... **[2]**

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Answers Section

1. M/J 17/P21/Q1/b(v)

(a) correct conversions of data to SI/consistent units
$p = 100\,000$; $V = 20 \times 10^{-6}$; $T = 393$ **1**

calculation of n ($= pV/RT$) from M1 values
$n = \frac{100 \times 10^3 \times 20 \times 10^{-6}}{8.31 \times 393}$ **1**

calculation of mass m ($= n \times Mr$) **AND** answer correct to **3sf**
$m = 6.12 \times 10^{-4} \times 60 = 0.0367$ (g) **1**

Alternative answer for using $C_4H_{10}O$: $m = 6.12 \times 10^{-4} \times 74 = 0.0453$ (g)

2. M/J 17/P21/Q2/c

(a) (i) X = liquid AND Z=solid **1**
Y = liquid and solid OR 'liquid / solid' OR 'liquid OR solid' **1**

(ii) (kinetic) energy reducing **1**
motion slowing *owtte* **1**

(iii) energy given out / released forming bonds / forming bonds exothermic
cooling *owtte* **1**

3. M/J 15/P21/Q2/a,b

(a) **(i)** Straight line drawn horizontally from same intercept **[1]**

(ii) T_1 because it shows greatest deviation/furthest from ideal **[1]**

(iii) reducing T (reduces KE of particles) so intermolecular forces of attraction become more significant **[1]**

(iv) greatest deviation is at high pressure **[1]**
increasing pressure decreases volume so volume of particles becomes more significant ora **[1]**

(b) **[2]**

Mass of air	= 100 × 0.00118	= 0.118 g
Mass of flask	= 47.930 – 0.118	= **47.812** g **[1]**
Mass of **Y**	= 47.989 – 47.812	= **0.177** g **[1]**

$pV = nRT = \frac{m}{M_r} RT$

$M_r = \frac{mRT}{pV} = \frac{0.177 \times 8.31 \times 299}{1 \times 10^5 \times 100 \times 10^{-6}}$ **[1]**

= **44.0** (43.979 to 2 or more sf) **[1] [4]**

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4. M/J 11/P21/Q1/d,e

(a) $n = \frac{PV}{RT} = \frac{6 \times 10^5 \times 710 \times 10^{-6}}{8.31 \times 293}$ **[1]**

$= 0.175$ **[1] [2]**

(b) $P = \frac{nRT}{V} = \frac{0.175 \times 8.31 \times 278}{710 \times 10^{-6}}$ **[1]**

$= 569410.5634\ Pa^5 = 5.7 \times 10$

allow ecf on **(d)** **[2]**

5. M/J 11/P23/Q2/a,b,c,d

(a) there are no inter-molecular forces present between ideal gas molecules
ideal gas molecules have no volume
collisions between ideal gas molecules are perfectly elastic
ideal gas molecules behave as rigid spheres (any 2) **[2]**

(b) high temperature **[1]**
low pressure **[1] [2]**

(c) **most ideal** ..... neon..... nitrogen..... ammonia..... **least ideal** **[1]**
nitrogen has stronger van der Waals' forces than argon **[1]**
ammonia has hydrogen bonding as well as van der Waals' forces **[1] [3]**

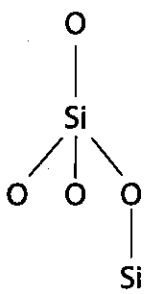
(d) with increasing temperature,
average kinetic energy of molecules increases **[1]**
intermolecular forces are more easily broken **[1] [2]**

6. O/N 09/P22/Q1

(a) CO_2 is simple molecular/simple covalent/has discrete molecules **[1]**
CO_2 has induced dipole – induced dipole interactions/
van der Waals' forces/weak intermolecular forces **[1]**
SiO_2 is giant molecular/giant covalent/macromolecular **[1]**
SiO_2 has strong covalent bonds **[1]**
[any 3]

(b) minimum is 4-valent Si-O **[1]**
and at least one Si-O-Si **[1]**

i.e.



[2]

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(c) **(i)** for an ideal gas, **any four** from the following

the molecules behave as rigid spheres **[1]**

there are no/negligible intermolecular forces between the molecules **[1]**

collisions between the molecules are perfectly elastic **[1]**

the molecules have no/negligible volume **[1]**

the molecules move in random motion **[1]**

the molecules move in straight lines **[1]**

the kinetic energy of the molecules is directly proportional to the temperature **[1]**

the pressure exerted by the gas is due to the collisions between the gas molecules and the walls of the container **[1]**

not an ideal gas obeys $pV = nRT$

(max 4)

(ii) there are intermolecular forces between CO_2 molecules/ CO_2 molecules have volume **[1] [5]**

(d) graphite has delocalised electrons **[1] [1]**

(e) **(i)** $SiO_2 + 2C \rightarrow SiC + CO_2$ **or** $SiO_2 + 3C \rightarrow SiC + 2CO$ **[1]**

(ii) diamond **because** SiC is hard **[1] [2]**

7. O/N 06/P2/Q2

(a) molecules

I_2 **[1]**

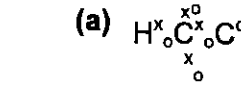
(b) **(i)** cations held in 'sea' of delocalised electrons **[1]**
by strong metallic bonds **[1]**

(ii) van der Waals' forces between molecules **[1]**
van der Waals' forces are weak **[1]**

(c) **(i)** oxidising agent **[1]**

(ii) iodine is a weaker oxidising agent than chlorine **[1]**

8. M/J 06/P2/Q2/a,b,c,

(a)  **(1) [1]**

(b) $n = \frac{PV}{RT} = \frac{(1515 \times 10^3) \times (76 \times 10^{-3})}{8.31 \times 298}$ **(1)**

$= 46.5$ **(1) [2]**

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(c) (i) $CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$ **(1)**

(ii) $n(C_2H_2) = n(CaC_2) = 100 \times 46.5$ **(1)**

mass of $CaC_2 = 100 \times 46.5 \times 64 =$ **(1)**

$= 297\ 570$ g

$= 297.6$ kg (accept 298 kg)

correct units necessary

allow e.c.f. on candidate's answer in **(b)** **[3]**

9. M/J 04/P2/Q1/a,b,c,

(a) The volume of the gas molecules / atoms / particles is insignificant compared with the volume of the vessel.
There are no forces of attraction between the gas molecules.
All collisions by the gas molecules are perfectly elastics. Any <u>two</u>. **[2]**

(b) (i) The pressure of / exerted <u>by the gas</u>. **[1]**
Pa / Nm^{-2} **[1]**

(ii) The volume of the containing vessel **[1]**
m^3 / dm^3 / cm^3

(iii) The absolute temperature **[1]**
In K <u>or</u> 273 + °C **[1]**

(c) (i) $pV \approx w/m \times RT$

$m = (0.103 \times 8.31 \times 297) / (99.5 \times 10 \times 63.8^3 \times 10^{-6})$ **[1]**

[1]

$= 40.0$ **[1]**

The gas is argon **[1]**

(ii) The hydrogen bonds between ammonia molecules (1)
are stronger than the Van De Waals' forces between N_2 and Ar molecules **(1)**
Ammonia is polar / has a dipole (1)
(Any two) **[2]**

10. M/J 03/P2/Q2,

(a) (i) That the volume of the gas molecules is negligible compared to the volume of gas (1)

(ii) That there are no intermolecular forces
OR collisions of the molecules are perfectly elastic
Particles are in constant motion, losing no energy on collision (1) any two **[2]**

(b) 6.02×10^{23} (1) **[1]**

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(c) **(i)** $r = \underline{0.192}$ nm (1) Assume most candidates will work in dm^3

$v = \frac{4}{3} \times 3.14 \times (1.92 \times 10^{-9})^3 = 2.96 \times 10^{-26}$ dm^3 (2.96×10^{-29} m^3 [1]

(ii) $2.96 \times 10^{-26} \times \underline{6.02 \times 10^{23}}$ (1) = 1.78×10^{-2} dm^3 (1.78×10^{-5} m^3) (1)

(iii) 24 dm^3 (0.024 m^3) (1)

(iv) $\frac{1.78 \times 10^{-2} \times 10^2}{24}$ = 0.074% (1)

(v) Some statement which connects with **(a) (i) above** [1]

(d)
- hot metals will react with oxygen in air (or nitrogen)
- to form oxides/will burn out/to a powder
- argon will not react
- at high temperatures O_2 and N_2 in air will react to give NO_x

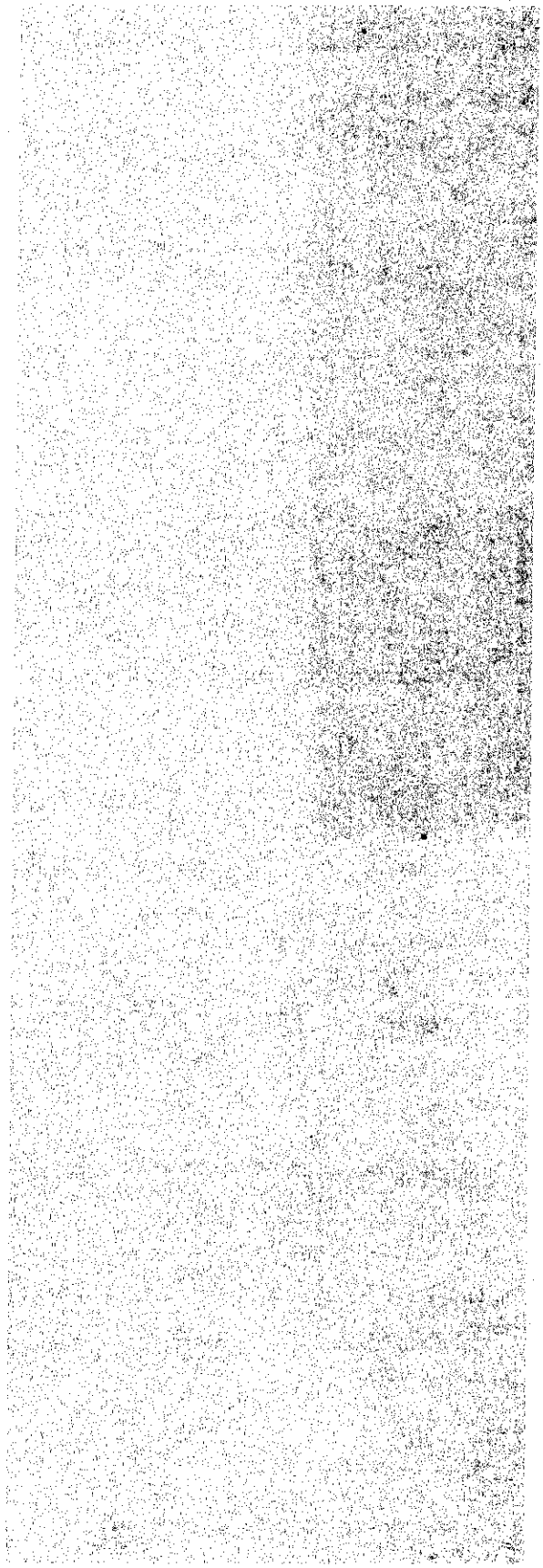
NOT expansion of gases on heating any two **[2]**

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UNIT 5

Chemical Energetics

A-Level
Chemistry Paper 2
Topical Workbook



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Unit 5: Chemical Energetics

1. MAR 17/P22/Q2/c(i)

(a) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

The reaction is carried out at 400 °C in the presence of a copper(II) chloride catalyst.

(i) Use the data in the table to calculate the overall enthalpy change of reaction.

compound	enthalpy change of formation / kJ mol^{-1}
$HCl(g)$	–92
$H_2O(g)$	–242

enthalpy change of reaction = ... kJ mol^{-1} **[2]**

2. M/J 16/P22/Q2/a

The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

element	bond energy / kJ mol^{-1}	standard enthalpy change of atomisation, $\Delta H_{at}^{\ominus}$ / kJ mol^{-1}	boiling point of element / K	boiling point of **hydrogen halide** / K
fluorine, F–F	158	79	85	293
chlorine, Cl–Cl	242	121	238	188
bromine, Br–Br	193	112	332	206
iodine, I–I	151	107	457	238

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(a) (i) Explain the meaning of the term *standard enthalpy change of atomisation.*

.....

.....

..... **[3]**

(ii) For fluorine and chlorine, the enthalpy changes of atomisation are half the value of the bond energies.

For bromine and iodine, the enthalpy changes of atomisation are much more than half the value of the bond energies.

Suggest a reason for this difference.

.....

.....

..... **[1]**

(iii) The standard enthalpy of formation of iodine monochloride, IC*l*, is –24.0 kJ mol^{-1}.

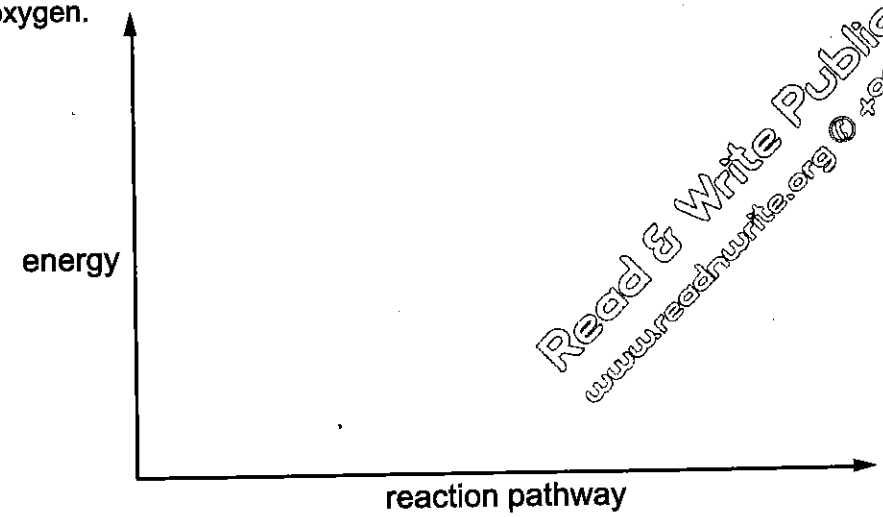
Use this information and the bond energies of iodine and chlorine to calculate the I–C*l* bond energy.

I–C*l* bond energy = ... kJ mol^{-1} **[2]**

3. M/J 16/P21/Q3/b(i)

(a) Magnesium oxide can be formed by the reaction of magnesium and oxygen in the air.

(i) Draw a **fully labelled** reaction pathway diagram for the reaction between magnesium and oxygen.



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[2]

4. O/N 15/P21/Q2/a,b, O/N 15/P23/Q2/a,b

(a) (i) Explain the meaning of the term *enthalpy change of formation*.

.....

.....

.....**[2]**

(ii) Give the equation for the reaction for which the enthalpy change corresponds to the standard enthalpy change of formation of liquid sulfur trioxide, SO_3. Include state symbols.

.....**[1]**

(b) Ammonia is manufactured by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(i) Use bond energies from the *Data Booklet* to calculate the enthalpy change of reaction for the Haber process. Include a sign in your answer.

enthalpy change ..... $kJ\,mol^{-1}$ **[3]**

(ii) State the essential operating conditions for the Haber process.

.....

.....

..... **[3]**

(iii) Explain the choices of temperature and pressure for the Haber process.

.....

.....

.....

.....

..... **[4]**

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5. M/J 15/P22/Q3/a(i)

Ethane reacts with chlorine to form chloroethane.

$$C_2H_6(g) + Cl_2(g) \rightarrow C_2H_5Cl(g) + HCl(g)$$

(a) (i) Use bond energies from the *Data Booklet* to calculate the enthalpy change for this reaction. Include a sign in your answer.

enthalpy change = ... $kJ\,mol^{-1}$ **[3]**

6. O/N 13/P22/Q5, O/N 13/P21/Q5/c, d

(a) Propane and butane have different values of standard enthalpy change of combustion.

Define the term *standard enthalpy change of combustion*.

.....

.....

..... **[2]**

(b) A 125 cm^3 sample of propane gas, measured at 20 °C and 101 kPa, was completely burnt in air.
The heat produced raised the temperature of 200 g of water by 13.8 °C.
Assume no heat losses occurred during this experiment.

(i) Use the equation $pV = nRT$ to calculate the mass of propane used.

(ii) Use relevant data from the *Data Booklet* to calculate the amount of heat released in this experiment.

(iii) Use the data above and your answers to **(i)** and **(ii)** to calculate the energy produced by the burning of 1 mol of propane.

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[5]

7. M/J 13/P21/Q2/c

(a) The standard enthalpy changes of formation of $NH_3(g)$ and $H_2O(g)$ are as follows.

$NH_3(g)$, $\Delta H_f^\ominus = -46.0\,kJ\,mol^{-1}$ $H_2O(g)$, $\Delta H_f^\ominus = -242\,kJ\,mol^{-1}$

Use these data and the value of $\Delta H^\ominus_{reaction}$ given below to calculate the standard enthalpy change of formation of NO(g).
Include a sign in your answer.

$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H^\ominus = -906\,kJ\,mol^{-1}$

[4]

8. M/J 13/P23/Q1/c

(a) Calculate the standard enthalpy change of formation of CS_2 from the following data. Include a sign in your answer.

standard enthalpy change of combustion of $CS_2 = -1110\,kJ\,mol^{-1}$

standard enthalpy change of formation of $CO_2 = -395\,kJ\,mol^{-1}$

standard enthalpy change of formation of $SO_2 = -298\,kJ\,mol^{-1}$

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[3]

9. M/J 12/P22/Q2/a,b

Alcohols such as methanol, CH_3OH, are considered to be possible replacements for fossil fuels because they can be used in car engines.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, ΔH_c^e, for methanol at 298 K.

equation .....

definition .....

.....

..... **[3]**

Methanol may be synthesised from carbon monoxide and hydrogen. Relevant ΔH_c^e values for this reaction are given in the table below.

compound	ΔH_c^e / kJ mol^{-1}
CO(g)	–283
H_2(g)	–286
CH_3OH(g)	–726

(b) Use these values to calculate $\Delta H^e_{reaction}$ for the synthesis of methanol, using the following equation. Include a sign in your answer.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$$

$\Delta H^e_{reaction}$ = ...kJ mol^{-1} **[3]**

10. M/J 12/P21/Q3/a,b

Methanol, CH_3OH, is considered to be a possible alternative to fossil fuels, particularly for use in vehicles.

Methanol can be produced from fossil fuels and from agricultural waste. It can also be synthesised from carbon dioxide and hydrogen.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of formation of carbon dioxide.

equation .....

definition .....

.....

..... **[3]**

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(b) Relevant $\Delta H_f^\ominus$ values for the reaction that synthesises methanol are given in the table.

compound	$\Delta H_f^\ominus$ / kJ mol^{-1}
$CO_2(g)$	–394
$CH_3OH(g)$	–201
$H_2O(g)$	–242

(i) Use these values to calculate $\Delta H^\ominus_{reaction}$ for this synthesis of methanol. Include a sign in your answer.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

$\Delta H^\ominus_{reaction}$ = ...kJ mol^{-1}

(ii) Suggest **one** possible environmental advantage of this reaction. Explain your answer.

.....

.....

[5]

11. M/J 12/P23/Q3/a,b

With the prospect that fossil fuels will become increasingly scarce in the future, many compounds are being considered for use in internal combustion engines. One of these is DME or dimethyl ether, CH_3OCH_3. DME is a gas which can be synthesised from methanol.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, $\Delta H_c^\ominus$, for DME at 298 K.

equation .....

definition .....

.....

..... **[3]**

(b) DME may be synthesised from methanol. Relevant enthalpy changes of formation, $\Delta H_f^\ominus$, for this reaction are given in the table below.

compound	$\Delta H_f^\ominus$ / kJ mol^{-1}
$CH_3OH(l)$	–239
$CH_3OCH_3(g)$	–184
$H_2O(l)$	–286

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Use these values to calculate $\Delta H^{\ominus}_{reaction}$ for the synthesis of DME, using the following equation. Include a sign in your answer.

$$2CH_3OH(l) \rightarrow CH_3OCH_3(g) + H_2O(l)$$

$\Delta H^{e}_{reaction}$ = ... kJ mol^{-1} **[3]**

12. O/N 11/P22/Q3, O/N 11/P21/Q3

For some chemical reactions, such as the thermal decomposition of potassium hydrogencarbonate, $KHCO_3$, the enthalpy change of reaction cannot be measured directly.

In such cases, the use of Hess' Law enables the enthalpy change of reaction to be calculated from the enthalpy changes of other reactions.

(a) State Hess' Law.

.....

.....

..... **[2]**

In order to determine the enthalpy change for the thermal decomposition of potassium hydrogencarbonate, two separate experiments were carried out.

experiment 1

30.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid (an excess) was placed in a conical flask and the temperature recorded as 21.0 °C.
When 0.0200 mol of potassium carbonate, K_2CO_3, was added to the acid and the mixture stirred with a thermometer, the maximum temperature recorded was 26.2 °C.

(b) (i) Construct a balanced equation for this reaction.

.....

(ii) Calculate the quantity of heat produced in **experiment 1**, stating your units.
Use relevant data from the *Data Booklet* and assume that all solutions have the same specific heat capacity as water.

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(iii) Use your answer to **(ii)** to calculate the enthalpy change per mole of K_2CO_3.
Give your answer in kJ mol^{-1} and include a sign in your answer.

(iv) Explain why the hydrochloric acid must be in an excess.

.....

..... **[4]**

experiment 2

The experiment was repeated with 0.0200 mol of potassium hydrogencarbonate, $KHCO_3$.
All other conditions were the same.
In the second experiment, the temperature fell from 21.0 °C to 17.3 °C.

(c) (i) Construct a balanced equation for this reaction.

.....

(ii) Calculate the quantity of heat absorbed in **experiment 2**.

(iii) Use your answer to **(ii)** to calculate the enthalpy change per mole of $KHCO_3$.
Give your answer in kJ mol^{-1} and include a sign in your answer.

[3]

(d) When $KHCO_3$ is heated, it decomposes into K_2CO_3, CO_2 and H_2O.

$$2KHCO_3 \longrightarrow K_2CO_3 + CO_2 + H_2O$$

Use Hess' Law and your answers to **(b)(iii)** and **(c)(iii)** to calculate the enthalpy change for this reaction.
Give your answer in kJ mol^{-1} and include a sign in your answer.

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[2]

[11]

13. M/J 11/P21/Q5/d

(a) The standard enthalpy change of combustion of C_2H_2, $\Delta H_c^{\ominus}$, is $-1300\,kJ\,mol^{-1}$ at 298 K.

Values of relevant standard enthalpy changes of formation, $\Delta H_f^{\ominus}$, measured at 298 K, are given in the table.

substance	$\Delta H_f^{\ominus}/kJ\,mol^{-1}$
$CO_2(g)$	−394
$H_2O(l)$	−286

(i) Write balanced equations, with state symbols, that represent

the standard enthalpy change of combustion, $\Delta H_c^{\ominus}$, of C_2H_2, and

.....

the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of C_2H_2.

.....

(ii) Use the data above and your answer to **(i)** to calculate the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of C_2H_2.
Show clearly whether the standard enthalpy change of formation of C_2H_2 has a positive or negative value.

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[6]

14. O/N 10/P21/Q3/d,e,f

(a) Define the term *standard enthalpy change of combustion.*

.....

.....[2]

When 0.47g of **E** was completely burnt in air, the heat produced raised the temperature of 200g of water by 27.5 °C. Assume no heat losses occurred during this experiment.

(b) (i) Use relevant data from the *Data Booklet* to calculate the amount of heat released in this experiment.

(ii) Use the data above and your answer to **(i)** to calculate the relative molecular mass, M_r, of **E**.

[4]

(c) Deduce the molecular formula of **E**.

[1]

15. O/N 09/P21/Q3

Alkanes such as methane, CH_4, undergo few chemical reactions. Methane will, however, react with chlorine but not with iodine.

Relevant standard enthalpy changes of formation for the reaction of methane with chlorine to form chloromethane, CH_3Cl, are given below.

	$\Delta H_f^{\ominus}$/kJ mol^{-1}
CH_4	–75
CH_3Cl	–82
HCl	–92

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(a) (i) Use the data to calculate $\Delta H^{\ominus}_{reaction}$ for the formation of CH_3Cl.

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

(ii) The corresponding reaction with iodine does **not** take place.

Use bond energy data from the *Data Booklet* to calculate a 'theoretical value' for $\Delta H_{reaction}$ for the following equation.

$$CH_4 + I_2 \rightarrow CH_3I + HI$$

(iii) Suggest why this reaction does **not** in fact occur.

.....

.....

[5]

(b) (i) By using equations, describe the mechanism of the reaction between chlorine and methane to form chloromethane, CH_3Cl.

Identify, by name, the separate steps of the overall reaction.

.....

.....

.....

.....

.....

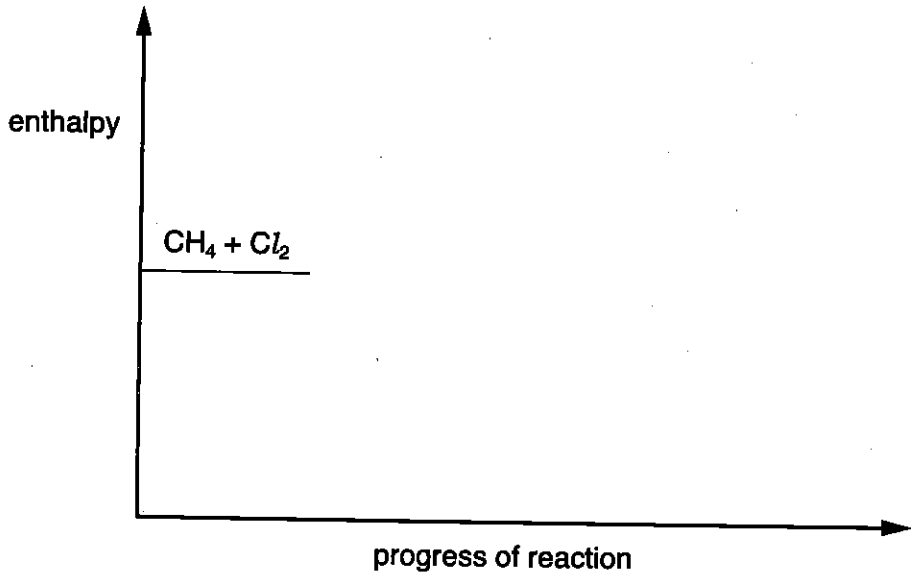
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(ii) What is the intermediate organic species in this reaction?

.....

[7]

(c) The energy of activation for the formation of CH_3Cl is 16 kJ mol^{-1}.
Use this figure and your answer to **(a)(i)** to complete the reaction pathway diagram below showing the formation of CH_3Cl from CH_4 and Cl_2.
Show clearly the intermediate organic species and the final products.
Indicate on your sketch the relevant enthalpy changes and their values.



[4]

[16]

16. M/J 09/P22/Q2/a(i, ii)

(a) Phosphorus is a very reactive non-metallic element which readily forms ionic compounds with metals such as calcium and covalent compounds with non-metals such as chlorine and oxygen.

(i) Write an equation, with state symbols, for the **second** ionisation energy of calcium.

.....

(ii) Use the *Data Booklet* to calculate the enthalpy change that occurs when one mole of gaseous calcium ions, Ca^{2+}, is formed from one mole of gaseous calcium atoms.
Include a sign in your answer.

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enthalpy change = ... kJ mol^{-1} [3]

17. O/N 09/P21/Q1/d

(a) Radium, like other Group II elements, forms a number of ionic compounds.

(i) What is the formula of the radium cation?

.....

(ii) Use the *Data Booklet* to suggest a value for the energy required to form one mole of the gaseous radium cation you have given in **(i)** from one mole of gaseous radium atoms. Explain your answer.

.....

.....

..... **[3]**

18. O/N 08/P2/Q2/c,d

(a) (i) Define the term *standard enthalpy change of formation.*

.....

.....

.....

(ii) Use the data below to calculate the standard enthalpy change of formation of ketene.

	$\Delta H^{\ominus}$/kJ mol^{-1}
standard enthalpy change of formation of CO_2	–395
standard enthalpy change of combustion of H_2	–286
standard enthalpy change of combustion of $CH_2{=}C{=}O$	–1028

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[6]

(b) Ketene can be converted directly into ethanoic acid, CH_3CO_2H, by reaction with a compound **A**.

Suggest the identity of **A**.

.....

[1]

19. O/N 07/P2/Q1/e

(a) Carbon, hydrogen and ethene each burn exothermically in an excess of air.

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H_c^{\ominus} = -393.7\,kJ\,mol^{-1}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l) \qquad \Delta H_c^{\ominus} = -285.9\,kJ\,mol^{-1}$$

$$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l) \qquad \Delta H_c^{\ominus} = -1411.0\,kJ\,mol^{-1}$$

Use the data to calculate the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, in $kJ\,mol^{-1}$, of ethene at 298 K.

$$2C(s) + 2H_2(g) \rightarrow C_2H_4(g)$$

$\Delta H_f^{\ominus}$ = ... $kJ\,mol^{-1}$

[3]

20. O/N 06/P2/Q4/d,e

(a) Define the term *standard enthalpy change of combustion.*

.....

..... **[2]**

When 0.47 g of **Z** were completely burnt in air, the heat produced raised the temperature of 200 g of water by 27.5 °C.

(b) **(i)** Calculate the amount of heat released in this experiment.

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(ii) Use the data above and your answer to **(i)** to calculate the relative molecular mass of **Z**.

[4]

21. M/J 06/P2/Q2/d,e

(a) The equation for the complete combustion of ethyne is given below.
Use appropriate bond energy data from the *Data Booklet* to calculate a value for the enthalpy change of combustion of ethyne.

$$C_2H_2(g) + 5/2O_2(g) \longrightarrow 2CO_2(g) + H_2O(g)$$

[3]

(b) The value for the standard enthalpy change of combustion of ethyne is $-1300\,kJ\,mol^{-1}$.

(i) Define the term *standard enthalpy change of combustion.*

.....

.....

.....

(ii) Explain why your answer to **(d)** does not have the same value as the standard enthalpy change of combustion.

.....

.....

[3]

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22. O/N 05/P2/Q2/c, d

(a) Explain the term *standard enthalpy change of formation*, $\Delta H_f^{\ominus}$.

.....

.....

..... **[3]**

(b) Calculate the standard enthalpy change of formation of CS_2 from the following data.

standard enthalpy change of formation of SO_2 = $-298\ kJ\ mol^{-1}$

standard enthalpy change of formation of CO_2 = $-395\ kJ\ mol^{-1}$

standard enthalpy change of combustion of CS_2 = $-1110\ kJ\ mol^{-1}$

[3]

23. O/N 04/P2/Q1/d

(a) (i) Explain how enthalpy changes, ΔH values, for covalent bonded molecules can be calculated from bond energies.

.....

.....

(ii) Use bond energies from the *Data Booklet* to calculate ΔH for the following dissociation.

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

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[3]

24. O/N 03/P2/Q3

(a) (i) What is meant by the *standard enthalpy change of formation*, $\Delta H^{\ominus}_f$, of a compound? Explain what is meant by the term *standard*.

.....

.....

.....

(ii) Write an equation, with state symbols, for the $\Delta H^{\ominus}_f$ of water.

.....

(iii) Explain why the $\Delta H^{\ominus}_f$ for water is identical to the standard enthalpy change of combustion of hydrogen.

.....

.....**[4]**

(b) When calcium is placed in water, aqueous calcium hydroxide is formed and hydrogen is given off.

(i) Write the equation for the reaction of calcium with water.

.....

(ii) When 1.00 g of calcium is placed in 200 g of water, the temperature increases by 12.2 °C when the reaction is completed. The specific heat capacity of water, c, is $4.2\,J\,g^{-1}\,K^{-1}$.

Calculate the heat released in the experiment.

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(iii) Calculate the standard enthalpy change of reaction in $kJ\,mol^{-1}$ for your equation in **(b)(i)**.

[4]

(c) (i) State *Hess' Law.*

.....

.....

.....

(ii) Use Hess' Law and your result in **(b)(iii)** to calculate the $\Delta H^{\ominus}_f$ of $Ca(OH)_2$ (aq). You also need the $\Delta H^{\ominus}_f$ of water which is $-286\ kJ\ mol^{-1}$.

[4]

(d) Calculate the volume of hydrogen, measured at room temperature and pressure, liberated in the experiment described in **(b)(ii)**.

[2]

25. O/N 02/P2/Q4/e

(a) Urea, $CO(NH_2)_2$, is a naturally occurring substance which can be hydrolysed with water to form ammonia according to the following equation.

$$H_2O(l) + CO(NH_2)_2(aq) \longrightarrow CO_2(aq) + 2NH_3(aq)$$

The standard enthalpy changes of formation of water, urea, carbon dioxide and ammonia (in aqueous solution) are given below.

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compound	$\Delta H_f^\ominus$/kJ mol^{-1}
$H_2O(l)$	−287.0
$CO(NH_2)_2(aq)$	−320.5
$CO_2(aq)$	−414.5
$NH_3(aq)$	−81.0

Use these data to calculate the standard enthalpy change for the hydrolysis of urea.

[2]

26. M/J 02/P2/Q2/a, b

Ethanol, C_2H_5OH, is a most important industrial chemical and is used as a solvent, a fuel and an intermediate in large scale organic synthesis.

Ethanol is prepared industrially by the reaction of ethene and steam in the presence of a catalyst.

$$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$$

The standard enthalpy change of the reaction can be determined by using the standard enthalpy changes of combustion, $\Delta H_c^\ominus$, at 298 K.

	$\Delta H_c^\ominus$/ kJ mol^{-1}
$C_2H_4(g)$	−1411
$C_2H_5OH(l)$	−1367

(a) Calculate the standard enthalpy change for the following reaction.

$$C_2H_4(g) + H_2O(l) \rightarrow C_2H_5OH(l)$$

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[2]

(b) (i) Define the term *standard enthalpy change of combustion.*

.....

.....

.....

(ii) Explain why the state symbols for water and ethanol given in the equation in **(a)** have been changed from those quoted in the industrial process.

.....

.....

.....

(iii) Write the equation for the complete combustion of ethanol.

.....

[4]

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Answers Section

1. MAR 17/P22/Q2/c(i)

(a) (i) $\Delta_r H = \Delta_r H\{\text{products}\} - \Delta_r H\{\text{reactants}\} = 2 \times (-242) - 4 \times (-92)$ **1**

$= -116$ (sign **AND** answer) **1**

2. M/J 16/P22/Q2/a

(a) (i) enthalpy / energy / heat change when one mole of gaseous atoms is produced [1]

from the element in its standard state. [1]

under standard conditions [1] [3]

(ii) fluorine and chlorine are gases / bromine liquid and iodine solid

OR

as ΔH_{at} for bromine / iodine also includes changes of state [1] [1]

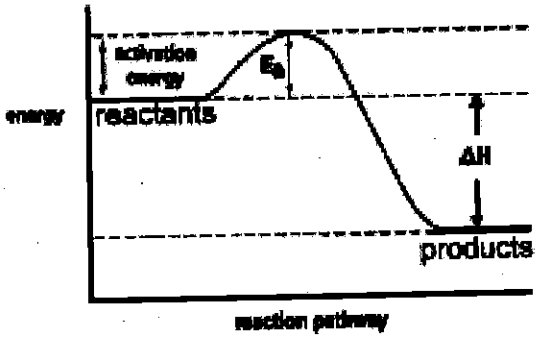
(iii) $(\frac{1}{2}Cl_2 + \frac{1}{2}I_2 \rightarrow ICl)$

$\Delta H_f = (\frac{1}{2}E(Cl_2) + \frac{1}{2}E(I_2)) - E(ICl)$ OR $E(ICl) = (151/2) + (242/2) + 24$ [1]

$E(ICl) = (+)\ 220.5/221$ [1] [2]

3. M/J 16/P21/Q3/b(i)

(a) (i)



M1 – general layout with products below reactants AND both labelled [1]

M2 – E_a and ΔH / energy change / released labelled with vertical lines [1]

4. O/N 15/P21/Q2/a,b, O/N 15/P23/Q2/a,b

(a) (i) The enthalpy change when one mole of a compound is formed from its element(s) [1]

(ii) $S(s) + 1\frac{1}{2}O_2(g) \rightarrow SO_3(l)$ [1]

(b) (i) $944 + (3 \times 436) = 2252$ [1]

$6 \times 390 = 2340$ [1]

$2252 - 2340 = -88\ (kJ\ mol^{-1})$ [1] [3]

(ii) Fe catalyst [1]

200 atm [1]

400–500 (°)C [1] [3]

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(iii) High T increases rate AND Low T improves yield owtte [1]
Chosen temp is a compromise [1]
High P favours/increases (both rate and) yield owtte [1]
pressure chosen limited by cost (of compression and 'thick walls') [1] [4]

5. M/J 15/P22/Q3/a(i)

(a) (i) Bond breaking = C*l*-C*l* = 242
C-H = 410 = 652 kJ [1]

Bond forming = C-C*l* = 340
H-C*l* = 431 = 771 kJ [1]

Enthalpy change = 652 – 771 = –119 [1] [3]

6. O/N 13/P22/Q5, O/N 13/P21/Q5/c, d

(a) enthalpy change when 1 mol of a substance
is burnt in an excess of oxygen/air under standard conditions (1)
or is completely combusted under standard conditions (1) [2]

(b) (i) $m = \frac{pVM_r}{RT} = \frac{1.01\times10^5 \times 125\times10^{-6} \times 44}{8.31\times293}$ g (1)

= 0.228147345 g
= 0.23 g (1)

(ii) heat released = m c δ T = 200 × 4.18 × 13.8 J (1)
= 11536.8 J = 11.5 kJ (1)

(iii) 0.23 g of propane produce 11.5 kJ

44 g of propane produce $\frac{11.5\times44}{0.23}$ kJ

= 2200 kJ mol^{-1} (1) [5]

7. M/J 13/P21/Q2/c

(a) let ΔH_f° for NO be *y* kJ mol^{-1}

$4NH_3(g) + 5O_2(g)$ $\quad$ $4NO(g) + 6H_2O(g)$

ΔH_f° $\quad 4 \times (-46.0)$ $\quad$ $4y$ $\quad 6 \times (-242)$ (1)

$\Delta H^\circ_{reaction}$ $= 4y + [6 \times (-242)] - [4 \times (-46.0)]$ (1)
$= 4y - 1452 + 184$

$\Delta H^\circ_{reaction}$ is –906 kJmol^{-1} so
$4y = -906 + 1452 - 184 = 362$
whence y = ΔH_f° for NO = +90.5 kJ mol^{-1} (1)
+ sign is required (1) [4]

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8. M/J 13/P23/Q1/c

(a)

	CS_2	+	$3O_2$	→	CO_2	+	$2SO_2$
$\Delta H_f^{\ominus}$/kJ mol^{-1}	x				−395		2(−298)

(1)

$\Delta H_{reaction} = -395 + 2(-298) - x = -1110$ kJ mol^{-1} (1)

gives $x = -395 + (-596) + 1110 = +119$ kJ mol^{-1} (1) [3]

9. M/J 12/P22/Q2/a,b

(a) $CH_3OH(l) + {}^3/_2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$ (1)

the enthalpy change/heat change/heat evolved when [1]

one mole of CH_3OH

is completely burned **or** [1] [3]

is burned in an excess of air/oxygen

(b) $\Delta H^{\ominus}_{reaction} = -283 + 2(-286) - (-726)$ [1]

$= -129$ kJ mol^{-1} [1]

correct sign [1] [3]

10. M/J 12/P21/Q3/a,b

(a) $C(s) + O_2(g) \rightarrow CO_2(g)$ [1]

the enthalpy change/energy change/heat change when [1]

one mole of a compound/CO_2

is formed from its elements in their standard states (1) [3]

(b) (i)

	$CO_2(g)$	+	$3H_2(g)$	⇌	$CH_3OH(g)$	+	$H_2O(g)$
$\Delta H^{\ominus}_f$/kJ mol^{-1}	−394		0		−201		−242

$\Delta H^{\ominus}_{reaction} = -201 + (-242) - (-394)$ [1]

−49 kJ mol^{-1} [1]

correct sign [1]

(ii) removal of CO_2 from the atmosphere (1)

CO_2 is a greenhouse gas/causes global warming (1) [5]

11. M/J 12/P23/Q3/a,b

(a) $CH_3OCH_3(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$ (1)

the enthalpy change/heat change/heat evolved when [1]

one mole of CH_3OCH_3/a compound

is completely burned **or** [1] [3]

burned in an excess of air/oxygen

(b)

	$2CH_3OH(l)$	→	$CH_3OCH_3(g)$	+	$H_2O(l)$
$\Delta H^{\ominus}_f$/kJ mol^{-1}	2(−239)		−184		−286

$\Delta H^{\ominus}_{reaction}$ $= -184 + (-286) - 2(-239)$ [1]

$= +8$ kJ mol^{-1} [1]

correct sign [1] [3]

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12. O/N 11/P22/Q3 O/N 11/P21/Q3

(a) the overall enthalpy change/energy change/ΔH for a reaction
is independent of the route taken **or**
is independent of the number of steps involved
provided the initial and final conditions are the same (1) (1) [2]

(b) (i) $K_2CO_3 + 2HCl \rightarrow 2KCl + H_2O + CO_2$ [1]

(ii) heat produced= m × c × δT = 30.0 × 4.18 × 5.2
= 652.08 J per 0.0200 mol of K_2CO_3 [1]

(iii) 0.020 mol $K_2CO_3 \equiv$ 652.08 J

1 mol $K_2CO_3 \equiv \frac{652.08 \times 1}{0.0200} = 32604$ J

enthalpy change = –32.60 kJmol^{-1} [1]

(iv) to prevent the formation of $KHCO_3$ **or**
to ensure complete neutralisation [1] [4]

(c) (i) $KHCO_3 + HCl \rightarrow KCl + H_2O + CO_2$ [1]

(ii) heat absorbed= m × c × δT = 30.0 × 4.18 × 3.7
= 463.98 J per 0.0200 mol of $KHCO_3$ [1]

(iii) 0.020 mol $KHCO_3 \equiv$ 463.98 J

1 mol $KHCO_3 \equiv \frac{463.98 \times 1}{0.0200} = 23199$ J

enthalpy change = +23.20 kJmol^{-1} [1] [3]

(d) $\Delta H = 2 \times (+23.20) - (-32.60) = +79.00$ kJ mol^{-1} [2] [2]

13. M/J 11/P21/Q5/d

(a) (i) combustion

$C_2H_2(g) + {}^5/_2O_2(g) \rightarrow 2CO_2(g) + H_2O(l)$ **or**
equation must be for the combustion of one mole of C_2H_2
H_2O must be shown as liquid [1]
correct state symbols in this equation [1]

formation

$2C(s) + H_2(g) \rightarrow C_2H_2(g)$
no mark for state symbols here [1]

(ii) let **Z** be $\Delta H^{\ominus}_f$ of C_2H_2

	C_2H_2 +	${}^5/_2O_2 \rightarrow$	$2CO_2$ +	H_2O
$\Delta H^{\ominus}_f$	**Z**	0	2(-394)	-286

$\Delta H^{\ominus}_c = -1300 = 2(-394) + (-286) - \mathbf{Z}$

whence **Z** = 2(-394) + (-286) – (-1300)
= +226 kJ mol^{-1} (1)
value (1)
sign (1)
allow ecf on wrong equation [6]

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14. O/N 10/P21/Q3/d,e,f

(a) enthalpy change when 1 mol of a substance (1)
or
is burnt in an excess of oxygen/air under standard conditions
is completely combusted under standard conditions **[1] [2]**

(b) (i) heat released = m c δT = 200 x 4.18 x 27.5 (1)

= 22990 J = 23.0 kJ (1)

(ii) 23.0 kJ produced from 0.47 g of **E**

2059 kJ produced from $\frac{0.47 \times 2059}{23.0}$ g of **E** (1)

= 42.08 g of **E** (1)

allow ecf in **(i)** or **(ii)** on candidate's expressions **[4]**

(c) C_3H_6 = 42

E is C_3H_6

for ecf, **E** must be unsaturated and be no larger than C_5 (1) **[1]**

15. O/N 09/P21/Q3

(a) (i)

	CH_4	+	Cl_2	→	CH_3Cl	+	HCl
ΔH_f°	–75		0		–82		–92

[1]

$\Delta H^\ominus_{reaction}$ = –82 + (–92) – (–75)
= –99 kJ mol^{-1} **[1]**

(ii)

	CH_4	+	I_2	→	CH_3I	+	HI
broken	C–H		I–I	made	C–I		H–I
	410		151		240		299

[1]

$\Delta H^\ominus_{reaction}$ = –240 + (–299) + 410 + 151
= +22 kJ mol^{-1} **[1]**

(iii) activation energy is too great **[1] [5]**

(b) (i) initiation **[1]**

Cl_2 + uvl → 2Cl **[1]**

propagation

$CH_4 + Cl \rightarrow CH_3 + HCl$

$CH_3 + Cl_2 \rightarrow CH_3Cl + Cl$ **both needed [1]**

termination **[1]**

$CH_3 + CH_3 \rightarrow C_2H_6$ **or**

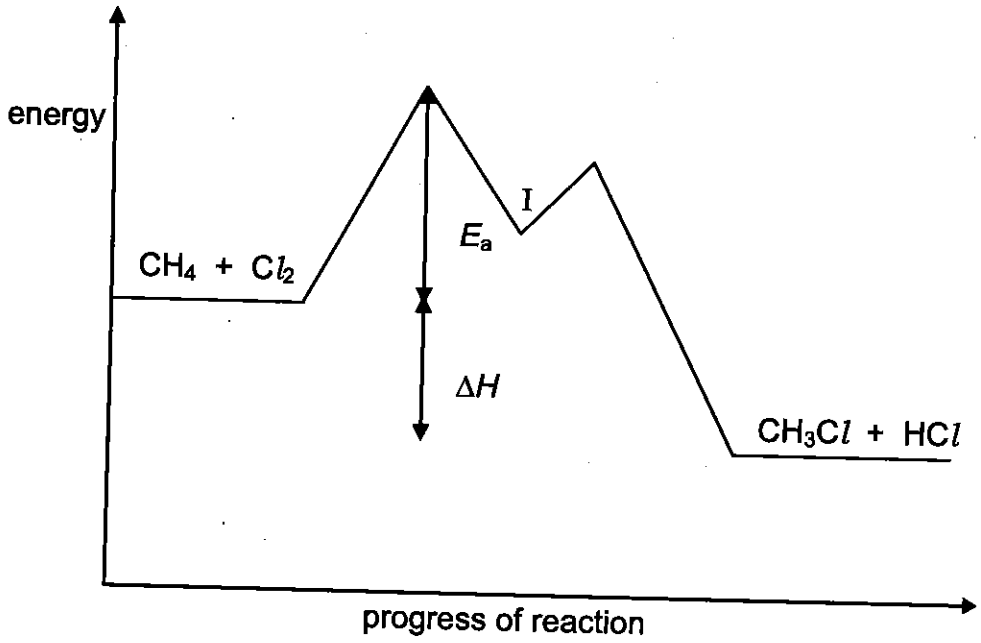
$CH_3 + Cl \rightarrow CH_3Cl$ **or**

$Cl + Cl \rightarrow Cl_2$ **[1]**

(ii) CH_3/methyl radical **[1] [7]**

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(c)



correct placement of 16 kJ [1]
correct placement of –99 kJ (allow ecf on wrong calculation in **(a) (i)**) [1]

intermediate clearly shown at I [1]
correct 'double peak' shape [1]
second peak lower than first [1] **[5]**

[16]

16. M/J 09/P22/Q2/a(i, ii)

(a) (i) $Ca^+(g) \rightarrow Ca^{2+}(g) + e^-$

equation (1)
state symbols (1)

(ii) 590 + 1150 = +1740 kJ mol^{-1} (1) [3]

17. O/N 09/P21/Q1/d

(a) (i) Ra^{2+} **[1]**

(ii) less than (502 + 966) **[1]**
allow answers in the range 1000–1400 kJ mol^{-1}

ionisation energies decrease down the Group
or must be less than IE for $Ba \rightarrow Ba^{2+}$
or size of atom increases down Group/
electrons are further away from nucleus
or
there is increased shielding down Group [1]
allow ecf on answer to(i) **[3]**

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18. O/N 08/P2/Q2/c,d

(a) (i) enthalpy change when
1 mol of a compound is formed (1)
from its elements (1)
in their standard states under standard conditions (1)

(ii) $C + O_2 \rightarrow CO_2$ -395 kJ mol^{-1}
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ -286 kJ mol^{-1}
$C_2H_2O + 2O_2 \rightarrow 2CO_2 + H_2O$ -1028 kJ mol^{-1}
$2C + H_2 + \frac{1}{2}O_2 \rightarrow C_2H_2O$ $\Delta H = 2(-395) + (-286) - (-1028)$
$= -48$ kJ mol^{-1}

correct cycle (1) use of 2 for C/CO_2 (1) answer (1) [6]

(b) H_2O/water/steam (1) [1]

19. O/N 07/P2/Q1/e

(a) $\Delta H_f^\circ = 2(-393.7) + 2(-285.9) - (-1411)$
$= +51.8$ kJ mol^{-1}(units given in qu.) [3]

penalise errors: no 2 for -393.7
no 2 for -285.9
wrong sign for $-(-1411)$ [3]

20. O/N 06/P2/Q4/d,e

(a) enthalpy change when 1 mol of a substance [1]
is burnt in an excess of oxygen/air
or undergoes complete combustion
under standard conditions [1]

(b) (i) heat released = m c δT = 200 x 4.18 x 27.5 [1]
= 22990 J = 23.0 kJ
(If candidate uses 4.2 answer is 23.1 kJ.) [1]

(ii) 23.0 kJ produced from 0.47 g

2059 kJ produced from $\frac{0.47 \times 2059}{23.0}$ g [1]

= 42.08g

(Use of 4.2 gives 41.89 g.)

allow ecf from **(i)** [1]

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21. M/J 06/P2/Q2/d,e

(a) $C_2H_2(g) + {}^5/_2O_2(g) \rightarrow 2CO_2(g) + H_2O(g)$

bonds broken:

2(H-C)	2 x 410	=	820	
C≡C	840	=	840	
${}^5/_2$(O=O)	${}^5/_2$ x 496	=	1240	
			2900	kJ mol^{-1}

[1]

bonds made:

4(C=O)	4 x 740	=	2960	
2(O-H)	2 x 460	=	920	
			3880	kJ mol^{-1}

[1]

ΔH_{comb} = -3880 + 2900 = -980 kJ mol^{-1} [1]
allow e.c.f. on incorrect bonds made/broken
[3]

(b) **(i)** the enthalpy/energy change when one mole of a substance [1]
is burned in an excess of air/oxygen
or completely combusted
under standard conditions
[1]

(ii) calculation in **(d)** includes $H_2O(g)$ whereas ΔH_{comb} involves $H_2O(l)$
or average bond energy terms are used in the *Data Booklet* [1] [3]

22. O/N 05/P2/Q2/c, d

(a) $C + O_2 \rightarrow CO_2$ -395

$S + O_2 \rightarrow SO_2$ -298

$CS_2 + 3O_2 \rightarrow CO_2 + 2SO_2$ -1110

$C + 2S \rightarrow CS_2$ ΔH = -395 + 2(-298) -(-1110)

= +119 kJ mol

cycle (1) use of 2 for S/SO_2 (1) answer [1] [3]

(b) CO_2 [1]

N_2 [1]

$CS_2 + 2NO \rightarrow CO_2 + 2S + N_2$ [1]

completely correct equation gets (3)
consequential errors to be decided at co-ordination [3]

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23. O/N 04/P2/Q1/d

(a) (i) ΔH_{reacn} = ΔH for bonds broken – ΔH for bonds made (1)

(ii) $2H-I \rightarrow H-H + I-I$

2 x 299 436 151 values (1)

$\Delta H = 2 \times 299 - (436 + 151)$

$= +11$ kJ mol^{-1} (1) **[3]**

24. O/N 03/P2/Q3

(a) (i) energy/enthalpy change when 1 mol of a compound is formed from its elements **[1]**

at 25°C and 1 atm **[1]**

(ii) $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ **[1]**

(b) (i) $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$ **[1]**

(ii) heat released = mcΔT **[1]**

$= 200 \times 4.2 \times 12.2 = 10.25$ kJ **[1]**

(iii) $\Delta H_{reacn} = 40.1 \times (-10.25) = -411$ kJ mol^{-1} sign necessary

for ecf, ΔH_{reacn} = 40.1 x [answer to **(b)(ii)**] **[1] [4]**

(c) (i) The enthalpy (energy) change for converting reactants into products **[1]**

is the same regardless of the route taken **[1]**

(ii) $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$ $\Delta H = -411$

$\Delta H^{\ominus}_f$ 2 x (–286) x **[1]**

$\Delta H_{reacn} = x - 2(-286) = -411$ **[1]**

$x = -411 + 2(-286) = -983$ kJ mol^{-1}

sign necessary

for ecf, x = ans. to (b)(iii) + (–572) **[1] [4]**

(d) 40.1 g of Ca give 24000 cm^3 of H_2

1 g of Ca gives $\frac{24000}{40.1} = 598.5$ cm^3 units needed **[1]**

allow 40 g of Ca giving 600 cm^3 **[2]**

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25. O/N 02/P2/Q4/e

(e) $H_2O + CO(NH_2)_2 \longrightarrow 2NH_3 + CO_2$

$-287 + (-332.5) \longrightarrow -162 \quad -414.5$ (1)

$-607.5 \longrightarrow -576.5$

$\Delta H = 31$ kJ mol^{-1} (1)

26. M/J 02/P2/Q2/a, b

2 (a) $C_2H_4 + H_2O \longrightarrow C_2H_5OH$

$-1418 \qquad -1367$

$\Delta H = (-)\ 44$ kJ mol^{-1} [2]

(b) (i) *ΔH when 1 mol of element or compound(1) in a substance is completely combusted (1)

(ii) Under standard conditions H_2O & C_2H_5OH are liquids (1)

(iii) $C_2H_5OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O$ (1) 4

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UNIT 6

Electro-chemistry

A-Level
Chemistry Paper 2
Topical Workbook

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Unit 6: Electrochemistry

1. M/J 15/P23/Q2/b(iv)

The elements in Group II, and their compounds, show a variety of trends in their properties.

(a) Apart from lithium nitrate, the nitrates of the Group I elements decompose in a different way to those of the Group II elements.

The equation for the thermal decomposition of potassium nitrate is

$$2KNO_3 \rightarrow 2KNO_2 + O_2$$

By identifying any changes in oxidation number, explain which element is reduced and which is oxidised in this decomposition.

.....

.....

.....

..... **[3]**

2. M/J 15/P22/Q2/a

Sulfuric acid is an important chemical with a variety of uses.

It is manufactured by the Contact process, the first stage of which involves the conversion of sulfur or a sulfide ore, such as galena, PbS, into sulfur dioxide, SO_2.

(a) (i) Write an equation for the reaction between galena and oxygen to form sulfur dioxide and lead(II) oxide.

..... **[2]**

(ii) Identify the oxidation number changes that take place during this reaction.

.....

..... **[2]**

3. M/J 14/P22/Q2/a(i)

A 6.30 g sample of hydrated ethanedioic acid, $H_2C_2O_4.xH_2O$, was dissolved in water and the solution made up to 250 cm^3.

A 25.0 cm^3 sample of this solution was acidified and titrated with 0.100 mol dm^{-3} potassium manganate(VII) solution. 20.0 cm^3 of this potassium manganate(VII) solution was required to react fully with the ethanedioate ions, $C_2O_4^{2-}$, present in the sample.

(a) The MnO_4^- ions in the potassium manganate(VII) *oxidise* the ethanedioate ions.

(i) Explain, in terms of electron transfer, the meaning of the term *oxidise* in the sentence above.

.....

..... **[1]**

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4. M/J 14/P21/Q2/a(i)

The commonest form of iron(II) sulfate is the heptahydrate, $FeSO_4.7H_2O$. On heating at 90 °C this loses **some** of its water of crystallisation to form a different hydrated form of iron(II) sulfate, $FeSO_4.xH_2O$.

3.40 g of $FeSO_4.xH_2O$ was dissolved in water to form 250 cm^3 of solution.

A 25.0 cm^3 sample of this solution was acidified and titrated with 0.0200 mol dm^{-3} potassium manganate(VII).

In this titration 20.0 cm^3 of this potassium manganate(VII) solution was required to react fully with the Fe^{2+} ions present in the sample.

(a) The MnO_4^- ions in the potassium manganate(VII) *oxidise* the Fe^{2+} ions in the acidified solution.

(i) Explain, in terms of electron transfer, the meaning of the term *oxidise* in the sentence above.

.....[1]

5. M/J 13/P23/Q1/d

Carbon disulfide, CS_2, is a volatile, flammable liquid which is produced in small quantities in volcanoes.

(a) Carbon disulfide reacts with nitrogen monoxide, NO, in a 1:2 molar ratio.
A yellow solid and two colourless gases are produced.

(i) Construct a balanced equation for the reaction.

.....

(ii) What is the change in the oxidation number of sulfur in this reaction?

from ..... to .....

[3]

6. M/J 13/P22/Q2/b

Chile saltpetre is a mineral found in Chile and Peru, and which mainly consists of sodium nitrate, $NaNO_3$. The mineral is purified to concentrate the $NaNO_3$ which is used as a fertiliser and in some fireworks.

In order to find the purity of a sample of sodium nitrate, the compound is heated in NaOH(aq) with Devarda's alloy which contains aluminium. This reduces the sodium nitrate to ammonia which is boiled off and then dissolved in acid.

$$3NaNO_3(aq) + 8Al(s) + 5NaOH(aq) + 18H_2O(l) \rightarrow 3NH_3(g) + 8NaAl(OH)_4(aq)$$

The ammonia gas produced is dissolved in an excess of H_2SO_4 of known concentration.

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

The amount of unreacted H_2SO_4 is then determined by back-titration with NaOH of known concentration.

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

(a) The above reaction is an example of a redox reaction.
What are the oxidation numbers of nitrogen in $NaNO_3$ and in NH_3?

$NaNO_3$ ..... NH_3 ..... [1]

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7. M/J 13/P21/Q3/a(ii)

This question refers to the elements in the section of the Periodic Table shown below.

		H						He
Li	Be		B	C	N	O	F	Ne
Na	Mg		Al	Si	P	S	Cl	Ar
K	Ca	..... transition elements	Ga	Ge	As	Se	Br	Kr

(a) From this list of elements, identify in **each** case **one** element that has the property described. Give the **symbol** of the element.

(i) An element that forms an oxide that is a reducing agent.

..... **[1]**

8. O/N 10/P23/Q2/d(ii)

Sulfur and its compounds are found in volcanoes, in organic matter and in minerals.
Sulfuric acid, an important industrial chemical, is manufactured from sulfur by the Contact process.

The Contact process may be considered to be a three-stage process in which sulfur is converted into sulfuric acid. Each stage consists of a single chemical reaction.

(a) Most of the sulfur that is used in the Contact process is recovered from sulfur compounds present in crude oil and natural gas by using the Claus process.

(i) The SO_2 formed is then reacted catalytically with the remaining H_2S, producing sulfur and water.

$$2H_2S + SO_2 \rightarrow 3S + 2H_2O$$

What are the oxidation numbers of each of the sulfur-containing substances in this reaction?

H_2S..... SO_2 ..... S .....

Which substance is reduced? Explain your answer.

substance .....

explanation ..... **[3]**

9. M/J 09/P22/Q2/c

Phosphorus is a very reactive non-metallic element which readily forms ionic compounds with metals such as calcium and covalent compounds with non-metals such as chlorine and oxygen.

(a) When phosphorus is heated with an excess of sulfur in an inert atmosphere, a pale yellow solid, with formula P_4S_{10} is formed.
P_4S_{10} reacts with water to give phosphoric acid, H_3PO_4, and hydrogen sulfide, H_2S.

(i) Complete the equation for the reaction of P_4S_{10} with water.

$$P_4S_{10} + 16H_2O \rightarrow$$

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(ii) Does a redox reaction occur when P_4S_{10} reacts with water?
Use the oxidation numbers of phosphorus to explain your answer.

.....

.....

.....

..... [4]

10. O/N 07/P2/Q3/c,d

The elements phosphorus, sulphur, and chlorine are regarded as having simple molecular structures.

(a) Sulphur and chlorine can be reacted together to form disulphur dichloride, S_2Cl_2.

Disulphur dichloride, S_2Cl_2, is decomposed by water forming sulphur and a mixture of hydrochloric acid and sulphurous acid.

When 2.7 g of S_2Cl_2 is reacted with an excess of water, 0.96 g of sulphur, S, is produced.

(i) What is the amount, in moles, of S_2Cl_2 present in 2.7 g?

(ii) What is the amount, in moles, of S produced from 1.0 mol of S_2Cl_2?

(iii) Construct a balanced equation for the reaction of S_2Cl_2 with water.

..... [4]

(b) The reaction between S_2Cl_2 and water is a redox reaction.

Which product has been formed by oxidation and which by reduction?

product formed by oxidation .....

product formed by reduction ..... [2]

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11. M/J 05/P2/Q2/d(i,ii)

Hydrogen sulphide burns with a blue flame in an excess of oxygen to form sulphur dioxide and water.

(a) **(i)** Write a balanced equation for the complete combustion of H_2S.

.....

(ii) What is the change in the oxidation number of sulphur in this reaction?

from ..... to .....

12. M/J 04/P2/Q3/e

Ammonia, NH_3, is a colourless, pungent-smelling gas which has been known to man from the beginning of recorded time. It is given off from urine such as that on a wet nappy from a baby.

The nitrogen-containing substance in urine is urea, $CO(NH_2)_2$, and this decomposes by hydrolysis into ammonia and another colourless gas.

Ammonia was named after the shrine of Jupiter Ammon which was near the Egyptian-Libyan border. In ancient times ammonia was obtained by distilling camel dung.

(a) Ammonia does not burn in air but will burn in pure oxygen.

(i) Balance the equation for this reaction:

$$\ldots\ldots\ NH_3(g) + \ldots\ldots\ O_2(g) \longrightarrow \ldots\ldots\ N_2(g) + \ldots\ldots\ H_2O(g)$$

(ii) Use oxidation numbers to explain why this is a redox reaction.

.....

.....

.....[3]

13. O/N 02/P2/Q3/d(ii)

The oxides of the third period include the following:

$$Na_2O; \quad MgO; \quad Al_2O_3; \quad SO_2; \quad SO_3.$$

(a) Antimony, Sb, has been known for about 6000 years. It is present in many ancient forms of bronze, but now its main use is to strengthen lead alloys.

Antimony is produced in a two-stage process from stibnite, a sulphide ore, Sb_2S_3.

The ore is first roasted in oxygen to form the oxide.

$$2Sb_2S_3 + \ldots\ldots\ O_2 \rightarrow Sb_4O_6 + \ldots\ldots SO_2$$

(i) What is the oxidation number of antimony in Sb_4O_6?

.....

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Answers Section

1. M/J 15/P23/Q2/b(iv)

(a) N from (+)5 to (+)3 [1]
O from –2 to 0 [1]
N is reduced **and** O is oxidised [1] [3]

2. M/J 15/P22/Q2/a

(a) (i) $2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$
reagents and formulae [1]
balancing [1] [2]

(ii) S (is oxidised) –2 to (+)4 [1]
O (is reduced) 0 to –2 [1] [2]

3. M/J 14/P22/Q2/a(i)

(a) (i) (The $C_2O_4^{2-}$ ions) lose electrons owtte/ora 1 [1]

4. M/J 14/P21/Q2/a(i)

(a) (i) (The MnO_4^- ions cause the Fe^{2+} ions to) lose electrons owtte/ora 1 [1]

5. M/J 13/P23/Q1/d

(i) $CS_2 + 2NO \rightarrow CO_2 + 2S + N_2$
or
$CS_2 + 2NO \rightarrow CO + 2S + N_2O$

correct products **(1)**
correct equation **(1)**

(ii) from –2 to 0 **both** required **(1)** [3]

6. M/J 13/P22/Q2/b

(a) $NaNO_3$ +5 **and** NH_3 -3 **both** required **(1)** [1]

7. M/J 13/P21/Q3/a(ii)

(a) (i) S **or** C **or** N **or** P **(1)**

8. O/N 10/P23/Q2/d(ii)

(a) H_2S –2 SO_2 +4 S 0 **all three** (1)
SO_2 **because** the oxidation number of S is reduced (1) [3]

9. M/J 09/P22/Q2/c

(a) (i) $P_4S_{10} + 16H_2O \rightarrow 4H_3PO_4 + 10H_2S$ **(1)**

(ii) P_4S_{10} P is +5 **(1)**
H_3PO_4 P is +5 **(1)**

No **because**
there is no change in the oxidation no. of P **(1)**
ecf on answer to **(c)(i)**
and on calculated oxidation numbers [4]

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10. O/N 07/P2/Q3/c,d

(a) (i) $S_2Cl_2 = (2 \times 32.1) + (2 \times 35.5) = 135.2$

$n(S_2Cl_2) = \frac{2.7}{135.2} = 0.0199 = 0.02$ **(1)**

$0.02 \text{ mol } S_2Cl_2 \rightarrow \frac{0.96}{32.1} = 0.03 \text{ mol S}$

$1.0 \text{ mol } S_2Cl_2 \rightarrow \frac{0.03 \times 1.0}{0.02} = 1.5 \text{ mol S}$ **(1)**

(iii) $2S_2Cl_2 + 3H_2O \rightarrow 3S + H_2SO_3 + 4HCl$

correct products **(1)**

balanced equation **(1)** **[4]**

(b) oxidation product is H_2SO_3 **(1)**

reduction product is S **(1)** **[2]**

11. M/J 05/P2/Q2/d(i,ii)

(a) (i) $2H_2S + 3O_2 \rightarrow 2H_2O + 2SO_2$ **(1)**

from -2 **(1)** to +4 **(1)**

allow e.c.f. on equation

(ii) 68.2g H_2S react with 3×24 dm^3 O_2 **(1)**

8.65g H_2S react with $\frac{3 \times 24 \times 8.65}{68.2} = 9.13$ dm^3 **(1)**

allow 9.16 dm^3 if $H_2S = 68$ is used

allow e.c.f on **(d)(i)** **[5]**

12. M/J 04/P2/Q3/e

(a) $4NH_3 + 3O_2 \longrightarrow 2N_2 + 6H_2O$ [1]

N goes from -3 to 0 ⟶ oxidation [1]

O goes from 0 to -2 ⟶ reduction [1]

13. O/N 02/P2/Q3/d(ii)

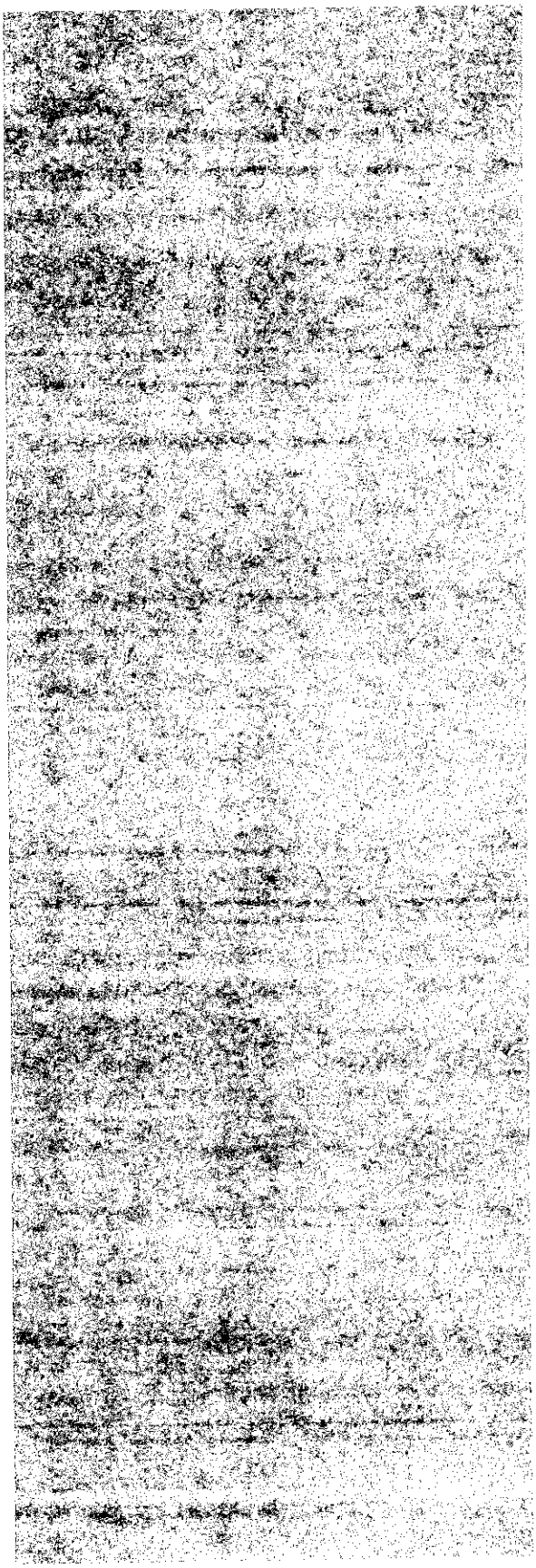
(a) +3 or 3 NOT 3+ (1)

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UNIT 7

Equilibria

A-Level
Chemistry Paper 2
Topical Workbook



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Unit 7: Equilibria

1. M/J 17/P23/Q3/d

Sulfur trioxide, SO_3, is manufactured from sulfur dioxide and oxygen by the Contact process.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196.0\,kJ\,mol^{-1}$$

(a) In another equilibrium mixture formed from different starting amounts of SO_2 and O_2, the partial pressures of SO_2, O_2 and SO_3 were as shown.

$$pSO_2 = 8.42 \times 10^2 Pa$$
$$pO_2 = 6.00 \times 10^4 Pa$$
$$pSO_3 = 9.10 \times 10^4 Pa$$

(i) Write the expression for the equilibrium constant, K_p, for the production of SO_3 from SO_2 and O_2

$K_p =$ [1]

(ii) Calculate the value of K_p for this reaction and state the units.

$K_p =$ .....

units = ...

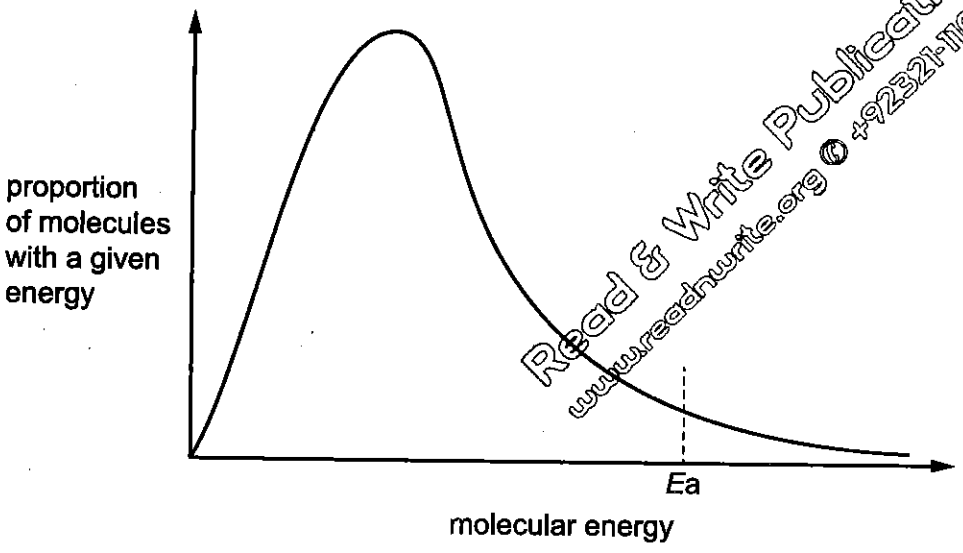
[2]

2. M/J 17/P22/Q3/b(iii,iv),c,d

The hydrogen halides, HCl, HBr and HI, can undergo thermal decomposition.
In a sealed container an equilibrium is established according to the equation shown.

$$2HX(g) \rightleftharpoons H_2(g) + X_2(g) \qquad \text{(where X = Cl, Br or I)}$$

(a) At a temperature of 700 K a sample of HBr is approximately 10% decomposed. Changing the temperature affects both the rate of decomposition of HBr and the percentage that decomposes.
The Boltzmann distribution for a sample of HBr at 700 K is shown. *E*a represents the activation energy for the reaction.



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(i) The decomposition of HBr is endothermic.
State the effect of increasing temperature on the **percentage** of HBr that decomposes.
Use Le Chatelier's principle to explain your answer.

.....

.....

.....

..... **[3]**

(ii) At 700K HBr is approximately 10% decomposed but hydrogen iodide, HI, is approximately 20% decomposed.
Explain this difference with reference to bond strengths and the factors that affect them.

.....

.....

.....

..... **[3]**

(b) At temperatures above 1500 K, HC*l* will decompose.

A sample of 0.300 mol of HC*l* decomposed in a sealed container.

The resulting equilibrium mixture was found to contain 1.50×10^{-2} mol of Cl_2.

(i) Calculate the amounts, in mol, of H_2 and HC*l* present in the equilibrium mixture.

H_2 = ... mol

HC*l* = ... mol
[2]

(ii) Calculate the mole fraction of each gas in the equilibrium mixture.

mole fraction of HC*l* = ...

mole fraction of H_2 = ...

mole fraction of Cl_2 = ...
[1]

(c) In another experiment under different conditions, an equilibrium mixture was produced with mole fractions for each species as shown.

species	mole fraction
HC*l*	0.88
H_2	0.06
Cl_2	0.06

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(i) Write the expression for the equilibrium constant, K_p, for the decomposition of HCl

$$2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$$

K_p =

[1]

(ii) Explain why the total pressure of the system does **not** need to be known for K_p to be calculated for this experiment.

.....

..... **[1]**

(iii) Calculate the value of K_p for this experiment.

K_p = ... **[1]**

3. MAR 17/P22/Q2/c(iii,iv,v,vi)

(a) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

The reaction is carried out at 400 °C in the presence of a copper(II) chloride catalyst.

(i) The reaction exists in dynamic equilibrium.
The reaction was repeated at 1000 °C and the same pressure.
State and explain the effect on the composition of the equilibrium mixture of the change in temperature.

.....

.....

.....

..... **[2]**

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(ii) When 1.60 mol of HCl are mixed in a sealed container with 0.500 mol of O_2 at 400 °C, 0.600 mol of Cl_2 and 0.600 mol of H_2O are formed.
The total pressure inside the container is 1.50×10^5 Pa.

- Calculate the amounts, in mol, of HCl and O_2 in the equilibrium mixture.

HCl = ... mol

O_2 = ... mol

- Calculate the mole fraction of Cl_2 and hence the partial pressure of Cl_2 in the equilibrium mixture.

mole fraction of Cl_2 = ...

p_{Cl_2} = ... Pa

[3]

(iii) In a separate experiment, an equilibrium reaction mixture was found to contain the four gases at the partial pressures shown in the table.

gas	HCl	O_2	Cl_2	H_2O
partial pressure/Pa	4.8×10^4	3.0×10^4	3.6×10^4	3.6×10^4

$$K_p = \frac{(p_{Cl_2})^2 \times (p_{H_2O})^2}{(p_{HCl})^4 \times p_{O_2}}$$

Use this information and the expression given for K_p to calculate a value for K_p. State the units of K_p.

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K_p = ...

units = ...

[2]

(iv) The reaction is repeated without a catalyst.
State the effect of this on K_p.

..... **[1]**

4. MAR 16/P22/Q3/b

(a) The reaction exists as a dynamic equilibrium.

(i) Explain what is meant by the term *dynamic equilibrium*.

.....

..... **[1]**

(ii) State and explain how the amounts of the chemicals present in the equilibrium mixture will change when the pressure is increased.

.....

.....

..... **[2]**

5. O/N 14/P23/Q2/d

(a) The Haber process is typically carried out at a temperature of 400 °C.

(i) With reference to Le Chatelier's Principle and reaction kinetics, state and explain one advantage and one disadvantage of using a higher temperature.

.....

.....

.....

.....

.....

..... **[4]**

(ii) State the expression for the equilibrium constant, K_p, for the formation of ammonia from nitrogen and hydrogen in the Haber process.

K_p =

[1]

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(iii) 2.00 moles of nitrogen and 3.00 moles of hydrogen were put in a vessel and left to reach equilibrium.
At equilibrium, the pressure was 2.00×10^7 Pa and the mixture contained 1.60 moles of ammonia.
Calculate K_p. Include the units.

K_p = ...

units = ...
[5]

6. O/N 14/P21/Q2/a,b,d

The Contact process for the manufacture of sulfuric acid was originally patented in the 19th century and is still in use today.

The key step in the overall process is the reversible conversion of sulfur dioxide to sulfur trioxide in the presence of a vanadium(V) oxide catalyst.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(a) One way in which the sulfur dioxide for this reaction is produced is by heating the sulfide ore iron pyrites, FeS_2, in air. Iron(III) oxide is also produced. Write an equation for this reaction.

..... **[2]**

(b) The sulfur trioxide produced in the Contact process is reacted with 98% sulfuric acid. The resulting compound is **then** reacted with water to produce sulfuric acid.

(i) Explain why the sulfur trioxide is not first mixed directly with water.

.....

..... **[1]**

(ii) Write equations for the two steps involved in the conversion of sulfur trioxide into sulfuric acid.

.....

..... **[2]**

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(c) The conversion of sulfur dioxide into sulfur trioxide is carried out at a temperature of 400 °C.

(i) With reference to Le Chatelier's Principle and reaction kinetics, state and explain one advantage and one disadvantage of using a higher temperature.

.....

.....

.....

.....

.....

..... **[4]**

(ii) State the expression for the equilibrium constant, K_p for the formation of sulfur trioxide from sulfur dioxide.

K_p =

[1]

(iii) 2.00 moles of sulfur dioxide and 2.00 moles of oxygen were put in a flask and left to reach equilibrium.
At equilibrium, the pressure in the flask was 2.00×10^5 Pa and the mixture contained 1.80 moles of sulfur trioxide.
Calculate K_p. Include the units.

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K_p = ...

units = ...

[5]

7. M/J 14/P23/Q3/a,b

Nitrogen dioxide, NO_2, can enter the atmosphere in a variety of ways.

(a) (i) State one natural and one man-made source of atmospheric NO_2.

natural .....

man-made .....

[1]

(ii) Write an equation to show how NO_2 leads to the formation of nitric acid in acid rain.

..... [1]

(iii) Use equations to illustrate the catalytic role of NO_2 in the formation of sulfuric acid in acid rain.

.....

.....

..... [3]

(b) Nitrogen dioxide exists in equilibrium with dinitrogen tetroxide, N_2O_4.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

2.00 mol of dinitrogen tetroxide was sealed in a container at 350 K. After equilibrium had been established the total pressure was 140 kPa and the mixture of gases contained 1.84 mol of dinitrogen tetroxide.

(i) Give the expression for the equilibrium constant, K_p, for this equilibrium.

K_p =

[1]

(ii) Calculate the number of moles of NO_2 present at equilibrium.

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[1]

(iii) Calculate the total number of moles of gas present at equilibrium and hence the mole fraction of each gas present at equilibrium.

[2]

(iv) Calculate the partial pressure of each gas present at equilibrium.

[2]

(v) Calculate the value of the equilibrium constant, K_p, at 350 K.
Give your answer to **three** significant figures and include the units.

K_p = ...

units = ...

[2]

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8. M/J 13/P23/Q2/a,b

Methanol, CH_3OH, can be produced industrially by reacting carbon monoxide, CO, with hydrogen, H_2.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91\,kJ\,mol^{-1}$$

The process is carried out at 4×10^3 kPa (40 atmospheres) and 1150K.

(a) (i) State Le Chatelier's Principle.

.....

.....

..... **[2]**

(ii) From your understanding of Le Chatelier's Principle, state the conditions of temperature and pressure that could be used in order to produce an increased yield of methanol in this process.
In **each** case, explain why the yield would increase.

temperature .....

explanation .....

.....

pressure .....

explanation .....

..... **[4]**

(b) The carbon monoxide for use in the production of methanol may be formed by reacting carbon dioxide with hydrogen.

$$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g) \qquad K_c = 1.44 \text{ at } 1200\,K$$

A mixture containing 0.70 mol of CO_2, 0.70 mol of H_2, 0.30 mol of CO and 0.30 mol of H_2O was placed in a 1 dm^3 flask and allowed to come to equilibrium at 1200 K.

Calculate the amount, in moles, of each substance present in the equilibrium mixture at 1200 K.

	CO_2	+	H_2	$\rightleftharpoons$	CO	+	H_2O
initial moles	0.70		0.70		0.30		0.30

[4]

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9. M/J 13/P22/Q1/a,b

Ammonium sulfate is a fertiliser which is manufactured by the reaction between ammonia and sulfuric acid.

(a) Ammonia is described as a weak base and sulfuric acid as a strong acid.

By using an equation, explain clearly what is meant by the term *weak base*.

.....

.....

.....

.....

..... [3]

(b) Ammonia and sulfuric acid are both manufactured by processes which involve chemical equilibria.

(i) Sulfuric acid is produced from sulfur trioxide which is made by the Contact process.

State **three** important operating conditions for the Contact process for the manufacture of sulfur trioxide.

For **each** of your conditions, you should avoid the use of vague phrases such as 'high temperature'.

condition 1 .....

.....

condition 2 .....

.....

condition 3 .....

.....

(ii) How is the sulfur trioxide produced converted into sulfuric acid?

.....

..... [4]

10. M/J 13/P21/Q2/a,b,c

Ammonium nitrate fertiliser is manufactured from ammonia. The first reaction in the manufacture of the fertiliser is the catalytic oxidation of ammonia to form nitrogen monoxide, NO. This is carried out at about 1×10^3 kPa (10 atmospheres) pressure and a temperature of 700 to 850 °C.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^\circ = -906\ kJ\,mol^{-1}$$

(a) Write the expression for the equilibrium constant, K_p, stating the units.

K_p =

units .....

[2]

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(b) What will be the effect on the yield of NO of **each** of the following?
In each case, explain your answer.

(i) increasing the temperature

.....

.....

.....

(ii) decreasing the applied pressure

.....

.....

.....

[4]

(c) The standard enthalpy changes of formation of $NH_3(g)$ and $H_2O(g)$ are as follows.

$NH_3(g)$, $\Delta H_f^\ominus = -46.0\,kJ\,mol^{-1}$ $H_2O(g)$, $\Delta H_f^\ominus = -242\,kJ\,mol^{-1}$

Use these data and the value of $\Delta H^\ominus_{reaction}$ given below to calculate the standard enthalpy change of formation of NO(g).
Include a sign in your answer.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^\ominus = -906\,kJ\,mol^{-1}$$

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[4]

11. O/N 12/P23/Q3

Hydrogen is the most abundant element in the Universe, although on Earth only very small quantities of molecular hydrogen have been found to occur naturally.

Hydrogen is manufactured on a large scale for use in the chemical industry and is also regarded as a possible fuel to replace fossil fuels in internal combustion engines.

(a) State **one** large scale use of hydrogen in the chemical industry.

..... **[1]**

One common way of producing hydrogen on a large scale for use in the chemical industry is by the steam 'reforming' of methane (natural gas), in which steam and methane are passed over a catalyst at 1000–1400 K to produce carbon monoxide and hydrogen.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206\,kJ\,mol^{-1}$$

(b) Use the information above to state and explain the effect on the equilibrium position of the following changes.

(i) increasing the pressure applied to the equilibrium

.....

.....

(ii) decreasing the temperature of the equilibrium

.....

.....

[4]

(c) What will be the effect on the rate of the reaction of increasing the pressure at which it is carried out? Explain your answer.

.....

.....

..... **[2]**

(d) Further hydrogen can be obtained by the 'water-gas shift' reaction in which the carbon monoxide produced is reacted with steam.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad K_c = 6.40 \times 10^{-1} \text{ at } 1100\,K$$

A mixture containing 0.40 mol of CO, 0.40 mol of H_2O, 0.20 mol of CO_2 and 0.20 mol of H_2 was placed in a 1 dm^3 flask and allowed to come to equilibrium at 1100 K

(i) Give an expression for K_c for this reaction.

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(ii) Calculate the amount, in moles, of each substance present in the equilibrium mixture at 1100 K.

	$CO(g)$	+	$H_2O(g)$	$\rightleftharpoons$	$CO_2(g)$	+	$H_2(g)$
initial moles	0.40		0.40		0.20		0.20

[5]

[12]

12. O/N 12/P21/Q2/b,c,d

Hydrogen iodide can be made by heating together hydrogen gas and iodine vapour. The reaction is incomplete.

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

(a) Write an expression for K_c and state the units.

K_c = ... units ..... [2]

(b) For this equilibrium, the numerical value of the equilibrium constant K_c is 140 at 500 K and 59 at 650 K.

Use this information to state and explain the effect of the following changes on the equilibrium position.

(i) increasing the pressure applied to the equilibrium

.....

.....

(ii) decreasing the temperature of the equilibrium

.....

.....

[4]

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(c) A mixture of 0.02 mol of hydrogen and 0.02 mol of iodine was placed in a 1 dm^3 flask and allowed to come to equilibrium at 650 K.

Calculate the amount, in moles, of each substance present in the equilibrium mixture at 650 K.

	$H_2(g)$	+	$I_2(g)$	⇌	2HI(g)
initial moles	0.02		0.02		0

[4]

13. M/J 12/P22/Q2/a,c

Alcohols such as methanol, CH_3OH, are considered to be possible replacements for fossil fuels because they can be used in car engines.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, ΔH_c^e, for methanol at 298 K.

equation .....

definition .....

.....

..... **[3]**

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Methanol may be synthesised from carbon monoxide and hydrogen. Relevant ΔH_c^e values for this reaction are given in the table below.

compound	ΔH_c^e / kJ mol^{-1}
CO(g)	–283
$H_2(g)$	–286
$CH_3OH(g)$	–726

(b) The operating conditions for this reaction are as follows.

pressure	200 atmospheres (2×10^7 Pa)
temperature	600 K
catalyst	oxides of Cr, Cu, and Zn

In the spaces below, explain how **each** of these conditions affects the **rate of formation** of methanol.

pressure

.....

.....

.....

temperature

.....

.....

.....

catalyst

.....

.....

.....

[6]

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14. M/J 12/P21/Q3/c

(a) The synthesis of methanol is carried out at about 500K with a pressure of between 40 and 100 atmospheres (between 4×10^6 Pa and 10×10^7 Pa) and using a catalyst. The use of such conditions will affect both the rate of reaction and the equilibrium yield.

In the spaces below, explain the effects of higher temperature, higher pressure, and the use of a catalyst on the **equilibrium yield** of methanol.

higher temperature

effect .....

explanation .....

.....

higher pressure

effect .....

explanation .....

.....

use of catalyst

effect .....

explanation .....

.....

[6]

15. M/J 11/P22/Q1

Ethanoic acid can be reacted with alcohols to form esters, an equilibrium mixture being formed.

$$CH_3CO_2H + ROH \rightleftharpoons CH_3CO_2R + H_2O$$

The reaction is usually carried out in the presence of an acid catalyst.

(a) Write an expression for the equilibrium constant, K_c, for this reaction, clearly stating the units.

K_c =

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units ..... **[2]**

In an experiment to determine K_c a student placed together in a conical flask 0.10 mol of ethanoic acid, 0.10 mol of an alcohol ROH, and 0.005 mol of hydrogen chloride catalyst.
The flask was sealed and kept at 25 °C for seven days.
After this time, the student titrated all of the contents of the flask with 2.00 mol dm^{-3} NaOH using phenolphthalein indicator.
At the end-point, 22.5 cm^3 of NaOH had been used.

(b) (i) Calculate the amount, in moles, of NaOH used in the titration.

(ii) What amount, in moles, of this NaOH reacted with the hydrogen chloride?

(iii) Write a balanced equation for the reaction between ethanoic acid and NaOH.

(iv) Hence calculate the amount, in moles, of NaOH that reacted with the ethanoic acid.

[4]

(c) (i) Use your results from **(b)** to calculate the amount, in moles, of ethanoic acid present at equilibrium. Hence complete the table below.

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	CH_3CO_2H	ROH	CH_3CO_2R	H_2O
initial amount/mol	0.10	0.10	0	0
equilibrium amount/mol				

(ii) Use your results to calculate a value for K_c for this reaction.

[3]

(d) Esters are hydrolysed by sodium hydroxide. During the titration, sodium hydroxide reacts with ethanoic acid and the hydrogen chloride, but not with the ester.
Suggest a reason for this.

.....

..... [1]

(e) What would be the effect, if any, on the amount of ester present if all of the water were removed from the flask and the flask kept for a further week at 25 °C?
Explain your answer.

.....

.....

..... [2]

16. M/J 10/P21/Q2/c

The reaction between nitrogen and hydrogen to produce ammonia in the Haber process is an example of a large-scale gaseous reaction that is catalysed.

(a) (i) State the catalyst used and give the operating temperature and pressure of the Haber process.

catalyst .....

temperature .....

pressure .....

(ii) **On the energy axis of the graph opposite** , mark the position, **clearly labelled C**, of the activation energy of the reaction when a catalyst is used.

(iii) Use your answer to **(ii)** to explain how the use of a catalyst results in reactions occurring at a faster rate.

.....

.....

.....

[3]

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17. M/J 9/P21/Q3

Concern over the ever-increasing use of fossil fuels has led to many suggestions for alternative sources of energy. One of these, suggested by Professor George Olah, winner of a Nobel Prize in chemistry, is to use methanol, CH_3OH, which can be obtained in a number of different ways.

Methanol could be used instead of petrol in a conventional internal combustion engine or used to produce electricity in a fuel cell.

(a) Construct a balanced equation for the **complete** combustion of methanol.

..... **[1]**

When hydrocarbon fuels are completely burned in an internal combustion engine, several toxic pollutants may be formed.

(b) State **two toxic** pollutants that can be produced after **complete** combustion of a hydrocarbon fuel in an internal combustion engine.

.....

..... **[2]**

Methanol may be manufactured catalytically from *synthesis gas*, a mixture of CO, CO_2 and H_2. The CO is reacted with H_2 to form methanol, CH_3OH.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91 \text{ kJ mol}^{-1}$$

(c) From your understanding of Le Chatelier's principle, state **two** conditions that could be used in order to produce a high yield of methanol.
In **each** case, explain why the yield would increase.

condition 1 .....

explanation .....

.....

condition 2 .....

explanation .....

..... **[4]**

Carbon monoxide, which can be used to make methanol, may be formed by reacting carbon dioxide with hydrogen.

$$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g) \qquad K_c = 1.44 \text{ at } 1200 \text{ K}$$

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(d) (i) It has been suggested that, on a large scale, this reaction could be helpful to the environment.
Explain, with reasons, why this would be the case.

.....

.....

(ii) A mixture containing 0.50 mol of CO_2, 0.50 mol of H_2, 0.20 mol of CO and 0.20 mol of H_2O was placed in a 1.0 dm^3 flask and allowed to come to equilibrium at 1200 K.
Calculate the amount, in moles, of each substance present in the equilibrium mixture at 1200 K.

	CO_2	+	H_2	$\rightleftharpoons$	CO	+	H_2O
initial moles	0.50		0.50		0.20		0.20

[6]

18. M/J 8/P2/Q3

When hydrocarbons such as petrol or paraffin wax are burned in an excess of air in a laboratory, carbon dioxide and water are the only products.
When petrol is burned in a car engine, nitrogen monoxide, NO, is also formed.

(a) Explain how NO is formed in an internal combustion engine but not formed when a small sample of petrol is burnt in an evaporating basin.

.....

.....

..... **[2]**

The engines of modern motor cars have exhaust systems which are fitted with catalytic converters in order to reduce atmospheric pollution from substances such as NO.

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(b) (i) State **three more** pollutants, other than CO_2 and H_2O, that are present in the exhaust gases of a car engine.

..... and ..... and .....

(ii) What is the active material present in the catalytic converter?

.....

(iii) Write **one** balanced equation to show how NO is removed from the exhaust gases of a car engine by a catalytic converter.

.....

[4]

NO is also formed when nitrosyl chloride, NO*Cl*, dissociates according to the following equation.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

Different amounts of the three gases were placed in a closed container and allowed to come to equilibrium at 230 °C. The experiment was repeated at 465 °C.

The equilibrium concentrations of the three gases at each temperature are given in the table below.

	concentration / mol dm^{-3}		
temperature / °C	NO*Cl*	NO	Cl_2
230	2.33×10^{-3}	1.46×10^{-3}	1.15×10^{-2}
465	3.68×10^{-4}	7.63×10^{-3}	2.14×10^{-4}

(c) (i) Write the expression for the equilibrium constant, K_c, for this reaction. Give the units.

(ii) Calculate the value of K_c at each of the temperatures given.

230 °C

465 °C

(iii) Is the forward reaction endothermic or exothermic? Explain your answer.

.....

.....

[5]

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(d) The temperature of the equilibrium was then altered so that the equilibrium concentrations of NOCl and NO were the same as each other.

What will be the effect on the equilibrium concentration of NOCl when the following changes are carried out on this new equilibrium? In each case, explain your answer.

(i) The pressure of the system is halved at constant temperature.

.....

.....

(ii) A mixture of NOCl(g) and NO(g) containing equal numbers of moles of each gas is introduced into the container at constant temperature.

.....

.....

[4]

19. M/J 7/P2/Q2/a,b,c

Alcohols and esters are important organic compounds which are widely used as solvents.

Esters such as ethyl ethanoate can be formed by reacting carboxylic acids with alcohols.

$$CH_3CO_2H + C_2H_5OH \rightleftharpoons CH_3CO_2C_2H_5 + H_2O$$

This reaction is an example of a dynamic equilibrium.

(a) Explain what is meant by the term *dynamic equilibrium*.

.....

.....**[1]**

(b) Write the expression for the equilibrium constant for this reaction, K_c.

[1]

(c) For this equilibrium, the value of K_c is 4.0 at 298 K.
A mixture containing 0.5 mol of ethanoic acid, 0.5 mol ethanol, 0.1 mol ethyl ethanoate and 0.1 mol water was set up and allowed to come to equilibrium at 298 K. The final volume of solution was V dm^3.

Calculate the amount, in moles, of each substance present at equilibrium.

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[4]

20. M/J 5/P2/Q2/a,b,e

Sulphur and its compounds are found in volcanoes, in organic matter and in minerals.

Sulphuric acid, an important industrial chemical, is manufactured from sulphur by the Contact process. There are three consecutive reactions in the Contact process which are essential.

(a) Write a balanced equation (using $\rightleftharpoons$ where appropriate) for **each** of these reactions **in the correct sequence.**

1 .....

2 .....

3 ..... **[4]**

(b) What catalyst is used?

..... **[1]**

Hydrogen sulphide, H_2S, is a foul-smelling compound found in the gases from volcanoes. Hydrogen sulphide is covalent, melting at –85 °C and boiling at –60 °C.

(c) (i) What is meant by the term *weak acid*?

.....

.....

(ii) Write an equation, with state symbols, for the **first** ionisation of H_2S when it dissolves in water.

..... **[3]**

21. O/N 4/P2/Q1/a,b,c,e

Hydrogen iodide dissociates into its elements according to the equation below.

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

(a) Write the expression for the equilibrium constant, K_c.

[1]

(b) At 120 °C the equilibrium mixture contains 1.47 mol dm^{-3} of HI(g), 0.274 mol dm^{-3} each of $H_2(g)$ and $I_2(g)$.
Calculate the value of K_c for the equilibrium at 120 °C. **[1]**

(c) Suggest and explain why it would be more difficult to determine K_c for this equilibrium at room temperature.

.....

.....

.....

..... **[2]**

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(d) HI dissolved in water behaves as a strong acid.

(i) Explain what is meant by a ***strong*** *acid*.

.....

(ii) Complete the equation.

$$HI + H_2O \rightarrow \text{.....} + \text{.....}$$

(iii) Identify the conjugate base of HI in this equation.

..... **[3]**

22. M/J 3/P2/Q3

In the Haber Process, ammonia is synthesised from its elements.

(a) Write an equation for the Haber process and state whether it is endo- or exo-thermic.

..... **[2]**

(b) What are the **three** usual operating conditions of the Haber Process?

.....

.....

..... **[2]**

(c) Explain the considerations which lead to the temperature you have stated in **(b)** being used.

.....

.....

.....

..... **[2]**

(d) Under certain conditions the equilibrium pressures of the three gases are

nitrogen	44.8 atm,
hydrogen	105.6 atm,
ammonia	37.2 atm.

(i) Write an expression for the equilibrium constant, K_p, for the Haber Process.

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(ii) Calculate K_p from these data, giving the units.

[4]

(e) One of the uses of ammonia is to form nitrates which are used as efficient inorganic fertilisers. The uncontrolled use of these fertilisers has led to environmental problems. Briefly describe and explain these problems.

.....

.....

.....

.....

.....

..... [3]

23. O/N 2/P2/Q2/a,b,c

Ethanoic acid is a common ingredient in cooking. It is also used in industry as a reagent.

(a) Ethanoic acid is a weak acid.

(i) Explain, in Bronsted-Lowry terms, what is meant by an *acid*.

.....

.....

(ii) Explain, with the aid of an equation, the term *weak acid*.

.....

..... [3]

(b) Ethanoic acid, CH_3CO_2H, reacts with ethanol, C_2H_5OH, to produce ethyl ethanoate and water. The reaction is an example of dynamic equilibrium.

$$CH_3CO_2H + C_2H_5OH \rightleftharpoons CH_3CO_2C_2H_5 + H_2O$$

(i) Explain what is meant by *dynamic equilibrium*.

.....

.....

(ii) Write an expression for the equilibrium constant, K_c, for this reaction.

[2]

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(c) A mixture of 6.0 g of ethanoic acid and 6.0 g of ethanol was added to 4.4 g of ethyl ethanoate and the overall mixture allowed to reach equilibrium. It was found that 0.040 mol of ethanoic acid was present in the equilibrium mixture.

(i) Calculate the number of moles of each compound, both initially and at equilibrium. Place the results in the spaces provided.

$CH_3CO_2H + C_2H_5OH \rightleftharpoons CH_3CO_2C_2H_5 + H_2O$

initially	.....	.....	.....	0.00
at equilibrium	0.040	.....	.....	.....

(ii) Calculate the equilibrium constant, K_c, for the reaction.

(iii) Explain why K_c in this reaction has no units.

..... **[4]**

24. M/J 02/P2/Q4

This question is shifted in Unit 12 -- question No. 14

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Answers Section

1. M/J 17/P23/Q3/d

(a) (i) $(K_p =) \frac{pSO_3^2}{pO_2 \times pSO_2^2}$ 1

(ii) 0.1946737305 1
Pa^{-1} 1

2. M/J 17/P22/Q3/b(iii,iv),c,d

(a) (i) increases (%) decomposition (of HBr) 1

(increasing T) shifts equilibrium to the right / in the forward direction / endothermic direction / towards $H_2 + Br_2$ 1

to oppose the change or oppose the increase in temperature OR to absorb (additional) energy / heat OR to decrease the temperature 1

(ii) H-I bond strength less than H-Br OR 1
less energy needed to break H-I *ora*

I (atom) is big(ger) (than Br) OR
I (atom) has more shielding (than Br) *ora*

Br (atom) has greater (%) orbital / outer shell overlap 1
OR
attraction (of nucleus in iodine) for shared (pair of) electrons is weak(er)
OR
attraction (of nucleus in iodine) for bonding pair (or electrons) is weak(er) *ora*

(b) (i) $H_2 = 0.015$ (mol) 1

$HCl = 0.27$ (mol) 1

(ii) $HCl = 9/10$ AND $xH_2 = 1/20$ AND $Cl_2 = 1/20$ OR 1
$HCl = 0.9(0)$ AND $H_2 = 0.05$ AND $Cl_2 = 0.05$ 1

(c) (i) $(K_p =) \frac{pH_2 \times pCl_2}{pHCl^2}$ 1

(ii) equal number of moles (of gas) on either side (of equation) / (total) pressure cancels 1

(iii) 4.649×10^{-3} 1

3. MAR 17/P22/Q2/c(iii,iv,v,vi)

(a) (i) reaction is exothermic 1

(ii) (increased temperature) shifts equilibrium to the left **AND** decreases yield of products (Cl_2 and / or H_2O) / less product formed 1

	HCl	O_2	Cl_2	H_2O
initial number of moles	1.60	0.500	0	0
M1 eqm number of moles	1.60 – 2 × 0.600 = 0.400	0.500 – ½ × 0.600 = 0.200	0.600	0.600
M2 mole fraction			$\frac{0.600}{1.80}$	
M3 partial pressure			$\frac{0.600}{1.80} \times p_{tot}$ = 5.00×10^4	

3

(iii) $K_p = \frac{(3.6 \times 10^4)^2 \times (3.6 \times 10^4)^2}{(4.8 \times 10^4)^4 \times 3.0 \times 10^4} = 1.05 \times 10^{-5}$ 1

- units = Pa^{-1} 1

(iv) K_p would not change 1

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4 MAR 16/P22/Q3/b

(a) (i) forward and backward reactions occurring <u>at same rate</u> [1]
OR
<u>the rate of</u> forward and backward reactions are equal [1]

(ii) M1 = decreased yield of products / less products formed / ora [1]
M2 = <u>left</u>-hand side has fewer moles of gas [2]
OR
q e uilibrium shifts to the left [1]

5. O/N 14/P23/Q2/d

(a) (i) Advantage = higher rate 1
Greater Kinetic Energy / speed / collision frequency / proportion of successful collisions 1

Disadvantage – reduced yield / less product / more reactants 1

(Forward reaction) **exothermic AND** (hence in accordance with Le Chatelier's Principle) equilibrium / reaction **shifts left** (to counteract increasing temp) ora 1 [4]

(ii) $K_p = \frac{pNH_3^2}{pN_2 \times pH_2^3}$ 1 [1]

(iii)

$N_2(g)$ +	$3H_2(g)$ ⇌	$2NH_3(g)$
2	3	0
(–0.8)	(–1.6×3/2)	
<u>1.2</u>	<u>0.6</u>	1.60

1

$xNH_3 = 1.6/3.4 (= 0.471)$
$xN_2 = 1.2/3.4 (= 0.353)$
$xH_2 = 0.6/3.4 (= 0.176)$ 1

$K_p = \frac{0.471^2 \times (2 \times 10^7)^2}{0.353 \times 2 \times 10^7 \times 0.176^3 \times (2 \times 10^7)^3} = 2.88 \times 10^{-13}\ Pa^{-2}$ 1+1 [5]

6. O/N 14/P21/Q2/a,b,d

(a) $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$ 1

(b) Very exothermic/gets very hot 1 [2]
OR creates (acid/H_2SO_4) spray/mist/fog/fumes 1

(i) $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ 1

(ii) $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$ 1 [2]

(c) (i) Advantage = higher rate 1
Greater KE/energy/speed/collision frequency/proportion of successful collisions/more particles with E>Ea 1
Disadvantage – reduced yield/less product 1

(Forward reaction) **exothermic AND** (hence in accordance with LCP) equilibrium/reaction **shifts left** (to counteract inc T) ora 1

(ii) $K_p = \frac{pSO_3^2}{pSO_2^2 \times pO_2}$ [4]

(iii)

$2SO_2(g) + O_2(g)$ ⇌	$2SO_3(g)$
2 2	0
(–1.8) (–0.9)	
<u>0.2 1.1</u>	1.80

1

$xSO_3 = 1.8/3.1 = 0.581$
$xSO_2 = 0.2/3.1 = 0.065$
$xO_2 = 1.1/3.1 = 0.355$ 1

$K_p = \frac{0.581^2 \times (2 \times 10^5)^2}{0.065^2 \times (2 \times 10^5)^2 \times 0.355 \times 2 \times 10^5} = 1.13 \times 10^{-3}\ Pa^{-1}$ 1+1 [5]

7. M/J 14/P23/Q3/a,b

(a) (i) (reaction between atmospheric N_2 and O_2) due to lightning/biological processes or bacteria <u>in soil</u> (1)
AND in car engines/power stations/metal refining/furnaces [1]

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(ii) $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ **OR** (1)
$2NO_2 + H_2O + 1/2O_2 \rightarrow 2HNO_3$ **OR**
$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$ [1]

(iii) $SO_2 + NO_2 \rightarrow SO_3 + NO$ (1)
$NO + 1/2O_2 \rightarrow NO_2$ (1)
$SO_3 + H_2O \rightarrow H_2SO_4$ (1) [3]

(b) (i) $K_p = pN_2O_4/(pNO_2)^2$ (1) [1]

(ii) moles of $NO_2 = 0.32$ (1) [1]

(iii) $x(N_2O_4) = 1.84/\ 2.16 = 0.85$ (1)
$x(NO_2) = 0.32/2.16 = 0.15$ (1) [2]
ecf from **(b)(ii)**

(iv) $pN_2O_4 = 0.85 \times 140 = 119$ (kPa) (1)
$pNO_2 = 0.15 \times 140 = 21$ (kPa) (1) [2]
ecf from **(b)(iii)**

(v) $K_p = 119/21^2 = 0.270\ kPa^{-1}$ (2) [2]
ecf from **(b)(i)** and **(b)(iv)**

8. M/J 13/P23/Q2/a,b

(a) (i) if the conditions of a system in equilibrium are changed (1)
the position of equilibrium moves so as to reduce that change (1) [2]

(ii) lower temperature (1)
because the forward reaction is exothermic (1)
higher pressure (1)
because the forward reaction shows a reduction in volume
or
there are fewer molecules/moles on RHS of equilibrium (1) [4]

(b)

	CO_2	+	H_2	⇌	CO	+	H_2O	
initial moles	0.70		0.70		0.30		0.30	
equil. moles	(0.70–x)		(0.70–x)		(0.30+x)		(0.30+x)	(1)
equil. concn.	$\frac{(0.70-x)}{1}$		$\frac{(0.70-x)}{1}$		$\frac{(0.30+x)}{1}$		$\frac{(0.30+x)}{1}$	

$K_c = \frac{(0.30+x)^2}{(0.70-x)^2} = 1.44$ (1)
gives x = 0.25 (1)
at equilibrium,
$n(CO_2) = n(H_2) = 0.70 - 0.25 = 0.45$ moles
and
$n(CO) = n(H_2O) = 0.3 + 0.25 = 0.55$ moles (1) [4]

9. M/J 13/P22/Q1/a,b

(a) a base is a proton acceptor **or** (1)
a lone pair donor (1)
a weak base is not fully ionised
e.g. $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$ **or**
$B + H^+ \rightleftharpoons BH^+$ **or** equivalent (1) [3]
⇌ is necessary

(b) (i) **stated** pressure greater than 1 atm up to 5 atm (1)
stated temperature 400 to 500 °C (1)
named catalyst V_2O_5/vanadium(V) oxide (1)

(ii) SO_3 is dissolved in concentrated H_2SO_4
and then diluted with water
not 'SO_3 dissolved in water' as the only statement (1) [4]

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10. M/J 13/P21/Q2/a,b,c

(a) $K_P = \dfrac{p(NO)^4\, p(H_2O)^6}{p(NH_3)^4\, p(O_2)^5}$ (1)

atmospheres **or** Pa **or** kPa (1)

allow ecf on incorrect powers **[2]**

(b) (i) increasing temperature

yield of NO is decreased **or** reaction moves to LHS (1)

forward reaction is exothermic (1)

(ii) decreasing the pressure

yield of NO is increased **or** reaction moves to RHS (1)

more moles/molecules of gas on RHS **or**

fewer moles/molecules of gas on LHS (1) **[4]**

(c) let ΔH_f° for NO be y kJ mol^{-1}

$4NH_3(g) + 5O_2(g)$ $4NO(g) + 6H_2O(g)$

ΔH_f° $4 \times (-46.0)$ $4y$ $6 \times (-242)$ (1)

$\Delta H^\circ_{reaction} = 4y + [6 \times (-242)] - [4 \times (-46.0)]$ (1)

$= 4y - 1452 + 184$

$\Delta H^\circ_{reaction}$ is -906 kJmol^{-1} so

$4y = -906 + 1452 - 184 = 362$ (1)

whence y = ΔH_f° for NO = +90.5 kJ mol^{-1}

+ sign is required (1) **[4]**

11. O/N 12/P23/Q3 **[10]**

(a) manufacture of ammonia/Haber process **or** hydrogenation of fats/oils **or** making margarine **or** hydrocracking (1) **[1]**

(b) (i) increasing the pressure

equilibrium will move to LHS (1)

fewer moles/molecules on LHS or more moles/molecules on RHS (1)

(ii) decreasing the temperature

equilibrium will move to LHS (1)

forward reaction is endothermic (1) **[4]**

(c) (i) rate will increase

collisions will occur more frequently (1) **[2]**

(d) (i) $K_c = \dfrac{[CO_2][H_2]}{[CO][H_2O]}$ (1)

(ii)

	$CO(g)$	+ $H_2O(g)$	⇌	$CO_2(g)$	+ $H_2(g)$
initial moles	0.40	0.40		0.20	0.20
equil moles	(0.40 – y)	(0.40 – y)		(0.20 + y)	(0.20 + y)
equil concn./mol dm^{-3}	$\frac{(0.40 - y)}{1}$	$\frac{(0.40 - y)}{1}$		$\frac{(0.20 + y)}{1}$	$\frac{(0.20 + y)}{1}$

$K_c = \dfrac{(0.20 + y)^2}{(0.40 - y)^2} = 6.40 \times 10^{-1}$ (1)

$\dfrac{(0.20 + y)}{(0.40 - y)} = \sqrt{6.40 \times 10^{-1}} = 0.8$

$(0.20 + y) = 0.8 \times (0.40 - y)$

$0.20 + y = 0.32 - 0.8y$

$1.8y = 0.12$

gives y = 0.067 (1)

at equilibrium

$n(CO) = n(H_2O) = (0.40 - 0.067) = 0.33$ mol **and**

$n(CO_2) = n(H_2) = (0.20 + 0.067) = 0.27$ mol (1)

allow ecf as appropriate **[5]**

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12. O/N 12/P21/Q2/b,c,d

(a) $K_c = \dfrac{[HI]^2}{[H_2]\times[I_2]}$ (1)

no units – must be clearly stated (1) **[2]**

(b) (i) no change (1)
K_c has no units **or**
same no. of molecules / moles each side of equilibrium (1)

(ii) equilibrium moves to RHS (1)
K_c increases with decreasing temperature **or**
forward reaction is exothermic **or**
reverse reaction is endothermic (1) **[4]**

(c)

	$H_2(g)$	+	$I_2(g)$	⇌	$2HI(g)$
initial moles	0.02		0.02		0
equil. moles	(0.02 – y)		(0.02 – y)		2y
equil. conc/mol dm^{-3}	$\frac{(0.02-y)}{1}$		$\frac{(0.02-y)}{1}$		$\frac{2y}{1}$

(1)

$K_c = \dfrac{HI^2}{[H_2]\times[I_2]} = \dfrac{(2y)^2}{(0.02-y)^2} = 59$ (1)

$\dfrac{2y}{(0.02-y)} = \sqrt{59} = 77$

$2y = (7.7 \times 0.02) - 7.7y$

$9.7y = 0.154$

gives $y = \dfrac{0.154}{9.7} = 0.0159 = 0.016$ (1)

at equilibrium

$n(HI) = 2 \times 0.016 = 0.032$ **and**
$n(H_2) = n(I_2) = (0.02 - 0.016) = 0.004$ (1)

allow ecf where possible **[4]**

[Total: 13]

13. M/J 12/P22/Q2/a,c

(a) $CH_3OH(l) + {}^3/_2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$ (1)
the enthalpy change/heat change/heat evolved when
one mole of CH_3OH (1)
is completely burned **or**
is burned in an excess of air/oxygen (1) **[3]**

(b) pressure
increases rate (1)
by increasing frequency of collisions **or**
by increasing concentration of reactants (1)

temperature
increases rate (1)
because more molecules have energy $>E_a$ (1)

catalyst
increases rate (1)
by providing an alternative route of lower E_a (1) **[6]**

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14. M/J 12/P21/Q3/c

(a) In this part, in each case, the 'effect' must be correctly stated in order to gain the explanation mark.

higher temperature
yield is reduced/equilibrium goes to LHS (1)
because forward reaction is exothermic/reverse reaction is endothermic (1)

higher pressure
yield is increased **or** equilibrium goes to RHS (1)
fewer moles/molecules on RHS **or** more moles/molecules on LHS (1)

use of catalyst
yield does not change (1)
forward and backward rates speeded up by same amount (1) **[6]**

[14]

15. M/J 11/P22/Q1

(a) $K_c = \dfrac{[CH_3CH_2R][H_2O]}{[CH_3CH_2H][ROH]}$ (1)

no units (1) **[2]**

(b) (i) $n(NaOH) = \dfrac{22.5 \times 2.00}{1000} = 0.045$ (1)

(ii) $n(NaOH) = n(HCl) = 0.005$ (1)

(iii) $CH_3CO_2H + NaOH \rightarrow CH_3CO_2Na + H_2O$ (1)

(iv) $n(NaOH) = 0.045 - 0.005 = 0.04$
allow ecf on **(i)** and/or **(ii)** (1) **[4]**

(c) (i) $n(NaOH)$ **and** $n(CH_3CO_2H) = 0.04$ (1)
$n(CH_3CO_2R)$ **and** $n(H_2O) = 0.06$ (1)

(ii) $K_c = \dfrac{0.06 \times 0.06}{0.04 \times 0.04} = 2.25$
allow ecf on wrong values in **(b)(i)**
allow ecf on wrong expression in **(a)** (1) **[3]**

(d) E_a for reaction with ester is high **or**
E_a for reaction with acid is low
or
reaction with ester is slow **or**
reaction with acid is fast (1) **[1]**

(e) equilibrium moves to RHS/more ester would be formed to maintain value of K_c **or**
to restore system to equilibrium (1) (1) **[2]**

[Total: 12]

16. M/J 10/P21/Q2/c

(a) (i) iron **or** iron oxide (1)
100 to 500 atm **and** 400–550°C
units necessary – allow other correct values and units (1)

(ii) **C** is placed to the left of **H** (1)

(iii) more molecules now have energy $> E_a$ (1) **[4]**

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17. M/J 9/P21/Q3

(a) $2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$ (1) [1]

(b) SO_2 (1)
NO_x / NO_2 / NO – **not** N_2O (1)
Pb compounds – **not** Pb (1) (any 2)
If more than two answers are given any wrong ones will be penalised. [2]

(c) low temperature (1)
because forward reaction is exothermic (1)
high pressure (1)
because forward reaction goes to fewer molecules (1)
or shows a reduction in volume
increase [CO] **or** $[H_2]$
or remove CH_3OH (1)
correct explanation in terms of the effect of the change
on the position of equilibrium or on the rate of reaction (1)
(any two pairs) [4]

(d) (i) removes CO_2 (1)
which causes greenhouse effect/global warming (1)

(ii)

	CO_2	+ H_2	⇌ CO	+ H_2O
initial moles	0.50	0.50	0.20	0.20
equil. moles	(0.50-x)	(0.50-x)	(0.20+x)	(0.20+x) (1)
equil. concn.	$\frac{(0.50-x)}{1}$	$\frac{(0.50-x)}{1}$	$\frac{(0.20+x)}{1}$	$\frac{(0.20+x)}{1}$

$K_c = \frac{[CO][H_2O]}{[CO_2][H_2]}$ (1)

$K_c = \frac{(0.20+x)^2}{(0.50-x)^2} = 1.44$ (1)

gives x = 0.18 (1)
at equilibrium,
$n(CO_2) = n(H_2) = 0.32$ **and**
$n(CO) = n(H_2O) = 0.38$ (1)
Allow ecf on wrong values of x that are less than 0.5. [7]

18. M/J 8/P2/Q3

(a) high temperature (and/or pressure) provide enough energy (1)
to break N≡N bond
or to provide E_a for N_2/O_2 reaction (1) [2]

(b) (i) **two** from C, CO, hydrocarbon, SO_2, H_2S, NO_2/NO_x (1 + 1)
not CO_2, H_2, H_2O, SO_3, NO
(ii) Pt **or** Pd **or** Pt/Rh **or** Pt/Pd/Rh (1)
(iii) $2NO + 2CO \rightarrow 2CO_2 + N_2$
or $2NO + C \rightarrow CO_2 + N_2$ (1) [4]

(c) (i) $K_c = \frac{[NO]^2[Cl_2]}{[NOCl]^2}$ (1)
units are $mol\ dm^{-3}$ (1)

(ii) at 230 °C $K_c = \frac{(1.46\times10^{-3})^2 \times 1.15\times10^{-2}}{2.33\times10^{-3\ 2}}$
$= 4.5 \times 10^{-3}$ mol dm^{-3} (1)

at 465 °C $K_c = \frac{(7.63\times10^{-3})^2 \times 2.14\times10^{-4}}{(3.68\times10^{-4})^2}$
$= 9.2 \times 10^{-2}$ mol dm^{-3} (1)

allow ecf on answer to part **(i)**

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(iii) endothermic **because** K_c increases with temperature
mark is for explanation
allow ecf on answer to part **(ii)** (1) **[5]**

(d) (i) equilibrium moves to RHS (1)
more moles on RHS (1)

(ii) no change to equilibrium position (1)
[NOCl] and [NO] change by same amount (1) **[4]**

19. M/J 7/P2/Q2/a,b,c

(a) rate of forward reaction equals
rate of backward reaction
or equilibrium concentrations remain constant
while reaction is occurring [1] **[1]**

(b) $K_C = \dfrac{[CH_3CO_2C_2H_5][H_2O]}{[CH_3CO_2H][C_2H_5OH]}$ [1] **[1]**

(c) $CH_3CO_2H + C_2H_5OH \rightleftharpoons CH_3CO_2C_2H_5 + H_2O$

initial moles	0.5	0.5	0.1	0.1
equil. moles	$(0.5 - x)$	$(0.5 - x)$	$(0.1 + x)$	$(0.1 + x)$
equil. concn./ mol dm^{-3}	$\frac{(0.5-x)}{V}$	$\frac{(0.5-x)}{V}$	$\frac{(0.1+x)}{V}$	$\frac{(0.1+x)}{V}$

[1]

$K_c = \dfrac{(0.1+x)^2}{(0.5-x)^2} = 4$ [1]

gives $x = 0.3$ [1]

$n(CH_3CO_2H) = n(C_2H_5OH) = 0.2$ **and**
$n(CH_3CO_2C_2H_5) = n(H_2O) = 0.4$ [1]

allow ecf on wrong equil. moles subject to $x < 0.5$ **[4]**

20. M/J 5/P2/Q2/a,b,e

(a) **1** $S + O_2 \rightarrow SO_2$ **(1)**

2 $2SO_2 + O_2 \rightleftharpoons 2SO_3$ equil **(1)** equation **(1)**

3 $SO_3 + H_2O \rightarrow H_2SO_4$ **(1)**

Allow sequences that start with SO_2
and include $H_2S_2O_7$ before H_2SO_4.

Equilibrium mark is only scored if $\rightleftharpoons$ only appears in
the SO_2/SO_3 equation. **[4]**

(b) vanadium pentoxide/vanadium(V) oxide/V_2O_5 **(1)** **[1]**

(c) (i) an acid that is partially dissociated into ions **(1)**

(ii) $H_2S(g) + H_2O(l) \rightarrow H_3O^+(aq) + HS^-(aq)$
or
$H_2S(g) + aq \rightarrow H^+(aq) + HS^-(aq)$
or
$H_2S(aq) \rightarrow H^+(aq) + HS^-(aq)$
equation **(1)** state symbols **(1)** **[3]**

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21. O/N 4/P2/Q1/a,b,c,e

(a) $K_c = \dfrac{[H_2][I_2]}{[HI]^2}$ **(1) [1]**

(b) $K_c = \dfrac{0.274 \times 0.274}{(1.47)^2} = 0.035$ **(1) [1]**

(c) At room temperature:

iodine is a solid/solids not K_c expression **(1)**

$[I_2(g)]$ is small/concn too small to be measured **(1)**

it takes longer to reach equilibrium/reaction is slower **(1) [2 max]**

(d) (i) An acid that is completely ionised **(1)**

(ii) $HI + H_2O \rightarrow H_3O^+ + I^-$

(iii) I^- (1) **[3]**

22. M/J 3/P2/Q3

(a) $N_2 + 3H_2 \leftrightharpoons 2NH_3$ (1) exothermic (1) **[2]**

(b) Pr. 50 atm upwards; Temp 400-600°C; catalyst of iron (1 each, conditions stated) **[3]**

(c) Too high a temp and equilibrium favours LHS, less ammonia at equilibrium (1)

Too low a temp, rate too slow/not enough molecules have E_{act} (1) **[2]**

(d) (i) $K_p = \dfrac{PNH_3^2}{PN_2 \times PH_2^3}$ (1)

(ii) $K_p = \dfrac{37.2^2}{44.8 \times 105.6^3}$ (1)

$= 2.62 \times 10^{-5}\ atm^{-2}$ (1) calculation and units **[3]**

(e) Excess (hence uncontrolled) nitrates leach out of fields into streams, seas (1)

Bacteria or algae grow fast/use oxygen/clog up water (1)

Balance destroyed/fish unable to live (1)

Process called eutrification (1) any 3 **[3]**

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23. O/N 2/P2/Q2/a,b,c

(a)(i) An acid is a proton (H^+) donor (1)

(ii) An acid which is partially ionised (1)

$HA \rightleftharpoons H^+ + A^-$ must have $\rightleftharpoons$ (1) [3]

(b) (i) The forward reaction proceeds at the same rate as the reverse reaction (1)

(ii) $K_c = \dfrac{[ester][H_2O]}{[acid][alcohol]}$ (1)

(c) (i)

	acid	+ alcohol	$\rightleftharpoons$ ester	+ water
initially.	$\frac{6}{60} = 0.1$	$\frac{6}{46} = 0.13$	$\frac{4.4}{88} = 0.050$	0
			All three (1)	
at equilm	[0.040]	0.13 − 0.06 = 0.07	0.050 + 0.06 = 0.11	0.06
				all three (1)

(ii) $K_c = \dfrac{0.11 \times 0.06}{0.04 \times 0.07} = 7.36$ (1)

(iii) Units 'cancel' / two concn terms 'top & bottom' (1) 4

Total: 10

24. M/J 2/P2/Q4

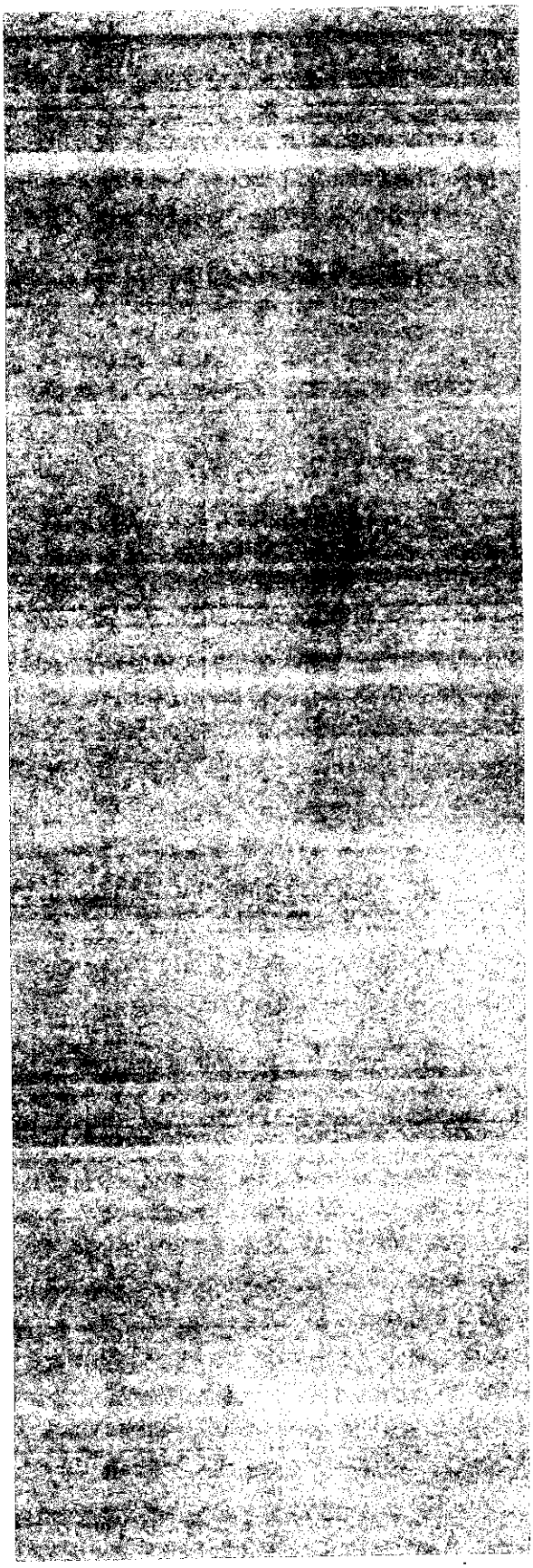
This question answer is shifted in Unit 12 -- answer No. 14

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UNIT 8

Reaction Kinetics

A-Level
Chemistry Paper 2
Topical Workbook



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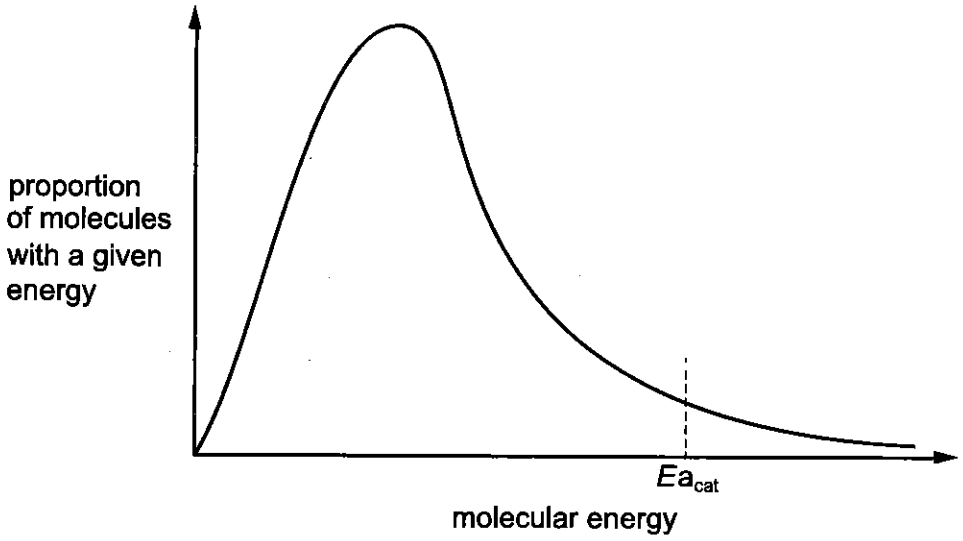
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Unit 8: Reaction Kinetics

1. M/J 17/P23/Q3/b

(a) The Contact process is usually carried out at a temperature of approximately 700 K, a pressure of approximately 150 kPa and in the presence of a vanadium(V) oxide catalyst, V_2O_5.

The Boltzmann distribution for a mixture of SO_2 and O_2 at 700 K is shown.
Ea_{cat} represents the activation energy for the reaction in the presence of the catalyst.



(i) Add a labelled mark, Ea_{uncat}, to the diagram to indicate the activation energy in the absence of the catalyst.

[1]

(ii) State the benefit of using a catalyst in this reaction. Explain how it achieves this effect.

.....

.....

.....

..... [2]

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(iii) State and explain how an increase in pressure would affect both the rate of reaction and the yield of SO_3 in the Contact process.

rate .....

.....

.....

yield .....

.....

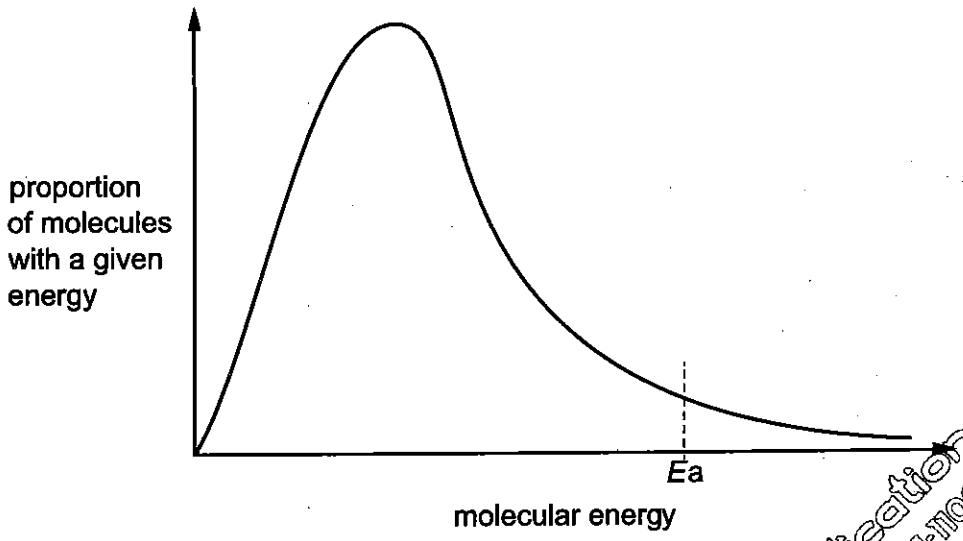
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[4]

2. M/J 17/P22/Q3/b(i & ii)

(a) At a temperature of 700 K a sample of HBr is approximately 10% decomposed. Changing the temperature affects both the rate of decomposition of HBr and the percentage that decomposes.

The Boltzmann distribution for a sample of HBr at 700 K is shown. *E*a represents the activation energy for the reaction.



(i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

(ii) With reference to the curves, state and explain the effect of increasing temperature on the **rate** of decomposition of HBr.

.....

.....

.....

..... [3]

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3. MAR 17/P22/Q2/c(ii)

(a) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

The reaction is carried out at 400 °C in the presence of a copper(II) chloride catalyst.

(i) State the **type** of catalyst used in this reaction. Explain how a catalyst is able to increase the rate of a chemical reaction.

.....

.....

.....

..... **[2]**

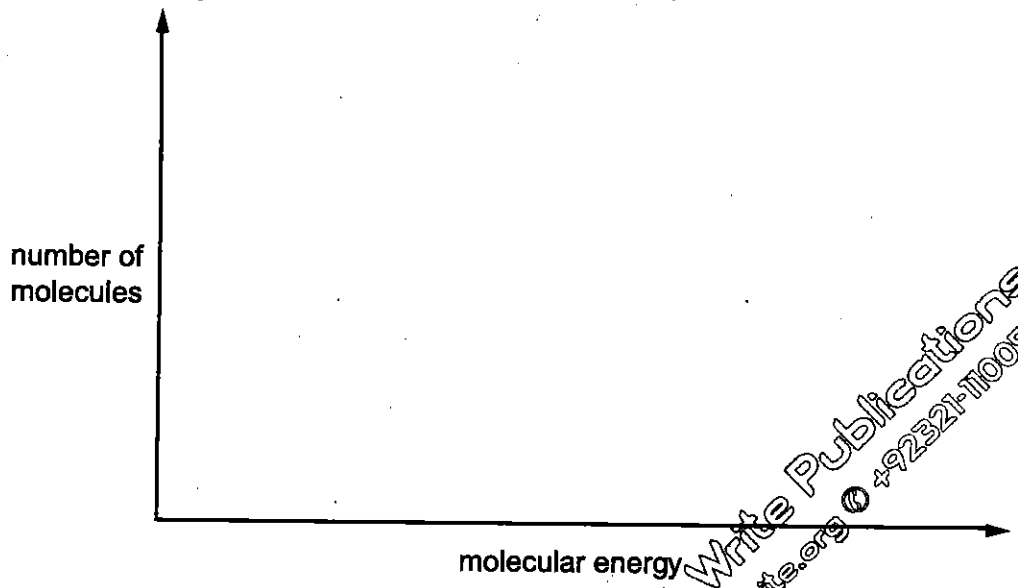
4. MAR 16/P22/Q3/c

Over one million tonnes of hydrogen cyanide, HCN, are produced each year using the Andrussow process. The overall equation for the reaction is shown.

$$CH_4(g) + NH_3(g) + 1\tfrac{1}{2}O_2(g) \rightleftharpoons HCN(g) + 3H_2O(g)$$

(a) The process uses a platinum catalyst, which increases the rate of reaction.

Sketch a Boltzmann distribution on the axes given below and use your diagram to explain how the platinum catalyst increases the rate of the reaction.



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.....

.....

.....

..... [3]

5. O/N 14/P23/Q2/a,b

The Haber process for the manufacture of ammonia, NH_3, was originally devised at the start of the 20th century and was developed into a full-scale industrial process by Carl Bosch in 1913.

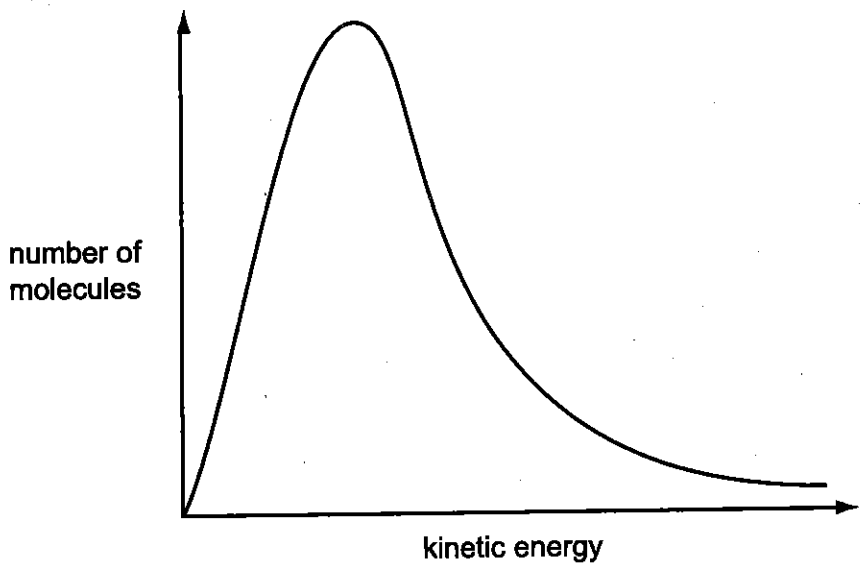
The key step in the process is the reversible reaction of nitrogen and hydrogen in the presence of an iron catalyst.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\ kJ\,mol^{-1}$$

(a) The hydrogen for this reaction can be formed by reacting methane with steam, during which carbon monoxide is also produced. Write an equation for this reaction.

..... [1]

(b) Use the Boltzmann distribution shown to explain why a catalyst increases the rate of this reaction.



.....

.....

.....

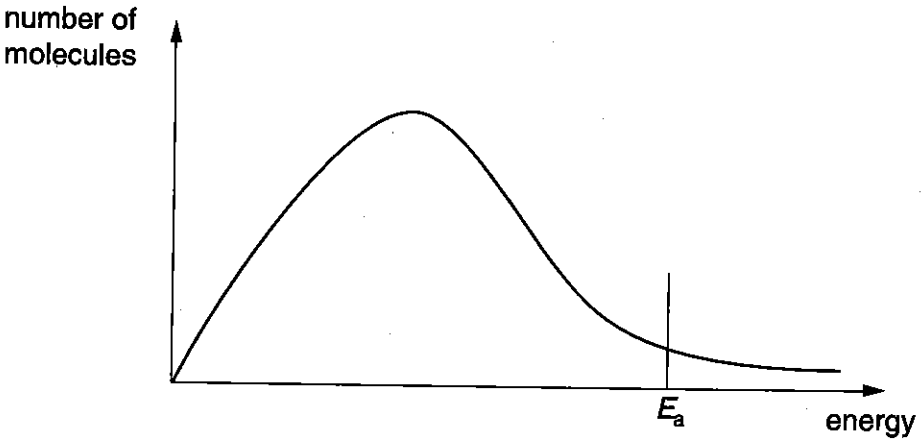
..... [4]

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6. M/J 10/P21/Q2/a,b

The diagram below shows, for a given temperature T, a Boltzmann distribution of the kinetic energy of the molecules of a mixture of two gases that will react together, such as nitrogen and hydrogen.

The activation energy for the reaction, E_a, is marked.



(a) On the graph above,

(i) draw a new distribution curve, **clearly labelled T′**, for the same mixture of gases at a higher temperature, **T′**;

(ii) **mark clearly, as H**, the position of the activation energy of the reaction at the higher temperature, **T′**.

[3]

(b) Explain the meaning of the term *activation energy*.

.....

.....

.....

..... [2]

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7. O/N 02/P2/Q1

(a) Draw a diagram to show the Boltzmann distribution of molecular energies. Label the axes.

[2]

(b) Comment on the shape of the distribution curve.

.....

.....

.....

.....[1]

(c) (i) Explain the meaning of the term *activation energy*.

.....

.....

.....

(ii) Insert and label the activation energy in your diagram in **(a)**. **[2]**

(d) (i) Use a dotted line added to your diagram in **(a)** to show how the distribution of molecular energies changes at a slightly higher temperature (label this curve $+\delta T$).

(ii) Use this new line to explain why reactions are faster at a higher temperature.

.....

.....

.....

.....[3]

[8]

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Answers Section

1. M/J 17/P23/Q3/b

(a) (i) Mark to right of original E_a — 1

(ii) 2 marks for any two points: — 2
- Benefit of using a catalyst in terms of increasing rate or economic benefit i.e. (less heat required)
- Creates alternative pathway with lower E_a
- More molecules with $E > E_a$

(iii) (rate) increases AND correct explanation in terms of 'more collisions' — 1

more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time — 1

(yield) increases and shifts equilibrium to the right / in the forward direction / towards SO_3 / towards the product / in exothermic direction — 1

to oppose the change or oppose the increase in pressure / fewer molecules on RHS so eqm moves to right (to oppose change) — 1

2. M/J 17/P22/Q3/b(i & ii)

(a) (i) general shape of the curve and peak are displaced to right of original and starts at origin — 1

the peak is lower and curve crosses once only finishing **above** original — 1

(ii) rate increases AND correct explanation in terms of 'more collisions' — 1

at higher T area above *E*a is greater / more molecules with $E \geq Ea$ — 1

higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time — 1

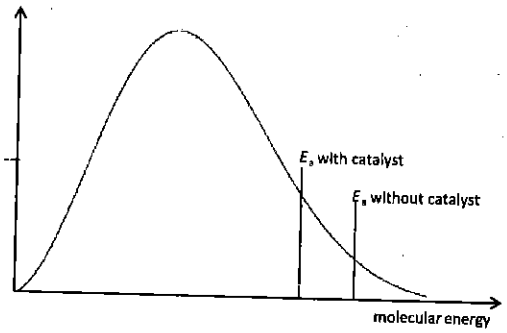
3. MAR 17/P22/Q2/c(ii)

(a) (i) heterogeneous (catalyst) — 1

provides an alternative reaction pathway of lower activation energy — 1

4. MAR 16/P22/Q3/c

(a)



[3]

M1 = correct Boltzmann curve — [1]

M2, M3 any 2 from:
- line for **both** E_a values or statement in text that catalyst lowers E_a — [1]
- (catalyst) increases proportion/number of molecules/particles with energy > activation energy — [1]
- so more frequent successful collisions — 1 [1]

5. O/N 14/P23/Q2/a,b

(a) $CH_4 + H_2O \rightarrow CO + 3H_2$

(b) Label on graph indicating catalysed and uncatalysed Ea
OR statement Ea catalysed is lower (than Ea uncatalysed) owtte — 1

Reference to catalyst creating alternative mechanism / reaction pathway / route — 1

Idea that more molecules have sufficient energy (to react) — 1

so greater chance / frequency of successful collisions — 1 [4]

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6. M/J 10/P21/Q2/a,b

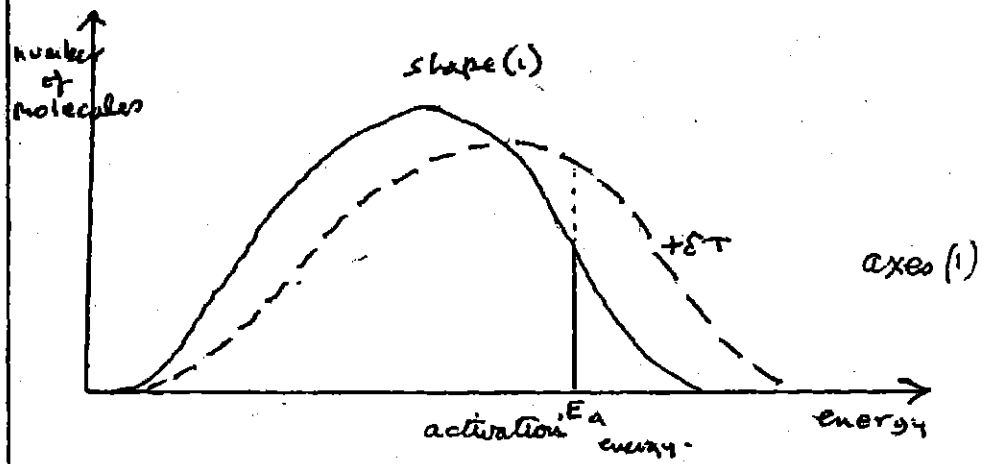
(a) (i) new graph has **lower** maximum **(1)**
maximum is **to the right of** previous maximum **(1)**

(ii) **H** is at E_a **(1)** **[3]**

(b) the minimum amount of energy molecules must have **or** energy required **(1)**
in order for the reaction to take place **(1)** **[2]**

7. O/N 02/P2/Q1

1 (a)



[2]

(b) not all molecules have the same energy / some have little, some a lot, distributed about a mean.
OR asymmetrical / not a normal distribution (1) [1]

(c) (i) Molecules require a certain / minimum energy before they can react // only molecules which have this energy can react successfully on collision. (1)

(ii) Line on graph (1) [2]

(d)(i) The ~~dotted~~ dashed line on the graph - maximum lower and to the right of the solid line maximum (1)

(ii) Larger area to right of E_a line is the number of molecules with energy greater than E_a. (1)
Rate is proportional to number of molecules with E_a (or more) (1)

Collision rate faster when molecular speed greater (1) (max 2) [3]

[Total: 8]

UNIT 9

The Periodic Table: Chemistry Periodicity

A-Level
Chemistry Paper 2
Topical Workbook

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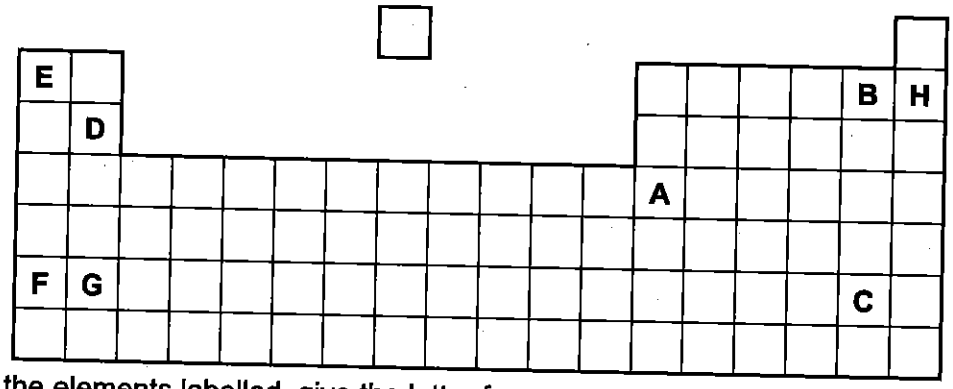
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Unit 9: The Periodic Table: Chemistry Periodicity

1. M/J 17/P21/Q3/a

The properties of elements and their compounds show similarities, differences and trends depending on the positions of the elements in the Periodic Table.

(a) The positions of some elements are indicated. The letters used are **not** the symbols of the elements.



From the elements labelled, give the letter for;

(i) the element that forms an amphoteric oxide, ... **[1]**

(ii) the element with the highest first ionisation energy, ... **[1]**

(iii) the element that forms a soluble hydroxide and an insoluble sulfate, ... **[1]**

(iv) the most volatile element in a group that contains elements in all three states of matter at room temperature and pressure,

..... **[1]**

(v) the element that forms the largest cation. ..... **[1]**

2. MAR 17/P22/Q1/a,b

(a) The table shows information about some of the elements in the third period.

element	Na	Mg	Al	P	S	Cl
atomic radius/nm	0.186	0.160	0.143	0.110	0.104	0.099
radius of most common ion/nm	0.095	0.065	0.050	0.212	0.184	0.181
maximum oxidation number of the element in its compounds	+1					+7

(i) Complete the table to show the maximum oxidation number of each element in its compounds. **[1]**

(ii) Explain why the atomic radius of elements in the third period decreases from Na to Cl.

.....

.....

.....

.....

..... **[3]**

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(iii) The radius of the most common ion of Mg is much smaller than the radius of the most common ion of S.

Identify both ions and explain the difference in their radii.

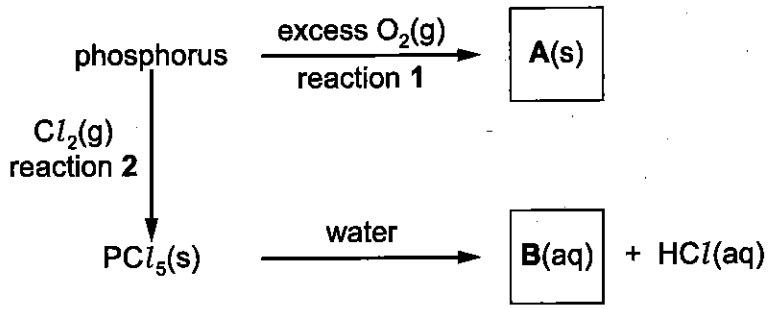
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..... **[2]**

(b) Phosphorus is a non-metal in the third period. It reacts vigorously with excess oxygen but slowly with chlorine.

Some reactions of phosphorus are shown.



(i) Write an equation to represent reaction **1**, the formation of compound **A**.

..... [1]

(ii) Give **two** observations you could make in reaction **2**.

1. .....

2. .....

[2]

(iii) Name compound **B**.

..... [1]

3. M/J 16/P22/Q2/d

The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

element	bond energy /kJ mol^{-1}	standard enthalpy change of atomisation, $\Delta H_{at}^{\ominus}$/kJ mol^{-1}	boiling point of element /K	boiling point of **hydrogen halide** /K
fluorine, F–F	158	79	85	293
chlorine, Cl–Cl	242	121	238	188
bromine, Br–Br	193	112	332	206
iodine, I–I	151	107	457	238

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(a) Chlorine reacts directly with many elements to form chlorides. Three such compounds are $MgCl_2$, $AlCl_3$ and $SiCl_4$.

(i) State and explain the pattern shown by the formulae of these three chlorides.

.....

.....

..... [2]

(ii) Write equations to show the behaviour of each of these chlorides when added to water.

$MgCl_2$ .....

$AlCl_3$ .....

$SiCl_4$ .....

[3]

4. M/J 16/P21/Q2

D, **E**, **F**, and **G** are four consecutive elements in the **fourth** period of the Periodic Table. (The letters are **not** the actual symbols of the elements.)

D is a soft, silvery metal with a melting point just above room temperature. Its amphoteric oxide, D_2O_3, has a melting point of 1900 °C and can be formed by heating **D** in oxygen.

G is a solid that can exist as several different allotropes, most of which contain G_8 molecules. **G** burns in air to form GO_2 which dissolves in water to form an acidic solution. This solution reacts with sodium hydroxide to form the salt Na_2GO_3.

(a) Suggest the identities of **D** and **G**.

D ..... **G** ..... [1]

(b) Write equations for the reactions of D_2O_3 with

(i) hydrochloric acid,

..... [2]

(ii) sodium hydroxide.

..... [2]

(c) Suggest the type of bonding and structure in D_2O_3.

..... [1]

(d) Write an equation for the formation of an acidic solution when GO_2 dissolves in water.

..... [1]

5. MAR 16/P22/Q1/a

This question is about Period 3 elements and their compounds.

(a) Give an explanation for each of the following statements.

(i) The atomic radius decreases across Period 3 (Na to Ar).

.....

.....

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.....

..... [2]

(ii) The first ionisation energy of sulfur is lower than that of phosphorus.

.....

.....

.....

..... [2]

(iii) Sodium is a better electrical conductor than phosphorus.

.....

.....

.....

..... [2]

(iv) Magnesium is a better electrical conductor than sodium.

.....

..... [1]

6. M/J 15/P22/Q1/d

(a) The acid/base behaviour of the oxides in the third period varies across the period.

(i) Describe this behaviour and explain it with reference to the structure and bonding of sodium oxide, Na_2O, aluminium oxide, Al_2O_3, and sulfur trioxide, SO_3.

.....

.....

..... [2]

(ii) Write equations for reactions of these three oxides with hydrochloric acid and/or sodium hydroxide as appropriate.

.....

.....

.....

..... [4]

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7. M/J 15/P21/Q1/c,d

(a) The element tellurium, Te, reacts with chlorine to form a single solid product, with a relative formula mass of 270. The product contains 52.6% chlorine by mass.

(i) Calculate the molecular formula of this chloride.

molecular formula ..... **[3]**

(ii) This chloride melts at 224 °C and reacts vigorously with water.

State the type of bonding **and** structure present in this chloride and explain your reasoning.

.....

.....

.....

.....**[2]**

(iii) Suggest an equation for the reaction of this chloride with water.

.....**[1]**

(b) Sodium and silicon also react directly with chlorine to produce the chlorides shown.

chloride	melting point/°C	difference between the electronegativities of the elements
$NaCl$	801	2.2
$SiCl_4$	–69	1.3

(i) Describe what you would **see** during the reaction between sodium and chlorine.

.....

.....

..... **[2]**

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(ii) Explain the differences between the melting points of these two chlorides in terms of their structure **and** bonding. You should refer to the difference between the electronegativities of the elements in your answer.

NaCl structure **and** bonding .....

.....

$SiCl_4$ structure **and** bonding .....

.....

explanation .....

.....

.....

.....

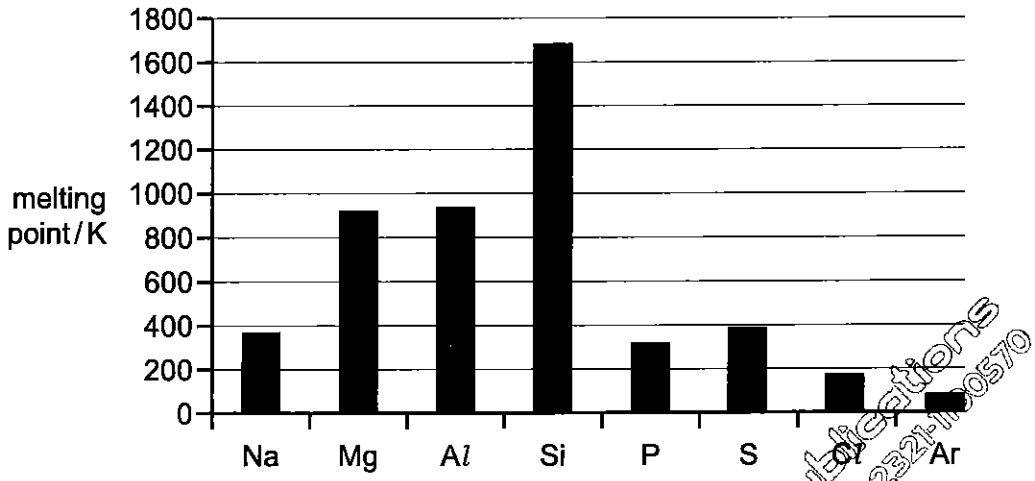
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..... **[4]**

8. M/J 14/P22/Q3

The elements in Period 3 of the Periodic Table show variations in their behaviour across the period.

(a) The bar chart below shows the variation of melting points of the elements across Period 3.



In each of the following parts of this question you should clearly identify the interactions involved and, where appropriate, explain their relative magnitudes.

(i) Explain the general increase in melting point from Na to Al.

.....

.....

.....

..... **[3]**

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(ii) Explain the variation of melting points from P to Ar.

.....

.....

.....

.....

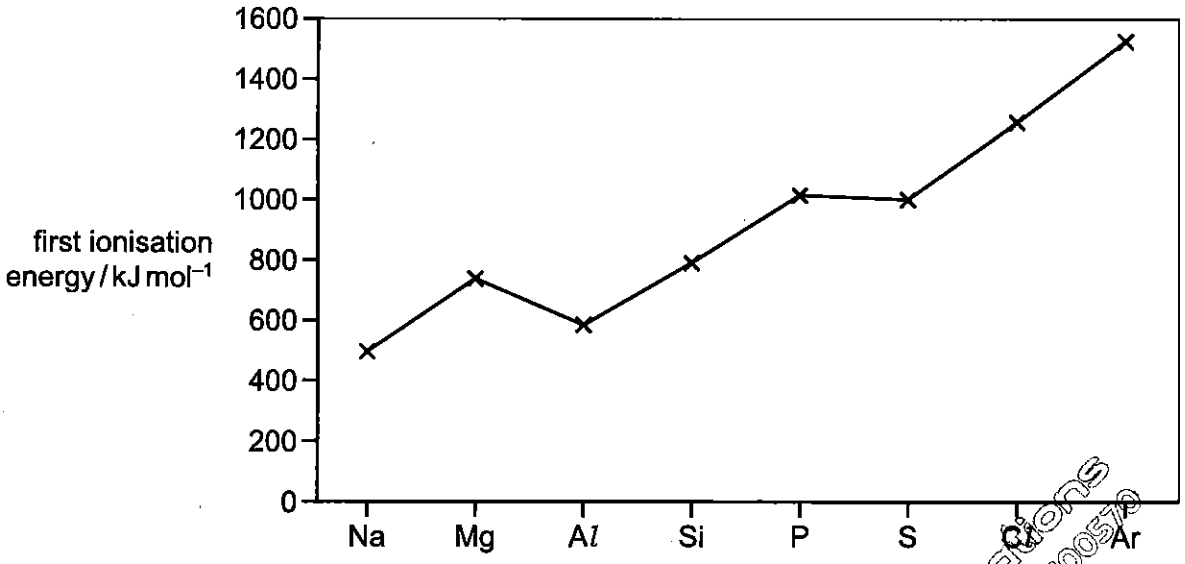
..... **[3]**

(iii) Explain why Si has a much higher melting point than any of the other elements in the period.

.....

..... **[1]**

(b) The graph below shows the variation of the first ionisation energies across Period 3.



(i) Explain why the first ionisation energy of Ar is greater than that of Cl.

.....

..... **[1]**

(ii) Explain why the first ionisation energy of Al is less than that of Mg.

.....

..... **[1]**

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(iii) Explain why the first ionisation energy of S is less than that of P.

.....

..... **[1]**

9. M/J 14/P21/Q1/d

(a) The chlorides of elements in Period 3 of the Periodic Table show different behaviours on addition to water, depending on their structure and bonding.

(i) Write equations to show the behaviour of sodium chloride, NaCl, and silicon chloride, SiCl_4, when separately added to an excess of water.

NaCl .....

SiCl_4 .....

[2]

(ii) State and explain the differences in behaviour of these two chlorides when added to water, in terms of their structure and the bonding found in the compounds.

.....

.....

.....

.....

..... **[4]**

10. O/N 13/P22/Q3/d, O/N 13/P21/Q3/d

This question is shifted in Unit 11 -- question No. 8

11. O/N 13/P21/Q3/c

This question is shifted in Unit 11 -- question No. 9

12. M/J 13/P23/Q3

This question refers to the elements in the section of the Periodic Table shown below.

		H							He
Li	Be				B	C	N	O	F	Ne
Na	Mg				Al	Si	P	S	Cl	Ar
K	Ca	..... transition elements			Ga	Ge	As	Se	Br	Kr

(a) From this list of elements, identify in **each** case **one** element that has the property described. Give the **symbol** of the element.

(i) An element that has molecules which consist of single atoms.

.....

(ii) An element that has a molecule which contains exactly four atoms.

.....

(iii) The element that is a liquid at room temperature and pressure.

.....

(iv) The element in Period 3 (Na to Ar) that has the largest atomic radius.

.....

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(v) The element in Period 3 (Na to Ar) that has the highest melting point.

.....

(vi) The element in Period 3 (Na to Ar) that forms the largest anion.

.....

(vii) An element that reacts with water to give a solution that can behave as an oxidising agent.

.....

[7]

(b) The formulae and melting points of some of the oxides of the elements in Period 3, Na to Cl, are given in the table.

formula of oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_6	SO_2	Cl_2O_7
m.p./°C	1132	2830	2054	1710	24	–73	–92

(i) Give the formulae of **two** of these oxides that have simple molecular structures.

..... and .....

(ii) Give the formula of one of these oxides that will give no reaction with water when placed in it for a long time.

.....

(iii) Give the formula of the product formed when MgO is reacted with SO_2.

.....

[4]

(c) The melting points of the elements Si to Cl are given in the table.

element	Si	P	S	Cl
m.p./°C	1414	44	115	–102

(i) Explain why the melting point of Si is very much greater than those of the other three elements.

.....

.....

(ii) Suggest why the melting points of the other three elements are in the order S > P > Cl.

.....

.....

.....

.....

[4]

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13. M/J 13/P22/Q3/a,i,iii,iv,v

This question refers to the elements in the section of the Periodic Table shown below.

		H										He
Li	Be						B	C	N	O	F	Ne
Na	Mg						Al	Si	P	S	Cl	Ar
K	Ca	..... transition elements					Ga	Ge	As	Se	Br	Kr

(a) From this list of elements, identify in **each** case **one** element that has the property described. Give the **symbol** of the element.

(i) An element that when placed in cold water sinks and reacts readily.

.....

(iii) An element that forms a gaseous toxic oxide.

.....

(iv) The element which has a giant molecular structure **and** forms an oxide which also has a giant molecular structure.

.....

(v) An element that forms a covalent chloride which dissolves in water to give a conducting solution.

.....

(vi) The element in Period 3 (Na to Ar) with the greatest electrical conductivity.

.....

[6]

14. M/J 13/P21/Q3/a,i,iii,iv,v,b

This question refers to the elements in the section of the Periodic Table shown below.

		H										He
Li	Be						B	C	N	O	F	Ne
Na	Mg						Al	Si	P	S	Cl	Ar
K	Ca	..... transition elements					Ga	Ge	As	Se	Br	Kr

(a) From this list of elements, identify in **each** case **one** element that has the property described. Give the **symbol** of the element.

(i) An element that floats on cold water and reacts readily with it.

.....

(ii) The element that has the smallest first ionisation energy.

.....

(iii) The element which has a giant molecular structure **and** forms an oxide which has a simple molecular structure.

.....

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(iv) The element in Period 3 (Na to Ar) that has the smallest anion.

.....

(v) The element in Period 3 (Na to Ar) which forms a chloride with a low melting point and an oxide with a very high melting point.

.....

[6]

(b) Use the elements in Period 3 (Na to Ar) in the section of the Periodic Table opposite to identify the oxide(s) referred to below.
In **each** case, give the **formula** of the oxide(s).

(i) An oxide which when placed in water for a long time has no reaction with it.

.....

(ii) An oxide which dissolves readily in water to give a strongly alkaline solution.

.....

(iii) Two acidic oxides formed by the same element.

..... and .....

(iv) An oxide which is amphoteric.

.....

[5]

15. M/J 12/P23/Q1

Although the actual size of an atom cannot be measured exactly, it is possible to measure the distance between the nuclei of two atoms. For example, the 'covalent radius' of the C*l* atom is assumed to be half of the distance between the nuclei in a Cl_2 molecule. Similarly, the 'metallic radius' is half of the distance between two metal atoms in the crystal lattice of a metal. These two types of radius are generally known as 'atomic radii'.
The table below contains the resulting atomic radii for the elements of period three of the Periodic Table, Na to C*l*.

element	Na	Mg	A*l*	Si	P	S	C*l*
atomic radius / nm	0.186	0.160	0.143	0.117	0.110	0.104	0.099

(a) (i) Explain qualitatively this variation in atomic radius.

.....

.....

.....

.....

.....

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(ii) Suggest why it is not possible to use the same type of measurement for argon, Ar.

.....

.....

[4]

(b) (i) Use the *Data Booklet* to complete the following table of radii of the cations and anions formed by some of the period three elements.

radius of cation / nm			radius of anion / nm		
Na^+	Mg^{2+}	Al^{3+}	P^{3-}	S^{2-}	Cl^-

(ii) Explain the differences in size between the cations and the corresponding atoms.

.....

.....

.....

(iii) Explain the differences in size between the anions and the corresponding atoms.

.....

.....

.....

[5]

(c) Each of the elements Na to Cl forms at least one oxide. Na_2O is an ionic oxide, SO_2 is a covalent oxide. Both oxides react with water.

(i) Write an equation for the reaction of **each** of these oxides with water.

Na_2O .....

SO_2 .....

(ii) What is the pH of the resulting solution in **each** case?

Na_2O ..... SO_2 .....

(iii) Write an equation for the reaction that occurs between the products of your reactions in **(i)**.

.....

[5]

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16. M/J 12/P22/Q1,a,b

The elements of the third period of the Periodic Table, sodium to sulfur, all form chlorides by direct combination.

(a) (i) Sulfur forms a number of chlorides which are liquid at room temperature.
Which other element of the third period forms a chloride which is liquid at room temperature?

.....

(ii) Name **one** element of the third period which burns in chlorine with a coloured flame.

.....

(iii) Aluminium chloride may be produced by passing a stream of chlorine over heated aluminium powder in a long hard-glass tube.
State **two** observations you could make during this reaction.

..... and .....

(iv) Write a balanced equation, with state symbols, for this reaction of aluminium with chlorine.

.....

(v) No chloride of argon has ever been produced.
Suggest a reason for this.

.....

.....

[7]

(b) When chlorides of the elements of the third period are added to water, some simply dissolve while others can be seen to react with the water.

(i) Complete the table below, stating how the chlorides of Na, Al, and Si behave when mixed with water. In the first column use only the terms 'dissolve' or 'react'.

element	Does the chloride dissolve or react?	approximate pH of the resulting solution
Na		
Al		
Si		

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(ii) What *type of reaction* takes place between a chloride and water?

.....

[7]

17. M/J 12/P21/Q1,a,b,c

Oxides are compounds which usually contain oxygen combined with one other element.

Oxides are classified as follows.

acidic alkaline amphoteric basic

(a) Using these terms only, complete the table to describe the oxides of the elements of the third period of the Periodic Table sodium to sulfur.

Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2	Cl_2O_7
						acidic

[4]

(b) Give the names of **two** elements from sodium to chlorine which form more than one oxide.

..... and ..... **[1]**

(c) Sodium reacts with water.

(i) Describe, as fully as you can, what you would see when a piece of sodium is reacted with water.

.....

.....

.....

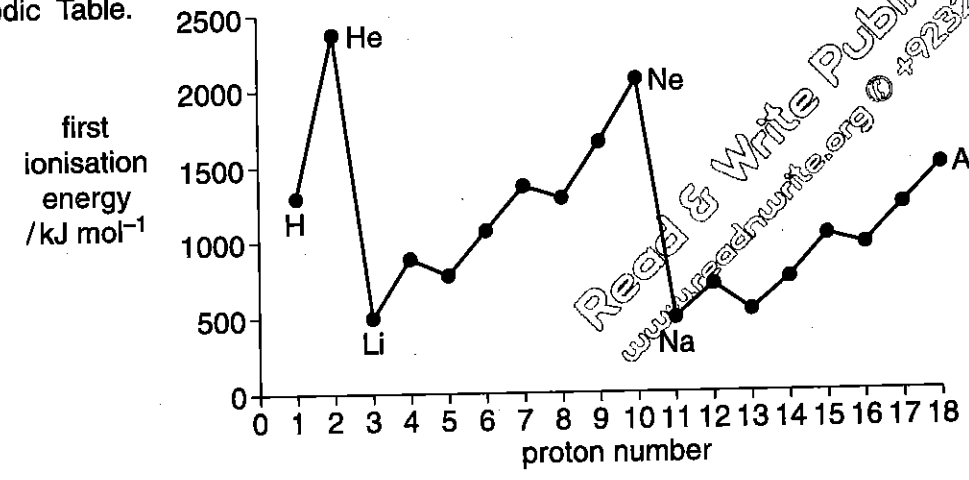
(ii) Write an equation for the reaction of sodium with water.

..... **[4]**

18. O/N 11/P23/Q3

The Periodic Table we currently use is derived directly from that proposed in 1869 by Mendeleev who had noticed patterns in the physical and chemical properties of the elements he had studied.

The diagram below shows the first ionisation energies of the first 18 elements of the Periodic Table.



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(a) Give the equation, including state symbols, for the first ionisation energy of carbon.

.....

[2]

(b) **(i)** Explain why sodium has a lower first ionisation energy than magnesium.

.....

.....

(ii) Explain why magnesium has a higher first ionisation energy than aluminium.

.....

.....

(iii) Explain why helium, He, and neon, Ne, occupy the two highest positions on the diagram.

.....

.....

(iv) Explain why the first ionisation energy of argon, Ar, is lower than that of neon, which is lower than that of helium.

.....

.....

.....

[8]

(c) **(i)** The first ionisation energies of the elements Na to Ar show a variation. Some physical properties show similar variations.

The atomic radius of the elements decreases from Na to Cl.

Give a brief explanation of this variation.

.....

.....

(ii) The cations formed by the elements Na to Al are smaller than the corresponding atoms.

Give a brief explanation of this change.

.....

.....

[3]

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(d) The oxides of the elements of the third Period behave differently with NaOH(aq) and HCl (aq). In some cases, no reaction occurs.

Complete the table below by writing a balanced equation for any reaction that occurs, with heating if necessary. If you think no reaction takes place write 'no reaction'.

You do not need to include state symbols in your answers.

.....MgO(s) + ... NaOH (aq) →
.....MgO(s) + ... HCl (aq) →
.....Al_2O_3(s) + ... NaOH (aq) + ...H_2O (l) →
.....Al_2O_3(s) + ... HCl (aq) →
.....SO_2(g) + ... NaOH (aq) →
.....SO_2(g) + ... HCl (aq) →

[6]

19. O/N 11/P22/Q2/d,e, O/N 11/P21/Q2,d,e
The table below refers to the elements of the third Period sodium to sulfur and is incomplete.

element	Na	Mg	Al	Si	P	S
conductivity			high			
melting point			high			

(a) (i) Complete the 'conductivity' row by using **only** the words 'high', 'moderate' or 'low'.

(ii) Complete the 'melting point' row by using **only** the words 'high' or 'low'. **[5]**

When Mendeleev published his first Periodic Table, he left gaps for elements that had yet to be discovered. He also predicted some of the physical and chemical properties of these undiscovered elements.

For one element, **E**, he correctly predicted the following properties.

melting point of the element	high
melting point of the oxide	high
boiling point of the chloride	low

The element **E** was in the fourth Period and was one of the elements from gallium, proton number 31, to bromine, proton number 35.

(b) By considering the properties of the third Period elements aluminium to chlorine, suggest the identity of the fourth Period element **E**.

.....

[1]

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20. M/J 11/P23/Q3

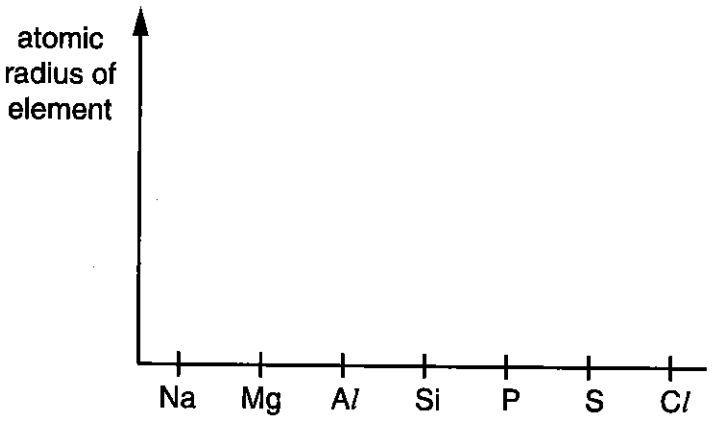
Elements in the same period of the Periodic Table show trends in physical and chemical properties. The grids on this page and on the opposite page refer to the elements of the third period, Na to Cl.

On **each** of these grids, draw a clear sketch to show the variation of the stated property.

Below **each** grid, briefly explain the variation you have described in your sketch.

For each explanation you should refer to the important factors that cause the differences in the property you are describing.

(a)



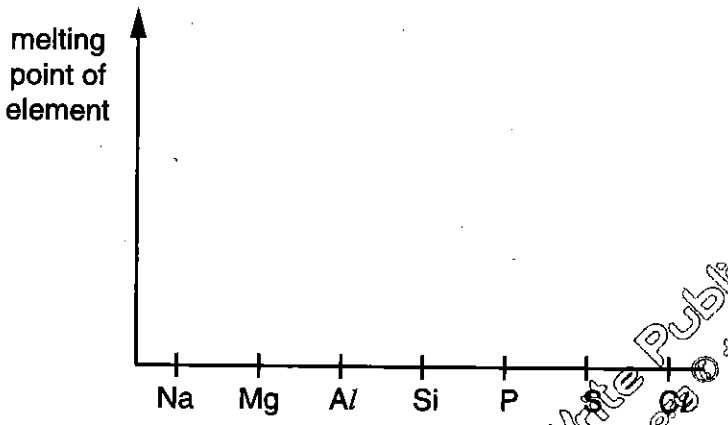
explanation .....

.....

.....

.....

(b) [3]



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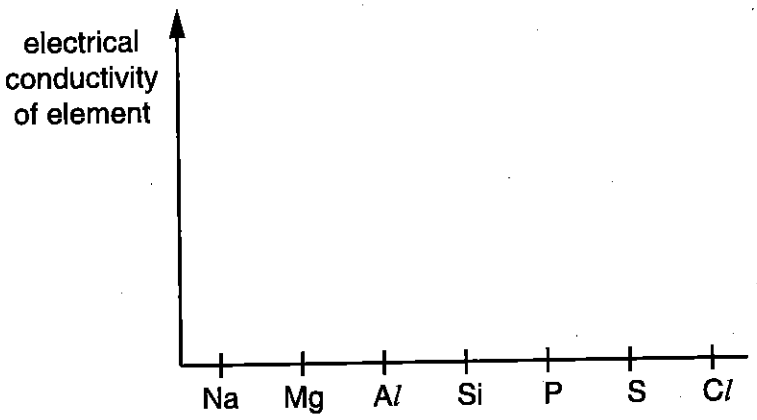
explanation .....

.....

.....

..... [4]

(c)



explanation .....

.....

.....

.....

[4]

(d) The melting points of some of the oxides of the elements sodium to sulfur are given in the table below.

compound	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_6	SO_2
mp/K	1193	3173	2313	1883	297	198

(i) What type of bond is broken when **each** of the following compounds is melted?

Na_2O .....

SiO_2 .....

P_4O_6 .....

(ii) Identify **one** of these six oxides that has no reaction at all with water.

.....

[4]

21. M/J 10/P22/Q3

The table below gives data for some of the oxides of Period 3 elements.

oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_6	SO_2
melting point/°C	1275	2827	2017	1607	24	–75
bonding						
structure						

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(a) Complete the table by filling in

(i) the 'bonding' row by using **only** the words 'ionic' **or** 'covalent',

(ii) the 'structure' row by using **only** the words 'simple' **or** 'giant'.

[2]

(b) From the table of oxides above, suggest the formula of **one** oxide that is **completely** insoluble in water.

.....

[1]

(c) Separate samples of Na_2O and SO_2 were added to water.

(i) For **each** oxide, write a balanced equation for its reaction with water and suggest a numerical value for the pH of the resulting solution.

Na_2O

equation .....

pH .....

SO_2

equation .....

pH .....

(ii) Construct a balanced equation for the reaction that occurs when a solution of Na_2O in water reacts with a solution of SO_2 in water.

.....

[5]

(d) Separate samples of the oxides MgO and SiO_2 are melted.
Each molten sample is then tested to see whether or not it conducts electricity.

Suggest what would be the results in **each** case. Explain your answers.

MgO .....

.....

.....

SiO_2 .....

.....

.....

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[4]

22. M/J 10/P21/Q3/a,b

This question refers to the elements shown in the portion of the Periodic Table given below.

							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr

(a) From this table, identify in **each** case **one** element that has the property described. Give the **symbol** of the element in each case.

(i) The element that has a molecule which contains exactly eight atoms.

.....

(ii) The element that forms the largest cation.

.....

(iii) An element that floats on water and reacts with it.

.....

(iv) An element that reacts with water to give a solution that can behave as an oxidising agent.

.....

(v) An element whose nitrate gives a brown gas on thermal decomposition.

.....

[5]

(b) (i) Give the formula of the oxide of the most electronegative element.

.....

(ii) Several of these elements form more than one acidic oxide.
Give the formulae of **two** such oxides formed by the **same** element.

..... and .....

[3]

23. O/N 9/P22/Q2/a,c,d

The elements of the third period of the Periodic Table form chlorides of general formula ECl_x where E represents the element. These chlorides show a variation in oxidation number from sodium to sulfur.

(a) (i) Use the information given to complete the table below.

formula of chloride	$NaCl$	$MgCl_2$	$AlCl_3$	$SiCl_4$	PCl_3	SCl_2
oxidation number of element in the chloride						

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(ii) By considering the electron configurations of the elements, explain the variation in oxidation number in the chlorides from Na to Al and from Si to S.

Na to Al .....

.....

Si to S .....

.....

[5]

(b) (i) What is the pH of the solutions formed when separate samples of sodium chloride, magnesium chloride, and aluminium chloride are dissolved in water?

chloride	sodium	magnesium	aluminium
pH			

(ii) Suggest an equation for the reaction between sodium hydride and water.

.....

(iii) Suggest a value for the pH of the solution formed in **(ii)**.

.....

[4]

At room temperature, the chlorides of silicon, phosphorus and sulfur are all low melting point solids or low boiling point liquids that can be seen to react with water.

(c) (i) Suggest what type of bonding is present in sulfur dichloride, SCl_2.

.....

(ii) Write a balanced equation for the reaction between the chloride of silicon, $SiCl_4$, and water.

.....

[2]

24. M/J 9/P2/Q1/b(i,ii),c

Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, Al, is in the third period of the Periodic Table; copper and titanium are both transition elements.

Aluminium reacts with chlorine.

(a) (i) Outline how, starting from aluminium powder, this reaction could be carried out in a school or college laboratory to give a small sample of aluminium chloride. A diagram is not necessary.

.....

.....

.....

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(ii) Describe what you would see during this reaction.

.....

.....

Copper forms two chlorides, $CuCl$ and $CuCl_2$.

(c) When copper is reacted directly with chlorine, only $CuCl_2$ is formed.
Suggest an explanation for this observation.

.....

..... [1]

25. M/J 9/P2/Q2/b

Phosphorus is a very reactive non-metallic element which readily forms ionic compounds with metals such as calcium and covalent compounds with non-metals such as chlorine and oxygen.

(a) Separate small samples of phosphorus(V) chloride and phosphorus(V) oxide are shaken with water. In **each** case, describe what you would see when this is done, and state the approximate pH of the water after the solid has been shaken with it.

(i) phosphorus(V) chloride

observation .....

approximate pH of the water .....

(ii) phosphorus(V) oxide

observation .....

approximate pH of the water ..... [4]

26. O/N 8/P2/Q3/d

(a) Chlorine is very reactive and will form compounds by direct combination with many elements.

Describe what you would see when chlorine is passed over separate heated samples of sodium and phosphorus. In **each** case write an equation for the reaction.

sodium .....

.....

.....

phosphorus .....

.....

..... [4]

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27. O/N 7/P2/Q3/a,b

The elements phosphorus, sulphur, and chlorine are regarded as having simple molecular structures.

(a) What are the molecular formulae of **each** of these three elements?

phosphorus .....

sulphur .....

chlorine ..... **[3]**

(b) **(i)** Place the three elements in order of their melting points **with the highest first.**

highest ..... lowest

(ii) Suggest an explanation for the order you have given in **(i).**

.....

.....

..... **[3]**

28. O/N 6/P2/Q3

This question refers to the elements shown in the Periodic Table below.

							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr

(a) From the elements shown, identify in **each** case **one** element that has the property described. Give the name or formula of the element.

(i) An element that has a molecule which contains only one atom.

.....

(ii) An element that has a molecule which contains only four atoms.

.....

(iii) The element that has the largest atomic radius.

.....

(iv) The element that is a liquid at room temperature and pressure.

.....

(v) The element in Period 3 (Na to Ar) that has the highest melting point.

.....

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(vi) The element in Period 3 (Na to Ar) that forms the largest anion.

.....

[6]

(b) Use the elements shown opposite to answer the following questions.

(i) Give the formulae of **two** acidic oxides formed by the same element.

..... and .....

(ii) Give the name or formula of an oxide that is amphoteric.

.....

(iii) Identify an element whose oxide dissolves readily in water to give a strongly alkaline solution.

.....

(iv) Identify an element in Period 3 (Na to Ar) whose chloride dissolves in water to give a neutral solution.

.....

(v) Identify an element that reacts with water to give a solution that can behave as an oxidising agent.

.....

[6]

29. M/J 5/P2/Q3

This question is shifted in Unit 10 -- question No. 11

30. O/N 4/P2/Q2

The table below gives data on some oxides of elements in Period 3 of the Periodic Table.

oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_3
melting point / K	1193	3125	2345	1883	853	290
boiling point / K	1548	3873	3253	2503	–	318

(a) Write an equation for the reaction of aluminium with oxygen to form aluminium oxide.

..... [1]

(b) Drawing diagrams where appropriate, suggest in terms of structure and bonding, explanations for the following.

(i) the high melting point and boiling point of Al_2O_3

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(ii) the low boiling point of SO_3

(iii) the melting point of SiO_2 is much higher than that of P_4O_{10}

[7]

(c) Water was added to each of the oxides in the table.
Choosing a suitable oxide in each case, write an equation for the formation of

(i) an alkaline solution, ...

(ii) an acidic solution. ..... **[2]**

31. M/J 4/P2/Q2/a,b,d

Compounds of phosphorus have many uses in everyday life, e.g. fertilisers, matches and in water softeners.

(a) State the full electronic configuration of phosphorus.

.....**[1]**

(b) Phosphoric acid, H_3PO_4, is used in the manufacture of phosphate fertilisers.
Deduce the oxidation number of phosphorus in H_3PO_4.

.....**[1]**

(c) Phosphorus sulphide, P_4S_3, is used in small amounts in the tip of a match. On striking a match, this compound burns.

(i) Construct an equation for this reaction.

.....

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(ii) Both oxides formed in **(i)** dissolve in water to give acidic solutions. Construct an equation for the reaction of each oxide with water.

.....

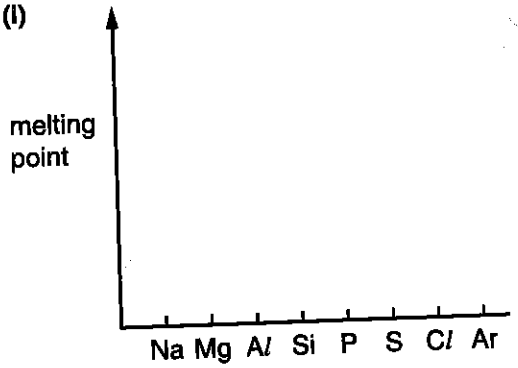
.....[4]

.....

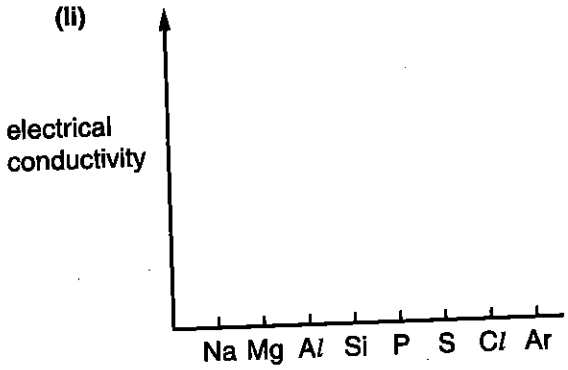
32. M/J 3/P2/Q4

(a) The use of the *Data Booklet* is relevant to this question. Complete these sketches for elements of the third period (sodium to argon) to show how each property changes along the period.

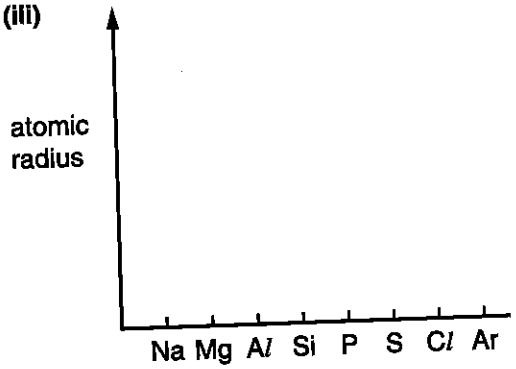
(i)



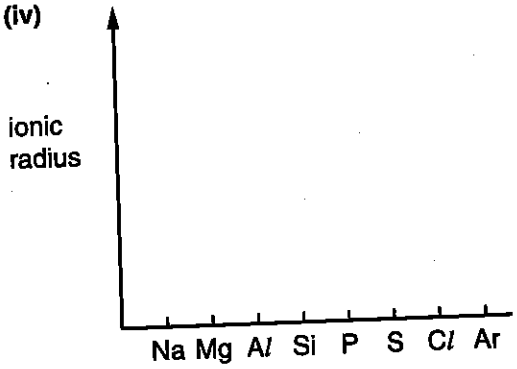
(ii)



(iii)



(iv)



[6]

(b) **(i)** In the boxes below, write the formulae of **one** of the oxides of each of these five elements.

sodium	magnesium	aluminium	phosphorus	sulphur

(ii) Write an equation for sodium oxide reacting with water.

.....

(iii) Write an equation for your chosen oxide of sulphur reacting with an alkali.

.....[3]

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33. O/N 2/P2/Q3/,b,c

The oxides of the third period include the following:

Na_2O; MgO; Al_2O_3; SO_2; SO_3.

(a) From the list above, identify one oxide (in each case) which fits the description given.

(i) An oxide that reacts with water forming a strongly alkaline solution.

.....

(ii) An oxide that is insoluble in water.

.....

(iii) An oxide that reacts vigorously with water forming a strongly acidic solution.

.....

(iv) An oxide that has a simple molecular structure.

.....

(v) An oxide that acts as a food preservative.

.....

[5]

(b) Write equations for the reaction of

(i) aluminium oxide and dilute hydrochloric acid,

.....

(ii) sulphur dioxide and aqueous sodium hydroxide.

.....

[2]

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Answers Section

1. M/J 17/P21/Q3/a

(a) (i) **A** 1

(ii) **H** 1

(iii) **G** 1

(iv) **B** 1

(v) **F** 1

2. MAR 17/P22/Q1/a,b

(a) (i) 1

max O.N.	+1	(+)2	(+)3	(+)5	(+)6	+7

(ii) (from Na to Cl) nuclear charge increases 1

electrons are in the same shell / have same shielding 1

greater / stronger attraction (of electrons to nucleus) 1

(iii) Mg^{2+} **AND** S^{2-} 1

ion of Mg / Mg^{2+} has one fewer shell (than ion of S / S^{2-}) 1

(b) (i) $P_4 + 5O_2 \rightarrow P_4O_{10} / 2P_2O_5$ 1

(ii) any 2 from: 2

- yellow / green colour (of chlorine gas) disappears
- white flame
- white solid
- solid melts

(iii) phosphoric(V) acid 1

3. M/J 16/P22/Q2/d

(a) (i) no of Cl increases by one each time / matches group number [1]

due to increasing number of valence/outer(most/shell) electrons / oxidation number / valency (of Mg, Al, Si) [1] [2]

(ii) $MgCl_2 (+aq) \rightarrow Mg^{2+} + 2Cl^-$ [1]

$AlCl_3 + 6H_2O \rightarrow Al(H_2O)_6^{3+} + 3Cl^- / Al(H_2O)_5(OH)^{2+} + H^+ + 3Cl^-$ [1]

$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4H^+ + 4Cl^-$ [1] [3]

4. M/J 16/P21/Q2

(a) **D** = Ga **G** = Se [1] [1]

(b) (i) $D_2O_3 + 6HCl \rightarrow 2DCl_3 + 3H_2O$

M1 = species; [1]

M2 = balancing [2]

(ii) $D_2O_3 + 2NaOH + 7H_2O \rightarrow 2NaD(OH)_4(H_2O)_2$ OR [1]

$D_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaD(OH)_4$ OR

$D_2O_3 + 2NaOH \rightarrow 2NaDO_2 + H_2O$ OR

$D_2O_3 + 2OH^- + 7H_2O \rightarrow 2[D(OH)_4(H_2O)_2]^-$ OR

$D_2O_3 + 2OH^- + 3H_2O \rightarrow 2[D(OH)_4]^-$ OR

$D_2O_3 + 2OH^- \rightarrow 2DO_2^- + H2O$ [2]

M1 = species; [1]

M2 = balancing [1]

(c) giant ionic / ionic lattice [1] [1]

(d) $GO_2 + H_2O \rightarrow H_2GO_3$ [1] [1]

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5. MAR 16/P22/Q1/a

(a) (i) greater attractive force [1]
OR
greater force between nucleus and (outer) electrons [2]

proton number/atomic number/nuclear charge increases across period AND electrons occupy same shell/shielding roughly constant [1]

(ii) sulfur's electron removed from full (3p) orbital [1]
OR
sulfur has two electrons in the same orbital [2]

electron–electron repulsion (reduces energy required) [1]

(iii) sodium has mobile/free electrons/electrons free (to move throughout the structure) [1] [2]
phosphorus is simple/covalent/molecular [1]

(iv) magnesium has two free/delocalised/outer/valence electrons per atom [1]
OR
more free/delocalised/outer electrons than sodium [1]

6. M/J 15/P22/Q1/d

(a) (i) Na_2O basic/alkaline; Al_2O_3 amphoteric/acidic and basic; SO_3 acidic [1]
Na O (giant) ionic **AND** SO (simple/molecular) covalent [1] [2]
$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$ [1]

(ii) $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ [1]

$Al_2O_3 + 2NaOH + 7H_2O \rightarrow 2NaAl(OH)_4(H_2O)_2$ **OR** [1]
$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$ **OR**
$Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$ **OR**
$Al_2O_3 + 2OH^- + 7H_2O \rightarrow 2[Al(OH)_4(H_2O)_2]^-$ **OR**
$Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2[Al(OH)_4]^-$ **OR**
$Al_2O_3 + 2OH^- \rightarrow 2AlO_2^- + H_2O$

$SO_3 + NaOH \rightarrow NaHSO_4$ **OR**
$SO_3 + 2NaOH \rightarrow Na_2SO_4 + H_2O$

7. M/J 15/P21/Q1/c,d

(a) (i)

	Te	C
	47.4	52.6 / 35.5
	0.370 / 0.370	1.48 / 0.370
	1	4

so EF = $TeCl_4$ [1]

Empirical Formula Mass = 270 so MF = $TeCl_4$ [1] [3]

(ii) Covalent **AND** simple/molecular [1]
low melting point/reaction with water [1] [2]

(iii) $TeCl_4 + 3H_2O \rightarrow H_2TeO_3 + 4HCl$
OR $TeCl_4 + 2H_2O \rightarrow TeO_2 + 4HCl$ [1] [1]

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(b) (i) Yellow/orange flame [1]
White fumes/solid [1]
Yellow/green gas disappears [1]
[max 2]

(ii) NaCl giant/lattice **AND** ionic [1]
$SiCl_4$ simple/molecular **AND** covalent [1]
For NaCl large difference in electronegativity (of sodium/Na and chlorine/Cl/Cl_2) (indicates electron transfer/ions) [1]
For $SiCl_4$ smaller difference (indicates sharing/covalency) with (weak) van der Waals'/IM forces (between molecules) ora [1] [4]

8. M/J 14/P22/Q3

(a) (i) metallic bonding 1
strength of attraction/metallic bonding increases (Na–Al)/more energy is needed to break 'bonds' 1
due to increasing cation charge/charge density/increasing number of delocalised electrons/decreasing ionic radius 1 3

(ii) van der Waals' (forces) 1
are greatest/more in sulfur/relative magnitude of forces S > P > Cl > Ar 1
because sulfur has the greatest number of electrons/as no. of electrons (in the molecules) decreases 1 3

(iii) Covalent bond(s) broken **OR** (Si has a) giant covalent (structure) 1 1

(b) (i) Nuclear charge (in Ar) greater (than Cl) **AND** same shielding owtte 1 1

(ii) p subshell/orbital in Al at higher energy (than s subshell in Mg) **ora** 1 1
OR
p subshell/orbital more shielded **ora**

(iii) repulsion due to electron pair (in same/p orbital) 1 1
10

9. M/J 14/P21/Q1/d

(a) (i) $NaCl\ (+\ aq) \rightarrow Na^+ + Cl^-$ 1
$NaCl + H_2O \rightarrow Na^+ + Cl^- + H_2O$ 1
$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$
$SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$
$SiCl_4 + 4H_2O \rightarrow SiO_2.2H_2O + 4HCl$
Allow correct equation with other molar amounts of water 2

(ii) NaCl is ionic **AND** giant/lattice 1
NaCl dissolves/does not react 1
$SiCl_4$ is covalent **AND** molecular/simple 1
$SiCl_4$ is hydrolysed/reacts 1 4

10. O/N 13/P22/Q3/d, O/N 13/P21/Q3/d

This question answer is shifted in Unit 11 -- answer No. 8

11. O/N 13/P21/Q3/c

This question answer is shifted in Unit 11 -- answer No. 9

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12. M/J 13/P23/Q3

(a) (i) He **or** Ne **or** Ar **or** Kr (1)

(ii) P **or** As (1)

(iii) Br (1)

(iv) Na allow Ar (1)

(v) Si (1)

(vi) P allow Si (1)

(vii) C*l* **or** F **or** Br (1) **[7]**

(b) (i) any **two** from P_4O_6, SO_2 and Cl_2O_7 (1+1)

(ii) Al_2O_3 **or** SiO_2 (1)

(iii) $MgSO_3$ (1) **[4]**

(c) (i) Si is giant molecular/giant covalent **or**
P, S, and C*l* are simple molecular (1)

(ii) the molecules are S_8, P_4, Cl_2 (1)
larger molecules have more electrons (1)
and hence greater van der Waals' forces (1) **[4]**

13. M/J 13/P22/Q3/a,i,iii,iv,v

(a) penalise (-1) the use of names of elements or formulae of compounds

(i) Ca (1)

(iii) C **or** N **or** S **or** F **or** C*l* **or** Br (1)

(iv) Si **or** Ge **or** B (1)

(v) A*l* **or** Si **or** P **or** S **or** H (1)

(vi) A*l* (1) **[6]**

14. M/J 13/P21/Q3/a,i,iii,iv,v,b

(a) penalise (–1) for names of elements

(i) Na **or** K **or** Li (1)

(ii) K (1)

(iii) C (1)

(iv) C*l* (1)

(v) A*l* **or** Si (1) **[6]**

(b) (i) Al_2O_3 **or** SiO_2 (1)

(ii) Na_2O (1)

(iii) P_2O_3 **or** P_4O_6 **and** P_2O_5 **or** P_4O_{10} **or** SO_2 **and** SO_3 (1)

(iv) Al_2O_3 (1+1)

(1) **[5]**

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15. M/J 12/P23/Q1

(a) (i) **from Na to Cl**
nuclear charge increases (1)
electrons are in the same shell/have the same shielding (1)
nuclear attraction increases (1)

(ii) argon does not form any bonds/compounds **or**
argon exists as single atoms/is monatomic (1) [4]

(b) (i)

radius of cation/nm			radius of anion/nm		
Na^+	Mg^{2+}	Al^{3+}	P^{3-}	S^{2-}	Cl^-
0.095	0.065	0.050	0.212	0.184	0.181

(1)

(ii) cations contain fewer electrons than the corresponding atoms **or**
cations contain fewer electrons than they do protons (1)
nucleus has a greater attraction (1)

(iii) anions contain more electrons than the corresponding atoms **or**
anions contain more electrons than they do protons (1)
nucleus has a smaller attraction (1) [5]

(c) (i) $Na_2O + H_2O \rightarrow 2NaOH$ (1)
$SO_2 + H_2O \rightarrow H_2SO_3$ (1)

(ii) for Na_2O 10 to 14 (1)
for SO_2 1 to 4 (1)

(iii) $NaOH + H_2SO_3 \rightarrow NaHSO_3 + H_2O$ **or**
$2NaOH + H_2SO_3 \rightarrow Na_2SO_3 + 2H_2O$ (1) [5]

16. M/J 12/P22/Q1,a,b

(a) (i) silicon/Si **or** phosphorus/P (1)

(ii) sodium **or** sulfur **name required** (1)

(iii) white solid formed/white fumes seen
chlorine gas decolourised
aluminium glows **or** burns any two (2)

(iv) $2Al(s) + 3Cl_2(g) \rightarrow Al_2Cl_6(s)$ **or**
$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$ (1)
equation
state symbols (1)

(v) outer shell of electrons is full/has a complete octet **or**
valence shell of electrons is full/has a complete octet **or**
activation energy is too high **or**
ionisation energy is too high (1) [7]

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(b) (i)

element	Does the chloride dissolve or react?	approximate pH of the resulting solution
Na	dissolve	7
Al	react	1 to 4
Si	react	1 to 4

one mark for each correct answer (6 × 1)

(ii) hydrolysis (1) [7]

17. M/J 12/P21/Q1,a,b,c

(a)

Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2	Cl_2O_7
alkaline	basic	amphoteric	acidic	acidic	acidic	acidic

Na_2O is alkaline – allow basic (1)

MgO is basic – allow alkaline (1)

Al_2O_3 is amphoteric (1)

SiO_2, P_4O_{10}, and SO_2 are **all** acidic (1) [4]

(b) any **two** from:
sodium, phosphorus, sulfur and chlorine
two names required (1) [1]

(c) (i) any **three** from:
floats
vigorous/violent reaction occurs
melts/forms a sphere
moves
disappears – allow dissolves
effervescence/gas produced **(any 3)**

(ii) $Na + H_2O \rightarrow NaOH + \frac{1}{2}H_2$
or
$2Na + 2H_2O \rightarrow 2NaOH + H_2$ (1) [4]

18. O/N 11/P23/Q3

(a) $C(g) \rightarrow C^+(g) + e^-$
correct equation (1)
correct state symbols (1) [2]

(b) (i) Na and Mg
Mg has greater nuclear charge/more protons than Na (1)
in both atoms, the 3s electrons are in the same orbital/same energy level/same shell (1)

(ii) Mg and Al
in Al outermost electron is in 3p rather than 3s (1)
3p electron is at higher energy **or**
is further away/is more shielded from nucleus (1)

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(iii) He and Ne
both He and Ne have the highest nuclear charges in their Period (1)

(iv) He, Ne, and Ar
going down the group,
valence/outer shell electrons are farther from the nucleus (1)
there is greater shielding (1)
attraction between valence electrons and nucleus is less **or** effective nuclear charge is less (1) [8]

(c) (i) from Na to Cl
increased nuclear charge/nuclear attraction (1)

(ii) cation has fewer electrons than atom **or** cation has lost outer electrons **or** cation has fewer shells (1)
but cation has same nuclear charge as atom **or** proton number is the same (1) [3]

(d) ignore any state symbols

$MgO(s) + NaOH(aq) \rightarrow$ NO REACTION (1)

$MgO(s) + 2HCl(aq) \rightarrow MgCl_2 + H_2O$ (1)

$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow 2NaAl(OH)_4$ **or**

$Al_2O_3(s) + 2NaOH(aq) + H_2O(l) \rightarrow 2NaAlO_2 + 2H_2O$ **or**

$Al_2O_3(s) + 6NaOH(aq) + 3H_2O(l) \rightarrow 2Na_3Al(OH)_6$

$Al_2O_3(s) + 6HCl(aq) \rightarrow 2AlCl_3 + 3H_2O$ **or**

$Al_2O_3(s) + 6HCl(aq) \rightarrow Al_2Cl_6 + 3H_2O$

$SO_2(g) + NaOH(aq) \rightarrow NaHSO_3$ **or**

$SO_2(g) + 2NaOH(aq) \rightarrow Na_2SO_3 + H_2O$

$SO_2(g) + HCl(aq) \rightarrow$ NO REACTION (1) [6]

19. O/N 11/P22/Q2/d,e, O/N 11/P21/Q2,d,e

(a) (i) and (ii)

element	Na	Mg	Al	Si	P	S
conductivity	high	high	—	moderate	low	low
melting point	low	high	—	high	low	low
	(1)	(1)		(1)	(1)	(1)

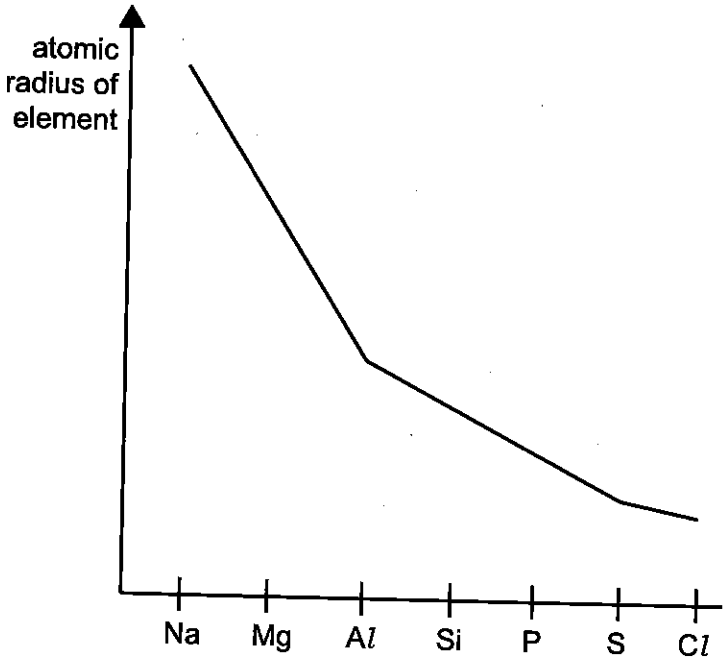
one mark for each correct column [5]

(b) germanium/Ge (1) [1]

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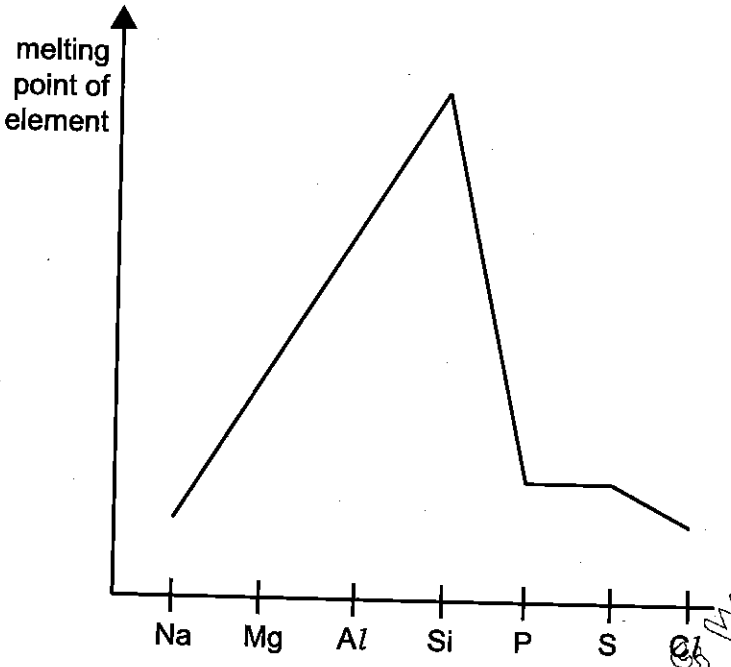
20. M/J 11/P23/Q3

(a)



general shape of curve
for Na → Ar (1)
nuclear charge increases
electrons are added to same shell (1)
(1) [3]

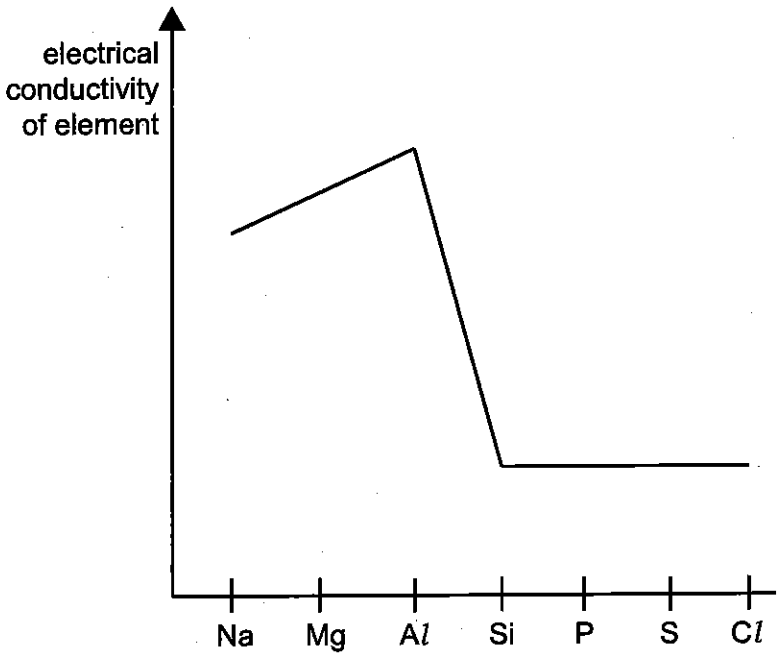
(b)



general shape of curve (1)
Na, Mg and Al have metallic bonding (1)
Si is giant molecular (1)
P, S, and Cl are simple molecular (1) [4]

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(c)



general shape of curve (1)
Na, Mg and Al have increasing no. of outer shell electrons (1)
Si is a semi-conductor (1)
P, S and Cl are covalent/simple molecular (1) [4]

(d) (i) Na_2O ionic (1)
SiO_2 covalent (1)
P_4O_6 van der Waals' forces/induced dipoles (1)

(ii) Al_2O_3 **or** SiO_2 (1) [4]

21. M/J 10/P22/Q3

(a)

oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_6	SO_2
bonding	ionic	ionic	ionic/covalent	covalent	covalent	covalent
structure	giant	giant	giant	giant	simple	simple

(i) fully correct 'bonding' row (1)
(ii) fully correct 'structure' row (1) [2]

(b) Al_2O_3 **or** SiO_2 (1) [1]

(c) (i) **Na_2O** $Na_2O + H_2O \rightarrow 2NaOH$ **(1)**
pH 10–14 **(1)**
SO_2 $SO_2 + H_2O \rightarrow H_2SO_3$ **(1)**
pH 2–5 **(1)**

(ii) $NaOH + H_2SO_3 \rightarrow NaHSO_3 + H_2O$
or $2NaOH + H_2SO_3 \rightarrow Na_2SO_3 + 2H_2O$ (1) [5]

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(d) MgO(l) conducts (1)
MgO(l) contains free/mobile ions (1)
SiO_2(l) does not conduct (1)
SiO_2(l) has no free ions (1) [4]

22. M/J 10/P21/Q3/a,b

(a) Accept only symbols.

(i) S or S_8 (1)

(ii) K or K^+ (1)

(iii) Na – allow K or Li (1)

(iv) C*l* **or** Br **or** F (1)

(v) Mg **or** Ca **or** Li
allow Ni, Cu, or Zn (1) [5]

(b) Accept only formulae.

(i) F_2O (1)

(ii) SO_2 **and** SO_3
or P_2O_3/P_4O_6 **and** P_2O_5/P_4O_{10}
or any two from N_2O_3, NO_2/N_2O_4, N_2O_5
or any two from Cl_2O, ClO_2, ClO_3, Cl_2O_7 (1+1) [3]

23. O/N 9/P22/Q2/a,c,d

(a) (i)

formula of chloride	NaC*l*	$MgCl_2$	$AlCl_3$	$SiCl_4$	PCl_3	SCl_2
oxidation number of element in the chloride	+1	+2	+3	+4	+3	+2

correct oxidation nos. for NaC*l* to SCl_2 (1)

(ii) **Na to A*l***
loss of outer/valence electrons (1)
to give configuration of Ne/to complete octet (1)
Si to S
gain or sharing of outer electrons (1)
to give configuration of Ar/to complete octet (1) [5]

(b) (i)

chloride	sodium	magnesium	aluminium
pH	7	6.5–6.9	1–4
	(no mark)	(1)	(1)

(ii) $NaH + H_2O \rightarrow NaOH + H_2$ (1)

(iii) 10–14 (1) [4]

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(c) (i) covalent **(1)**

(ii) $SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$ **or**
$SiCl_4 + 4H_2O \rightarrow SiO_2.2H_2O + 4HCl$ **or**
$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$ **(1) [2]**

24. M/J 9/P2/Q1/b(i,ii),c

(a) (i) pass chlorine gas **(1)**
over heated aluminium **(1)**

(ii) aluminium glows **(1)**
white/yellow solid formed **(1)**
chlorine colour disappears/fades **(1) (any 2)**

(b) chlorine is a strong/powerful oxidising agent **(1) [1]**

25. M/J 9/P2/Q2/b

(a) (i) dissolves/vigorous reaction/
white or steamy fumes of HCl **(1)**
0 – 4 **(1)**

(ii) dissolves/vigorous reaction **(1)**
0 – 4 **(1) [4]**

26. O/N 8/P2/Q3/d

(a) Na burns with a yellow flame/forms a white solid **(1)**
$2Na + Cl_2 \rightarrow 2NaCl$ **(1)**

P burns with a white flame/forms a colourless liquid (PCl_3) **or** a white solid (PCl_5) **(1)**
$P + 1\frac{1}{2}Cl_2 \rightarrow PCl_3$ **or** $P_4 + 6Cl_2 \rightarrow 4PCl_3$
or $P + 2\frac{1}{2}Cl_2 \rightarrow PCl_5$ **or** $P_4 + 10Cl_2 \rightarrow 4PCl_5$ **(1) [4]**

27. O/N 7/P2/Q3/a,b

(a) P_4 **(1)**
S_8 **(1)**
Cl_2 **(1) [3]**

(b) (i) highest S_8 ..... P_4..... Cl_2 lowest
allow S ... P ... Cl **or** names **(1)**

(ii) from S_8 to P_4 to Cl_2
there are fewer electrons in each molecule **(1)**
hence weaker van der Waals' forces **(1) [3]**

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28. O/N 6/P2/Q3

Allow names or formula throughout **(a)**.

(i) He **or** Ne **or** Ar **or** Kr **(1)**

(ii) P **or** P_4 - allow As **or** As_4 **(1)**

(iii) K **(1)**

(iv) Br/Br_2 **(1)**

(v) Si **(1)**

(vi) P - allow S **(1)**

(b) Accept only formulae in **(b)(i)**.
Allow names or formula throughout the rest of **(b)**.

(i) SO_2 **and** SO_3 **or**

P_2O_3/P_4O_6 **and** P_2O_5/P_4O_{10} **or**

NO_2 **and** N_2O_5 **or**

ClO_2 **and** Cl_2O_7

oxides must be from same element **(1 + 1)**

(ii) Al_2O_3 **or** BeO **or** ZnO **(1)**

(iii) Li **or** Na **or** K **(1)**

(iv) Na **or** Mg **(1)**

(v) F/F_2 **or** Cl/Cl_2 **or** Br/Br_2 **(1)** **[6]**

29. M/J 5/P2/Q3

This question answer is shifted in Unit 10 -- answer No. 11

30. O/N 4/P2/Q2

(a) $4Al + 3O_2 \rightarrow 2Al_2O_3$ **(1)** **[1]**

(b) some answers may contain diagrams which are equivalent to the words given below

(i) Al_2O_3 has a giant structure of ions (Al^{3+} and O^{2-}) **(1)**

held together by strong ionic bonds **(1)**

or a giant structure of atoms **(1)**

with strong covalent bonding throughout the lattice **(1)** **(2 max)**

(ii) SO_3 consists of small molecules

or is simple molecular

not simple covalent **(1)**

held together by weak van Waals' forces **(1)**

(iii) SiO_2 is giant covalent/macromolecular **(1)**

with strong covalent bonds **(1)**

P_4O_{10} is a simple molecular (as in SO_3) **(1)** **[7]**

(c) (i) $Na_2O + H_2O \rightarrow NaOH$
or $MgO + H_2O \rightarrow Mg(OH)_2$ **(1)**

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(ii) $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$
or $P_4O_{10} + 2H_2O \rightarrow 4HPO_3$
or $SO_3 + H_2O \rightarrow H_2SO_4$ (1) **[2]**

31. M/J 4/P2/Q2/a,b,d

(a) $1s^2$ $2s^2\,2p^6$ $3s^2\,3p^3$ **[1]**

(b) 5 or V **[1]**

(c) (i) $P_4S_3 + 8O_2 \longrightarrow P_4O_{10} + 3SO_2$ (or $2P_2O_5$) balanced = 2 marks

OR $+ 6O_2 \longrightarrow P_4O_6 + 3SO_2$ (or $2P_2O_3$) unbalanced = 1 mark **[2]**

(ii) $P_4O_{10} + 6H_2O \longrightarrow 4H_3PO_4$ **[1]**

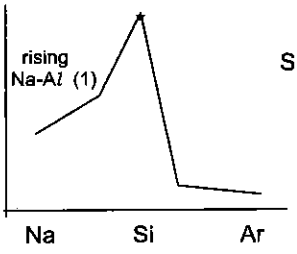
OR $P_4O_6 + 6H_2O \longrightarrow 4H_3PO_3$

$SO_2 + H_2O \longrightarrow H_2SO_3$ **[1]**

(if SO_3 then e.c.f.)

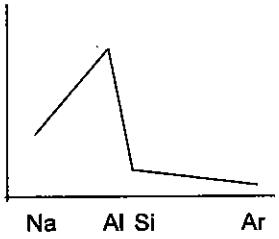
32. M/J 3/P2/Q4

(a) (i) m.p.



Si to Ar (1) **[2]**

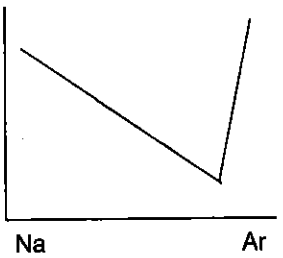
(ii) el. cond.



rising Na-Al (1)

P – Ar (below Na) (1) **[2]**

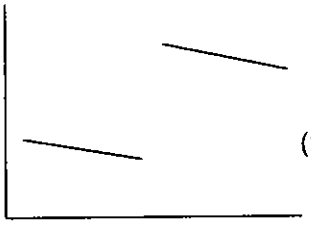
(iii) at. rad.



(in data booklet)

(1) **[1]**

(iv) ionic rad.



(in data booklet)

(1) **[1]**

[6]

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(b) **(i)** Na_2O MgO Al_2O_3 P_2O_5 (or P_4O_{10} or P_2O_3) SO_2 or SO_3 (1)

(ii) $Na_2O + H_2O \rightarrow 2NaOH$ (1)

(iii) $2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$ (1) or $NaHSO_3$

<u>OR</u> $2NaOH + SO_3 \rightarrow Na_2SO_4 + H_2O$ (1) $NaHSO_4$ **[3]**

33. O/N 2/P2/Q3/,b,c

(b) (i) Na_2O

(ii) MgO or Al_2O_3

(iii) SO_3 (allow SO_2)

(iv) SO_2 or SO_3

(v) SO_2 1 each [5]

(c) (i) $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$

(ii) $NaOH + SO_2 \rightarrow NaHSO_3$ or $2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$

1 each [2]

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UNIT 10

Group II

A-Level
Chemistry Paper 2
Topical Workbook



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Unit 10: Group II

1. **MAR 17/P22/Q1/c (i, ii)**

(a) Cerium is a lanthanoid metal that shows similar chemical reactions to some elements in th third period. Most of cerium's compounds contain Ce^{3+} or Ce^{4+} ions.

(i) Cerium shows the same structure and bonding as a typical metal.

Draw a labelled diagram to show the structure and bonding in cerium.

[2]

(ii) Cerium(IV) oxide, CeO_2, is a ceramic.

Suggest **two** physical properties of cerium(IV) oxide.

1. .....

2. .....

[2]

2. **M/J 17/P21/Q3/b (i, ii, iii)**

(a) The elements in Group 2 all react with oxygen and with water.

(i) State and explain the conditions needed for magnesium to react with oxygen.

.....

..... [2]

(ii) State what would be seen during the reaction in **(b)(i)**.

.....

..... [1]

(iii) Write an equation for the reaction of magnesium with cold water.
Include state symbols.

..... [2]

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3. M/J 16/P21/Q3/a,b (ii, iii, iv), c

The elements in Group 2, and their compounds, show many similarities and trends in their properties.

(a) Magnesium, calcium, strontium and barium all react with cold water.

(i) Describe what you would **see** when some calcium is added to cold water.

.....

.....

..... [3]

(ii) Write an equation for the reaction taking place in **(i)**.

.....[1]

(iii) Describe how the reaction of barium with cold water would differ from the reaction of calcium in **(i)** in terms of what you would **see**.

.....

..... [1]

(b) Magnesium oxide can be formed by the reaction of magnesium and oxygen in the air.

(i) Explain why there is no visible reaction when a piece of magnesium ribbon is exposed to the air.

.....

.....

.....[2]

(ii) Magnesium oxide is used to manufacture heat-resistant bricks for furnace linings in the steel-making industry.

State and explain the property of magnesium oxide that makes it suitable for this use.

.....

.....

.....

..... [2]

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(iii) Suggest a reason why magnesium oxide cannot be used as a lining for any furnaces containing acidic materials.

.....

..... [1]

(c) The nitrates and carbonates of the Group 2 elements, from magnesium to barium, decompose when heated.

(i) State the trend in the temperature of thermal decomposition of these Group 2 nitrates and carbonates.

.....

..... [1]

(ii) Give the equation for the thermal decomposition of magnesium carbonate.

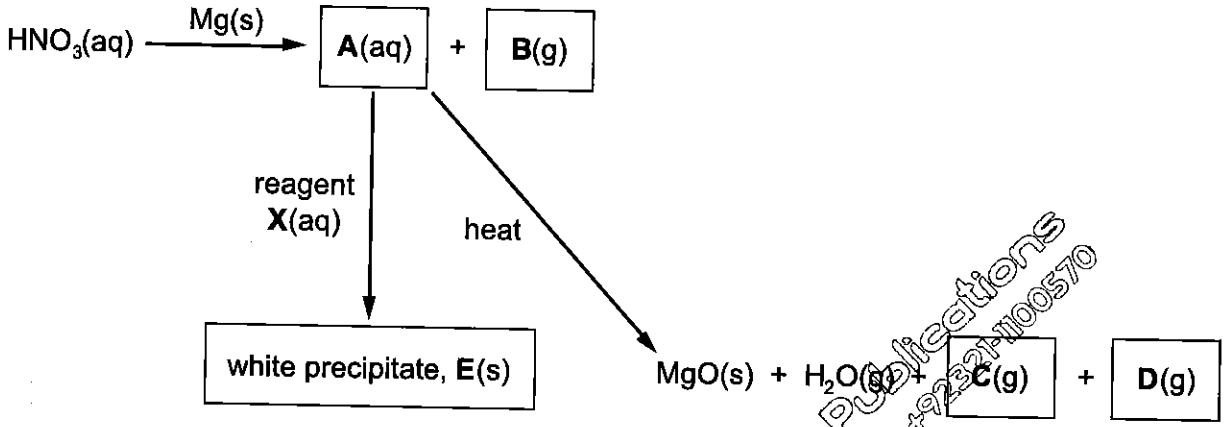
..... [1]

(iii) Give the equation for the thermal decomposition of calcium nitrate.

..... [1]

4. MARCH 16/P22/Q1/b (i)

(a) The flow chart below shows a series of reactions.



(i) Give the **formula** of each of the compounds **A** to **D**.

A ..... **B** .....

C ..... **D** .....

[4]

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5. M/J 15/P23/Q2

The elements in Group II, and their compounds, show a variety of trends in their properties.

(a) Magnesium, calcium and barium all react with cold water to form hydroxides.

(i) Describe and explain the trend in reactivity of these three elements with cold water.

.....

.....

.....

.....

..... [3]

(ii) Give the equation for the reaction of magnesium with cold water.

..... [1]

(iii) Suggest why the water eventually turns cloudy during the reaction of magnesium with cold water.

.....

..... [1]

(iv) Suggest the equation for the reaction of hot magnesium with steam.

..... [1]

(b) The oxides of magnesium, calcium and barium all react with dilute nitric acid to form nitrates.

(i) Give the equation for the reaction of magnesium oxide with nitric acid.

..... [1]

(ii) State the trend in thermal stability of the nitrates of Group II.

.....

..... [1]

(iii) Give the equation for the thermal decomposition of magnesium nitrate.

..... [1]

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(iv) Apart from lithium nitrate, the nitrates of the Group I elements decompose in a different way to those of the Group II elements.
The equation for the thermal decomposition of potassium nitrate is

$$2KNO_3 \rightarrow 2KNO_2 + O_2$$

By identifying any changes in oxidation number, explain which element is reduced and which is oxidised in this decomposition.

.....

.....

.....

..... [3]

(c) A refractory material is one that does not decompose or melt at very high temperatures. Over 50% of magnesium oxide production is for use as a refractory material.

Explain why magnesium oxide has a very high melting point.

.....

.....

..... [2]

(d) The word 'lime' is usually used to refer to a range of calcium-containing compounds that have a range of uses.

(i) Write equations to show how calcium carbonate can be converted into calcium hydroxide by a two-step process.

.....

..... [2]

A garden pond, with a total volume of 8000 dm^3, has been contaminated in such a way that its pH has fallen to 4. This means that the concentration of hydrogen ions, H^+, in the water is 1×10^{-4} mol dm^{-3}.

(ii) Write an ionic equation for the neutralisation reaction that occurs between hydrogen ions and carbonate ions, CO_3^{2-}.

..... [1]

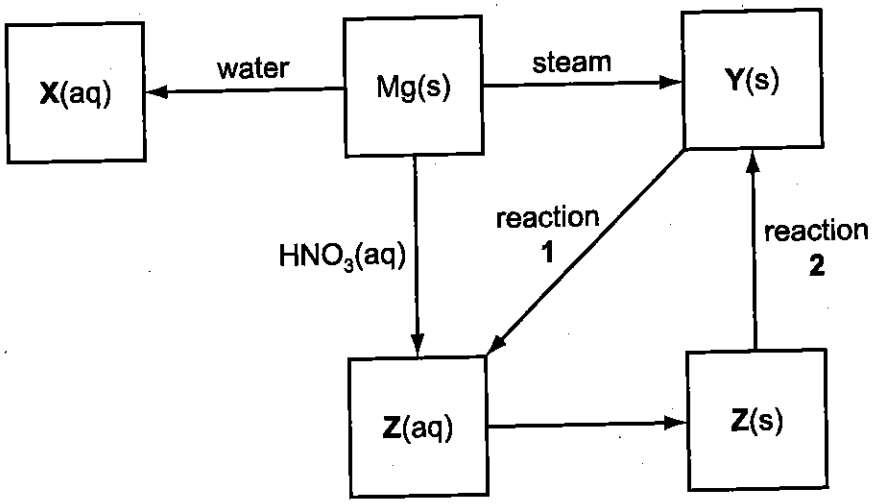
(iii) Use your equation to calculate the mass of powdered calcium carbonate that would need to be added to the pond to neutralise the acidity.

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mass = ... g [2]

6. O/N 14/P22/Q1/d

(a) Some reactions involving magnesium and its compounds are shown in the reaction scheme below.



(i) Give the **formulae** of the compounds **X**, **Y** and **Z**.

X .....

Y .....

Z .....

[3]

(ii) Name the reagent needed to convert **Y**(s) into **Z**(aq) in reaction **1** and write an equation for the reaction.

reagent .....

equation .....

[2]

(iii) How would you convert a sample of **Z**(s) into **Y**(s) in reaction **2**?

..... [1]

(iv) Give equations for the conversions of Mg into **X**, and **Z**(s) into **Y**.

Mg to **X** .....

Z to **Y** .....

[2]

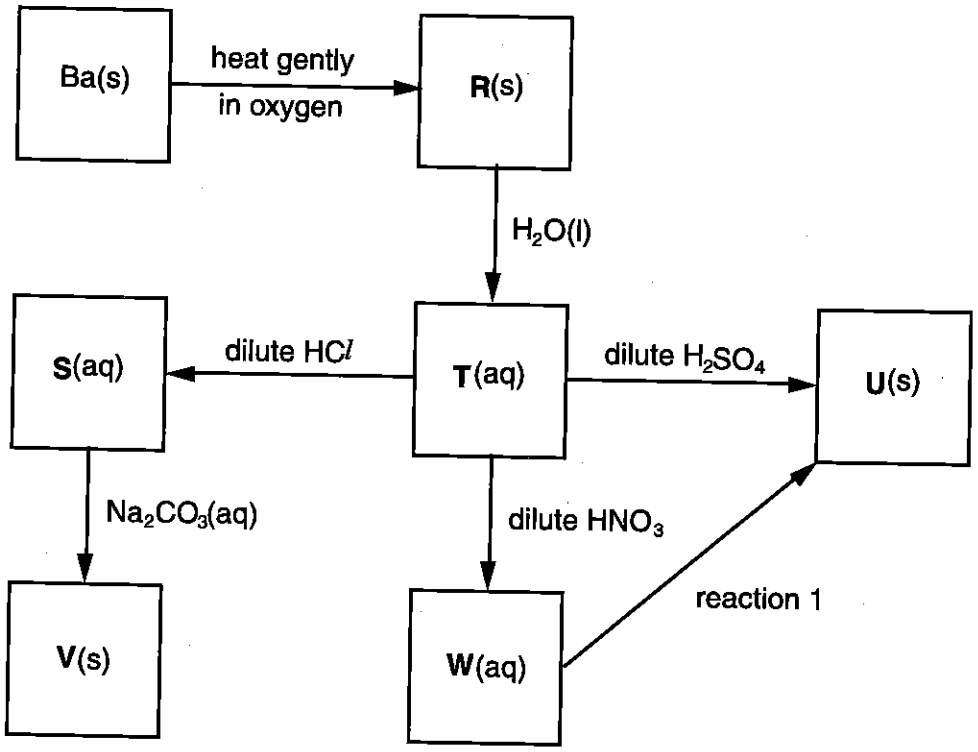
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7. M/J 11/P22/Q3

Barium, proton number 56, is a Group II element which occurs in nature as the carbonate or sulfate.

The element was first isolated by Sir Humphry Davy in 1808.

Some reactions of barium and its compounds are shown in the reaction scheme below.



(a) State the formula of **each** of the barium compounds **R** to **W**.

R ..... **S** .....

T..... **U** .....

V ..... **W** ..... [6]

(b) (i) Write balanced equations for the following reactions.

compound **T** to compound **W**

.....

the roasting of **V** in air

.....

(ii) Suggest a gaseous reagent for the conversion of **T** into **V** and write a balanced equation for the reaction.

reagent .....

equation ..... [4]

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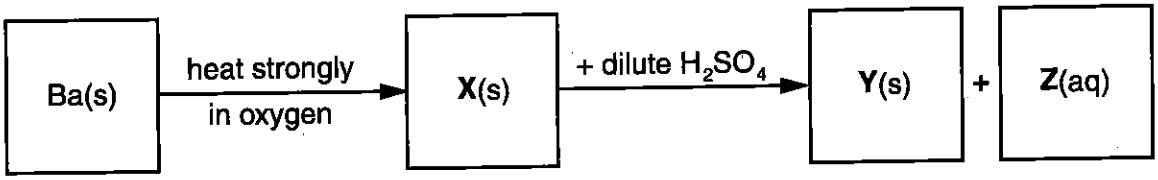
(c) Suggest the formula of an aqueous reagent, other than an acid, for reaction 1.

.....

[1]

When barium is heated strongly in oxygen, an oxide **X** is formed.
The oxide **X** contains 18.9% of oxygen by mass.

The oxide **X** reacts with dilute sulfuric acid in a 1:1 ratio.
Two products, one insoluble and one soluble, are formed.



(d) (i) Calculate the empirical formula of **X**.

(ii) Suggest the identity of the solid **Y**.

.....

(iii) Use your answers to **(i)** and **(ii)** to construct an equation for the reaction of **X** with H_2SO_4.

.....

[4]

[15]

(ii) Construct a balanced equation for the effect of heat on solid compound **W**.

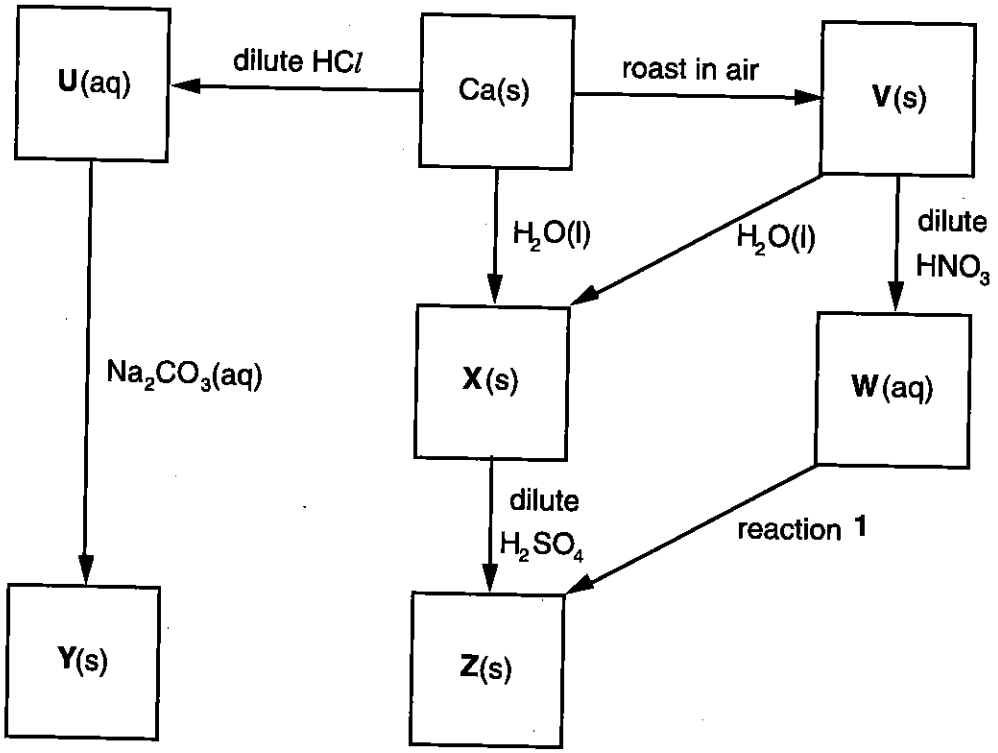
.....

[4]

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8. M/J 11/P21Q3

Calcium is the fifth most common element in the Earth's crust.
Calcium compounds occur in bones and teeth and also in many minerals.
Some reactions of calcium and its compounds are shown in the reaction scheme below.



(a) State the formula of **each** of the calcium compounds **U** to **Y**.

U .....

V .....

W .....

X .....

Y ..... [5]

(b) Compound **Y** may be converted into compound **V**.
Outline how this reaction would be carried out in a school or college laboratory using a small sample of **Y**.

.....

..... [1]

(c) **(i)** Construct balanced equations for the following reactions.

calcium to compound **U**

.....

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compound **V** to compound **W**

.....

compound **U** to compound **Y**

.....

(ii) Construct a balanced equation for the effect of heat on solid compound **W**.

.....

[4]

(d) Suggest the formula of an aqueous reagent, other than an acid, for reaction **1**.

..... **[1]**

(e) What would be observed when **each** of the following reactions is carried out in a test-tube?
the formation of **X** from Ca(s)

.....

the formation of **X** from **V**

.....

[2]

9. O/N 09/P21/Q2/a,c,

(a) Radium has chemical reactions that are typical of Group II metals and forms ionic compounds.

(i) What is the characteristic feature of the electronic configurations of all Group II metals?

.....

(ii) Radium sulfate is extremely insoluble. From your knowledge of the simple salts of Group II metals, suggest another very insoluble radium salt.

..... **[2]**

(b) (i) Describe what you would see when magnesium reacts with

cold water, ...

.....

steam. .....

.....

(ii) Write an equation for the reaction with steam.

.....

[5]

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10. M/J 07/P2/Q3

This question is about the elements in Group II of the Periodic Table, magnesium to barium.

(a) Complete the table below to show the electronic configuration of calcium atoms and of strontium ions, Sr^{2+}.

	1s	2s	2p	3s	3p	3d	4s	4p	4d
Ca	2	2	6						
Sr^{2+}	2	2	6						

[2]

(b) Explain the following observations.

(i) The atomic radii of Group II elements increase down the Group.

.....

.....

(ii) The strontium ion is smaller than the strontium atom.

.....

.....

(iii) The first ionisation energies of the elements of Group II decrease with increasing proton number.

.....

.....

.....

.....

[4]

(c) Samples of magnesium and calcium are placed separately in cold water and left for some time. In **each case**, describe what you would see and write a balanced equation for each reaction.

(i) magnesium

observation .....

.....

equation .....

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(ii) calcium

observation .....

.....

equation .....

[6]

(d) Strontium nitrate, $Sr(NO_3)_2$ undergoes thermal decomposition.

(i) State one observation you would make during this reaction.

.....

.....

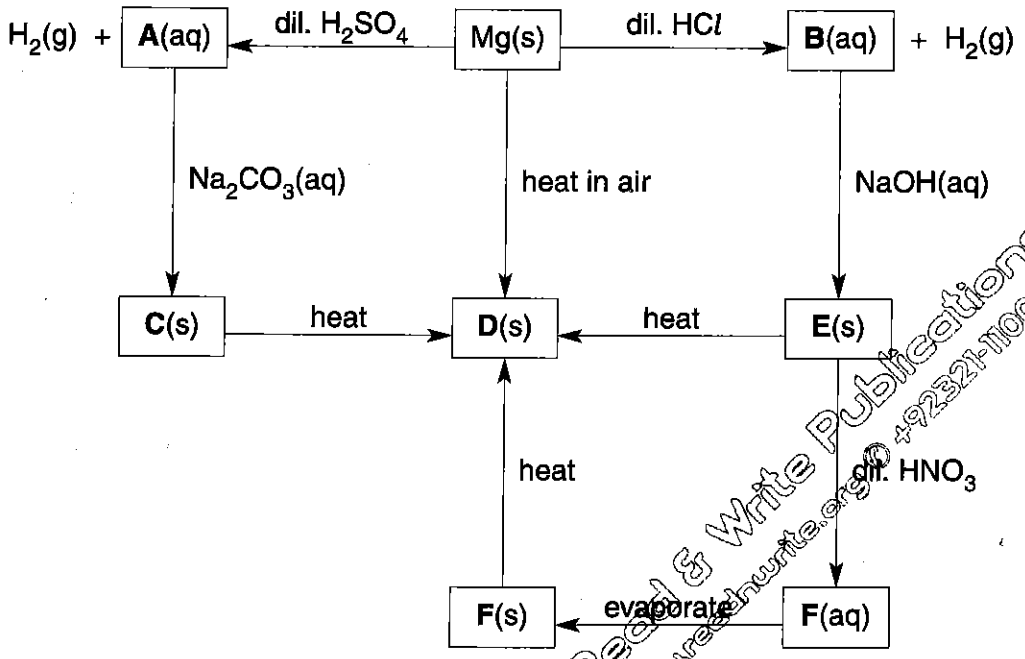
(ii) Write a balanced equation for this reaction.

.....

[4]

11. M/J 5/P2/Q3

Magnesium is the eighth most common element in the Earth's crust.
The metal is widely used in alloys which are light and strong.
Some reactions of magnesium and its compounds are shown in the reaction scheme below.



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(a) Identify, by name or formula, compounds **A** to **F**.

A .....

B .....

C .....

D .....

E .....

F .....

[6]

(b) **(i)** Construct balanced equations for the following reactions.
magnesium to compound **A**

.....

compound **C** to compound **D**

.....

compound **F** to compound **D**

.....

(ii) Suggest a balanced equation for the effect of heat on compound **E**.

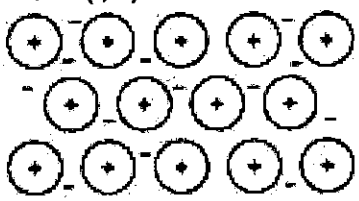
..... [4]

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Answers Section

1. MAR 17/P22/Q1/c (i, ii)

(a) (i)



2

diagram showing regular arrangement of (positive) ions 1
surrounded by 1

(ii) any 2 from: 2
- high melting
- electrical
- hard / rigid
- retains strength at high temperature pressure

2. M/J 17/P21/Q3/b (i, ii, iii)

(a) (i) (strong) heating 1
(to provide / overcome) high activation energy 1

(ii) white flame / white light / white smoke / white solid 1

(iii) $Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$ 2

3. M/J 16/P21/Q3/a,b (ii, iii, iv), c

(a) (i) bubbles / effervescence / fizzing [1]
calcium gets smaller / disappears [1] max
water turns cloudy / milky [1] [3]
calcium sinks [1]

(ii) $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$ [1] [1]

(iii) faster bubbling / disappearance of Ba
OR
no / less precipitate forms (owtte) [1] [1]

(b) (i) activation energy is high [1] [2]
so few/no particles with $E > E_a$ [1]

(ii) high melting / boiling point [1] [2]
strong forces (of attraction / between oppositely charged ions) / strong (ionic) bonding [1]

(iii) MgO is basic / reacts with acid [1] [1]

(c) (i) increases (down the group) [1] [1]

(ii) $MgCO_3 \rightarrow MgO + CO_2$ [1] [1]

(iii) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$ [1] [1]

4. MARCH 16/P22/Q1/b (i)

(a) (i) **A** = $Mg(NO_3)_2$ [1]
B = H_2 [1] [4]
C = NO_2 OR O_2 [1]
D = O_2 OR NO_2 [1]

5. M/J 15/P23/Q2

(a) (i) Reactivity increases down the group [1]
OR reference to observations that indicate trend
Outer electrons lost more easily down group [1]
Due to increased distance/shielding of outer electrons from nucleus [1] [3]

(ii) $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$ [1] [1]

(iii) Magnesium hydroxide sparingly soluble/insoluble [1] [1]

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(iv) $Mg + H_2O \rightarrow MgO + H_2$ [1] [1]

(b) **(i)** $MgO + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$ [1] [1]

(ii) (thermal stability) increases down the group [1] [1]

(iii) $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$ [1] [1]

(iv) N from (+)5 to (+)3 [1]
O from –2 to 0 [1]
N is reduced **and** O is oxidised [1] [3]

(c) (Very) strong electrostatic attraction/ionic bond [1]
High charge (density) of cation and anion/Mg^{2+} and O^{2-} [1] [2]

(d) **(i)** $CaCO_3 \rightarrow CaO + CO_2$ [1]
$CaO + H_2O \rightarrow Ca(OH)_2$ [1] [2]

(ii) $2H^+ + CO_3^{2-} \rightarrow CO_2 + H_2O$ [1] [1]

(iii) $1 \times 10^{-4} \times 8000 = 0.8$ mol H^+ [1]

$\frac{0.8}{2} \times 100.1 =$ mass $CaCO_3 = 40$ g [1] [2]

6. O/N 14/P22/Q1/d

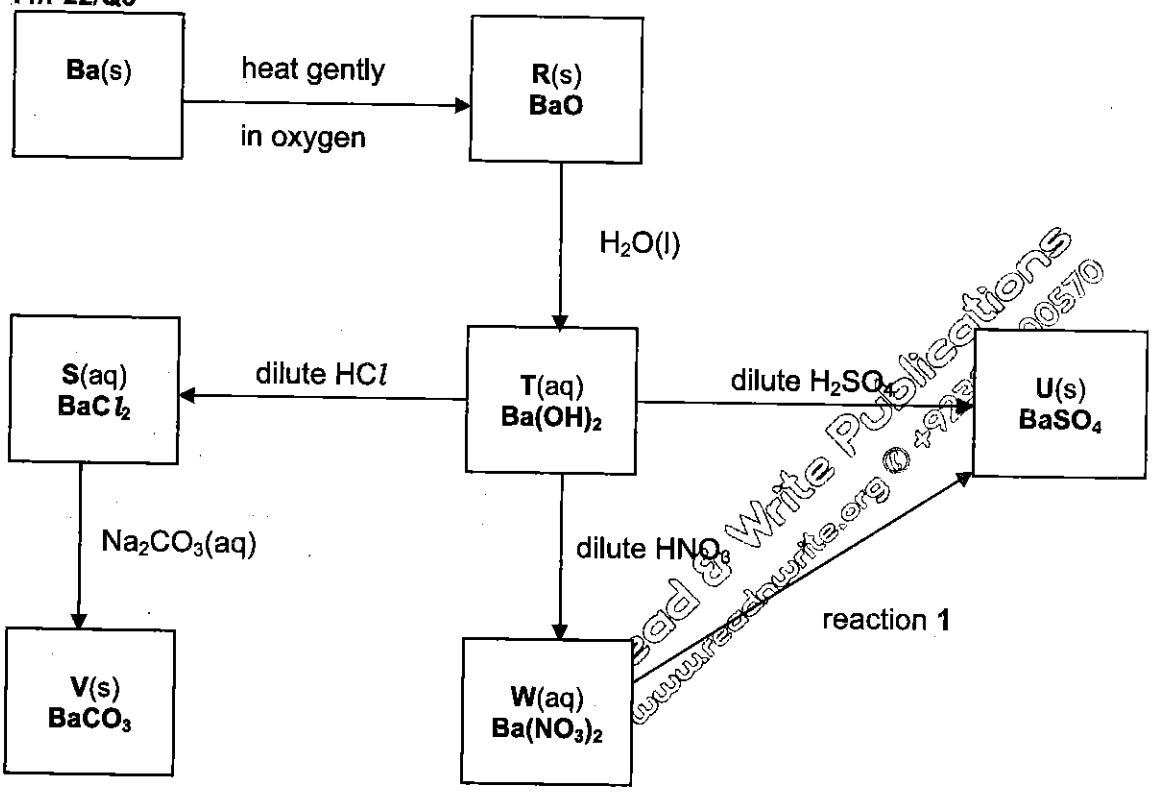
(d) **(i)** **X** = $Mg(OH)_2$ 1
Y = MgO 1
Z = $Mg(NO_3)_2$ 1 [3]

(ii) reagent = nitric acid 1
$MgO + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$ 1 [2]

(iii) Heat / thermal decomposition 1 [1]

(iv) $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$ 1
$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$ 1 [2]

7. M/J 11/P22/Q3



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(a) **R** BaO (1)
S $BaCl_2$ (1)
T $Ba(OH)_2$ (1)
U $BaSO_4$ (1)
V $BaCO_3$ (1)
W $Ba(NO_3)_2$ (1) [6]

(b) **(i)** **T** to **W**
$Ba(OH)_2 + 2HNO_3 \rightarrow Ba(NO_3)_2 + 2H_2O$ (1)

heat on **V**
$BaCO_3 \rightarrow BaO + CO_2$ (1)

(ii) **T** to **V**
CO_2 (1)
$Ba(OH)_2 + CO_2 \rightarrow BaCO_3 + H_2O$ (1) [4]

(c) $Na_2SO_4(aq)/K_2SO_4(aq)$ or any soluble sulfate (1) [1]

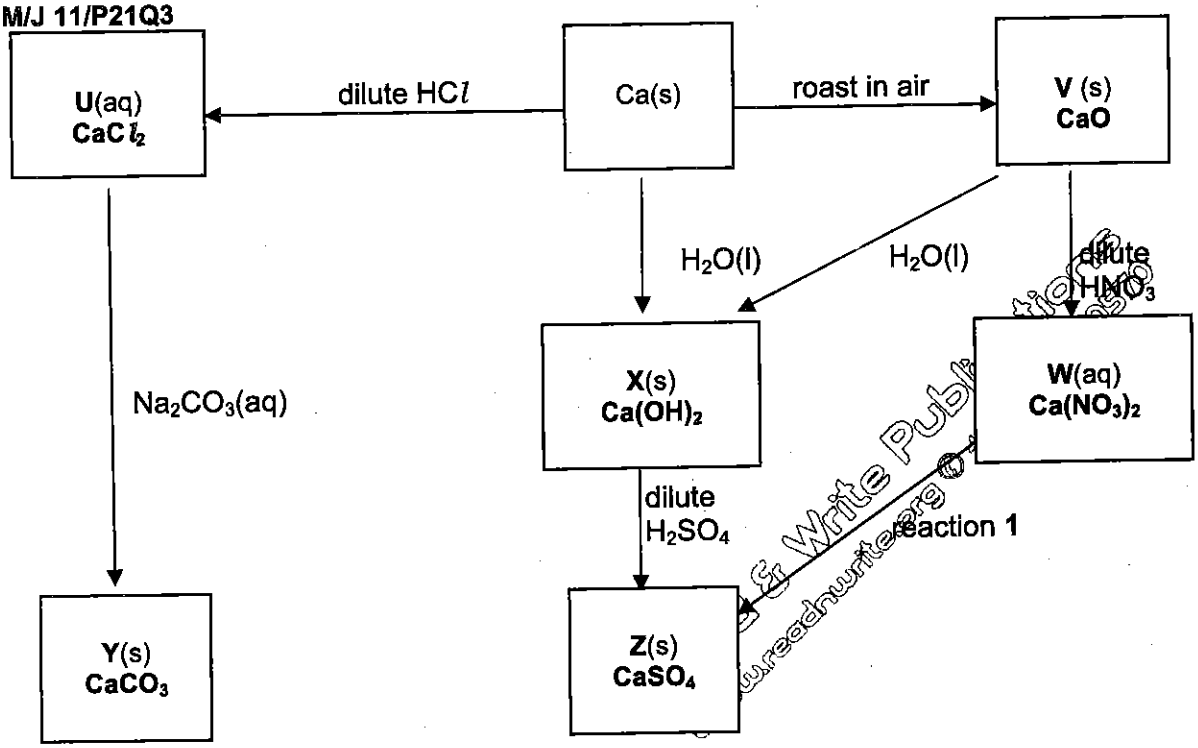
(d) **(i)** Ba:O = $\frac{81.1}{137} : \frac{18.9}{16}$ (1)

= 0.59 : 1.18
= 1 : 2
gives BaO_2 (1)

(ii) $BaSO_4$ (1)

(iii) $BaO_2 + H_2SO_4 \rightarrow BaSO_4 + H_2O_2$ (1) [4]

8. **M/J 11/P21Q3**



(a) **U** $CaCl_2$ (1)
V CaO (1)
W $Ca(NO_3)_2$ (1)

X $Ca(OH)_2$ (1)
Y $CaCO_3$ (1) [5]

(b) heat strongly in a test-tube or a boiling tube
do not allow 'heat gently' or 'reflux' (1) [1]

(c) **(i)** Ca to **U**
$Ca + 2HCl \rightarrow CaCl_2 + H_2$ (1)

V to **W**
$CaO + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$ (1)

U to **Y**
$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$ (1)

(ii) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$ (1) [4]

(d) $Na_2SO_4(aq)/K_2SO_4(aq)$ **or** formula of any **soluble** sulfate (1) [1]

(e) (i) Ca to X
colourless gas formed/fizzing/effervescence/bubbles
Ca dissolves or
white precipitate/suspension formed (1)

(ii) strongly exothermic/vigorous reaction
steam formed/steamy fumes
surface crumbles (1)
do not allow white ppt. [2]

9. O/N 09/P21/Q2/a,c,

(a) **(i)** configuration ends in s^2
or there are two electrons in outermost/valence shell (1)

(ii) $RaCO_3$/radium carbonate (1) [2]

(b) **(i)** water: slow reaction; gas bubbles; gas is colourless — any 2 (2)

steam: Mg glows; vigorous reaction; white solid formed — any 2 (2)

(ii) $Mg + HO_2 \rightarrow MgO + H_2$ (1) [5]

10. M/J 07/P2/Q3

(a)

	1s	2s	2p	3s	3p	3d	4s	4p	4d	
Ca	2	2	6	2	6	0	2	0	0	[1]
Sr^{2+}	2	2	6	2	6	10	2	6		[1]

[2]

(b) **(i)** more shells of electrons [1]

(ii) outermost shell has been removed [1]

(iii) outermost electrons are further from nucleus/there are more shells [1]
ncreased shielding [1] **[4]**

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(c) (i) very slow reaction [1]
ormation of bubbles of gas [1]

$Mg + H_2O \rightarrow MgO + H_2$ [1]
allow $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$

(ii) faster reaction than with Mg [1]

white suspension formed
or evolution of gas [1]
or calcium dissolves/disappears [1]

$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$ [1]

allow 1 mark in **(i)** *or* **(ii)** if gas is described as colourless [1] **[7]**

(d) (i) gas evolved [1]
gas is brown

(ii) $2Sr(NO_3)_2 \rightarrow 2SrO + 4NO_2 + O_2$ [1]
correct products [1]
balanced equation **[4]**

11. M/J 5/P2/Q3

(a) **A** $MgSO_4$
B $MgCl_2$
C $MgCO_3$
D MgO
E $Mg(OH)_2$
F $Mg(NO_3)_2$

Accept name or formula
but penalise when name and formula do not agree **(6 x 1) [6]**

(b) (i) Mg to cpd **A** (1)
$Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$
cpd **C** to cpd **D** (1)
$MgCO_3 \rightarrow MgO + CO_2$
cpd **F to** cpd **D** (1) **[3]**
$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$

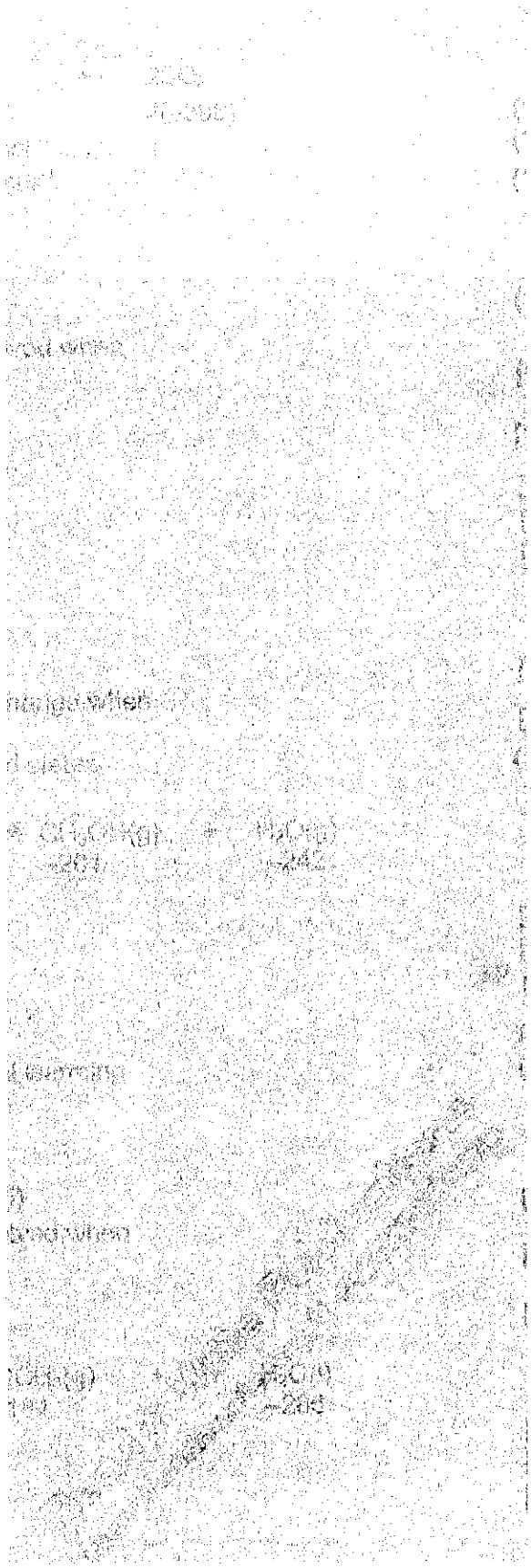
(ii) $Mg(OH)_2 \rightarrow MgO + H_2O$ (1) **[1]**

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UNIT 11

Group 17

A-Level
Chemistry Paper 2
Topical Workbook



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Unit 11: Group 17

1. M/J 17/P23/Q2

The halogens, chlorine, bromine and iodine, and their compounds, show a variety of similarities and trends in their physical and chemical properties.

(a) (i) Give the colours and states of chlorine, bromine and iodine at room temperature and pressure.

halogen	colour	state
chlorine		
bromine		
iodine		

[2]

(ii) The halogens become less volatile down the group.

Explain this trend in volatility.

.....

.....

..... **[2]**

(b) The halogens are oxidising agents.

State and explain the trend in oxidising power of the halogens.

.....

.....

.....

..... **[3]**

(c) Concentrated sulfuric acid reacts with solid sodium halides.

(i) State any observations that would be made on addition of concentrated sulfuric acid to

- solid sodium chloride, ...

.....

- solid sodium iodide. .....

.....

[2]

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(ii) Give reasons for the difference in the observations in **(i)**.

.....

.....

..... [2]

(iii) The addition of concentrated sulfuric acid to solid sodium bromide, NaBr, produces brown fumes and an acidic gas that decolourises acidified potassium manganate(VII) solution. This acidic gas is a significant contributor to acid rain.

Write the equation for the reaction of concentrated sulfuric acid with sodium bromide.

..... [2]

(d) An aqueous solution, **Z**, contains a mixture of sodium chloride and sodium iodide.

(i) Excess aqueous silver nitrate is added to **Z** in a test-tube. A yellow precipitate forms.

Explain the colour of this precipitate.

.....

..... [1]

(ii) Aqueous ammonia is then added to the test-tube in **(i)**. The mass of precipitate decreases.

Explain this observation.

.....

..... [1]

[15]

2. M/J 17/P22/Q3/a

The hydrogen halides, HCl, HBr and HI, can undergo thermal decomposition.
In a sealed container an equilibrium is established according to the equation shown.

$$2HX(g) \rightleftharpoons H_2(g) + X_2(g) \quad \text{(where X = Cl, Br or I)}$$

(a) Some bond energies are shown in the table.

	bond energy / kJ mol^{-1}
H–Br	366
H–H	436
Br–Br	193

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Use these data to calculate a value for the enthalpy change, ΔH, for the thermal decomposition of hydrogen bromide, HBr, according to the equation shown.

ΔH = ... kJ mol^{-1} **[1]**

3. MAR 17/P22/Q2/a(iii),b

Hydrogen halides are compounds formed when halogens (Group 17 elements) react with hydrogen. The bond polarity of the hydrogen halides decreases from HF to HI.

Some relevant data are shown in the table.

hydrogen halide	HF	HC*l*	HBr	HI
boiling point / °C	19	–85	–67	–35
H–X bond energy / kJ mol^{-1}	562	431	366	299

(a) Describe and explain the relative thermal stabilities of the hydrogen halides.

.....

.....

.....

.....

.....

..... **[3]**

(b) The equation for the preparation of hydrogen chloride using concentrated sulfuric acid is shown.

$$H_2SO_4 + NaCl \rightarrow NaHSO_4 + HCl$$

(i) Use the Brønsted-Lowry theory of acids and bases to identify the base and its conjugate acid in this reaction. Explain your answer.

Brønsted-Lowry base (base-I) = ...

conjugate acid (acid-II) = ...

.....

.....

..... **[2]**

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(ii) Explain why the reaction of concentrated sulfuric acid and sodium iodide is **not** suitable for the preparation of hydrogen iodide.

.....

.....

.....

..... [2]

4. M/J 16/P22/Q2/b,c

The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

element	bond energy /kJ mol^{-1}	standard enthalpy change of atomisation, ΔH_{at}^{e} /kJ mol^{-1}	boiling point of element /K	boiling point of **hydrogen halide** /K
fluorine, F–F	158	79	85	293
chlorine, C*l*–C*l*	242	121	238	188
bromine, Br–Br	193	112	332	206
iodine, I–I	151	107	457	238

(a) (i) Explain the trend in the boiling points of the hydrogen halides, HC*l*, HBr and HI.

.....

.....

..... [2]

(ii) Suggest why the hydrogen halide HF does not follow the trend in boiling points shown by HC*l*, HBr and HI.

.....

.....

..... [2]

(b) In an experiment, two of the halogens are represented as $\mathbf{P}_2$ and $\mathbf{Q}_2$.

$\mathbf{P}_2$ combines with hydrogen on heating to form H**P**, which can be easily broken down into its elements. A solution of H**P** in water reacts with aqueous silver ions to form a yellow precipitate that is insoluble in dilute aqueous ammonia.

$\mathbf{Q}_2$ combines explosively with hydrogen in sunlight to form H**Q**, which is stable to heat. A solution of H**Q** in water reacts with aqueous silver ions to form a white precipitate that is soluble in dilute aqueous ammonia.

(i) Identify the halogens $\mathbf{P}_2$ and $\mathbf{Q}_2$.

$\mathbf{P}_2$ = ... $\mathbf{Q}_2$ = ...

[1]

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(ii) HP readily decomposes into its elements when heated but HQ is stable to heat. Explain this with reference to bond energies.

.....

.....

..... [2]

(iii) Write an equation for the thermal decomposition of HP.

..... [1]

(iv) Write ionic equations, including state symbols, for

1. the formation of the white precipitate on addition of aqueous silver ions to aqueous HQ,

.....

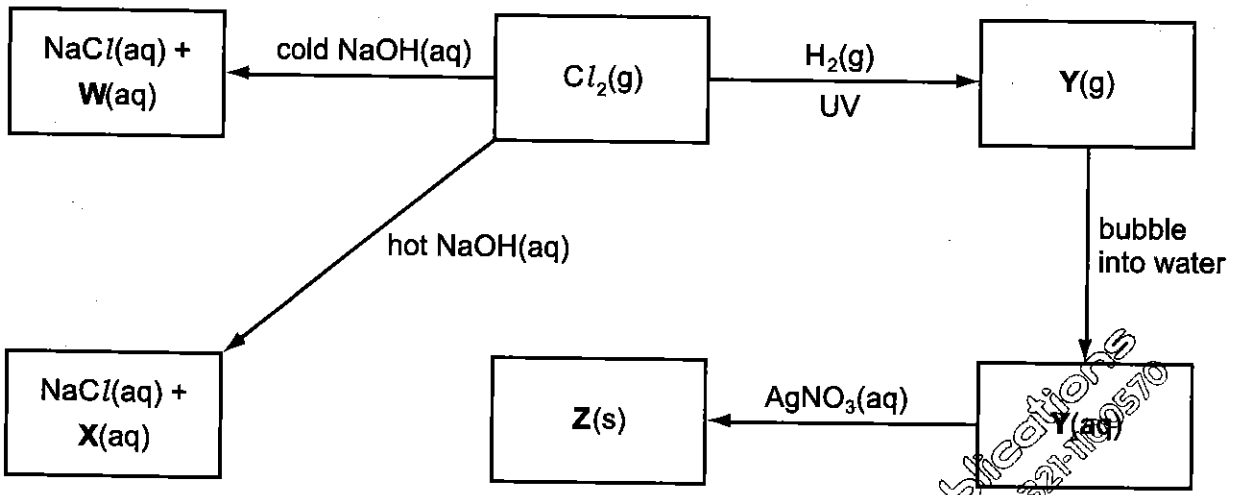
2. the subsequent dissolving of this precipitate in dilute aqueous ammonia.

.....

[2]

5. O/N 14/P23/Q1/d

(a) Some reactions involving chlorine and its compounds are shown in the reaction scheme below.



(i) Give the **formulae** of **W**, **X**, **Y** and **Z**.

W .....

X .....

Y .....

Z .....

[4]

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(ii) Write an equation for the reaction of chlorine with **hot** NaOH(aq).

..... [2]

(iii) State the oxidation numbers of chlorine at the start and at the end of the reaction in (ii).

..... [2]

(iv) Write an **ionic** equation for the reaction of **Y** with $AgNO_3$(aq). Include state symbols.

..... [1]

6. M/J 14/P23/Q4/a,b

The halogens and their compounds have a wide variety of uses and the chemical and physical properties of the elements show regular patterns related to their positions in Group VII.

(a) Chlorine, bromine and iodine all react with hydrogen.

(i) State the trend in the reactivities of the halogens with hydrogen.

.....

..... [1]

(ii) Explain this trend in terms of bond energies.

.....

.....

..... [2]

(b) In the laboratory it is not very convenient to prepare hydrogen halides from their elements.

Hydrogen halides can be prepared from their salts.

(i) Write an equation for the reaction of calcium chloride, $CaCl_2$, with concentrated sulfuric acid.

..... [1]

(ii) Explain why hydrogen iodide is not prepared in this way.

.....

..... [1]

(iii) When potassium bromide, KBr, reacts with concentrated sulfuric acid, sulfur dioxide, SO_2, is produced. State what you would **see** and write an equation for this reaction.

.....

..... [3]

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7. M/J 14/P21/Q3/a

(a) In this question, **K**, **L** and **M** refer to a halogen atom or halide ion.
For each part question, read the information and complete the answer lines below.

(i) When concentrated sulfuric acid is added to solid Na**K**, white fumes are produced that turn damp blue litmus paper red. No other colour changes are observed.

identity of **K** = ...

equation for reaction .....

explanation of observation .....

..... **[3]**

(ii) When silver nitrate solution is added to an aqueous solution of Na**L**, a precipitate forms that remains after the addition of concentrated ammonia solution.

identity of **L** = ...

colour of precipitate .....

equation for reaction ..... **[3]**

(iii) $\mathbf{M}_2$ is a liquid at room temperature with a boiling point higher than that of chlorine but lower than that of iodine.

identity of **M** = ...

explanation .....

.....

.....

.....

..... **[2]**

8. O/N 13/P22/Q3/d

Chlorine gas is manufactured by the electrolysis of brine using a diaphragm cell.

(a) Magnesium chloride, $MgCl_2$, and silicon tetrachloride, $SiCl_4$, each dissolve in or react with water.

Suggest the approximate pH of the solution formed in **each** case.

$MgCl_2$ ..... $SiCl_4$ .....

Explain, with the aid of an equation, the difference between the two values.

.....

.....

.....

..... **[5]**

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9. O/N 13/P21/Q3/c

(a) Chlorine reacts with aqueous sodium hydroxide in two different ways, depending on the conditions used. In each case, water, sodium chloride and one other chlorine-containing compound are formed.

For **each** condition below, give the formula of the **other** chlorine-containing compound and state the oxidation number of chlorine in it.

condition	formula of **other** chlorine-containing compound	oxidation number of chlorine in this compound
cold dilute NaOH(aq)		
hot concentrated NaOH(aq)		

[4]

10. O/N 13/P23/Q3

The elements of Group VII of the Periodic Table show variation in their properties.

(a) (i) Complete the table below, stating the colour of each element in its normal state at room temperature.

halogen	melting point/°C	colour
chlorine	–101	
bromine	–7	
iodine	114	

(ii) Briefly explain why the melting points of the halogens increase from chlorine to iodine.

.....

.....

.....

[4]

(b) The halogens form many interhalogen compounds in which two different halogens are combined. One such compound is bromine monochloride, BrCl.

(i) Complete the electronic configurations of chlorine and bromine.

chlorine	$1s^2 2s^2 2p^6$
bromine	$1s^2 2s^2 2p^6$

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(ii) Draw a 'dot-and-cross' diagram of the BrCl molecule.
Show outermost electrons only.

[2]

(c) Interhalogen compounds like BrCl have similar properties to the halogens.

(i) By considering your answers to **(a)** and **(b)**, predict the physical state of BrCl at room temperature. Explain your answer.

physical state .....

explanation .....

.....

.....

(ii) Suggest the colour of BrCl.

.....

[4]

(d) Cl_2 and BrCl each react with aqueous KI.

(i) Describe what would be seen when Cl_2 is bubbled through aqueous KI for several minutes.

initially .....

.....

after several minutes .....

.....

(ii) Construct an equation for the reaction that occurs.

.....

(iii) Suggest an equation for the reaction that occurs between BrCl and aqueous KI.

.....

(iv) How do Cl_2 and BrCl behave in these reactions?

.....

[5]

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11. O/N 12/P23/Q2

Concentrated sulfuric acid may be used in a school or college laboratory to produce hydrogen chloride by reaction with solid chlorides such as sodium chloride.

(a) (i) What will be seen when concentrated sulfuric acid is carefully added to solid sodium chloride?

.....

(ii) Write a balanced equation for this reaction.

.....

(iii) Solutions of both H_2SO_4 and HC*l* are strong acids.
What is meant by the term *strong acid*?

.....

.....

[3]

(b) If the same reaction is carried out with solid sodium iodide and concentrated sulfuric acid, hydrogen iodide is **not** produced.

(i) State **one** observation you would make when carrying out this reaction with solid sodium iodide.

.....

(ii) Explain why hydrogen iodide is **not** a product of this reaction.

.....

.....

[3]

(c) Aqueous silver nitrate and aqueous ammonia are used to test for the presence of halide ions.

(i) Aqueous silver nitrate is slowly added to aqueous sodium chloride and the resulting mixture is then shaken with an excess of aqueous ammonia.
Describe what you would observe at **each** stage of this process.

.....

.....

.....

.....

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(ii) Write balanced equations, with state symbols, for **all** reactions that occur in this process.

(iii) The same process of adding aqueous silver nitrate followed by an excess of aqueous ammonia is repeated using aqueous sodium iodide instead of aqueous sodium chloride.

State **two** differences that would be observed with aqueous sodium iodide.

.....

.....

[8]

12. O/N 12/P22/Q2/a

Each of the Group VII elements chlorine, bromine and iodine forms a hydride.

(a) (i) Outline how the relative thermal stabilities of these hydrides change from HC*l* to HI.

.....

.....

(ii) Explain the variation you have outlined in **(i)**.

.....

.....

.....

[3]

13. O/N 10/P22/Q5

The gaseous hydrogen halides HC*l*, HBr and HI, may be prepared by reacting the corresponding sodium salt with anhydrous phosphoric(V) acid, H_3PO_4.

When the sodium halide Na*X* was used, the following reaction occurred and a sample of gaseous H*X* was collected in a gas jar.

$$NaX + H_3PO_4 \longrightarrow NaH_2PO_4 + HX$$

A hot glass rod was placed in the sample of H*X* and immediately a red/orange colour was observed.

(a) What is the identity of Na*X*?

.....

[1]

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(b) What gas, other than H*X*, would be formed if concentrated sulfuric acid were used with Na*X* instead of phosphoric(V) acid?

.....

[1]

(c) Suggest why phosphoric(V) acid rather than concentrated sulfuric acid is used to make samples of H*X* from the corresponding sodium salt.
Explain your answer.

.....

.....[1]

14. M/J 06/P2/Q3

This question is about the elements of Group VII, the halogens.

(a) Complete the following table.

halogen	colour	physical state at room temperature
chlorine		
bromine		
iodine		

[2]

(b) Concentrated sulphuric acid is added to separate solid samples of magnesium chloride, magnesium bromide, and magnesium iodide.

(i) Describe, in **each** case, **one** observation you would be able to make.

$MgCl_2$ .....

.....

$MgBr_2$ .....

.....

MgI_2 .....

.....

(ii) Give an equation for the reaction of concentrated sulphuric acid with magnesium chloride.

.....

[4]

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(c) When dilute nitric acid and aqueous silver nitrate are added to a solution of a magnesium halide, MgX_2, a pale cream precipitate is formed.
This precipitate is soluble in concentrated aqueous ammonia but not soluble in dilute aqueous ammonia.

(i) What is the identity of the precipitate?

.....

(ii) Give an equation, with state symbols, for the reaction of the precipitate with concentrated aqueous ammonia.

.....

[3]

(d) A hot glass rod is plunged into separate gas jars, one containing hydrogen chloride and one containing hydrogen iodide.

(i) For **each** gas, state what you would observe, if anything, and write an equation for any reaction that takes place.

HC*l* .....

.....

HI .....

.....

(ii) Explain your answer to **(i)** in terms of enthalpy changes.

.....

.....

.....

(iii) What is the role of the hot glass rod in any reaction that occurs?

.....

.....

[6]

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15. O/N 04/P2/Q3/b,c

(a) Hydrochloric acid is manufactured by burning the hydrogen formed in this electrolysis in chlorine and dissolving the product in water.

(i) Construct an equation for the burning of hydrogen in chlorine.

.....

(ii) When the product of **(i)** dissolves in water there is a change in bonding. Explain with the aid of an equation what change in bonding has occurred.

[2]

(b) Describe, with the aid of equations including state symbols, what happens when

(i) hydrochloric acid is added to aqueous silver nitrate,

.....

.....

(ii) an excess of aqueous ammonia is added to the resulting mixture.

.....

.....

..... [5]

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Answers Section

1. M/J 17/P23/Q2

(a) (i)

halogen	colour	state
chlorine	yellow / green	gas
bromine	red / brown / orange	liquid
iodine	grey / black	solid

2

(ii) increasing number of electrons — 1

(gives) increasing strength of van der Waals' / id-id forces / London / dispers on forces — 1

(b) oxidising power decreases down the group. *ora* — 1

ability to accept electrons decreases (down the group) *ora* — 1

because (outer shell experiences) more shielding — 1

OR

increased distance from nucleus (to outer shell) (outweighs the increasing nuclear charge down the group) *ora*

(c) (i) solid sodium chloride: steamy / misty / white fumes — 1

solid sodium iodide: purple fumes — 1

(ii) (conc sulfuric) not powerful enough oxidising agent (to oxidise chloride) — 1

OR

chloride not powerful enough reducing agent (to reduce sulfuric acid)

iod de reduces sulfuric acid

OR

iodide / I^- is oxidised

OR

sulfuric acid oxidises iodide

(iii) $2NaBr + 2H_2SO_4 \rightarrow Br_2 + SO_2 + Na_2SO_4 + 2H_2O$ — 2

OR

$NaBr + H_2SO_4 \rightarrow NaHSO_4 + HBr$ AND $2HBr + H_2SO_4 \rightarrow Br_2 + SO_2 + 2H_2O$

OR

$2NaBr + H_2SO_4 \rightarrow Na_2SO_4 + 2HBr$ AND $2HBr + H_2SO_4 \rightarrow Br_2 + SO_2 + 2H_2O$

(d) (i) AgI (and AgCl solid) / silver ions reacting with iodide ions — 1

(ii) AgCl (precipitate) dissolves (in ammonia) owtte — 1

2. M/J 17/P22/Q3/a

(a) (+) 103 — 1

3. MAR 17/P22/Q2/a(iii),b

(a) thermal stability of the hydrogen halides decreases down group (17) — 1

larger (halogen) atoms/ atomic radius (down group) / increased shielding — 1

bond energies decrease/ less energy required to break H–X — 1

(b) (i) **M1** — 1

base is Cl^- **AND** conjugate acid is HCl

OR

base is HSO_4^- **AND** conjugate acid is H_2SO_4

M2 — 1

Cl^- / HSO_4^- / base is a proton acceptor

OR

HCl / H_2SO_4 / (conjugate) acid has one more H^+

(ii) H_2SO_4 is (too strong) an oxidising agent — 1

I_2 would be formed instead — 1

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4. M/J 16/P22/Q2/b,c

(a) (i) stronger / more / greater id–id / London / dispersion forces [1]
due to increasing numbers of electrons [1] [2]

(ii) (intermolecular forces in HF are) hydrogen bonds [1]
(which are) stronger (than vd*W*) / more energy needed to separate molecules [2]

OR
HF much more polar / F much more electronegative [1]
Intermolecular forces in HF stronger (than in HC*l*, HBr, HI) [1]

(b) (i) **P** = iodine / I_2 /I; **Q** = chlorine / Cl_2 / C*l* [1] [1]

(ii) weaker H–**P** than H–**Q** bond ORA / easier /less energy to break H–**P** than H–**Q** ORA [1]
due to greater distance / shielding of nucleus from bond pair ORA [1] [2]

(iii) 2H**P** (or 2HI) → (or ⇌) H_2 + $\mathbf{P}_2$ (or I_2) [1] [1]

(iv) $Ag^+(aq)$ + $\mathbf{Q}^-(aq)$ (or Cl^-) → Ag**Q**(s) (or AgC*l*(s)) [1]

Ag**Q**(s) / AgC*l*(s) + $2NH_3(aq)$ → $Ag(NH_3)_2^+(aq)$ + $\mathbf{Q}^-(aq)$ / $Cl^-(aq)$ [1] [2]

5. O/N 14/P23/Q1/d

(a) (i) **W** = NaC*l*O; 1
X = $NaClO_3$; 1
Y = HC*l*; 1
Z = AgC*l* [4]

(ii) $3Cl_2$ + 6NaOH → 5NaC*l* + $NaClO_3$ + $3H_2O$ 1
M1: correct species 1 [2]
M2: balanced equation 1

(iii) 0 to –1 1
(0 to) +5 1 [2]

(iv) $Ag^+(aq)$ + $Cl^-(aq)$ → AgC*l*(s) [1]

6. M/J 14/P23/Q4/a,b

(a) (i) decreases down the group **ora** (1) [1]

(ii) X–X bond strength decreases from C*l*–C*l* to I – I (1)
But decreasing strength of H–X down group more significant (1) [2]

(b) (i) $CaCl_2$ + H_2SO_4 → $CaSO_4$ + 2HC*l* **OR** (1)
$CaCl_2$ + $2H_2SO_4$ → $Ca(HSO_4)_2$ + 2HC*l* [1]

(ii) HI / I^- reduces / is oxidised by conc H_2SO_4 / because iodine is produced instead (1) [1]

(iii) brown gas / fumes produced (1)
$2H_2SO_4$ + 2KBr → SO_2 + Br_2 + $2H_2O$ + K_2SO_4 (or ionic) (1+1) [3]

7. M/J 14/P21/Q3/a

(a) (i) **K** = Cl^- / chloride / F^- / fluoride 1
H_2SO_4 + 2NaC*l* → Na_2SO_4 + 2HC*l* (or equation with F or **K** for C*l*) **OR** 1
H_2SO_4 + NaC*l* → $NaHSO_4$ + HC*l* (or equation with F or **K** for C*l*)
ecf from identity of **K** so long as halide
H**K** is acidic / H**K** is a gas / an acidic gas is produced 1 3

(ii) **L** = I^- / iodide 1
colour = yellow 1
ecf from identity of **L** i.e. Cl^- (white) or Br^- (cream) 3
Ag^+ + I^- → AgI (or equation with **L**) 1
$AgNO_3$ + NaI → AgI + $NaNO_3$ (or equation with **L**)
ecf from identity of **L** so long as halide

(iii) Br_2 / bromine has **fewer electrons** than iodine / **more electrons** than chlorine 1
intermolecular / van der Waals' forces (in Br_2 / $\mathbf{M}_2$) **weaker** than in iodine / **stronger** than in chlorine 1 2

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8. O/N 13/P22/Q3/d

(a) $MgCl_2$ 6.5 to 6.9 (1)

$SiCl_4$ 0 to 3 (1)

$MgCl_2$ dissolves without reaction **or** slight **or** partial hydrolysis occurs (1)

$SiCl_4$ reacts with water **or** hydrolysis occurs (1)

$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$ **or**
$SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$ **or**
$SiCl_4 + 4H_2O \rightarrow SiO_2.2H_2O + 4HCl$ (1) **[5]**

9. O/N 13/P21/Q3/c

(a) cold dilute aqueous NaOH

$NaOCl$ (1)
+1 (1)

hot concentrated aqueous NaOH

$NaClO_3$ (1)
+5 (1) **[4]**

10. O/N 13/P23/Q3

(a) (i)

halogen	melting point/°C	colour
chlorine	-101	green, yellow **or** greenish-yellow
bromine	-7	orange **or** red **or** brown
iodine	114	grey **accept** black

chlorine and bromine **both** correct (1)
iodine correct **for solid** (1)

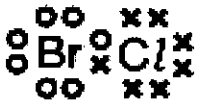
(ii) down the Group
there are more electrons in the molecule (1)
hence stronger van der Waals' forces (1) **[4]**

(b) (i)

chlorine	$1s^2 2s^2 2p^6 3s^2 3p^5$
bromine	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$
or	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$

both needed (1)

(ii)



(1) **[2]**

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(c) **(i)** gas **or** low boiling liquid (1)
BrCl has fewer electrons than Br_2 (1)
hence weaker van der Waals' forces (1)

(ii) accept colours in the range yellow, orange, red, brown (1) **[4]**

(d) **(i)** **initially** solution begins to turn yellow/brown (1)
after several minutes black/dark grey solid formed (1)

(ii) $Cl_2 + 2KI \rightarrow 2KCl + I_2$ (1)

(iii) $BrCl + 2KI \rightarrow KCl + KBr + I_2$ (1)

(iv) as oxidising agents (1) **[5]**

11. O/N 12/P23/Q2

(a) **(i)** white fumes/steamy fumes (1)

(ii) $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ **or**
$2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$ (1)

(iii) an acid that is completely ionised in solution **or**
an acid that is completely dissociated into H^+ ions in solution (1) **[3]**

(b) **(i)** purple/violet vapour (I_2) or black/brown solid (I_2) **or**
irritating/acrid gas (SO_2) or stinking gas (H_2S) **or**
yellow solid (S) (1)

(ii) conc. H_2SO_4 is an oxidising agent **or** HI is a reducing agent (1)
which oxidises HI **or** which reduces H_2SO_4 (1) **[3]**

(c) **(i)** white ppt formed – **not** creamy white or off white (1)
which dissolves in $NH_3(aq)$ (1)

(ii) $NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$ **or**
$Cl^-(aq) + Ag^+(aq) \rightarrow AgCl(s)$
equation (1)
all state symbols correct (1)
$AgCl(s) + 2NH_3(aq) \rightarrow [Ag(NH_3)_2]^+ Cl^-(aq)$ **or**
$AgCl(s) + 2NH_3(aq) \rightarrow [Ag(NH_3)_2] Cl(aq)$
equation (1)
all state symbols correct (1)

(iii) precipitate is yellow (1)
precipitate does not dissolve (1) **[8]**

12. O/N 12/P22/Q2/a

(a) **(i)** thermal stability decreases down Group VII (1)

(ii) from Cl to I, atomic size increases **or**
the bonding pair is further from the nucleus of X **or**
H—X bond becomes longer **or**
smaller orbital overlap occurs (1)
hence H—X bond strength decreases down Group VII (1) **[3]**

13. O/N 10/P22/Q5

(a) NaBr/sodium bromide **[1]**

(b) Br_2/bromine or SO_2/sulfur dioxide **[1]**

(c) concentrated sulfuric acid is an oxidising agent
or
phosphoric(V) acid is **not** an oxidising agent **[1]**

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14. M/J 06/P2/Q3

(a)

halogen	colour	physical state at room temperature
chlorine	green/yellow	gas
bromine	orange/red	liquid
iodine	black	solid

three colours correct (1)
three states correct (1) **[2]**

(b) (i) $MgCl_2$ white fumes/steamy fumes (of HCl) (1)

$MgBr_2$ red colour (of Br_2) **or** steamy fumes (of HBr) (1)

MgI_2 purple colour (of I_2) **or** black solid (I_2) **or** yellow solid (S) **or** stinking gas (H_2S) (1)

(ii) $MgCl_2 + H_2SO_4 \rightarrow MgSO_4 + 2HCl$
allow
$MgCl_2 + 2H_2SO_4 \rightarrow Mg(HSO_4)_2 + 2HCl$ (1) **[4]**

(c) (i) AgBr/silver bromide (1)

(ii) $AgBr(s) + 2NH_3(aq) \rightarrow Ag(NH_3)_2Br(aq)$

equation (may be ionic) (1)
state symbols (1)
allow ecf on wrong halide in **(i)** **[3]**

(d) (i) **HCl** no reaction (1)

HI purple vapour/black solid (1)

$2HI \rightarrow H_2 + I_2$ (1)

(ii) bond energy in HCl is high (1)

bond energy in HI is lower/more easily broken (1)

(iii) hot glass rod provides activation energy (1) **[6]**

15. O/N 04/P2/Q3/b,c

(a) (i) $H_2 + Cl_2 \rightarrow 2HCl$ (1)

(ii) $HCl + H_2O \rightarrow H_3O^+ + Cl^-$ (1)

thus bonding goes form covalent to ionic **[2]**

(b) (i) $AgNO_3(aq) + HCl(aq) \rightarrow AgCl(s) + HNO_3(aq)$

or $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$ (1)

white ppt. forms (1)

(ii) ppt. dissolves to give colourless solution (1)

$AgCl(s) + 2NH_3(aq) \rightarrow [Ag(NH_3)_2]\,Cl(aq)$

or $Ag^+(s) + 2NH_3(aq) \rightarrow [Ag(NH_3)_2]^+(aq)$ (1)

Correct state symbols in **either (i) or (ii)** (1) **[5]**

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UNIT 12

Nitrogen and Sulfur

A-Level
Chemistry Paper 2
Topical Workbook

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Unit 12: Nitrogen and Sulfur

1. M/J 17/P23/Q1

This question is shifted in Unit 14 -- question No. 34

2. O/N 15/P21/Q2/d, O/N 15/P23/Q2/d

(a) The use of nitrate fertilisers can give rise to environmental consequences in terms of effects on both rivers and the atmosphere.

(i) Explain how the uncontrolled use of nitrate fertilisers can result in a severe reduction in water quality in rivers.

.....

.....

.....

..... **[3]**

(ii) Oxides of nitrogen are produced by the action of bacteria on nitrate fertilisers.

Explain the problems associated with the release of oxides of nitrogen into the atmosphere. Include an equation in your answer.

.....

.....

..... **[2]**

3. M/J 15/P22/Q2/b,c,d

Sulfuric acid is an important chemical with a variety of uses.

It is manufactured by the Contact process, the first stage of which involves the conversion of sulfur or a sulfide ore, such as galena, PbS, into sulfur dioxide, SO_2.

(a) The second stage of the Contact process involves the production of sulfur trioxide, SO_3, from sulfur dioxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -197\ kJ\ mol^{-1}$$

(i) State the temperature usually chosen for this conversion and explain this in terms of reaction rates and Le Chatelier's principle.

temperature .....

explanation .....

.....

.....

..... **[3]**

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(ii) State and explain the pressure conditions that would give the best rate and best yield of sulfur trioxide. Explain why these conditions are **not** actually used.

.....

.....

.....

.....

..... [3]

(b) In the third stage of the process the sulfur trioxide is dissolved in 98% sulfuric acid followed by carefully controlled addition of water.

(i) Explain why the sulfur trioxide is not dissolved directly in water to produce sulfuric acid.

.....

..... [1]

(ii) Write equations for the reaction of sulfur trioxide with sulfuric acid and for the subsequent reaction with water.

.....

..... [2]

(c) Explain why sulfur dioxide is used as an additive in some foods and wines.

.....

.....

..... [2]

4. **M/J 15/P21/Q2/c**

(a) Although nitrogen gas makes up about 79% of the atmosphere it does not easily form compounds.

(i) Explain why nitrogen is so unreactive.

.....

..... [1]

(ii) Explain why the conditions in a car engine lead to the production of oxides of nitrogen.

.....

..... [1]

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(iii) Give an equation for a reaction involved in the removal of nitrogen monoxide, NO, from a car's exhaust gases, in the catalytic converter.

..... [1]

One of the main reasons for reducing the amounts of oxides of nitrogen in the atmosphere is their contribution to the formation of acid rain.

(iv) Write an equation for the formation of nitric acid from nitrogen dioxide, NO_2, in the atmosphere.

..... [1]

(v) Write equations showing the catalytic role of nitrogen monoxide, NO, in the oxidation of atmospheric sulfur dioxide, SO_2.

.....

..... [2]

5. M/J 13/P21/Q1/b,c

(a) The uncontrolled use of nitrogenous fertilisers can cause environmental damage to lakes and streams. This is known as *eutrophication*.
What are the processes that occur when excessive amounts of nitrogenous fertilisers get into lakes and streams?

.....

.....

.....[2]

(b) Large quantities of ammonia are manufactured by the Haber process.
Not all of this ammonia is used to make fertilisers.
State **one** large-scale use for ammonia, **other than** in the production of nitrogenous fertilisers.

..... [1]

6. O/N 12/P21/Q3/a,b, O/N 12/P22/Q3/a,b

Ammonia is an important industrial chemical which is manufactured on a large scale by using the Haber process.

(a) (i) Write a balanced equation, with state symbols, for the reaction occurring in the Haber process.

.....

(ii) Give **three** essential operating conditions that are used in the Haber process.

.....

.....

.....

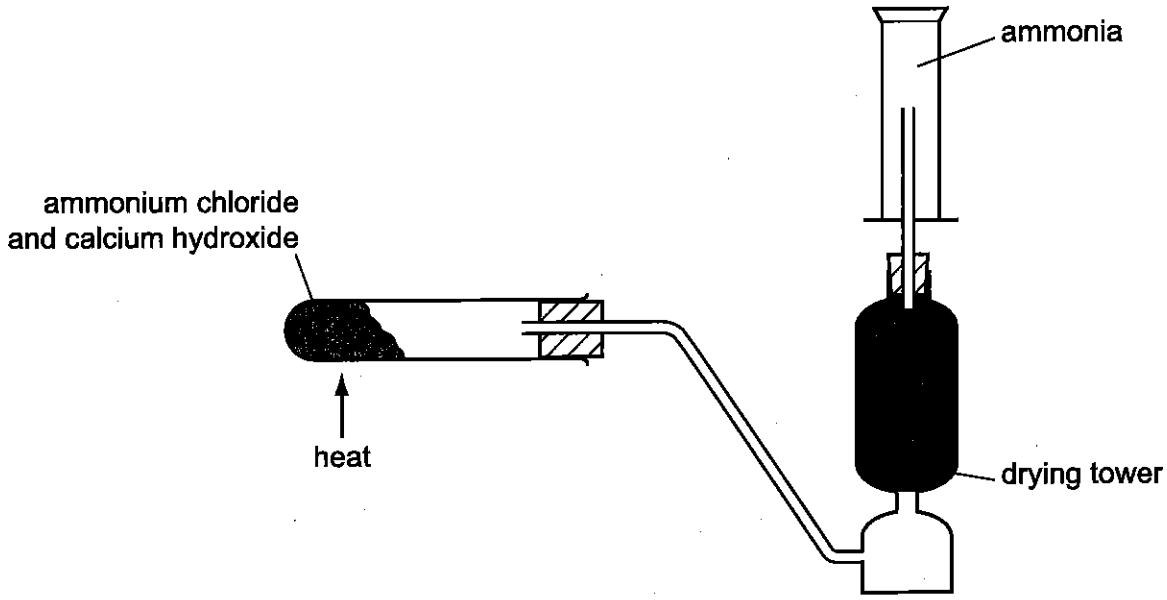
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(iii) State **one** large scale use of ammonia.

.....

[5]

(b) Ammonia may be prepared in a school or college laboratory by using the apparatus below.



The reaction involves the displacement of ammonia from one of its compounds.

(i) Give the formulae of the two reactants that are heated together to produce ammonia.

..... and .....

(ii) Construct a balanced equation for the reaction between your two reagents.

.....

(iii) Common drying agents include calcium oxide, concentrated sulfuric acid and phosphorus(V) oxide.
Which **one** of these would be used in the drying tower in this experiment? Explain your answer.

.....

.....

[5]

7. M/J 12/P21/Q1/d,e

(a) Sulfur dioxide is present in small, but significant, amounts in the Earth's atmosphere.

(i) State **one** way by which sulfur dioxide enters the atmosphere.

.....

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(ii) Give the formula of another sulfur compound which is formed in the atmosphere from sulfur dioxide.

.....

(iii) What are the environmental consequences of the compound you have identified in **(ii)**?

.....

[3]

(b) Sulfur dioxide is used as a food preservative.
What property of sulfur dioxide enables it to act in this way?

.....**[1]**

8. O/N 10/P23/Q2

Sulfur and its compounds are found in volcanoes, in organic matter and in minerals.
Sulfuric acid, an important industrial chemical, is manufactured from sulfur by the Contact process.
The Contact process may be considered to be a three-stage process in which sulfur is converted into sulfuric acid. Each stage consists of a single chemical reaction.

(a) Write a balanced equation for **each** of these reactions **in the correct sequence**.
Where appropriate, use $\rightleftharpoons$ to indicate that the reaction is an equilibrium.

first reaction .....

second reaction .....

third reaction ..... **[4]**

(b) Give **three** different operating conditions that are used in the **second** stage.

condition 1 .....

condition 2 .....

condition 3 ..... **[3]**

(c) State **one** large scale use of sulfuric acid.

..... **[1]**

(d) Most of the sulfur that is used in the Contact process is recovered from sulfur compounds present in crude oil and natural gas by using the Claus process.

(i) In this process, about one third of the hydrogen sulfide, H_2S, present in the oil or gas, is converted into sulfur dioxide, SO_2.

Balance the equation for this reaction.

$$.....H_2S + ...O_2 \rightarrow .....SO_2 + ...H_2O$$

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(ii) The SO_2 formed is then reacted catalytically with the remaining H_2S, producing sulfur and water.

$$2H_2S + SO_2 \rightarrow 3S + 2H_2O$$

What are the oxidation numbers of each of the sulfur-containing substances in this reaction?

H_2S..... SO_2 ..... S .....

Which substance is reduced? Explain your answer.

substance .....

explanation ..... **[3]**

The sulfur present in crude oil is removed in order to prevent the formation of sulfur dioxide when fuels such as petrol (gasoline) or diesel fuel are burned in internal combustion engines.
Other substances that may be present in the exhaust gases of motor vehicles include CO, CO_2, NO/NO_2, and unburnt hydrocarbons.

The emission of sulfur dioxide can produce 'acid rain'.

(e) **(i)** Outline, with the aid of equations, how acid rain is formed from the exhaust gases of motor vehicles.

.....

.....

.....

.....

(ii) State **one** environmental effect of acid rain.

..... **[4]**

(f) Sulfur dioxide is used to preserve dried fruits and vegetables.

What chemical property of SO_2 enables it to be used as a food preservative?

..... **[1]**

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9. O/N 10/P21/Q2,O/N 10/P22/Q2

Nitrogen makes up about 79% of the Earth's atmosphere. As a constituent element of proteins, it is present in living organisms.

Atmospheric nitrogen is used in the Haber process for the manufacture of ammonia.

(a) Write an equation for the formation of ammonia in the Haber process.

..... [1]

(b) The Haber process is usually carried out at a high pressure of between 60 and 200 atmospheres (between 60×10^5 Pa and 200×10^5 Pa).
State **two further** important operating conditions that are used in the Haber process.
For **each** of your conditions, explain why it is used.

condition 1 .....

reason .....

condition 2 .....

reason ..... [4]

(c) State **one** large-scale use for ammonia, other than in the production of nitrogenous fertilisers.

..... [1]

(d) The uncontrolled use of nitrogenous fertilisers can cause environmental damage to lakes and streams. This is known as 'eutrophication'.

What are the processes that occur when excessive amounts of nitrogenous fertilisers get into lakes and streams?

.....

.....

..... [2]

In many countries, new cars have to comply with regulations which are intended to reduce the pollutants coming from their internal combustion engines.

Two pollutants that may be formed in an internal combustion engine are carbon monoxide, CO, and nitrogen monoxide, NO.

(e) (i) Outline how **each** of these pollutants may be formed in an internal combustion engine.

CO .....

.....

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NO .....

.....

(ii) State the main hazard associated with **each** of these pollutants.

CO .....

NO ..... [4]

Pollutants such as CO and NO are removed from the exhaust gases of internal combustion engines by catalytic converters which are placed in the exhaust system of a car.

(f) (i) What metal is most commonly used as the catalyst in a catalytic converter?

.....

(ii) Construct **one** balanced equation for the reaction in which **both** CO **and** NO are removed from the exhaust gases by a catalytic converter.

..... [2]

10. O/N 05/P2/Q3

Nitrogen, which makes up about 80% of the Earth's atmosphere, is very unreactive.

(a) (i) Explain the lack of reactivity of nitrogen.

.....

.....

.....

(ii) Nitrogen does, however, undergo some reactions. Write an equation for **one** reaction of nitrogen, stating the conditions under which it occurs.

equation .....

conditions .....

.....

.....

(iii) Suggest why nitrogen does react in the example you have chosen.

.....

..... [6]

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Ammonium nitrate, NH_4NO_3, is a commercially important compound of nitrogen.

(b) **(i)** State **one** large-scale use of ammonium nitrate.

.....

(ii) What are the environmental consequences of the uncontrolled use of ammonium nitrate?

.....

.....

.....

.....

[4]

When solid ammonium nitrate is heated with solid sodium hydroxide in a test-tube, three products are formed. A colourless alkaline gas, **Y**, is given off, and a colourless liquid can be seen on the cooler parts of the test-tube. A white solid remains in the tube.

(c) **(i)** Identify gas **Y**.

.....

(ii) Write an equation, with state symbols, for the reaction of ammonium nitrate with sodium hydroxide.

.....

[3]

(d) In order to produce gas **Y** in a pure state in the laboratory, it must be passed through a drying agent.

Why is concentrated sulphuric acid not suitable for drying gas **Y**?

.....

..... [1]

11. M/J 04/P2/Q3/b

Ammonia, NH_3, is a colourless, pungent-smelling gas which has been known to man from the beginning of recorded time. It is given off from urine such as that on a wet nappy from a baby.

Ammonia was named after the shrine of Jupiter Ammon which was near the Egyptian-Libyan border. In ancient times ammonia was obtained by distilling camel dung.

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(a) Now ammonia is synthesised from its elements in the Haber Process.

(i) Write an equation for this process.

.....

(ii) State the **three** usual operating conditions of the Haber Process.

.....

.....

.....

(iii) State **two** modern commercial uses of ammonia.

.....

..... [4]

12. M/J 03/P2/Q3/e

(a) One of the uses of ammonia is to form nitrates which are used as efficient inorganic fertilisers. The uncontrolled use of these fertilisers has led to environmental problems. Briefly describe and explain these problems.

.....

.....

.....

.....

.....

..... [3]

13. O/N 02/P2/Q4/a,b,c,d

Ammonia is manufactured from nitrogen and hydrogen by the Haber process.

Hydrogen is usually obtained by reacting methane and steam; the by-product is carbon monoxide.

(a) Construct a balanced equation for this production of hydrogen.

..... [1]

The reaction between nitrogen and hydrogen is exothermic and incomplete.

(b) **(i)** Write an equation for the Haber process.

.....

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(ii) State the **three** conditions necessary for the efficient working of a Haber process plant.

1. .....

2. .....

3. .....

(iii) Draw a flow diagram to show how the gases pass through the plant. The part where the ammonia is formed should be called the **converter**. Label the flow diagram to explain the process.

[6]

(c) Explain why the pressure you have quoted in **(b)(ii)** is used.

.....

.....

.....

.....

..... **[2]**

(d) Most of the ammonia produced which is not used as fertiliser is oxidised to nitric acid, HNO_3.

Construct an equation for the oxidation of ammonia by atmospheric oxygen to form nitric acid.

..... **[1]**

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14. M/J 02/P2/Q4

Sulphuric acid is used in many industrial processes of major importance.

The first stage in the manufacture of sulphuric acid is to pass air over burning sulphur. The emerging gas has the following composition by volume.

sulphur dioxide	10%
sulphur trioxide	0.2%
oxygen	10%
nitrogen etc.	79–80%

(a) (i) Write an equation for sulphur burning in air.

.....

(ii) Suggest why the air is passed so fast that only half the oxygen is used.

.....

.....

[2]

The emerging gas is passed over a catalyst maintained at 450–550 °C in the reaction chamber.

(b) Name the catalyst used in the Contact process.

..... **[1]**

Sulphur trioxide is formed in 98% yield; 2% of sulphur dioxide remains unconverted.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -197\ kJ\ mol^{-1}$$

(c) The high yield is only achieved under certain conditions.

After each condition explain why this leads to an increased yield of sulphur trioxide.

(i) There needs to be an excess of air in the reacting gas mixture.

explanation .....

.....

(ii) The catalyst needs to be cooled.

explanation .....

.....

(iii) The air used to burn the sulphur must be as clean as possible.

explanation .....

.....

[3]

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(d) In modern plants, nearly all the SO_2/SO_3 mixture is absorbed but up to 0.05% by volume of SO_2 may be allowed to pass into the atmosphere through a chimney stack.

Give **two** reasons why SO_2 should not be discharged into the atmosphere.

.....

.....

..... **[2]**

(e) **(i)** When concentrated sulphuric acid is warmed with solid sodium chloride, misty fumes are produced.

Identify the fumes. .....

Write an equation for the reaction.

.....

(ii) When concentrated sulphuric acid is warmed with solid sodium iodide, purple fumes are produced.

Identify the fumes. .....

[3]

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Answers Section

1. M/J 17/P23/Q1

This question answer is shifted in Unit 14 -- answer No. 34

2. O/N 15/P21/Q2/d ,O/N 15/P23/Q2/d

(i) nitrates / fertilisers wash into rivers [1]

eutrophication / algal bloom / promote algal growth [1]

bacteria use up oxygen in decay process [1]

(ii) (oxides of nitrogen/ NO_x / NOs) cause acid rain [1]

$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ [1]

OR

$4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$ [2]

OR

$SO_2 + NO_2 \rightarrow SO_3 + NO$ AND $SO_3 + H_2O \rightarrow H_2SO_4$

3. M/J 15/P22/Q2/b,c,d

(a) (i) T = 400 – 600 °C (chosen as a compromise because) [1]

High T increases rate ora [1]

High T decreases yield / moves eqm left / makes less SO_3 as forward reaction exothermic ora [1] [3]

(ii) High pressure increases rate as collision frequency increases ora [1]

High pressure moves eqm right / favours forward reaction as more moles on left ora [1]

Uneconomic to use high pressures / high yield at low pressure [1] [3]

(b) (i) Reaction (too) exothermic / acid spray produced [1] [1]

(ii) $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ [1]

$H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$ [1] [2]

(c) Preservative owtte [1]

antimicrobial/antioxidant/reducing agent [1] [2]

4. M/J 15/P21/Q2/c

(a) (i) strong <u>triple</u> bond [1] [1]

(ii) high temperature (needed for reaction between N_2 and O_2) [1] [1]

(iii) $2NO + 2CO \rightarrow N_2 + 2CO_2$ [1]

OR $2NO + C \rightarrow N_2 + CO_2$ [1]

(iv) $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$ [1] [1]

(v) $NO + \frac{1}{2}O_2 \rightarrow NO_2$ [1]

$NO_2 + SO_2 \rightarrow NO + SO_3$ [1]

OR $NO_2 + SO_2 + H_2O \rightarrow NO + H_2SO_4$ [2]

5. M/J 13/P21/Q1/b,c

(a) fertiliser in the river causes

excessive growth of aquatic plants/algae **or** algal bloom (1)

when plants and algae die O_2 is used up **or** fish or aquatic life die (1) [2]

(b) manufacture of HNO_3 **or** explosives **or** nylon **or**

as a cleaning agent **or** as a refrigerant (1) [2]

not detergent

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6. O/N 12/P21/Q3/a,b O/N 12/P22/Q3/a,b

(a) (i) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ **or**

$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ **(1)**

state symbols required **(1)**

(ii) **pressure** between 60 and 250 atm **or**
between 60×10^5 Pa and 250×10^5 Pa **(1)**

temperature between 300 and 550 °C

catalyst iron / iron oxide **(1)**

(iii) manufacture of HNO_3 / as a cleaning agent / refrigerant / fertiliser / manufacture of fertilisers / explosives / to remove SO_2 from combustion products of hydrocarbon fuels **(1)** **[5]**

(b) (i) NH_4Cl **and** $Ca(OH)_2$
both formulae required

(ii) $2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2NH_3 + 2H_2O$ **or**
$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$
correct products
correctly balanced equation

(iii) CaO **(1)**
it is not an acid / it is basic / it does not react with NH_3 **or** **(1)**
both P O / P O **and** H SO are acidic / react with NH **(1)** **[3]**

7. M/J 12/P21/Q1/d,e

(a) (i) combustion of fossil fuels – e.g. from car engines
from car exhausts **or**
during the extraction of metals from sulfide ores or
volcanic eruptions/burning sulfur from volcanoes or
burning biomass **(1)**

(ii) H_2SO_4
or
SO_3 allow H_2SO_3 **formula required** **(1)**

(iii) acid rain
or
its consequences e.g. damage to buildings,
damage to crops, plants, marine life
deforestation
or
SO_3 is toxic **(1)** **[2]**

(b) it is a reducing agent/antioxidant
or
it kills bacteria **(1)** **[1]**

8. O/N 10/P23/Q2

(a) 1 $S + O_2 \rightarrow SO_2$ (1)

2 $2SO_2 + O_2 \rightleftharpoons 2SO_3$ equation (1)
equilibrium sign (1)

3 $SO_3 + H_2O \rightarrow H_2SO_4$ **or**
$SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ (1) **[4]**

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(b) condition 1 400 – 600 °C (650 – 900K) (1)
condition 2 1–10 atm/just above atmospheric pressure
allow equivalent pressure units (1)
condition 3 vanadium pentoxide/vanadium(V) oxide/V_2O_5 (1) **[3]**

(c) fertilisers/phosphates/ammonium sulfate **or**
lead/acid batteries **or** paints/pigments **or** dyestuffs **or**
steel pickling **or** metal treatment **or** detergents **or** explosives (1) **[1]**

(d) **(i)** $2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$ (1)
(ii) H_2S –2 SO_2 +4 S 0 **all three** (1)
SO_2 **because** the oxidation number of S is reduced (1) **[3]**

(e) **(i)** $2NO + O_2 \rightarrow 2NO_2$ (1)
$SO_2 + NO_2 \rightarrow SO_3 + NO$ (1)
$SO_3 + H_2O \rightarrow H_2SO_4$
final product must be H_2SO_4 (1)

(ii) corrosion of buildings **or**
dissolving of Al^{3+} ions from soil **or**
pollution of rivers/killing aquatic life **or**
making soil acidic/killing trees/corrosion of metals (1) **[4]**

(f) it is a reducing agent/inhibits oxidation (1) **[1]**

9. O/N 10/P21/Q2,O/N 10/P22/Q2

(a) $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (1) **[1]**

(b) temperature between 300 and 550°C (1)
correct explanation of effect of temperature on
rate of formation of NH_3 **or** on position of equilibrium (1)

(c) manufacture of HNO_3
or explosives
or nylon
or as a cleaning agent
or as a refrigerant (1) **[1]**

(d) fertiliser in rivers causes excessive growth of aquatic plants/algae (1)
when plants and algae die O_2 is used up/fish or aquatic life die (1) **[2]**

(e) **(i)** CO by incomplete combustion of the hydrocarbon fuel (1)
NO by reaction between N_2 and O_2 in the engine (1)
(ii) CO toxic/effect on haemoglobin (1)
NO toxic/formation of acid rain (1) **[4]**

(f) **(i)** platinum/Pt – allow palladium/Pd **or** rhodium/Rh (1)
(ii) $2CO + 2NO \rightarrow 2CO_2 + N_2$ (1) **[2]**

10. O/N 05/P2/Q3

(a) **(i)** N≡N bond is very strong (1)
large amount of energy required to break it
or E_a is very high (1)

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(ii) $N_2 + 3H_2 \rightarrow 2NH_3$
or $N_2 + O_2 \rightarrow 2NO$
or $3Mg + N_2 \rightarrow Mg_3N_2$ (may be others) (1)
N_2/H_2 high pressure, high temperature, catalyst
N_2/O_2 high pressure, high temperature, lightning
Mg/N_2 high temperature, burning Mg
any 2 conditions which correspond to the eqn given (2)

(iii) E_a overcome/ high energy input/
E_a lowered by catalyst (1) [6]

(b) (i) fertiliser **or** explosive (1)

(ii) NH_4NO_3 in rivers causes excessive growth of aquatic plants/algae (1)
when plants/algae die O_2 is used up (1)
fish/aquatic life die (1)
'eutrophication' for 2 marks [4]

(c) (i) NH_3 (1)

(ii) $NH_4NO_3(s) + NaOH(s) \rightarrow NH_3(g) + NaNO_3(s) + H_2O(l)$
equation (1) state symbols (1) [3]

(d) reacts with ammonia (1) [1]

11. M/J 04/P2/Q3/b

(a) (i) $N_2 + 3H_2 \leftrightarrow 2NH_3$

(ii) 100 ATMs or over
400 - 500°C
iron catalyst

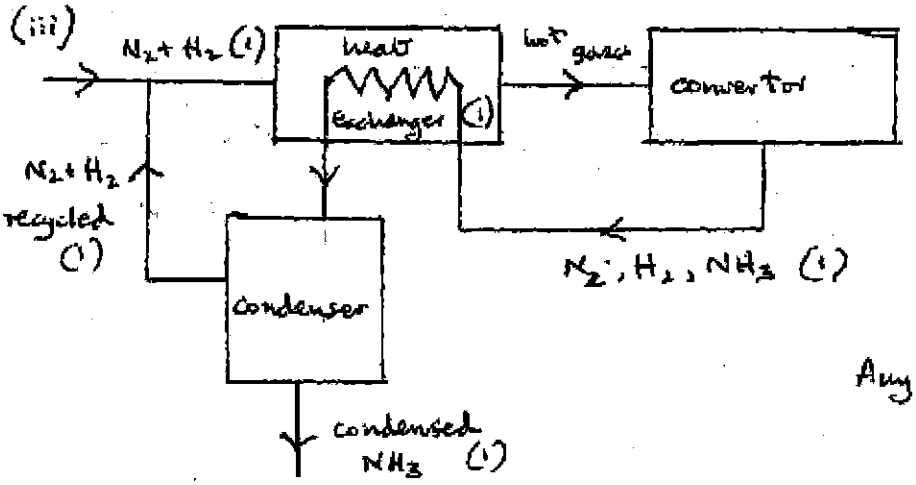
(iii) Fertiliser, making nitric acid, explosives etc. 1 mark for each [4]

12. M/J 03/P2/Q3/e

(a) Excess (hence uncontrolled) nitrates leach out of fields into streams, seas (1)
Bacteria or algae grow fast/use oxygen/clog up water (1)
Balance destroyed/fish unable to live (1)
Process called eutrification (1) any 3 [3]

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13. O/N 02/P2/Q4/a,b,c,d

4 (a)	$CH_4 + H_2O \longrightarrow 3H_2 + CO$	1
(b)	(i) $N_2 + 3H_2 \rightleftharpoons 2NH_3$ ⇌ necessary (1)	1
	(ii) • pressure over 100 atm • temp 400–600°C range • iron / iron oxide (catalyst) } all (1)	1
	(iii)  Any 4	4
		[6]
(c)	Reaction 4 → 2 (mols, vols) favoured by high P (1) Collision frequency greater at high P (1)	[2]
(d)	$NH_3 + 2O_2 \longrightarrow HNO_3 + H_2O$	[1]

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14. M/J 02/P2/Q4

(a) (i)	$S + O_2 \longrightarrow SO_2$ (1)	
(ii)	Air (oxygen) required for Contact stage (1)	[2]
(b)	Vanadium oxide (1) or V_2O_5	[1]
(c) (i)	Le Chatelier: To favour RHS side of equilm (1)	
(ii)	Reaction exothermic ∴ reasonable catalyst gets hot (1)	
	or exothermic reaction - Le Chatelier: high temp favours LHS (1)	
(iii)	Catalysts are easily poisoned (1) damage to catalyst.	[3]
(d)	SO_2 damages buildings - marble, limestone etc (1)	
	damages living things - animals, trees etc. (1)	
	acid rain (1) any two effects max	[2]
(e) (i)	hydrogen chloride / HCl gas (1) allow HCl	
	$NaCl + H_2SO_4 \longrightarrow NaHSO_4 + HCl$	
	or $2NaCl + H_2SO_4 \longrightarrow Na_2SO_4 + 2HCl$ (1)	
(ii)	Iodine (1)	[3]
	[Total: 11]	

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UNIT 13

An Introduction to Organic Chemistry

A-Level
Chemistry Paper 2
Topical Workbook

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Unit 13: An Introduction to Organic Chemistry

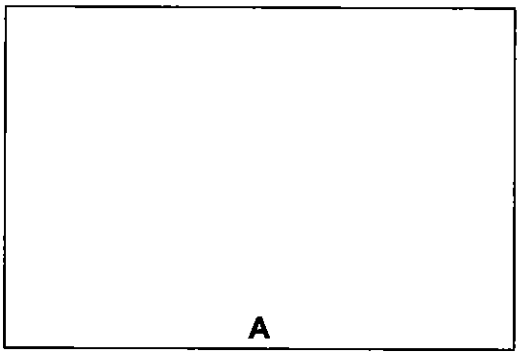
1. **M/J 17/P22/Q4/a (a,b,c)**

(a) The hydrocarbons **A**, C_4H_{10}, and **B**, C_4H_8, are both unbranched.

A does **not** decolourise bromine.

B decolourises bromine and shows geometrical isomerism.

(i) Draw the skeletal formula of **A**.



[1]

(ii) The hydrocarbon **A**, C_4H_{10}, has a branched isomer.

Suggest why unbranched **A** has a higher boiling point than its branched isomer.

.....

.....

.....

.....

..... **[2]**

(iii) Give the structural formula of **B**.

..... **[1]**

(iv) Explain why **B** shows geometrical isomerism.

.....

.....

.....

..... **[2]**

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(v) Draw the mechanism of the reaction of **B** with bromine, Br_2.
Include all necessary charges, dipoles, lone pairs and curly arrows.

[4]

(vi) Explain the origin of the dipole on Br_2 in this mechanism.

.....

.....

..... [1]

2. M/J 17/P21/Q4/a(i),b,d

P, **Q** and **R** all have the molecular formula C_3H_6O. They are all structural isomers of each other.
P and **Q** each contain an oxygen atom bonded directly to a carbon atom that is sp^2 hybridised.
R contains an oxygen atom bonded directly to a carbon atom that is sp^3 hybridised.

(a) (i) Explain the meaning of the term *structural isomers*.

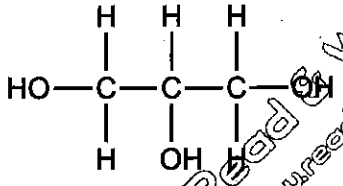
.....

.....

.....

..... [2]

(b) **R** contains two different functional groups, one of which is an alkene group.
R reacts with cold, dilute, acidified manganate(VII) ions to form propane-1,2,3-triol.



propane-1,2,3-triol

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(i) Give the displayed formula of **R**.

[1

(ii) State the type of reaction and what you would observe when **R** reacts with bromine water

.....

..... [2

(iii) Draw the structure of the product formed when **R** reacts with bromine water.

[1

(iv) Identify the gaseous product formed when **R** reacts with hot, concentrated acidified manganate(VII) ions.

..... [1

(c) **P** and **Q** each react with hydrogen cyanide to form a single product.
The product formed from **P** exists as a pair of optical isomers.
The product formed from **Q** does not exhibit optical isomerism.

(i) Explain the meaning of the term *optical isomers*.

.....

.....

.....

..... [2]

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(ii) Ethanal, CH_3CHO, also reacts with hydrogen cyanide. The product of this reaction is $CH_3CH(OH)CN$.
Draw the mechanism of this reaction.
Include all necessary charges, dipoles, lone pairs and curly arrows.

[3]

[19]

3. M/J 17/P23/Q4

A, **B** and **C** all have the formula C_4H_8. They all decolourise bromine and are structural isomers of each other.

(a) State the name of the process by which **A**, **B** and **C** could be obtained from $C_{10}H_{22}$.

..... [1]

(b) Draw the structures of these three **structural** isomers.

[1]

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(c) Only **A** shows geometrical isomerism.

(i) Explain the meaning of the term *geometrical isomerism.*

.....

.....

.....

..... **[2]**

(ii) Draw the displayed formula of **A** and use it to show the mechanism of the reaction of **A** with HBr. Include all necessary charges, dipoles, lone pairs and curly arrows.

[4]

(d) **B** does **not** show geometrical isomerism.

B reacts with HBr to form a mixture of two structural isomers, **X** and **Y**.

B + HBr → **X** (has a chiral centre and is produced in higher yield than **Y**)

B + HBr → **Y** (does not have a chiral centre)

(i) State the meaning of the term *chiral centre*

.....

.....

.....

..... [1]

(ii) Name **B**.

..... [1]

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(iii) **X** exists as a pair of optical isomers.
Draw these isomers using the conventional three-dimensional representation.

[2]

(iv) Explain why **X** is produced in higher yield than **Y**.

.....

.....

.....

..... [2]

(e) **C** does **not** show geometrical isomerism.
C reacts with HBr to form a mixture of two structural isomers, neither of which has a chiral centre.

(i) Name **C**.

..... [1]

(ii) Draw the **displayed** formula of each of the structural isomers produced by the reaction of **C** with HBr.

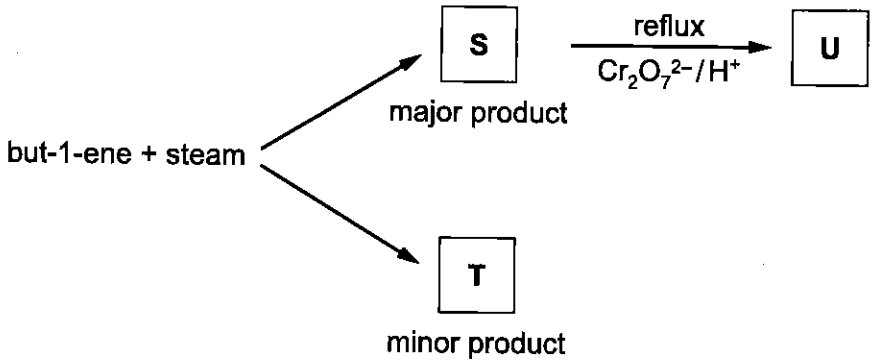
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[2]

[17]

4. MAR 17/P22/Q3/c(i,ii)

(a) But-1-ene reacts with steam as shown to form a mixture of two structural isomers, **S** and **T**.



S can be oxidised with acidified potassium dichromate(VI) to form compound **U**.
S and **U** both react with alkaline aqueous iodine.

(i) Identify the *type of reaction* that occurs when but-1-ene reacts with steam.

..... [1]

(ii) State what can be deduced about the structure of **S** from its reaction with alkaline aqueous iodine.

..... [1]

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5. M/J 13/P21/Q4

Organic chemistry is the chemistry of carbon compounds. The types of organic reactions that you have studied are listed below.

addition	elimination	hydrolysis
oxidation	reduction	substitution

Addition and substitution reactions are further described as follows.

electrophilic	nucleophilic	free radical

Complete the table below.
Fill in the central column by using **only** the types of reaction given in the lists above.
Use **both** lists when appropriate.
In the right hand column give the formula(e) of the reagent(s) you would use to carry out the reaction given.

organic reaction	type of reaction	reagent(s)
$CH_3CH_2CH_2CH_2Br \rightarrow CH_3CH_2CH_2CH_2NH_2$		
$CH_3CH_2CH_2CH_2OH \rightarrow BrCH_2CH_2CH_2CH_2OH$		
$CH_3COCH_3 \rightarrow CH_3C(OH)(CN)CH_3$		
$CH_3CH(OH)CH_2CH_3 \rightarrow CH_3CH{=}CHCH_3$		

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[11]

6. O/N 11/P23/Q2/b

(a) Analysis of another organic compound, **B**, gave the following composition by mass: C, 64.86%; H, 13.50%, O, 21.64%.

(i) Use these values to calculate the empirical formula of **B**.

(ii) The empirical and molecular formulae of **B** are the same.

B is found to be chiral.

Draw displayed formulae of the two optical isomers of this compound, indicating with an asterisk (*) the chiral carbon atom.

(iii) There are three other structural isomers of **B** which are not chiral but which contain the same functional group as **B**.

In the boxes below, draw the structural formulae of these isomers.

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[7]

7. M/J 10/P21/Q5

Isomerism occurs in many organic compounds. The two main forms of isomerism are structural isomerism and stereoisomerism. Many organic compounds that occur naturally have molecules that can show stereoisomerism, that is *cis-trans* or optical isomerism.

(a) (i) Explain what is meant by *structural isomerism*.

.....

.....

(ii) State **two** different features of molecules that can give rise to **stereoisomerism**.

.....

.....

[3]

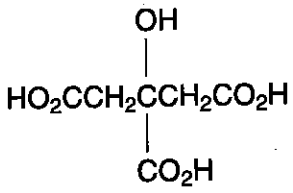
Unripe fruit often contains polycarboxylic acids, that is acids with more than one carboxylic acid group in their molecule.

One of these acids is commonly known as tartaric acid, $HO_2CCH(OH)CH(OH)CO_2H$.

(b) Give the structural formula of the organic compound produced when tartaric acid is reacted with an excess of $NaHCO_3$.

[1]

Another acid present in unripe fruit is citric acid,



(c) Does citric acid show optical isomerism? Explain your answer.

.....

.....

..... **[1]**

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A third polycarboxylic acid present in unripe fruit is a colourless crystalline solid, **W**, which has the following composition by mass: C, 35.8%; H, 4.5%; O, 59.7%.

(d) **(i)** Show by calculation that the empirical formula of **W** is $C_4H_6O_5$.

(ii) The M_r of **W** is 134. Use this value to determine the molecular formula of **W**.

[3]

A sample of **W** of mass 1.97 g was dissolved in water and the resulting solution titrated with 1.00 mol dm^{-3} NaOH. 29.4 cm^3 were required for complete neutralisation.

(e) **(i)** Use these data to deduce the number of carboxylic acid groups present in one molecule of **W**.

(ii) Suggest the displayed formula of **W**.

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[5]

[13]

8. O/N 08/P2/Q4

Organic chemistry is the chemistry of carbon compounds. The types of organic reactions that you have studied are listed below.

addition	elimination	hydrolysis
oxidation	reduction	substitution

Addition and substitution reactions are further described as follows.

electrophilic	nucleophilic	free radical

Complete the table below.

Fill in the central column by using **only** the types of reaction given in the lists above. Use **both** lists when appropriate.

In the right hand column give the name(s) or formula(e) of the reagent(s) you would use to carry out the reaction given.

organic reaction	type of reaction	reagent(s)
$CH_3CHO \rightarrow CH_3CH(OH)CN$		
$CH_3CH_2CH_2CH_3 \rightarrow CH_3CH_2CHBrCH_3$		
$CH_3CH(OH)CH_3 \rightarrow CH_3CH{=}CH_2$		
$CH_3CH{=}CH_2 \rightarrow CH_3CH(OH)CH_2OH$		

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[10]

Answers Section

1. M/J 17/P22/Q4/a (a,b,c)

(a) (i) (A =)  1

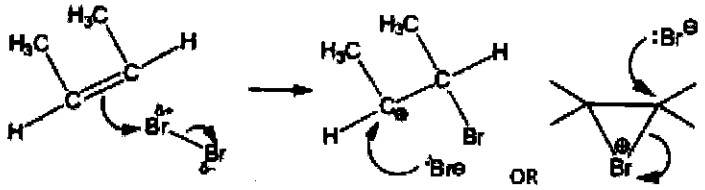
(ii) (**A** / straight chain) has strong(er) (temporary dipole-) induced dipole (attractions) *ora* 1

(because **A** / straight chain has) bigger (surface) area / more (points of) contact (in unbranched isomer) *ora* 1
OR
(so) more energy required to break the intermolecular forces *ora*

(iii) $CH_3CHCHCH_3$ OR $CH_3CH{=}CHCH_3$ 1

(iv) No rotation / restricted / limited rotation of C=C / (carbon) double bond 1

One (of the two) methyl groups / one (of the two) H (atoms) is on each C (of C=C) 1

(v) 

arrow from the C=C double bond drawn to the bromine 1

dipole on Br_2 in correct orientation AND arrow from the Br-Br bond to the $Br^{\delta-}$ 1

correct carbocation / bromonium ion from the structure with C=C drawn 1

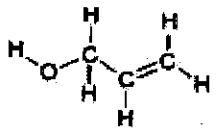
Br^- with lone pair, negative charge AND arrow from lone pair to the carbon atom of intermediate 1
OR
using both arrows shown (in alternative diagram)

(vi) electrons in pi bond induce it (the dipole) OR 1
(high) electron density in pi bond / double bond / C=C repels electrons (away from nearest Br)
OR
polarised by (high) electron density in pi bond / double bond / C=C

2. M/J 17/P21/Q4/a(i),b,d

(a) (i) (molecules / isomers with) the same molecular formula / same number of atoms of each element 1

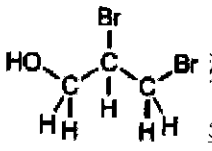
different structural / displayed formulae / arrangement of bonds 1

(b) (i)  1

(ii) (electrophilic) addition 1

bromine decolourises / turns colourless / fades (from orange / brown) 1

(iii) 1

$HOCH_2CHBrCH_2Br$ OR 

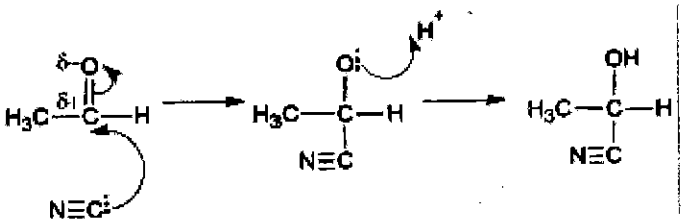
(iv) CO_2 / carbon dioxide 1

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(c) (i) (molecules / isomers with) the same (molecular and) structural formula 1

Any two of: 1
chiral centre / C attached to four different groups / atoms
non-super(im)posable mirror images
different spatial / 3D arrangement of atoms (owtte)
different rotation of plane-polarised light

(ii)



curly arrow from lone pair on :C≡N to $C^{(\delta+)}$ 1

correct dipole on carbonyl $^{\delta+}C=O^{\delta-}$ AND curly arrow from bond to $O^{(\delta-)}$ 1

correct intermediate, including $C–O^-$ AND curly arrow from lone pair to H^+ 1

3. M/J 17/P23/Q4

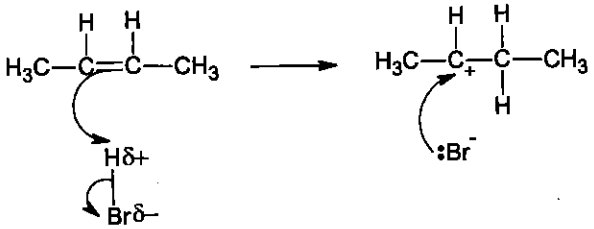
(a) cracking 1

(b) **In any order** 1
$CH_2=CHCH_2CH_3$ / $CH_2CHCH_2CH_3$ / $CH_2CHC_2H_5$
AND
$CH_3CH=CHCH_3$ / $CH_3CHCHCH_3$
AND
$(CH_3)_2C=CH_2$ / $(CH_3)_2CCH_2$

(c) (i) (different) molecules with the same (molecular and) structural formula 1

(due to) different arrangement in space caused by C=C / double bond 1

(c) (ii)



arrow from the C=C double bond drawn to the H 1

dipole on H–Br in correct orientation AND arrow from the H-Br bond to the $Br^{\delta-}$ 1

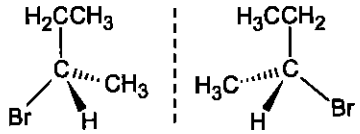
correct carbocation from the structure with C=C drawn 1

Br^- with lone pair, negative charge AND arrow from lone pair to the positively charged carbon atom of intermediate 1

(d) (i) a (tetrahedral) atom with four different groups / atoms / substituents attached 1
OR
a carbon (atom) with four different groups / atoms / substituents attached

(ii) but–1–ene 1

(iii)



1

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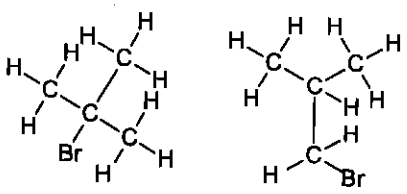
One 3D structure of 2–bromobutane which must have 2 bonds shown the same and two different i.e. **three** bond types altogether, e.g. two solid lines, one wedge and one dash. If two bonds are drawn in the plane of the paper, i.e. single solid lines, they must **not** be at 180 degrees to each other.

Second structure either mirror of first OR all bonds drawn the same with position of two groups swapped. **1**

(iv) intermediate / (secondary carbo) cation from **X** is more stable ora **1**
OR
charge density of C^+ (of the intermediate of **X**) is reduced

(due to) electron-releasing character / (positive) inductive effect of alkyl groups / / due to electron releasing alkyl group **1**

(e) (i) (2–)methylpropene / (2–)methylprop–1–ene **1**

(ii)  **2**

4. MAR 17/P22/Q3/c(i,ii)

(a) (i) (electrophilic) addition **1**

(ii) **S** has CH_3CHOH **OR** methyl / CH_3 group next to CHOH **1**

5. M/J 13/P21/Q4

Types of reaction used must come from the list in the question.

organic reaction	type of reaction	reagent(s)
$CH_3CH_2CH_2CH_2Br \rightarrow$ $CH_3CH_2CH_2CH_2NH_2$	nucleophilic (1) substitution (1)	NH_3 (1)
$CH_3CH_2CH_2CH_2OH \rightarrow$ $BrCH_2CH_2CH_2CH_2OH$	free radical (1) substitution (1)	Br_2 **or** Br_2 in an organic solvent (1) **not** Br_2(aq)
$CH_3COCH_3 \rightarrow$ $CH_3C(OH)(CN)CH_3$	nucleophilic (1) addition (1)	HCN **or** HCN and CN^- **or** NaCN/KCN + H^+ (1)
$CH_3CH(OH)CH_2CH_3$ $\rightarrow$ $CH_3CH=CHCH_3$	elimination (1) **not** dehydration	conc. H_2SO_4 **or** P_4O_{10} **or** Al_2O_3 **or** H_3PO_4 (1)

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[11]

6. O/N 11/P23/Q2/b

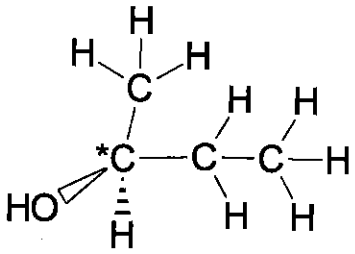
(a) (i) C : H : O = $\frac{64.86}{12} : \frac{13.50}{1} : \frac{21.64}{16}$ **(1)**

= 5.41: 13.50 : 1.35

= 4 : 10 : 1

gives $C_4H_{10}O$ **(1)**

(ii)



correct compound **and** correct chiral C* **(1)**
correct mirror object/ mirror
image relationship in 3D **(1)**

(iii)

$CH_3CH_2CH_2CH_2OH$	$CH_3CH(CH_3)CH_2OH$	$CH_3C(OH)(CH_3)CH_3$
(1)	(1)	(1)

[7]

7. **M/J 10/P21/Q5**

(a) (i) same molecular formula
but different structural formula/structure (1)

(ii) asymmetric C atom/chiral centre present (1)
>C=C< bond present (1) **[3]**

(b) $NaO_2CCH(OH)CH(OH)CO_2Na$ (1) **[1]**

(c) no **because** there is no chiral carbon atom present (1) **[1]**

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(d) (i) C : H : O = $\frac{35.8}{12} : \frac{4.5}{1} : \frac{59.7}{16}$ this mark is for correct use of A_r values (1)

C : H : O = 2.98 : 4.5 : 3.73

C : H : O = 1 : 1.5 : 1.25 this mark is for evidence of correct calculation (1)

gives empirical formula of **W** is $C_4H_6O_5$

(ii) $C_4H_6O_5 = 12 \times 4 + 1 \times 6 + 16 \times 5 = 134$

molecular formula of **W** is $C_4H_6O_5$ (1) **[3]**

(e) (i) $n(OH^-) = \frac{29.4 \times 100}{1000} = 0.0294$ (1)

n(**W**) = $\frac{1.97}{134} = 0.0147$ (1)

no. of $-CO_2H$ groups present

in one molecule of **W** = $\frac{0.0294}{0.0147} = 2$ (1)

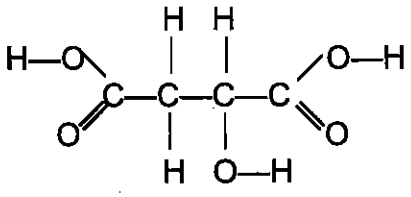
or $n(OH^-) = \frac{29.4 \times 1.00}{1000} = 0.0294$ (1)

1.97 g **W** ≡ 0.0294 mol NaOH

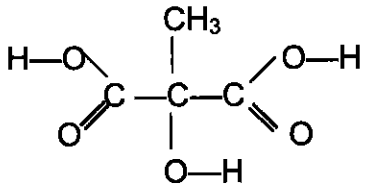
134 g **W** ≡ $\frac{0.0294 \times 134}{1.97} = 1.999 \approx 2$ mol NaOH (1)

no. of $-CO_2H$ groups present in 1 molecule of **W** = 2 (1) **[3]**

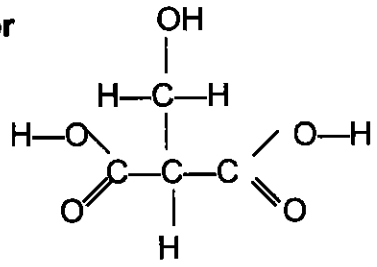
(ii)



or



or



one correct structure (1)

correctly displayed (1)

allow any **correct** ether **[2]**

[13]

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8. O/N 08/P2/Q4

organic reaction	type of reaction	reagent(s)
$CH_3CHO \rightarrow$	nucleophilic (1)	HCN
$CH_3CH(OH)CN$	addition (1)	**or** HCN and CN^- (1)
$CH_3CH_2CH_2CH_3 \rightarrow$	free radical (1)	Br_2
$CH_3CH_2CHBrCH_3$	substitution (1)	**or** Br_2 in an organic solvent **not** $Br_2(aq)$ (1)
$CH_3CH(OH)CH_3 \rightarrow$	elimination (1)	conc. H_2SO_4 (1)
$CH_3CH=CH_2$		
$CH_3CH=CH_2 \rightarrow$	addition	$KMnO_4/MnO_4^-$ (1)
$CH_3CH(OH)CH_2OH$	**or** oxidation (1)	

[10]

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UNIT 14

Hydrocarbons

A-Level
Chemistry Paper 2
Topical Workbook

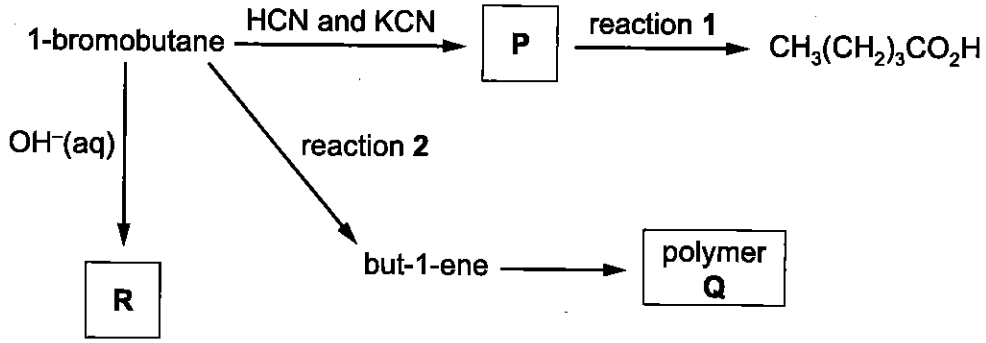
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Unit 14: Hydrocarbons

1. MAR 17/P22/Q3/a

(a) A series of reactions starting from 1-bromobutane is shown.



(i) Draw the **displayed** formula of compound **P**.

[1]

(ii) Identify the reagent(s) and conditions for reactions **1** and **2**.

reaction **1** .....

reaction **2** .....

[2]

(iii) Draw the structure of the repeat unit of polymer **Q**.

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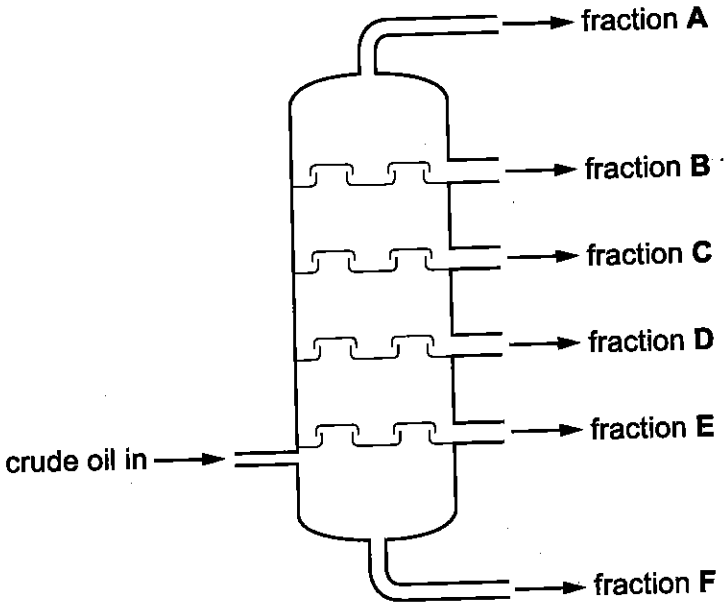
[2]

2. M/J 16/P23/Q3

Crude oil is a mixture of hydrocarbons and provides many useful chemicals when processed.

Two of the stages involved in the processing of crude oil are fractional distillation and cracking.

(a) The diagram is a simplified representation of a fractional distillation column.



(i) What has to be done to the crude oil before it enters the column?

..... [1]

(ii) What trend in **structure** is there from fraction **A** to fraction **F**?

.....

..... [1]

(iii) State the trends in **two** properties of the fractions from **A** to **F**.

.....

.....

..... [2]

(b) The naphtha fraction from fractional distillation of crude oil is used as a starting material for cracking.

(i) Write an equation for the cracking of $C_{12}H_{26}$ to form the products ethene and one other hydrocarbon in a 2 : 1 mole ratio.

..... [1]

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(ii) Suggest a use for each of the products from your equation in **(i)**. Explain what makes each product from **(i)** suitable for the use you suggest.

use of ethene .....

.....

explanation .....

.....

use of other product .....

.....

explanation .....

..... [4]

(c) Burning hydrocarbons can cause a number of environmental problems.

The products of internal combustion engines can include oxides of nitrogen and oxides of carbon.

Sulfur dioxide is a by-product of burning coal in power stations.

(i) Explain how and why oxides of nitrogen are produced in internal combustion engines.

.....

.....

..... [2]

(ii) Write an equation for the reaction between nitrogen monoxide and carbon monoxide in a catalytic converter.

..... [1]

(iii) Write equations to show the involvement of nitrogen monoxide in the formation of acid rain from atmospheric sulfur dioxide.

.....

.....

..... [3]

(iv) Describe two of the problems associated with acid rain.

.....

.....

..... [2]

[17]

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3. M/J 16/P21/Q4

This question is about molecules with molecular formula C_4H_8.

(a) Give the structures of a pair of **positional** isomers with the formula C_4H_8.

[1]

(b) Give the structures of a pair of **chain** isomers with the formula C_4H_8, that do **not** exhibit stereoisomerism.

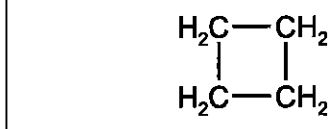
[1]

(c) Give the structures and full names of a pair of **stereoisomers** with the formula C_4H_8.

....

[2]

(d) The structure of a molecule, **A**, of formula C_4H_8 is shown.
Draw a functional group isomer of molecule **A** in box **B**. Explain how molecules **A** and **B** could be distinguished by a chemical test.



A

B

.....

.....

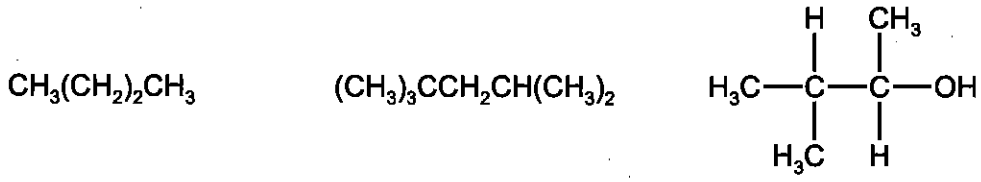
..... [3]

[7]

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4. MAR 16/P22/Q4

The following compounds were all found to be components of a sample of petrol.



G **H** **J**

(a) (i) Give the **molecular** formula of compound **G**.

..... [1]

(ii) Give the **empirical** formula of compound **H**.

..... [1]

(iii) Draw the **skeletal** formula of compound **J**.

[1]

(b) Write an equation to represent the complete combustion of compound **H**.

..... [1]

(c) Fossil fuels are often contaminated with sulfur.

State and explain why supplies of fossil fuels that contain sulfur pose a problem to the environment.

.....

.....

..... [2]

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(d) The boiling points of compounds **G**, **H** and **J** are shown below.

compound	G	H	J
boiling point/°C	0	99	112

Explain the differences in the boiling points of the three compounds.

.....

.....

.....

.....

.....

.....

..... **[4]**

(e) Compound **J** can be produced from 2-chloro-3-methylbutane, $C_5H_{11}Cl$.

Give the reagent(s) and conditions for this reaction.

..... **[1]**

[11]

5. O/N 15/P21/Q3

Heptane, C_7H_{16}, is an undesirable component of petrol as it burns explosively causing 'knocking' in an engine.

(a) There are nine structural isomers with the formula C_7H_{16}, only two of which contain chiral centres.

(i) Explain the meanings of the terms *structural isomers* and *chiral*.

structural isomers .....

.....

.....

chiral .....

.....

.....

[2]

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(ii) Give the structures and names of the two structural isomers of C_7H_{16} which contain a chiral centre.

[4]

(b) (i) Write an equation for the complete combustion of heptane.

..... [1]

(ii) Write an equation for the incomplete combustion of heptane leading to the production of a solid pollutant.

..... [1]

(iii) Incomplete combustion can also lead to emission of unburnt hydrocarbons.

State one environmental consequence of this.

..... [1]

(c) The reaction of heptane with chlorine in the presence of UV light produces a wide variety of products.

Formation of the monochloroheptanes can be represented by the following equation.

$$C_7H_{16} + Cl_2 \rightarrow C_7H_{15}Cl + HCl$$

(i) Name the mechanism of the reaction between heptane and chlorine in the presence of UV light.

..... [1]

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(ii) Describe this mechanism, using suitable equations and including the names of each stage in the process.

.....

.....

.....

.....

.....

.....

.....

.....

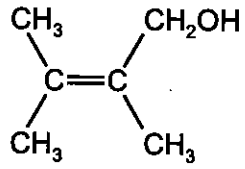
..... **[5]**

[15]

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6. M/J 15/P23/Q4

The structure of **H** is shown.



H

(a) **H** reacts with both cold, dilute, acidified potassium manganate(VII) and with hot, concentrated, acidified potassium manganate(VII).

(i) Give the structure of the organic product of the reaction of **H** with cold, dilute, acidified potassium manganate(VII).

[1]

(ii) Give the structures of the organic products of the reaction of **H** with hot, concentrated, acidified potassium manganate(VII).

[2]

(b) **(i)** Complete the reaction scheme to show the mechanism of the reaction of **H** with bromine to form **J**.

Include all necessary curly arrows, lone pairs and charges.



J

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[3]

(ii) Explain the origin of the dipole on the bromine molecule.

.....

..... [1]

J is formed as an equimolar mixture of isomers.

(iii) State the type of isomerism shown by **J**.

..... [1]

(iv) Draw the structures of the two isomers of **J**.

[2]

[10]

7. M/J 15/P22/Q3/a

Ethane reacts with chlorine to form chloroethane.

$$C_2H_6(g) + Cl_2(g) \rightarrow C_2H_5Cl(g) + HCl(g)$$

(a) (i) Use bond energies from the *Data Booklet* to calculate the enthalpy change for this reaction. Include a sign in your answer.

enthalpy change = ... $kJ\,mol^{-1}$ [3]

(ii) State the conditions needed for this reaction to occur.

..... [1]

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(iii) Use a series of equations to describe the mechanism of this reaction including the names of each stage and an indication of how butane can be produced as a minor by-product.

.....

.....

.....

.....

.....

..... **[5]**

8. M/J 14/P22/Q5

A hydrocarbon, **P**, with the formula C_6H_{12} readily decolourises bromine.

On reaction with hot, concentrated, acidified potassium manganate(VII) solution a single organic product, **Q**, is obtained.

Q gives an orange precipitate when reacted with 2,4-dinitrophenylhydrazine, 2,4-DNPH reagent, but has no reaction with Tollens' reagent.

(a) (i) Explain these observations.

.....

.....

.....

.....

.....

.....

.....

..... **[4]**

(ii) Draw the skeletal formula of **P** and give its name.

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name of **P** .....

[2]

(iii) Draw the skeletal formula of **Q** and give its name.

name of **Q** .....

[2]

(b) There are several structural isomers of **P** that also decolourise bromine, but only four of these structural isomers exhibit geometrical (cis-trans) isomerism.
Give the structures of any **three** structural isomers of **P** that exhibit geometrical (cis-trans) isomerism.

[3]

[11]

9. M/J 14/P22/Q4

Crude oil is processed to give a wide variety of hydrocarbons.

(a) Give the names of one physical process and one chemical process carried out during the processing of crude oil.

physical process .....

chemical process .....

[2]

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(b) Alkanes and alkenes can both be obtained from crude oil.

(i) Explain why alkanes are unreactive.

.....

..... **[2]**

(ii) State the bond angles in a molecule of

ethane, ...

ethene. .....

[1]

(iii) State the shape of each molecule in terms of the arrangement of the atoms bonded to each carbon atom.

ethane ..... ethene ..... **[1]**

(iv) Explain why these molecules have different shapes in terms of the carbon-carbon bonds present.

.....

..... **[1]**

(c) **(i)** Use a series of equations to describe the mechanism of the reaction of ethane with chlorine to form chloroethane. Name the steps in this reaction.

.....

.....

.....

.....

..... **[5]**

(ii) Write an equation to show how butane could be produced as a by-product of this reaction.

..... **[1]**

[13]

10. M/J 14/P21/Q4

Alkanes and alkenes both react with bromine.

(a) Explain how and why bromine can be used to distinguish between an alkene and an alkane.

.....

.....

..... **[2]**

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(b) The reaction of ethane with bromine forms a mixture of products.

(i) State the essential conditions for this reaction to occur.

..... [1]

(ii) Give the full name of the mechanism of this reaction.

..... [2]

(iii) Give the equation for a **termination** step that could occur, producing a **hydrocarbon**.

..... [1]

(iv) Give the equation for one **propagation** step involved in the formation of dibromoethane from bromoethane during this reaction.

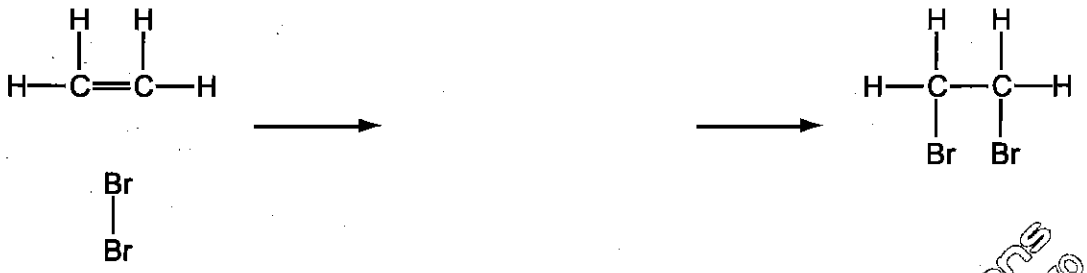
..... [1]

(c) The reaction of ethene with bromine forms a single product.

(i) Give the full name of the mechanism of this reaction.

..... [2]

(ii) Complete the diagram below to illustrate this mechanism.
Include all relevant charges, partial charges, curly arrows and lone pairs.



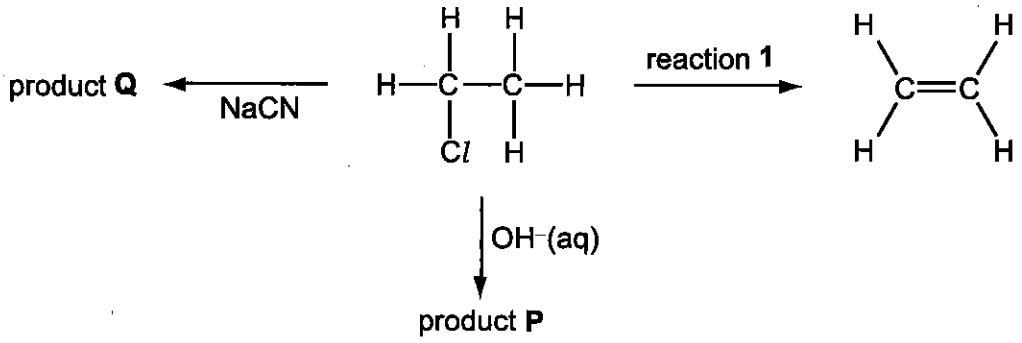
[4]

(d) Chloroethene can be polymerised to form a polymer commonly known as PVC.
Draw a diagram of the structure of PVC including **three** repeat units.

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[2]

(e) Chloroethane undergoes a series of reactions as shown in the diagram below.



(i) Give the reagent and conditions necessary for reaction **1**.

.....

..... **[2]**

(ii) Give the **skeletal** formula of product **P**.

[1]

(iii) Give the **displayed** formula and the name of product **Q**.

..... **[2]**

[20]

11. O/N 13/P23/Q2

Petrol and diesel fuel are both used in internal combustion engines.
Petrol may be regarded as having the formula C_9H_{20} and diesel fuel as having the formula $C_{14}H_{30}$.

(a) (i) To which class of compounds do these two hydrocarbons belong?

.....

(ii) Write a balanced equation for the complete combustion of petrol.

.....

[2]

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(b) When petrol or diesel fuel are used in internal combustion engines, several different products of the incomplete combustion of the fuel may be formed.

(i) Name **two** of these products that do not contain hydrogen.

..... and .....

(ii) Choose one of these and state a hazard it causes.

product .....

hazard .....

(iii) Write a balanced equation for the formation of **one** of the products in **(i)** from diesel fuel.

.....

[4]

(c) Define the term *standard enthalpy change of combustion*.

.....

.....

..... **[2]**

(d) A 1.00 cm^3 sample of $C_{14}H_{30}$ was completely burnt in air.
The heat produced raised the temperature of 250 g of water by 34.6 °C.
Assume no heat losses occurred during this experiment.
The density of $C_{14}H_{30}$ is 0.763 g cm^{-3}.

(i) Use relevant data from the *Data Booklet* to calculate the amount of heat released in this experiment.

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(ii) Use the data above and your answer to **(i)** to calculate the energy produced by the combustion of 1 mol of $C_{14}H_{30}$.

[5]

[13]

12. O/N 13/P22/Q5/a,b

Propane, C_3H_8, and butane, C_4H_{10}, are components of Liquefied Petroleum Gas (LPG) which is widely used as a fuel for domestic cooking and heating.

(a) (i) To which class of compounds do these two hydrocarbons belong?

.....

(ii) Write a balanced equation for the complete combustion of butane.

.....

[2]

(b) When propane or butane is used in cooking, the saucepan may become covered by a solid black deposit.

(i) What is the chemical name for this black solid?

.....

(ii) Write a balanced equation for its formation from butane.

.....

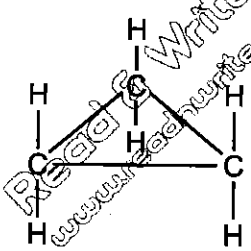
[2]

13. O/N 13/P22/Q2

The molecular formula C_3H_6 represents the compounds propene and cyclopropane.



propene



cyclopropane

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(a) What is the H–C–H bond angle at the terminal $=CH_2$ group in propene?

.....

[1]

(b) Under suitable conditions, propene and cyclopropane each react with chlorine.

(i) With propene, 1,2-dichloropropane, $CH_3CHClCH_2Cl$ is formed.

State fully what type of reaction this is.

..... [1]

(ii) When cyclopropane reacts with chlorine, three different compounds with the molecular formula $C_3H_4Cl_2$ can be formed.

Draw displayed structures of **each** of these three compounds.

[3]

[5]

14. O/N 12/P23/Q1

Carbon dioxide, CO_2, makes up about 0.040 % of the Earth's atmosphere. It is produced by animal respiration and by the combustion of fossil fuels.

In animal respiration, oxygen reacts with a carbohydrate such as glucose to give water, carbon dioxide and energy.

The typical daily food requirement of a human can be considered to be the equivalent of 1.20 kg of glucose, $C_6H_{12}O_6$.

You should express all of your numerical answers in this question to <u>three</u> significant figures.

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(a) (i) Construct a balanced equation for the complete oxidation of glucose.

.....

(ii) Use your equation to calculate the amount, in moles, of CO_2 produced by one person in one day from 1.20 kg of glucose.

(iii) On the day on which this question was written, the World population was estimated to be 6.82×10^9.

Calculate the total mass of CO_2 produced by this number of people in one day. Give your answer in tonnes. [1 tonne = 1.00×10^6 g]

[6]

(b) When fossil fuels are burned in order to give energy, carbon dioxide and water are also produced.

The hydrocarbon octane, C_8H_{18}, can be used to represent the fuel burned in motor cars. A typical fuel-efficient motor car uses about 4.00 dm^3 of fuel to travel 100 km.

(i) Construct a balanced equation for the complete combustion of octane.

.....

(ii) The density of octane is 0.700 g cm^{-3}.

Calculate the amount, in moles, of octane present in 4.00 dm^3 of octane.

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(iii) Calculate the mass of CO_2 produced when the fuel-efficient car is driven for a distance of 100 km.

[5]

(c) Calculate how many kilometres the same fuel-efficient car would have to travel in order to produce as much CO_2 as is produced by the respiration of 6.82×10^9 people during one day. Use your answer to **(a)(iii)**

[2]

(d) Carbon dioxide is one of a number of gases that are responsible for global warming. When fossil fuels such as octane are burned in a car engine, other atmospheric pollutants are also produced.
Give the formula of **one** atmospheric pollutant that may be produced in a car engine, other than CO_2, and state how this pollutant damages the environment.

pollutant .....

damage caused ..... **[2]**

[14]

15. M/J 12/P23/Q4
But-2-ene, $CH_3CH{=}CHCH_3$, is an important compound which is obtained from the cracking of hydrocarbons present in crude oil.

(a) Give **two** different conditions under which long chain hydrocarbons may be cracked.

.....

.....

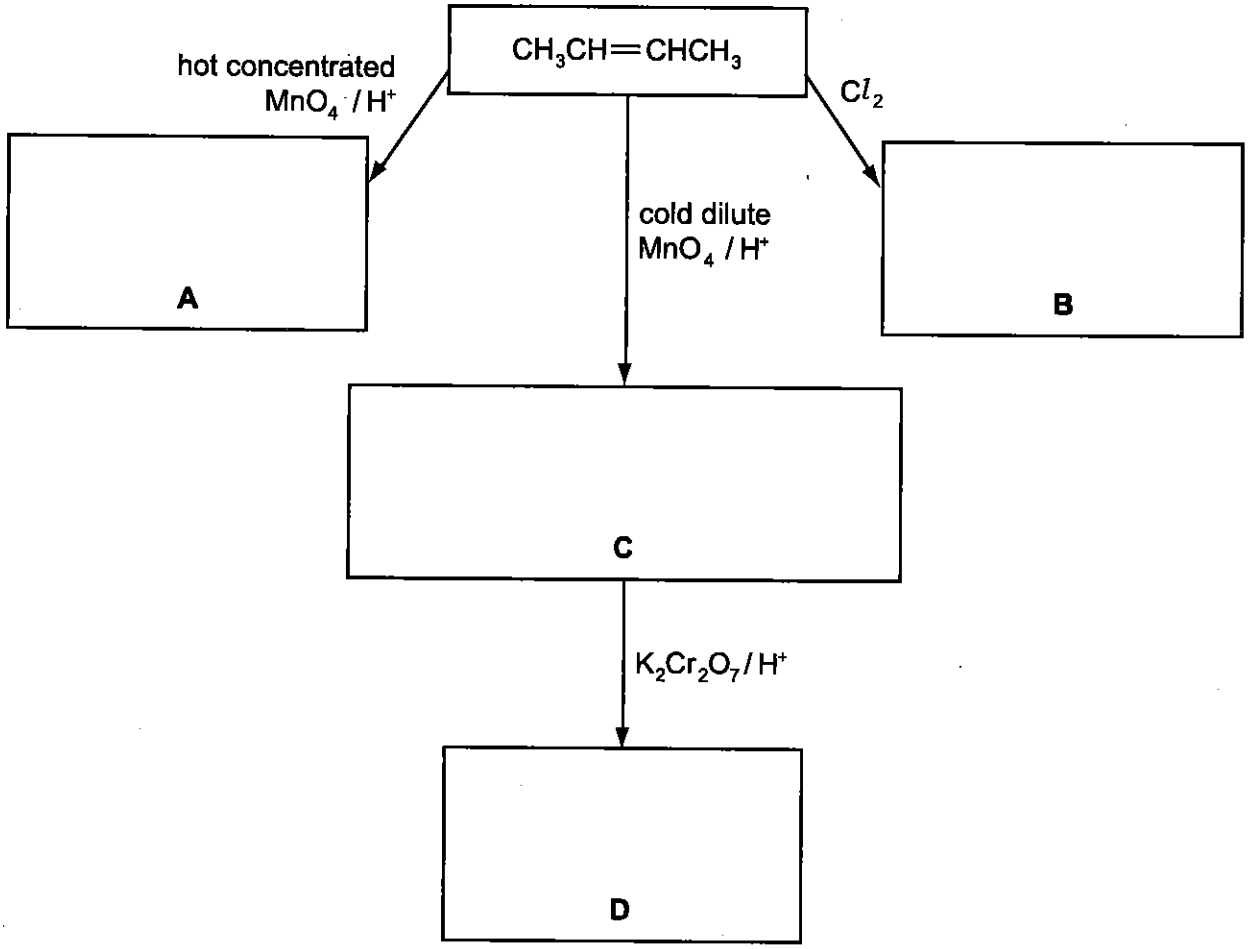
..... **[2]**

(b) Dodecane, $C_{12}H_{26}$, is a long chain hydrocarbon which is present in crude oil and which can be cracked to form but-2-ene and an alkane.
Write a balanced equation for this reaction.

..... **[1]**

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(c) Some reactions of but-2-ene are shown below.
In the boxes below, give the **structural** formulae of the organic compounds **A** to **D**.



[4]

(d) (i) Draw the **skeletal** formula of compound **D**.

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(ii) By using the letters **A** to **D** as appropriate, identify those compounds which are chiral. If there are none, write 'none'.

.....

[3]

(e) But-2-ene can be polymerised to give poly(butene).
Draw the **structural** formula of a portion of the polymer chain in poly(butene) showing **two** repeat units.

[1]

(f) Compound **C** is a liquid which can be reacted with concentrated sulfuric acid to give a gas, **E**, which will decolourise aqueous bromine when passed through it.

(i) Suggest the **structural** formula of **E**.

(ii) Suggest the **structural** formula of the product of the reaction between **E** and an excess of bromine.

(iii) What *type of reaction* occurs between **E** and an excess of bromine?

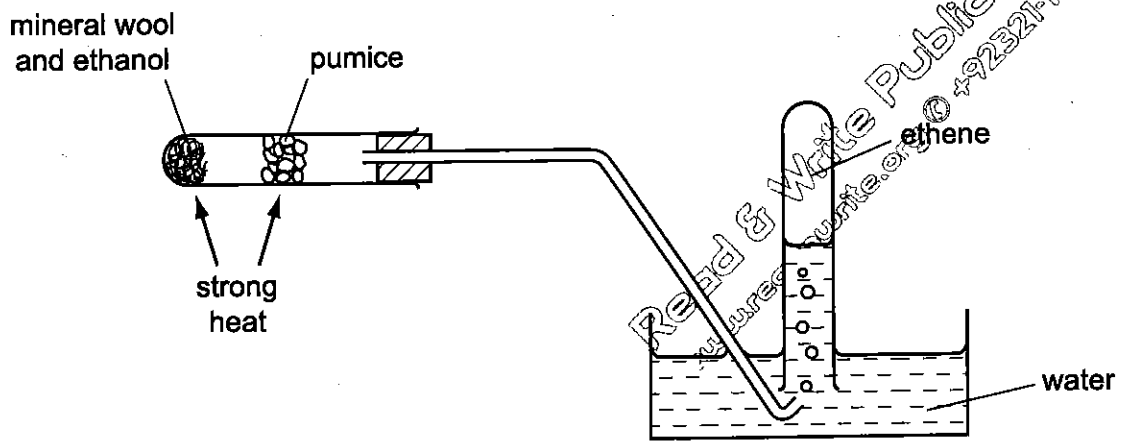
.....

[3]

[14]

16. M/J 12/P21/Q4

One method of preparing ethene in a school or college laboratory is from ethanol by using the apparatus shown below.



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(a) **(i)** Write a balanced equation for this reaction.

.....

(ii) What *type of reaction* is this?

.....

(iii) Give the chemical name of a reagent other than pumice that could be used to carry out this reaction. It is not necessary to use the same apparatus.

.....

[3]

(b) Ethene is bubbled into two separate test-tubes, one containing aqueous hydrogen bromide and the other containing cold, dilute acidified potassium manganate(VII).

In **each** case, describe any colour changes you would see and give the structural formula of the organic product.

	aqueous hydrogen bromide	cold, dilute acidified potassium manganate(VII)
colour at start		
colour after reaction		
structural formula of organic product		

[4]

(c) Cyclohexene has the following structural formula.



(i) What is the molecular formula of cyclohexene?

.....

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(ii) Draw the structural formula of the compound formed when cyclohexene is reacted with bromine.

(iii) State as fully as you can what *type of reaction* this is.

.....

(iv) Draw the structural formula of the compound formed when cyclohexene is reacted with hot concentrated acidified potassium manganate(VII).

[5]

[12]

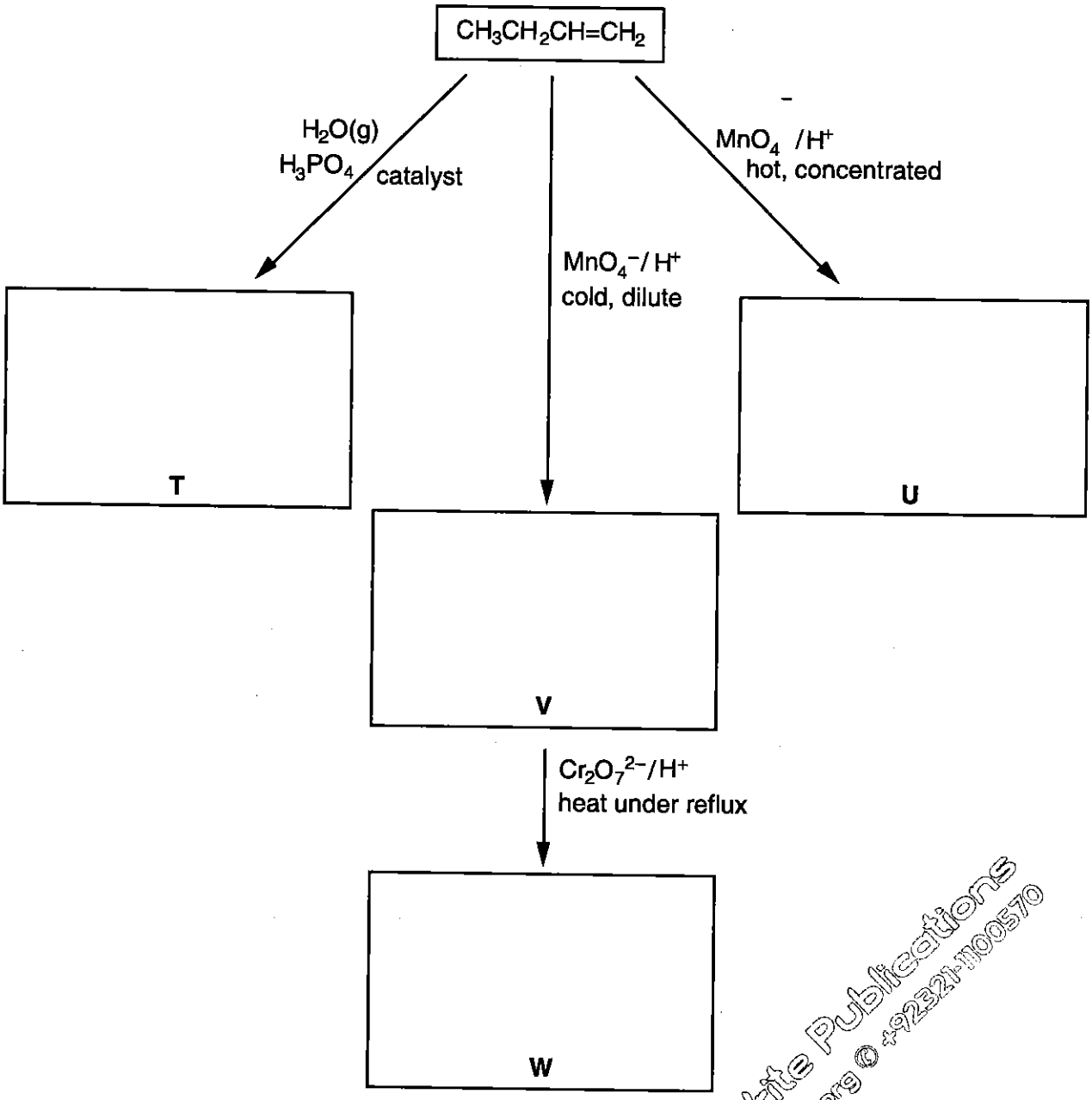
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17. O/N 11/P22/Q4

But-1-ene, $CH_3CH_2CH=CH_2$, is an important compound in the petrochemical industry.

(a) Some reactions of but-1-ene are given below.

In **each** empty box, draw the structural formula of the organic compound formed.



[5]

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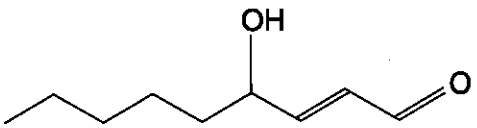
(b) Compound **T** reacts with compound **U**.
Draw the **displayed** formula of the organic product of this reaction.

[2]

[7]

18. M/J 11/P23/Q4

The compound *trans*-4-hydroxy-2-nonenal (HNE) is thought to lead to infections of the lung when cigarettes are smoked.



$CH_3(CH_2)_4CH(OH)CH=CHCHO$

***trans*-4-hydroxy-2-nonenal**

(a) What is the empirical formula of *trans*-4-hydroxy-2-nonenal?

.....

[1]

(b) (i) HNE contains an alkene group. Name as fully as you can **two** other functional groups which are present in the HNE molecule.

.....

.....

(ii) How would you confirm the presence of the alkene group in HNE?
State the reagent used and the observation you would make.

reagent .....

observation .....

[5]

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HNE is a reactive compound.

(c) Give the structural formulae of all of the carbon-containing compounds formed in each case when HNE is reacted separately with the following reagents.

(i) hot concentrated manganate(VII) ions in acid solution

(ii) hot phosphorus trichloride, PCl_3

(iii) sodium tetrahydridoborate(III), $NaBH_4$

[4]

[10]

19. M/J 11/P22/Q5/d,e

(a) (i) Suggest the meaning of the term *polyunsaturated fatty acid.*

.....

.....

(ii) What reagent and condition(s) are used for the hydrogenation of an unsaturated fatty acid?

reagent .....

condition(s) .....

[3]

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In cooking, unsaturated fats are often oxidised to give aldehydes or ketones.

(b) (i) Give the structural formulae of the two aldehydes formed by the partial oxidation of the unsaturated fat below.
In the structure, *X*, represents the rest of the fat molecule.

$$CH_3(CH_2)_7CH{=}CH(CH_2)_7X$$

$\downarrow$

(ii) Name the reagent you would use to show that the product contained **either** an aldehyde **or** a ketone. What change would be seen?

reagent .....

observation .....

(iii) What reagent would you use to **confirm** the presence of an aldehyde? What change would be seen?

reagent .....

observation .....

[6]

20. M/J 11/P21/Q5/a,b,c

The gas ethyne, C_2H_2, more commonly known as acetylene, is manufactured for use in the synthesis of organic compounds. It is also used, in combination with oxygen, in 'oxy-acetylene' torches for the cutting and welding of metals.

Industrially, ethyne is made from calcium carbide, CaC_2, or by cracking liquid hydrocarbons.

(a) When calcium carbide is reacted with water, ethyne and calcium hydroxide are formed.
Construct a balanced equation for this reaction.

.....**[1]**

Ethyne can also be obtained from ethene by using the following sequence of reactions.

$$CH_2CH_2 \xrightarrow{\text{step 1}} ClCH_2CH_2Cl \xrightarrow{\text{step 2}} HC{\equiv}CH$$

(b) (i) What types of reaction are step 1 and step 2?

step 1 .....

step 2 .....

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(ii) Suggest what reagent and conditions would be used in a laboratory in step 2.

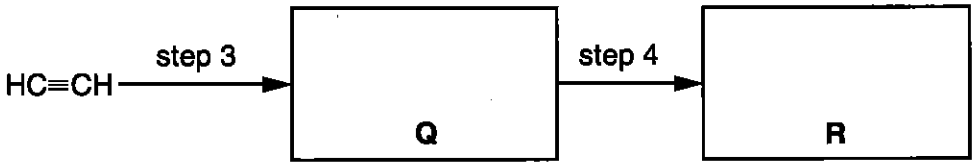
reagent .....

conditions ..... **[5]**

When ethyne is passed into water at 60 °C, in the presence of a little H_2SO_4 and Hg^{2+} ions, a pungent, colourless organic liquid, **Q**, with M_r of 44 is obtained. This is step 3.

When **Q** is warmed with Tollens' reagent in a test-tube, a silver mirror is formed.
On acidification, the solution remaining in the test-tube is found to contain the organic compound **R** which has M_r of 60. This is step 4.

(c) (i) Give the structural formulae of **Q** and **R**.



(ii) What type of reaction is step 3 and step 4?

step 3 .....

step 4 ..... **[4]**

21. M/J 11/P21/Q2/a,b

Crude oil contains a mixture of hydrocarbons together with other organic compounds which may contain nitrogen, oxygen or sulfur in their molecules.

At an oil refinery, after the fractional distillation of crude oil, a number of other processes may be used including 'cracking', 'isomerisation', and 'reforming'.

(a) (i) What is meant by the term '*cracking*' and why is it carried out?

.....

.....

.....

.....

(ii) Outline briefly how the cracking of hydrocarbons would be carried out.

.....

.....

(iii) Construct a balanced equation for the formation of heptane, C_7H_{16}, by cracking tetradecane, $C_{14}H_{30}$.

.....

[4]

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One of the sulfur-containing compounds present in crude oil is ethanethiol, C_2H_5SH, the sulfur-containing equivalent of ethanol. Ethanethiol is toxic and is regarded as one of the smelliest compounds in existence.

(b) The boiling point of ethanol, C_2H_5OH, is higher than that of C_2H_5SH.
Suggest a reason for this difference.

.....

.....**[1]**

22. M/J 11/P21/Q1/a,b,c

Some intercontinental jet airliners use kerosene as fuel. The formula of kerosene may be taken as $C_{14}H_{30}$.

(a) To which homologous series of compounds does kerosene belong?

..... **[1]**

(b) When kerosene burns in an excess of air, carbon dioxide and water form.
Balance the following equation for the complete combustion of kerosene.

$$.....C_{14}H_{30}(l) + ...O_2(g) \rightarrow .....CO_2(g) + ...H_2O(g) \quad [1]$$

(c) In this section, give your answers to <u>one</u> decimal place.

The flight path from Beijing to Paris is approximately 8195 km.
A typical intercontinental jet airliner burns 10.8 kg of kerosene for each kilometre covered.

(i) Calculate the mass, in tonnes, of $C_{14}H_{30}$ burnt on a flight from Beijing to Paris.
[1 tonne = 1 000 kg]

(ii) Use your equation in **(b)** to calculate the mass, in tonnes, of CO_2 produced during this flight.

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[4]

23. M/J 11/P21/Q2/c,d,e

When ethanethiol is burned in an excess of air, three oxides of different elements are formed.

(a) (i) Construct a balanced equation for this reaction.

.....

(ii) **Two** of the oxides formed cause serious environmental damage.

For **each** of these oxides, identify the type of pollution caused and describe one consequence of this pollution.

.....

.....

.....

.....

.....

[6]

(b) A small amount of ethanethiol is added to liquefied gases such as butane that are widely used in portable cooking stoves.

Suggest a reason for this.

.....**[1]**

Sulfur-containing compounds are removed from oil products at the refinery. The sulfur is recovered and converted into SO_2, which is then used in the Contact process.

(c) State the main operating details of the formation of SO_3 in the Contact process.

.....

.....

.....

.....

.....**[3]**

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24. O/N 10/P22/Q3/b,c

(a) Undecane, $C_{11}H_{24}$, is a long chain hydrocarbon which is present in crude oil. Such long chain hydrocarbons are 'cracked' to produce alkanes and alkenes which have smaller molecules.

(i) Give the conditions for **two different** processes by which long chain molecules may be cracked.

process 1 .....

.....

process 2 .....

.....

(ii) Undecane, $C_{11}H_{24}$, can be cracked to form pentane, C_5H_{12}, and an alkene. Construct a balanced equation for this reaction.

..... **[3]**

Pentane, C_5H_{12}, exhibits structural isomerism.

(b) (i) Draw the three structural isomers of pentane.

isomer **B**	isomer **C**	isomer **D**

(ii) The three isomers of pentane have different boiling points.

Which of your isomers has the highest boiling point?

isomer .....

Suggest an explanation for your answer.

.....

.....

..... **[6]**

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25. O/N 09/P21/Q3/b

(a) (i) By using equations, describe the mechanism of the reaction between chlorine and methane to form chloromethane, CH_3Cl

Identify, by name, the separate steps of the overall reaction.

.....

.....

.....

.....

.....

.....

(ii) What is the intermediate organic species in this reaction?

..... **[7]**

26. O/N 08/P2/Q2/a,b

Ketene, C_2H_2O, is a member of a class of unsaturated organic compounds that is widely used in pharmaceutical research for the synthesis of organic compounds.

$CH_2=C=O$

ketene

(a) (i) Suggest values for the H-C-H and C=C=O bond angles in ketene.

H-C-H ..... C=C=O .....

(ii) By considering the structure of the molecule, suggest why the name *ketene* is used.

.....

..... **[3]**

(b) Ketene burns completely in air to form carbon dioxide and water.

(i) Write a balanced equation for this reaction.

.....

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(ii) Use your equation to calculate the volume of CO_2, in dm^3, measured at room temperature and pressure, which will be formed when 3.5 g of ketene are burned in an excess of air.

Give your answer to **two** significant figures.

volume of CO_2 = ... dm^3 **[4]**

27. O/N 07/P2/Q4/a,b,c,e,f)

The molecular formula of a compound states the number of atoms of each element that are present in one molecule. It contains no information about the structure of the molecule. Hydrocarbons with the molecular formula C_5H_{10} may be branched chain, straight chain or cyclic.

(a) Draw a displayed formula of C_5H_{10} as a branched chain hydrocarbon.

[1]

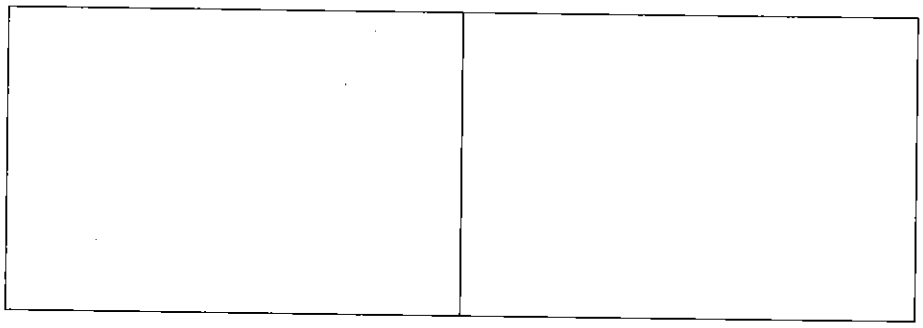
Pent-2-ene is one straight chain hydrocarbon with formula C_5H_{10}.

(b) Pent-2-ene exhibits *cis-trans* isomerism. Draw and label the structural formulae of the two *cis-trans* isomers of pent-2-ene.

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[2]

(c) In the spaces below draw the structural formulae of **two** alcohols which would **each** produce pent-2-ene on dehydration.



[2]

(d) Pent-2-ene decolourises aqueous bromine. Suggest the structural formula of an isomer of C_5H_{10} which does **not** decolourise aqueous bromine.

[1]

(e) Pent-2-ene can be polymerised. Draw a section of the polymer chain produced showing **two** repeat units.

[1]

[9]

28. O/N 06/P2/Q4/a,b,c

Octadecane, $C_{18}H_{38}$, is a long chain hydrocarbon which is present in crude oil. Such long chain hydrocarbons are 'cracked' to produce alkanes and alkenes which have smaller molecules.

(a) Give **two** different conditions under which long chain molecules may be cracked.

.....

.....

..... [2]

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(b) Octadecane, $C_{18}H_{38}$, can be cracked to form hexane and an alkene.
Write a balanced equation for this reaction.

..... [1]

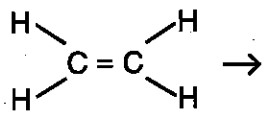
Alkenes are important industrially because the C=C bond makes them very reactive.

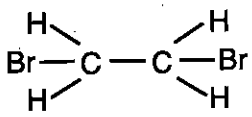
(c) Ethene reacts with bromine to give 1,2-dibromoethane.

(i) What type of reaction is this?

.....

(ii) Outline the mechanism of this reaction, giving the structure of the intermediate.
Show clearly any relevant dipoles, charges and lone pairs of electrons.







[4]

29. M/J 04/P2/Q5

A number of organic compounds containing the halogens fluorine and/or chlorine are commercially important because of their chemical inertness.

(a) Name **three** such compounds, and for each state a use where its inertness is important.

(i) .....

.....

(ii) .....

.....

(iii) .....

.....[6]

(b) Under certain conditions in the upper atmosphere, some of these compounds break down.

(i) Explain how this happens and what effects this has, in chemical terms.

.....

.....

.....

.....

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(ii) Suggest alternative compounds, which do not contain a halogen, for **two** of the uses you have given in **(a)**.

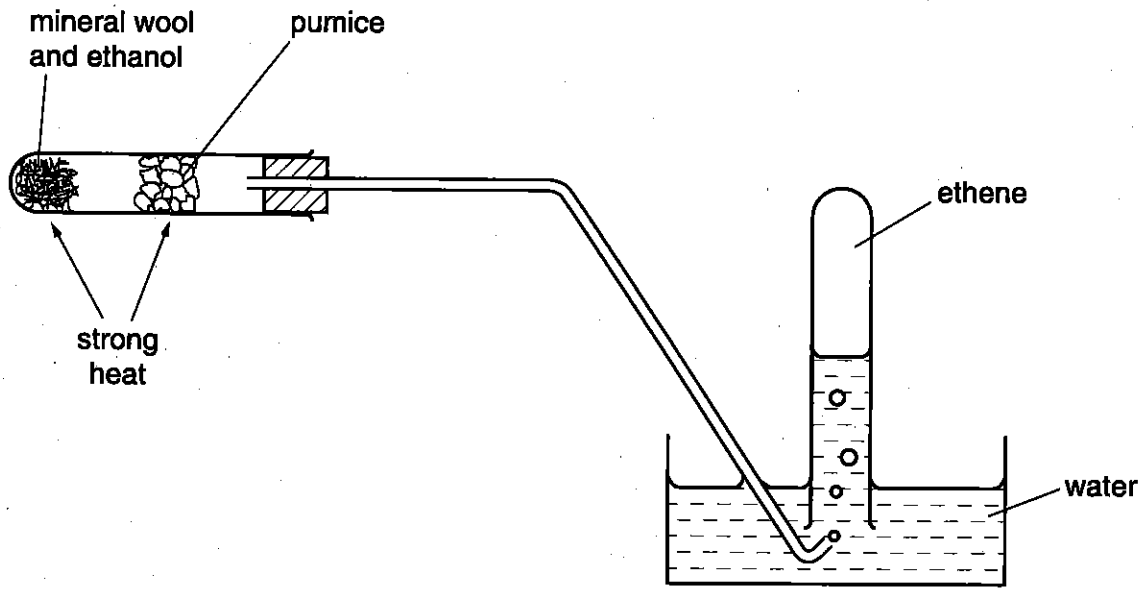
.....

.....[5]

[11]

30. O/N 03/P2/Q4

The apparatus shown can be used to prepare ethene from ethanol.



(a) (i) State what type of reaction takes place on the hot pumice.

.....

(ii) Write an equation for this preparation.

.....

[2]

(b) Describe the colour changes which are observed and write equations for the reaction of ethene with the following two reagents.

(i) bromine

colour change from ..... to .....

equation .....

(ii) cold, dilute, acidified manganate(VII) ions

colour change from ..... to .....

equation .....

[4]

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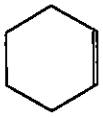
(c) Draw structures for each of the following polymers showing **two** repeat units.

(i) poly(ethene)

(ii) pvc [poly(chloroethene)]

[2]

(d) The formula of the alkene cyclohexene can be written as shown.



(i) State the molecular formula of cyclohexene. .....

(ii) Calculate the percentage of carbon by mass in cyclohexene.

[3]

[11]

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31. O/N 03/P2/Q2

A car can be considered to run on octane, C_8H_{18}.

(a) Write an equation for the complete combustion of octane.

.....[1]

The composition of the exhaust gases (fumes) from a petrol (gasoline) engine is given below.

Gas	Percentage by volume
carbon dioxide	9
water vapour	8
oxygen	4
hydrogen	2
carbon monoxide	3–6
hydrocarbons	0.2
nitrogen oxides	0.4–0.05

(b) (i) What gas, omitted from the table, makes up most of the remainder of the exhaust fumes?

.....

(ii) Explain why there is always water vapour in the exhaust fumes.

.....

[2]

(c) (i) State two gases in the exhaust fumes which are poisonous to humans. Also state briefly for each the particular effect on humans.

gas I .....

effect .....

gas II .....

effect .....

(ii) The two gases you have given in **(c)(i)** can be removed by reaction in a platinised catalytic converter. The products of the reaction in the converter are not hazardous. For each of your gases in **(c)(i)** give an equation which shows how it is removed to form less harmful substances.

I .....

II .....

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(iii) Suggest **one** reason why the exhaust fumes from a car fitted with a catalytic converter are still hazardous to human health to some degree.

.....

.....

.....[5]

[8]

32. M/J 03/P2/Q5

(a) Draw a section of poly(propene), showing three repeat units.

[1]

(b) To what homologous series does poly(propene) belong?

.....[1]

(c) When a rupture (hernia) or a deep wound, e.g. as a result of a sports accident, is repaired by surgery, a mesh is inserted below the muscle tissue so that on healing the wound is less likely to reopen and the repair is stronger.

Poly(propene) is the recommended material for the mesh.

(i) Suggest **two** reasons why poly(propene) is used rather than a natural fibre such as cotton.

.....

.....

.....

(ii) Members of the homologous series you have given in **(b)** are considered to have two different kinds of reactions. Explain why neither of them can take place in a poly(propene) mesh inserted in living body tissues.

.....

.....

.....

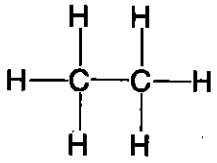
.....[4]

[6]

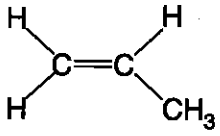
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33. M/J 02/P2/Q5

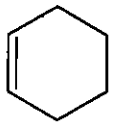
Crude oil is the principal source of hydrocarbons. The following are examples of such hydrocarbons.



ethane



propene



cyclohexene

(a) Give the structural formulae of the organic products in the following reactions.

(i) The reaction of ethane with bromine in the presence of u.v. light.

(ii) The polymerisation of propene.

(iii) The oxidation of propene with cold, acidified potassium manganate(VII).

(iv) The reaction of cyclohexene with hydrogen bromide.

(v) The reaction of cyclohexene with hot acidified potassium manganate(VII).

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[5]

(b) Write equations for the following reactions.

(i) The complete combustion of ethane.

(ii) The action of steam on propene in the presence of a catalyst.

(iii) The reaction of cyclohexene with hydrogen in the presence of a catalyst.

[3]

(c) The process of cracking produces useful substances from oil.

(i) Explain why cracking is useful.

.....

.....

.....

.....

(ii) Suggest an equation for the cracking of $C_{16}H_{34}$ into at least three fragments.

[3]

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34. M/J 17/P23/Q1

Combustion data can be used to calculate the empirical formula, molecular formula and relative molecular mass of many organic compounds. Combustion data cannot distinguish between different structural isomers.

(a) Define the term *structural isomers*.

.....

.....

.....

..... [2]

(b) **P** is a hydrocarbon, C_xH_y. A gaseous sample of **P** occupied a volume of 25 cm^3 at 37 °C and 100 kPa.

The sample was completely burned in 200 cm^3 of oxygen (an excess).
The final volume, measured under the same conditions as the gaseous sample (so that the water produced is liquid and its volume can be ignored), was 150 cm^3.
Treating the remaining gaseous mixture with concentrated alkali, to absorb carbon dioxide, decreased the volume to 50 cm^3.

The equation for the complete combustion of **P** can be represented as shown.

$$C_xH_y + (x + \frac{y}{4})O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

(i) Use the data given to calculate the value of x.

x = ... [1]

(ii) Use the data given to calculate the value of $(x + \frac{y}{4})$.

$(x + \frac{y}{4})$ = ... [1]

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If you were unable to calculate values in **(b)(i)** and **(b)(ii)** then use the data in this box for the remaining parts of this question. These are **not** the correct values.

$x = 6$ $\left(x + \frac{y}{4}\right) = 9$

(iii) Give the molecular formula and the empirical formula of **P**.

molecular formula of **P** .....

empirical formula of **P** .....

[2]

(iv) **P** is unbranched.

Give the skeletal formulae for two possible structures of **P** that are positional isomers of each other.

[2]

(v) Use the general gas equation to calculate the mass of **P** present in the original 25 cm^3 gaseous sample, which was measured at 37 °C and 100 kPa.

Give your answer to **three** significant figures.

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mass = ... g **[3]**

35. M/J 07/P2/Q1/d,e

(a) When ethene is reacted with HCl, C_2H_5Cl is the only product.

(i) Using structural formulae, give an equation for the reaction between ethene and HCl.

(ii) What type of reaction occurs between HCl and ethene?

.....

(iii) Explain why there is no further reaction between C_2H_5Cl and HCl.

.....

[3]

(b) When aqueous hydrazine is reacted with HCl, a solid compound of formula N_2H_5Cl may be isolated. When an excess of HCl is used, a second solid, $N_2H_6Cl_2$, is formed.

(i) Suggest what type of reaction occurs between hydrazine and HCl.

.....

(ii) What feature of the hydrazine molecule enables this reaction to occur?

.....

(iii) Suggest why one molecule of hydrazine is able to react with one or two molecules of HCl.

.....

.....

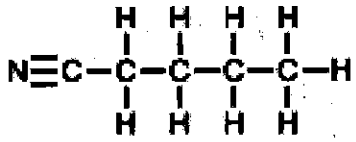
[3]

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Answers Section

1. MAR 17/P22/Q3/a

(a) (i)

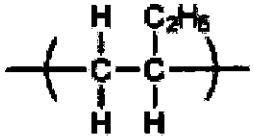


1

(ii) reaction 1 = HC*l*(aq) 1

reaction 2 = (conc.) NaOH/KOH **AND** ethanol 1

(iii)



2

C–C backbone with dangling bonds 1
rest of structure 1

2. M/J 16/P23/Q3

(a) (i) vaporise/boil/turn to gas [1] [1]

(ii) increasing molecular size/no of carbon atoms per molecule/length of carbon chain [1] [1]

(iii) increasing b.pt/decreasing volatility [1] [2]
increasing viscosity [1]
increasing density
increasing depth of colour
decreasing flammability/decreasing 'cleanliness' of flame owtte

(b) (i) $C_{12}H_{26} \rightarrow 2C_2H_4 + C_8H_{18}$ [1] [1]

(ii) ethene use = <u>making</u> polythene/plastic/polymers [1] [4]
feature of ethene = double bond/unsaturated [1]
octane/alkane use = fuel/petrol [1]
feature of octane/alkane = flammability/releases energy when burned/combusted [1]

(c) (i) (produced by) reaction of (atmospheric) oxygen and nitrogen [1] [2]
due to high temperature/engine provides energy/combustion provides energy [1]

(ii) $2NO + 2CO \rightarrow N_2 + 2CO_2$ / $NO + CO \rightarrow \frac{1}{2}N_2 + CO_2$ [1] [1]

(iii) $NO + \frac{1}{2}O_2 \rightarrow NO_2$ [1] [3]
$NO_2 + SO_2 \rightarrow SO_3 + NO$ [1]
$SO_3 + H_2O \rightarrow H_2SO_4$ / $2H^+ + SO_4^{2-}$ / $H^+ + HSO_4^-$ [1]

(iv) lowers pH of rivers/lakes/kills fish [1] [max 2]
leaches (toxic) aluminium from soil (into rivers/lakes) [1]
leaches away soil nutrients [1]
damage to buildings/statues/trees/plants/crops [1]
ocean acidification/damage to coral [1]

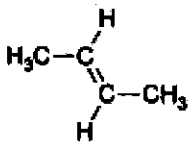
3. M/J 16/P21/Q4 **[17]**

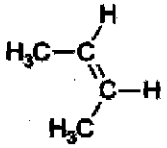
(a) $CH_2=CHCH_2CH_3$/$CH_2CHCH_2CH_3$ [1]
AND
$CH_3CH=CHCH_3$/$CH_3CHCHCH_3$ [1]

(b) $CH_2=CHCH_2CH_3$/$CH_2CHCH_2CH_3$ [1]
AND
$(CH_3)_2C=CH_2$/$(CH3)_2CCH_2$ [1]

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(c)





trans-but-2-ene (or *E*) [1]

cis-but-2-ene (or *Z*) [1] [2]

(d) **B** is $CH_2=CHCH_2CH_3$ OR $CH_3CH=CHCH_3$ OR $(CH_3)_2C=CH_2$ [1]

distinguished by addition of bromine [1] [3]

brown/red/orange/yellow to colourless/decolourises with **B** (but not **A**) [1]

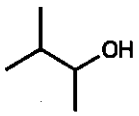
[7]

4. MAR 16/P22/Q4

(a) **(I)** $\underline{C_4H_{10}}$ [1] [1]

(II) $\underline{C_4H_8}$ [1] [1]

(iii)



[1] [1]

(b) $C_8H_{18} + 12½O_2 \rightarrow 8CO_2 + 9H_2O$ [1] [1]

(c) sulfur dioxide would be produced on combustion [1]
(which contributes to) acid rain [1] [2]

(d) M1 = **H** has more/greater/stronger van der Waals'/intermolecular forces than **G** / ora [1]
M2 = (because) **H** has more electrons (than **G**) [1]
M3 = **J** has hydrogen bonding (between molecules) [1]
M4 = strong(er)/great(er) forces require AND high/more energy to overcome [1] [4]

(e) NaOH(aq) [1] [1]

[11]

5. O/N 15/P21/Q3

(a) **(i)** structural isomers: (different molecules with) same molecular formula but different structural formulae [1]

chiral: has a carbon/C attached to 4 different groups/atoms/chains OR has no plane/line of symmetry/has non-superimposable mirror images [1] [2]

(ii) $CH_3CH_2CH(CH_3)CH_2CH_2CH_3$ [1]
3-methylhexane [1]

$CH_3CH(CH_3)CH(CH_3)CH_2CH_3$/$(CH_3)_2CHCH(CH_3)CH_2CH_3$ [1]
2,3-dimethylpentane [1] [4]

(b) **(I)** $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ [1] [1]

(ii) $C_7H_{16} + 4O_2 \rightarrow 7C + 8H_2O$ [1] [1]

(III) global dimming/PAN/smog/global warming [1] [1]

(c) **(i)** (Free) Radical Substitution [1] [1]

(ii) $Cl_2 \rightarrow 2Cl\bullet$ [1]
OR
$Cl_2 \rightarrow Cl\bullet + Cl\bullet$

$C_7H_{16} + Cl\bullet \rightarrow \bullet C_7H_{15} + HCl$ [1]
$\bullet C_7H_{15} + Cl_2 \rightarrow C_7H_{15}Cl + Cl\bullet$ [1] [5]

$\bullet C_7H_{15} + Cl\bullet \rightarrow C_7H_{15}Cl$ OR $\bullet C_7H_{15} + \bullet C_7H_{15} \rightarrow C_{14}H_{30}$ [1]

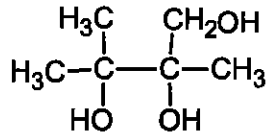
Initiation; Propagation; Termination (used correctly) [1]

[15]

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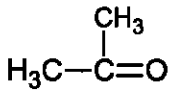
6. M/J 15/P23/Q4

(a) (i)

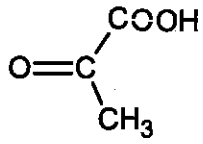


[1] [1]

(ii)

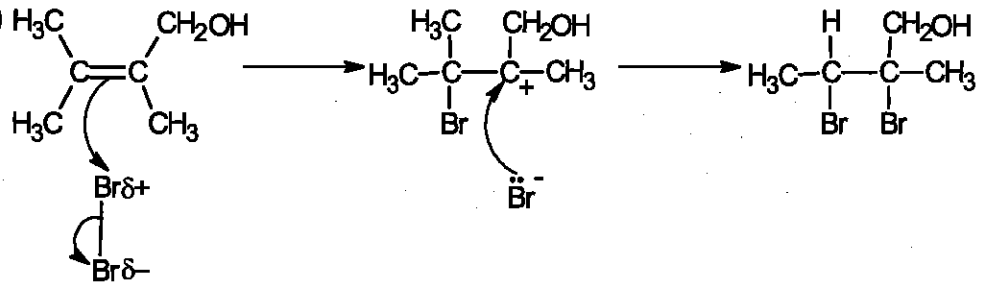


[1]



[1] [2]

(b) (i)

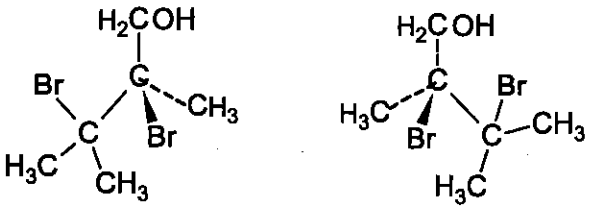


M1 = 2 curly arrows [1]
M2 = intermediate ion [1]
M3 = Br with –ve charge, lone pair and curly arrow to C+ [1] [3]

(ii) dipole is induced by proximity to C=C [1] [1]

(iii) Optical [1] [1]

(iv)



[2]

[1+1]

7. M/J 15/P22/Q3/a

(a)(i) Bond breaking = C*l*-C*l* = 242
C-H = 410 = 652 kJ [1]

Bond forming = C-C*l* = 340
H-C*l* = 431 = 771 kJ [1]

Enthalpy change = 652 – 771 = –119 [1] [3]

(ii) UV/High T/sunlight [1] [1]

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(iii) Initiation
$Cl_2 \rightarrow 2Cl\bullet$ [1]

Propagation
$C_2H_6 + Cl\bullet \rightarrow \bullet C_2H_5 + HCl$ [1]
$\bullet C_2H_5 + Cl_2 \rightarrow C_2H_5Cl + Cl\bullet$ [1]

Termination
$\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_4H_{10}$ [1]

All three names correctly assigned [1] [5]

8. M/J 14/P22/Q5

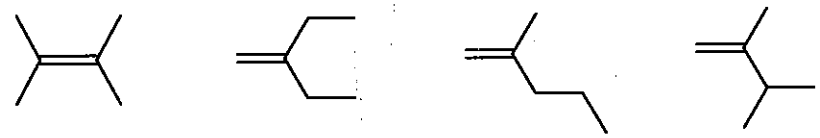
(a) (i) decolourisation of bromine: P is an alkene / contains C=C / is unsaturated 1

hot conc. manganate(VII): breaks C=C **OR** single product implies P is symmetrical **OR** single organic product implies terminal $=CH_2$ as methanal is oxidised to CO_2 1

2,4–DNPH confirms >C=O / carbonyl / ketone in Q 1

no reaction with Tollens': Q is not an aldehyde / is a ketone 1 **4**

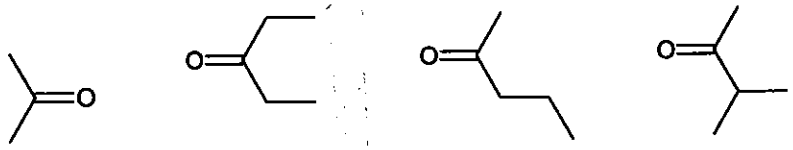
(ii)



1

(2,3–)dimethylbut–2–ene, 2–ethylbut(–1–)ene, 2–methylpent–1–ene, (2,3–)dimethylbut(–1–)ene 1 **2**

(iii)



1

propan(–2–)one / acetone, pentan–3–one, pentan–2–one, 3–methylbutan(–2–)one
ecf possible on **a ii** 1 **2**

(b) any 3 of

$CH_3CH=C(CH_3)C_2H_5$ 1
$CH_3CH=CHCH_2CH_2CH_3$
$CH_3CH=CHCH(CH_3)_2$ 1
$C_2H_5CH=CHC_2H_5$ 1 **max 3**

11

9. M/J 14/P22/Q4

(a) physical: <u>fractional</u> distillation / fractionation 1
chemical: crack(ing) (allow: reforming, isomerisation, thermal decomposition, desulfurisation) 1 2

(b) (i) Strong (C–C and C–H) bonds / high bond energies 1
Non-polar / C and H have similar electronegativities 1 2

(ii) 109.5° **AND** 120° (117° – 122°) 1 1

(iii) ethane = tetrahedral
ethene = trigonal planar 1 1

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(iv) 4 × σ / single bonds on Cs in ethane **AND**
3 × σ and 1 × π on Cs in ethene **OR**
2 × single and 1 × double on Cs in ethene
allow from suitable labelled diagram — 1 — 1

(c) (i) $Cl_2 \rightarrow 2Cl\bullet$ — 1

$C_2H_6 + Cl\bullet \rightarrow \bullet C_2H_5 + HCl$ — 1
$\bullet C_2H_5 + Cl_2 \rightarrow C_2H_5Cl + Cl\bullet$ — 1

$\bullet C_2H_5 + Cl\bullet \rightarrow C_2H_5Cl$ — 1

correct alternative terminations allowed

initiation, propagation, termination (correctly assigned) — 1 — 5

(ii) $\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_4H_{10}$ — 1 — 1

13

10. M/J 14/P21/Q4

(a) decolourisation with an alkene at room conditions / quickly / easily / **OR** alkane needs higher temp / UV / is slow at room conditions — 1

double / π / pi bond / C = C present in alkenes — 1 — 2

(b) (i) UV light / sunlight / high temperature — 1 — 1

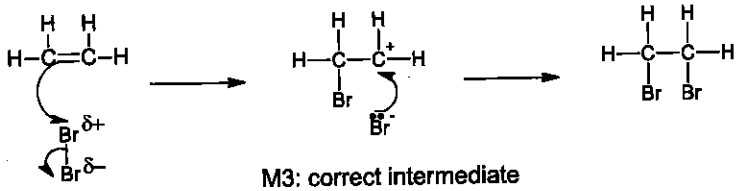
(ii) (Free) radical — 1
Substitution — 1 — 2

(iii) $\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_4H_{10}$ — 1 — 1

(iv) $C_2H_5Br + Br\bullet \rightarrow \bullet C_2H_4Br + HBr$ **OR**
$\bullet C_2H_4Br + Br_2 \rightarrow C_2H_4Br_2 + Br\bullet$ — 1 — 1

(c) (i) Electrophilic — 1
Addition — 1 — 2

(ii)



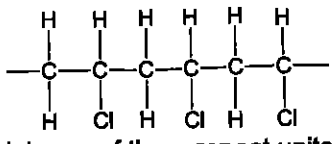
M1: 2 correct curly arrows

M2: correct dipole

M3: correct intermediate

M4: curly arrow from lone pair on Br^- to C^+ — 4

(d)



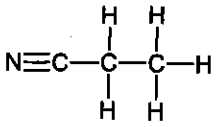
minimum of three repeat units — 2 — 2

(e) (i) NaOH/KOH — 1

ethanolic / alcoholic **AND** heat / reflux — 1 — 2

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(ii)  1 1

(iii)  1

Propanenitrile / propanonitrile / propionitrile / ethyl cyanide / cyanoethane 1 2

20

11. O/N 13/P23/Q2

(a)(i) alkanes **or** paraffins **not** hydrocarbons **(1)**

(ii) $1C_9H_{20} + 14O_2 \rightarrow 9CO_2 + 10H_2O$ **(1) [2]**

(b) (i) carbon **(1)**
carbon monoxide **(1)**
(names required)

(ii) CO is toxic **or** affects or combines with haemoglobin
or carbon causes respiratory problems **(1)**

(iii) $2C_{14}H_{30} + 15O_2 \rightarrow 28C + 30H_2O$ **or**

$2C_{14}H_{30} + 29O_2 \rightarrow 28CO + 30H_2O$

or other balanced equations such as

$C_{14}H_{30} + 11O_2 \rightarrow 7C + 7CO + 15H_2O$

$C_{14}H_{30} + 18O_2 \rightarrow 7CO + 7CO_2 + 15H_2O$ **(1) [4]**

(c) enthalpy change when 1 mol of a substance **(1)**
is burnt in an excess of oxygen/air under standard conditions
or is completely combusted under standard conditions **(1) [2]**

(d) working **must** be shown

(i) heat released = m c δT = 250 × 4.18 × 34.6 **(1)**
= 36157 J = 36.2 kJ **(1)**

(ii) M_r of $C_{14}H_{30}$ = 198 **(1)**
mass of $C_{14}H_{30}$ = 1.00 × 0.763 = 0.763 g **(1)**
0.763 g of $C_{14}H_{30}$ produce 36.2 kJ
198 g of $C_{14}H_{30}$ produce $\frac{36.2 \times 198}{0.763}$
= 9394 kJ mol^{-1} **(1) [5]**

[13]

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12. O/N 13/P22/Q5/a,b

(a)(i) alkanes **or** paraffins **not** hydrocarbons **(1)**

(ii) $\mathbf{2}C_4H_{10} + \mathbf{13}O_2 \rightarrow \mathbf{8}CO_2 + \mathbf{10}H_2O$ **(1)** **[2]**

(b) (i) **carbon** allow graphite **(1)**

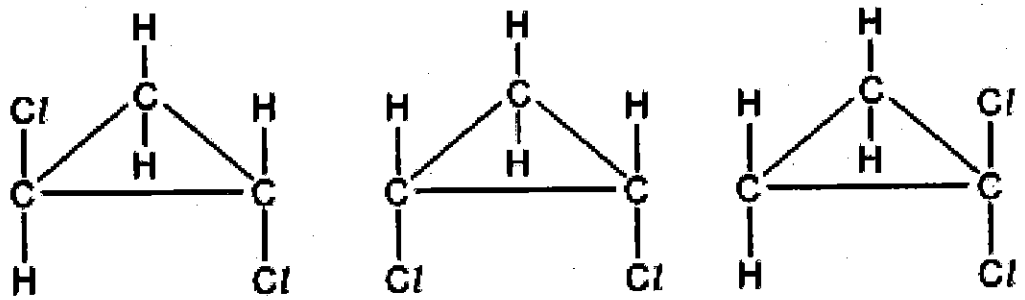
(ii) $\mathbf{2}C_4H_{10} + \mathbf{5}O_2 \rightarrow \mathbf{8}C + \mathbf{10}H_2O$
allow balanced equations which include CO and/or CO_2 **(1)** **[2]**

13. O/N 13/P22/Q2 **(1)** **[1]**

(a) 117° to 120°

(b) (i) electrophilic addition **(1)**

(ii)



1 mark for each correct structure
allow correctly drawn optical isomers of the first structure **(3 × 1)** **[4]**

[5]

14. O/N 12/P23/Q1

In this question, numerical answers should be given to three significant figures.

(a) (i) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ **(1)**

(ii) $M_r\ C_6H_{12}O_6 = 180$ **(1)**

$180\ g\ C_6H_{12}O_6 \rightarrow 6\ mol\ CO_2$

$1200\ g\ C_6H_{12}O_6 \rightarrow \frac{6 \times 200}{180}\ mol\ CO_2$

$= 40.0\ mol$ to 3 sf

allow ecf on wrong equation and/or wrong M_r **(1)**

(iii) 6.82×10^9 people will produce $6.82 \times 10^9 \times 40.0$ mol CO_2

$= 2.728 \times 10^{11}\ mol\ CO_2$ **(1)**

$2.728 \times 10^{11}\ mol\ CO_2 \equiv 2.728 \times 10^{11} \times 44 = 1.20032 \times 10^{13}\ g$

$= 1.20 \times 10^7$ tonnes CO_2 to 3 sf **(1)** **[5]**

allow ecf on answer from **(ii)**

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(b) (i) $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$ **or**

$C_8H_{18} + 12\frac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$ (1)

(ii) $M_r\ C_8H_{18} = (8 \times 12) + (18 \times 1) = 114$ (1)

mass of 4.00 dm^3 of octane = $4000 \times 0.70 = 2800$ g (1)

$n(C_8H_{18}) = \frac{2800}{114} = 24.56140351$ mol in 4.00 dm^3

= 24.6 mol to 3 sf (1)

(iii) 2 mol C_8H_{18} produce 16×44 g CO_2

24.6 mol C_8H_{18} produce $\frac{16 \times 44 \times 24.6}{2}$ g CO2

= 8659.2 g CO_2

= 8660 g CO_2 to 3 sf (1) [5]

(c) 6.82×10^9 people produce 1.20×10^7 tonnes CO_2 per day

8660 g CO_2 produced when car travels 100 km

when travelling 1 km, car produces $\frac{8660}{100} = 8.66 \times 10^{-1}$ g

$= 8.66 \times 10^{-5}$ tonnes (1)

to produce 1.20×10^7 tonnes CO_2 car must travel

$\frac{1.20 \times 10^7}{8.66 \times 10^{-5}}$

$= 1.385681293 \times 10^{11} = 1.39 \times 10^{11}$ km to 3 sf (1) [2]

(d) possible pollutants and the damage they cause

CO	NO_X		SO_2	H_2O	CO_2	unburned C_8H_{18}
	NO	NO2				
toxic	toxic	toxic	toxic			
	global warming	respiratory problems	respiratory problems	global warming	respiratory problems	respiratory problems
	photochemical smog	acid rain	acid rain			

compound (1)
damage (1) [2]

[14]

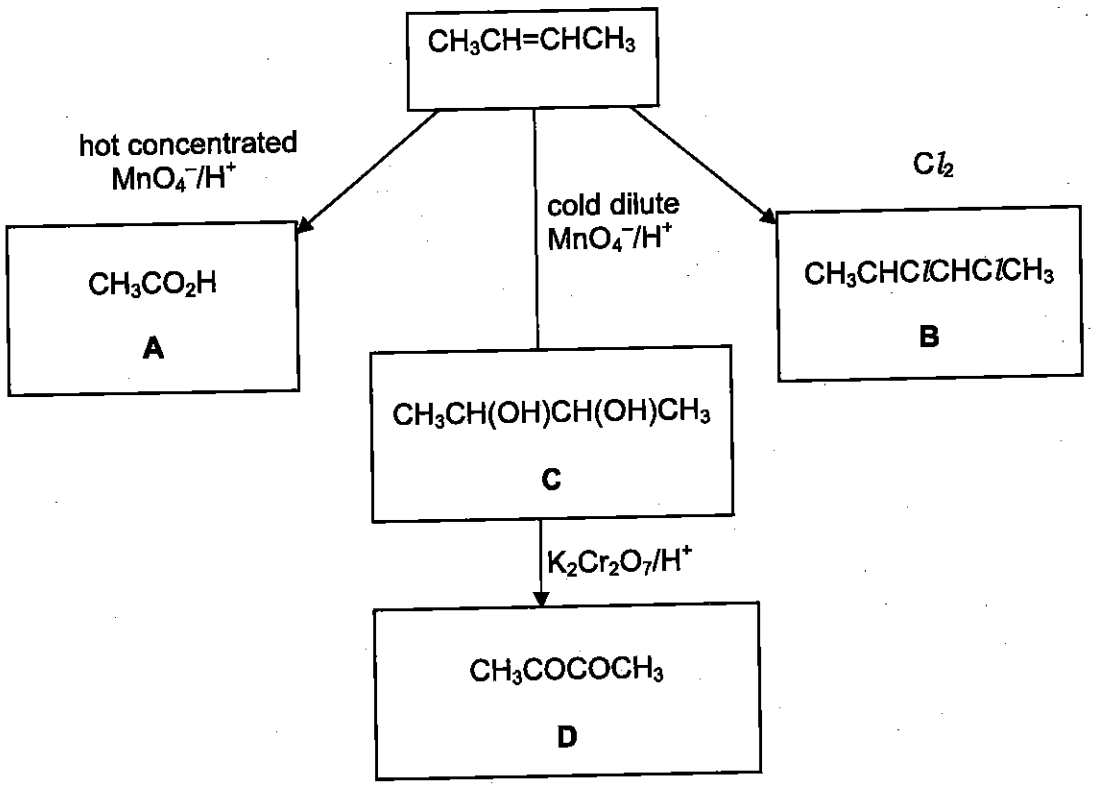
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15. M/J 12/P23/Q4

(a) high temperature and high pressure (1)
high temperature and catalyst (1) [2]

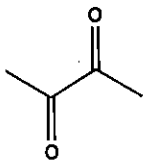
(b) $C_{12}H_{26} \rightarrow C_4H_8 + C_8H_{18}$ **or**
$C_{12}H_{26} \rightarrow 2C_4H_8 + C_4H_{10}$ (1) [1]

(c)



(4 × 1) [4]

(d) (i)

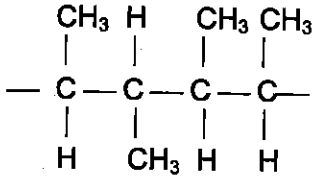


(1)

(ii) compound **B** (1)
compound **C** (1) [3]

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(e)



allow any orientation of CH_3– groups (1) [1]

(f) (i) $CH_2=CH—CH=CH_2$
allow $CH_3CHOHCH=CH_2$ and $CH_3C\equiv CCH_3$ (1)

(ii) $CH_2BrCHBrCHBrCH_2Br$
allow $CH_3CBr_2CBr_2CH_3$ from $CH_3CHOHCH=CH_2$
allow $CH_3CHOHCHBrCH_2Br$ from $CH_3C\equiv CCH_3$ (1)

(iii) electrophilic addition
both words required (1) [3]

[14]

16. M/J 12/P21/Q4

(a)(i) $C_2H_5OH \rightarrow C_2H_4 + H_2O$ (1)

(ii) elimination **or** dehydration (1)

(iii) phosphoric acid **or** concentrated sulfuric acid
sulfuric acid must be 'concentrated'
allow aluminium oxide (1) [3]

(b)

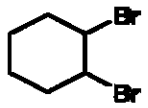
	with HBr	**with MnO_4^-**
colour at start	colourless	purple **or** pink
colour after reaction	colourless	colourless **or** decolourised
structural formula of product	CH_3CH_2Br	$HOCH_2CH_2OH$

with hydrogen bromide
from colourless **to** colourless **both** colours required (1)
do not allow 'clear' instead of colourless
CH_3CH_2Br (1)
with potassium manganate(VII)
from purple/pink **to** colourless/decolourised **both** colours required (1)
$HOCH_2CH_2OH$ (1) [4]

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(c) (i) C_6H_{10} (1)

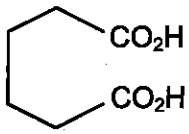
(ii)



accept answers which have $-CH_2-$ in the ring (1)

(iii) electrophilic (1)
addition (1)

(iv)



or

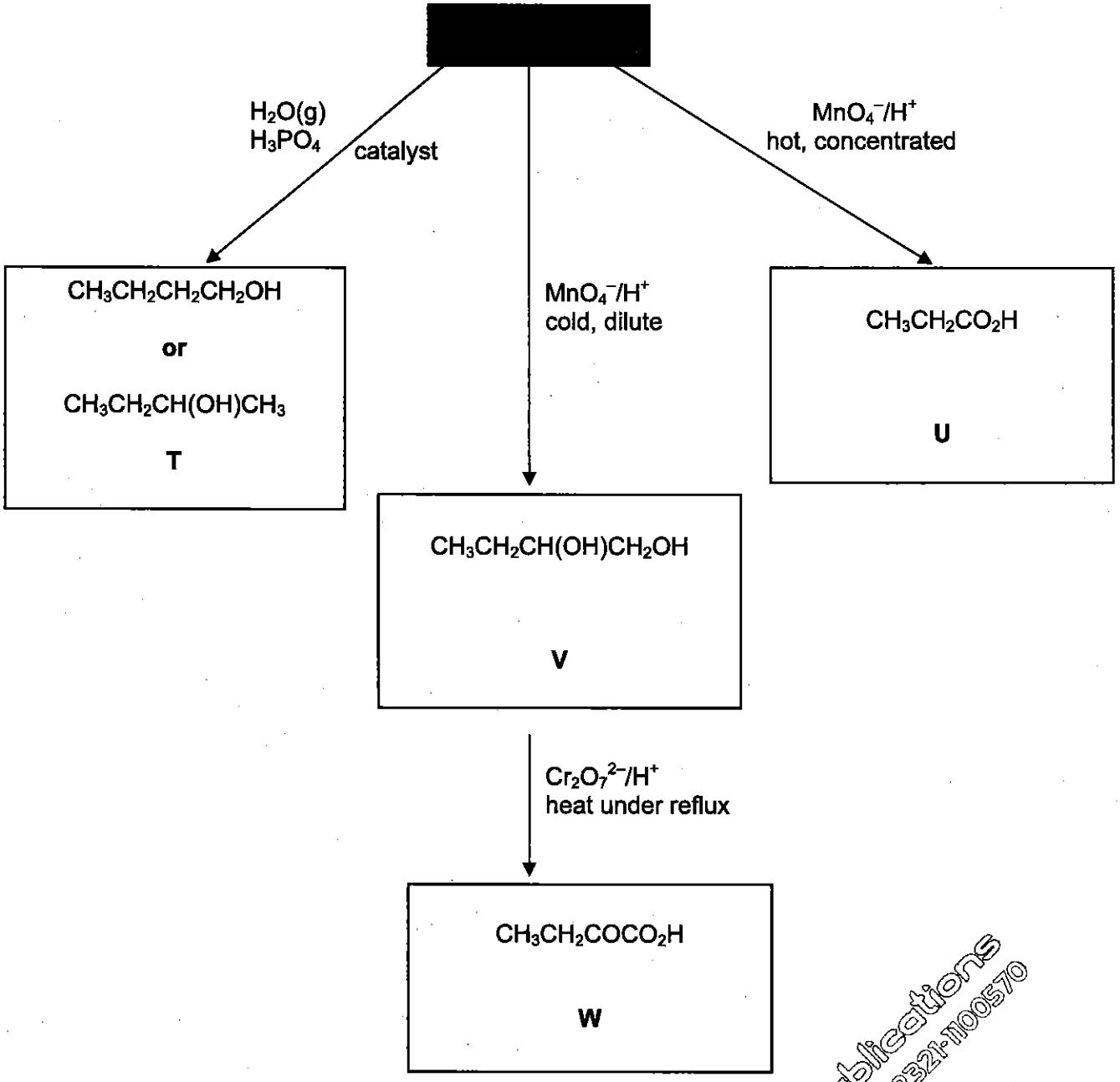
$HO_2C(CH_2)_4CO_2H$ **or**
$HO_2CCH_2CH_2CH_2CH_2CO_2H$ (1)
accept answers which have $-CH_2-$ in the ring [5]

[12]

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17. O/N 11/P22/Q4

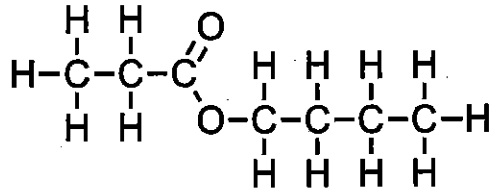
(a)



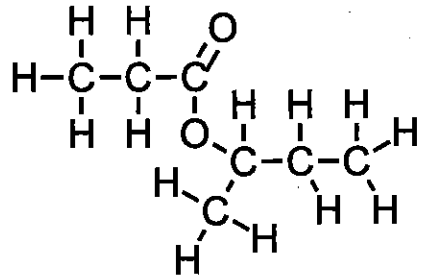
correct **T**	(1)	
correct **U**	(1)	
correct **V**	(1)	
correct > CO group in **W**	(1)	
correct $-CO_2H$ group in **W**	(1)	[5]

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(b) T + U



or



correct structures (1)
correctly displayed ester group (1) [2]
[7]

18. M/J 11/P23/Q4

(a) $C_9H_{16}O_2$ (1) [1]

(b) (i) aldehyde **not** carbonyl (1)
secondary (1)
alcohol (1)

(ii) Br_2/bromine **allow** $KMnO_4/H^+$ (1)
decolourised decolourised (1) [5]

(c) (i) $CH_3(CH_2)_4COCO_2H$ (1)
HO_2CCO_2H **or** CO_2 (1)

(ii) $CH_3(CH_2)_4CH(Cl)CH=CHCHO$ (1)

(iii) $CH_3(CH_2)_4CH(OH)CH=CHCH_2OH$ (1) [4]
[10]

19. M/J 11/P22/Q5/d,e

(a) (i) fatty acid that contains more than one C=C bond (1)

(ii) hydrogen (1)
nickel/Raney nickel/platinum/palladium (1) [3]

(b) (i) $CH_3(CH_2)_7CHO$ (1)
$OHC(CH_2)_7CX$ (1)

(ii) 2,4-dinitrophenylhydrazine (1)
yellow/orange/red precipitate (1)

(iii) Tollens' reagent **or** Fehling's/Benedict's solution (1)
silver mirror/ **or** brick red ppt.
grey precipitate (1) [6]

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20. M/J 11/P21/Q5/a,b,c

(a) $CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$ (1) [1]

(b) (i) step 1 electrophilic (1)
addition (1)
step 2 elimination **or** dehydrohalogenation (1)

(ii) reagent NaOH/KOH/OH^- (1)
conditions in alcohol/ethanol (1)
only allow conditions mark if reagent is correct [5]

(c) (i) **Q** is CH_3CHO (as minimum) (1)
R is CH_3CO_2H (as minimum) (1)

(ii) step 3 is addition (1)
step 4 is oxidation/redox (1) [4]

21. M/J 11/P21/Q2/a,b

(a) **(i)** break large hydrocarbons into smaller hydrocarbons **or**
break down large hydrocarbons (1)

smaller hydrocarbons are more useful **or**
smaller hydrocarbons are more in demand (1)

(ii) using high temperatures/thermal cracking **or**
using catalysts/catalytic cracking (1)

(iii) $C_{14}H_{30} \rightarrow C_7H_{16} + C_7H_{14}$ **or**
$C_{14}H_{30} \rightarrow C_7H_{16} + C_2H_4 + C_5H_{10}$ **or**
$C_{14}H_{30} \rightarrow C_7H_{16} + C_3H_6 + C_4H_8$ **or**
$C_{14}H_{30} \rightarrow C_7H_{16} + 2C_2H_4 + C_3H_6$ (1)

do not allow any equation with H_2 [4]

(b) ethanol has hydrogen bonding, ethanethiol does not (1) [1]

22. M/J 11/P21/Q1/a,b,c

(a) alkanes/paraffins
not hydrocarbon (1) [1]

(b) $2\ C_{14}H_{30} + 43\ O_2 \rightarrow 28\ CO_2 + 30\ H_2O$ **or**

$C_{14}H_{30} + {}^{43}/_{2}O_2 \rightarrow 14\ CO_2 + 15\ H_2O$ (1) [1]

(c) (i) **mass of $C_{14}H_{30}$ burnt**

$\frac{8195 \times 10.8}{1000} = 88.506 = 88.5$ t (1)

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(ii) mass of CO_2 produced

M_r of $C_{14}H_{30}$ = (14 x 12 + 30 x 1) = 198 (1)

2 x 198 t of $C_{14}H_{30} \rightarrow$ 28 x 44 t of CO_2

88.5 t of $C_{14}H_{30} \rightarrow \frac{28 \times 44 \times 88.5}{2 \times 198}$ (1)

= 275.3 t of CO_2 (1)

allow 275.4 t if candidate has used 88.506
allow ecf on wrong value for M_r of $C_{14}H_{30}$ [4]

23. M/J 11/P21/Q2/c,d,e

(a) (i) $C_2H_5SH + {}^9/_2\, O_2 \rightarrow 2CO_2 + SO_2 + 3H_2O$ **or**
$2C_2H_5SH + 9O_2 \rightarrow 4CO_2 + 2SO_2 + 6H_2O$
correct products (1)
correct equation which is balanced (1)

(ii) for CO_2
enhanced greenhouse effect (1)
global warming (1)

for SO_2
formation of acid rain (1)
damage to stonework of buildings/
dissolving of aluminium ions into rivers/
damage to watercourses or forests/
aquatic life destroyed/
corrosion of metals (1) [6]

(b) help detect leaks of gas (1) [1]

(c) temperature of 450°C (1)
pressure of 1 – 2 atm (1)
V_2O_5/vanadium(V) oxide/vanadium pentoxide catalyst (1) [3]

24. O/N 10/P22/Q3/b,c

(a)(i) high temperature **and** high pressure (1)

high temperature **and** catalyst (1)

(ii) $C_{11}H_{24} \rightarrow C_5H_{12} + C_6H_{12}$ **or**

$C_{11}H_{24} \rightarrow C_5H_{12} + 2C_3H_6$ **or**

$C_{11}H_{24} \rightarrow C_5H_{12} + 3C_2H_4$ (1) [3]

(b) (i)

$CH_3CH_2CH_2CH_2CH_3$	$CH_3CH_2CHCH_3$ (with CH_3 branch)	CH_3CCH_3 (with CH_3 above and CH_3 below)
isomer **B**	isomer **C**	isomer **D**
(1)	(1)	(1)

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(ii) the straight chain isomer (isomer **B** above) (1)

it has the greatest van der Waals' forces (1)

because unbranched molecules have greater area of contact/ can pack more closely together (1) [6]

25. O/N 09/P21/Q3/b

(a) (i) initiation (1)

Cl_2 + uvl → 2Cl (1)

propagation (1)

$CH_4 + Cl \rightarrow CH_3 + HCl$

$CH_3 + Cl_2 \rightarrow CH_3Cl + Cl$ both needed (1)

termination (1)

$CH_3 + CH_3 \rightarrow C_2H_6$ **or**

$CH_3 + Cl \rightarrow CH_3Cl$ **or**

$Cl + Cl \rightarrow Cl_2$ (1)

(ii) CH_3/methyl radical (1) [7]

26. O/N 08/P2/Q2/a,b

(a) (i) H–C–H 117 to 120° (1)

C=C=O 180° (1)

(ii) molecule contains **both** ketone **and** alkene (1) [3]

(b) (i) $C_2H_2O + 2O_2 \rightarrow 2CO_2 + H_2O$ (1)

(ii) from eqn., 42 g $C_2H_2O \rightarrow 48\ dm^3$ of CO_2 (1)

whence 3.5 g $C_2H_2O \rightarrow \frac{48 \times 3.5}{42}\ dm^3$ of CO_2 (1)

$= 4.0\ dm^3$ of CO_2 (1)

or $n(C_2H_2O) = \frac{42}{3.5} = 0.0833$ (1)

$n(CO_2) = 2 \times 0.083 = 0.0166$ (1)

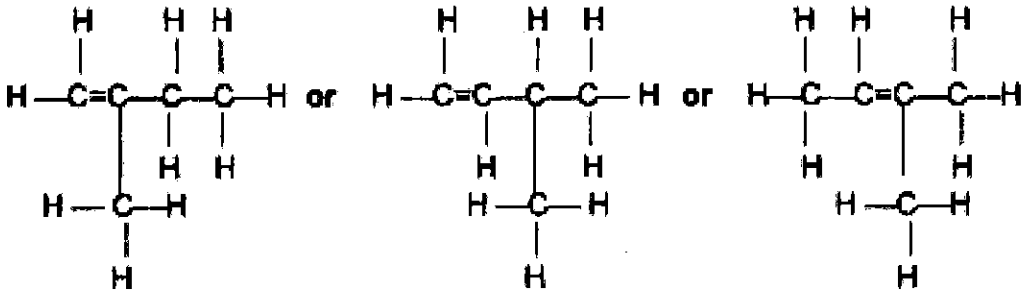
vol. of $CO_2 = 0.0166 \times 24 = 4.0\ dm^3$ (1)

allow e.c.f. on wrong eqn. in **(b)(i)**

penalise significant figure error [4]

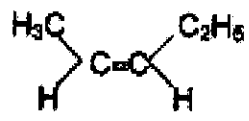
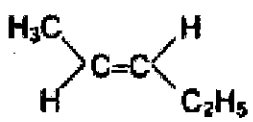
27. O/N 07/P2/Q4/a,b,c,e,f)

(a)



H atoms must be shown.

Structure must not contain any CH_3 groups (1) [1]

(b)  

cis *trans* (1) [2]

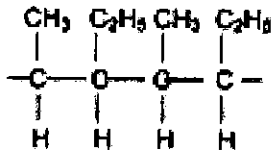
(c) $CH_3CH(OH)CH_2CH_2CH_3$ (1)

$CH_3CH_2CH(OH)CH_2CH_3$ (1) [2]

(d)  e.g. cyclopentane structure

allow methylcyclobutane **or** dimethylcyclopropane (1) [1]

(e) e.g.



two repeat units must be shown
relative positions of $-CH_3$ and $-C_2H_5$ may differ from those shown above (1) [1]

28. O/N 06/P2/Q4/a,b,c

(a) high temperature (above 450 °C) (1)

use of a catalyst (1)

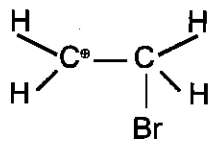
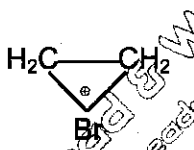
(b) $C_{18}H_{38} \rightarrow C_6H_{14} + C_{12}H_{24}$ (1)

(c)(i) electrophilic addition (1)

(ii) dipole on Br_2 clearly shown by $\delta+$ and $\delta-$ (1)

curly arrow from π bond of $CH_2=CH_2$ to $Br^{\delta+}$ (1)

formation of carbocation

 **or**  (1)

Br^- formed (1)

attack by lone pair of Br^- on carbocation (1)

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29. M/J 04/P2/Q5

(a) Example (1) reason (1) MUST BE ORGANIC

e.g.
PVC (1) used in food packaging (& needs to be inert) (1)
Teflon / PTFE (1) used in non-stick kitchenware (1)
Freons (1) used as deoderants, anaesthetics etc. (1)
CCl_4 etc (1) solvent (1)

3 x 2 [6]

(b) (i) U.V. radiation [1]
Breaks C-C*l* bond OR giving C*l* free radicals [1]
These react with ozone [1]

(ii) e.g polypropene for PVC
alkanes e.g. butane for aerosols

OR equivalent answers need not be organic
e.g. N_2O as anaesthetic

[2]
[11]

30. O/N 03/P2/Q4

(a) (i) dehydration/elimination/cracking (1)

$C_2H_5OH - H_2O \rightarrow CH_2 = CH_2$

or $C_2H_5OH \rightarrow CH_2 = CH_2 + H_2O$ (1) **[2]**

(b) (i) yellow/red/orange/brown to colourless

do **not** allow clear or white (1)

$CH_2 = CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$ (1)

(ii) purple to colourless (1)

$CH_2 = CH_2 + H_2O + [O] \rightarrow CH_2OHCH_2OH$ (1) **[4]**

(c) (i) $-CH_2CH_2CH_2CH_2-$ 'tails required' (1)

$-CH_2CHClCH_2CHCl-$ 'tails required' (1) **[2]**

(d) (i) C_6H_{10} (1)

(ii) $M_r = 82$ (1)

(iii) % carbon = $\frac{72 \times 100}{82}$ = 87.8% (1) **[3]**

[11]

31. O/N 03/P2/Q2

(a) $C_8H_{18} + 12\frac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$ (1) **[1]**

(b) (i) nitrogen (1)

(ii) from the combustion of the fuel (1) **[2]**

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(c)(i) CO reacts with haemoglobin/reduces absorption of oxygen

nitrogen oxides/NO/NO_2/NO_x
acidic/breathing problems/acid rain/photochemical smog

hydrocarbons – breathing problems

SO_2 – breathing problems/acid rain (any 2)

(ii) $CO + NO \rightarrow CO_2 + \frac{1}{2}N_2$

or $CO + \frac{1}{2}O_2 \rightarrow CO_2$

$NO + CO \rightarrow CO_2 + \frac{1}{2}N_2$ (again)

or $NO + HC \rightarrow CO_2 + H_2O + N_2$ (qualitative)
or $NO + H_2 \rightarrow H_2O + \frac{1}{2}N_2$ (1)

(iii) toxic gases are not removed until the catalytic converter has warmed up

or there is too much CO to be completely removed as in **(c)(ii)**

or the converter may become less efficient over a period of time/gets clogged up

or CO_2 passes through – causes global warming

or SO_2 passes through – causes acid rain (1) **[5]**

32. M/J 03/P2/Q5

(a)



(1) **[1]**

(b) Alkane (1) **[1]**

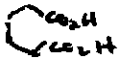
(c) (i) Not biodegradable/does not decompose/unreactive
Not affected by enzymes
Not attacked by aqueous or polar reagents found in tissues
Insoluble/does not absorb water/cotton absorbs water
NOT is stronger than cotton
[equivalent worthy points; they may overlap - but allow - max 2] **[2]**

(ii) Alkanes react with oxygen (combustion)
Not possible in muscle (1)
also react with halogens/in U.V. light
muscle is internal and no halogens (1)
[ecf for alkene answers in **(b)**] **[2]**

[6]

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33. M/J 02/P2/Q5

(a)(i)	C_2H_5Br allow any brominated ethane.	5
(ii)	$-CH_2-CH(CH_3)-$	
(iii)	$CH_3CH(OH)CH_3$	
(iv)		
(v)	 1 each	
(b) (i)	$C_2H_6 + 3\frac{1}{2}O_2 \longrightarrow 2CO_2 + 3H_2O$	3
(ii)	$CH_2=CHCH_3$ (C_3H_6) $+ H_2C \longrightarrow CH_3CH(OH)CH_3$ or $CH_3CH_2CH_2OH$ (or C_3H_7OH)	
(iii)	 $+ H_2 \longrightarrow$  or C_6H_{12} 1 each	
(c) (i)	There is a greater demand for the gasoline (petrol) fraction / about C_8 than for the heavier gasoils / diesel (1) The introduction of the alkene group gives more reactive products (1) OR gives ethene	3
(ii)	Balanced equation (1) If products are labelled alkenes give the (i) mark	
	[Total : 11]	

34. M/J 17/P23/Q1

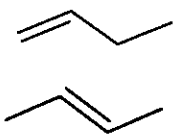
(a) (molecules / isomers with) the same molecular formula / same number of atoms of each element **1**
different structural / displayed formulae / different arrangement of bonds **1**

(b) **(i)** 4 **1**

(ii) 6 **1**

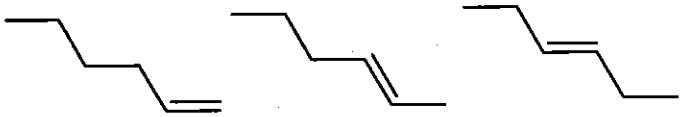
(iii) molecular = C_4H_8 **1**
empirical = CH_2 **1**
using alternative supplied data
molecular = C_6H_{12}
empirical = CH_2

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(iv)  1

 1

alternative using supplied data: any two

 1

(v) correct conversions of data to SI / consistent units
$P = 100\,000$; $V = 25 \times 10^{-6}$; $T = 310$ 1

calculation of n ($= pV / RT$)

$$n = \frac{100 \times 10^3 \times 25 \times 10^{-6}}{8.31 \times 310}$$ 1

calculation of mass m ($= n \times M_r$) AND answer correct to **3sf**

$m = 9.705 \times 10^{-4} \times 56 = 0.0543$ (g)

Alternative answer for using C_6H_{12}:

$m = 9.705 \times 10^{-4} \times 84 = 0.0815$ (g)

35. M/J 07/P2/Q1/d,e

(a) (i) $CH_2 = CH_2 + HCl \rightarrow CH_3CH_2Cl$ [1]

(ii) electrophilic addition [1]

(iii) there is no further unsaturation
or CH_3CH_2Cl molecule is saturated
or no possibility of addition
*or*no free radicals are present [1] **[3]**

(b) (i) acid – base/neutralization [1]

(ii) N atom has a lone pair of electrons
or N atom can behave as a base
*or*N atom can form dative bond [1]

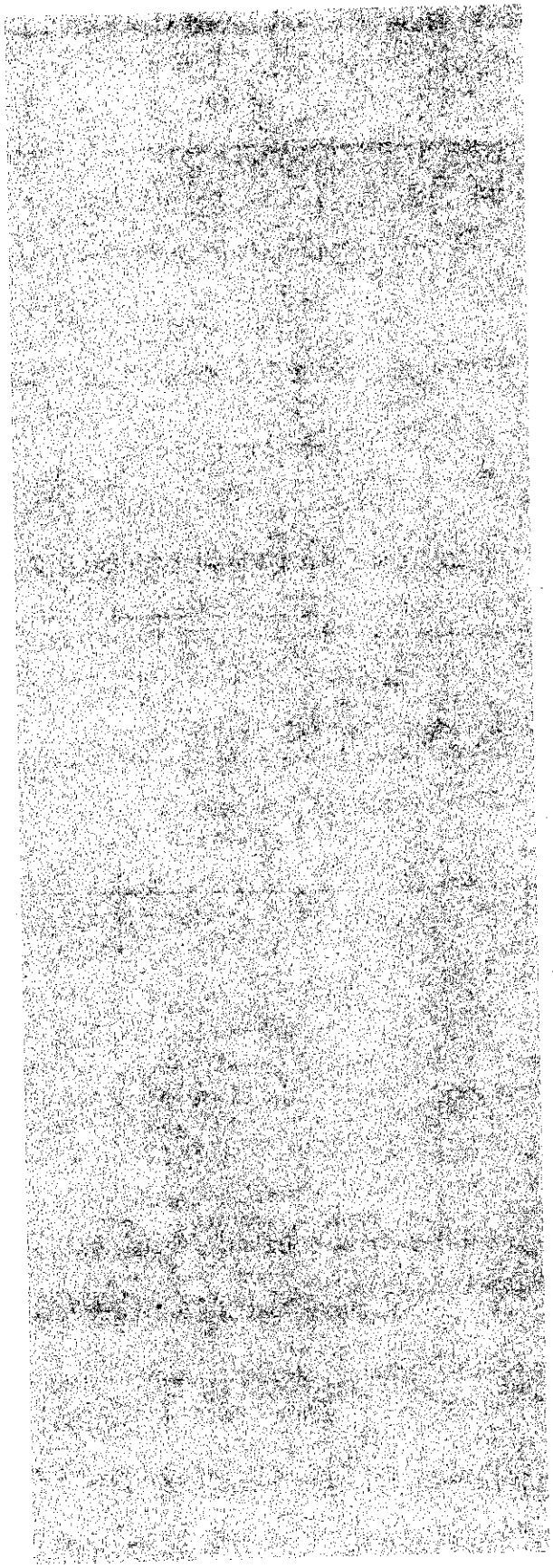
(iii) each N atom has a lone pair
or each nitrogen atom can behave as a base
or each nitrogen atom can form a dative bond [1] **[3]**

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UNIT 15

Halogen Derivatives

A-Level
Chemistry Paper 2
Topical Workbook



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Unit 15: Halogen Derivatives

1. MAR 17/P22/Q3/c(iii,iv,v)

(a) (i) Explain why **S** is the major product of the reaction of but-1-ene with steam.

.....

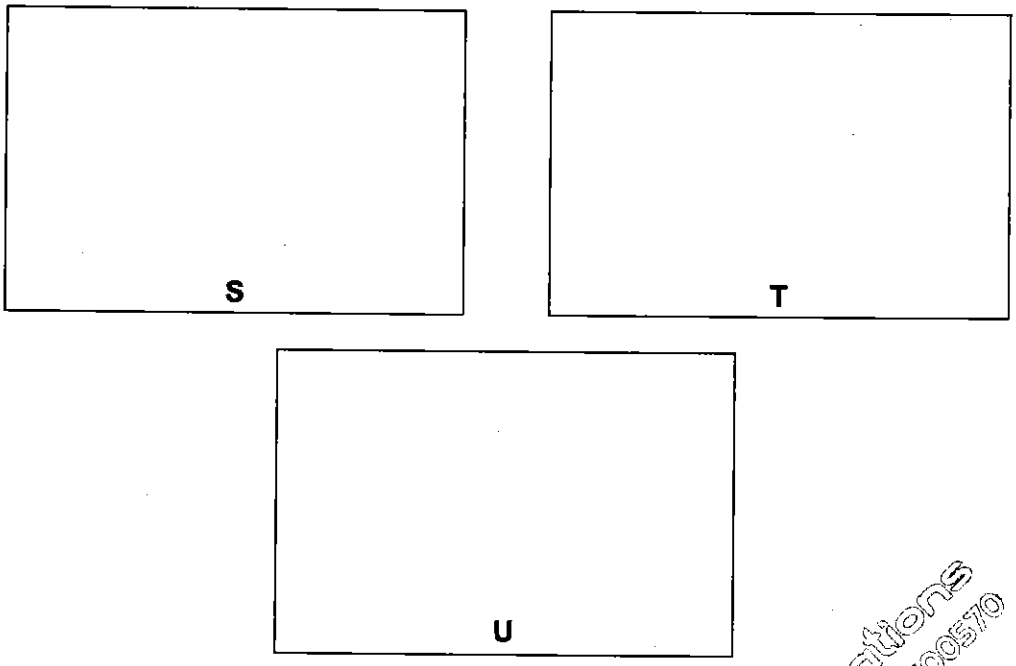
.....

.....

.....

..... [2]

(ii) Draw the **skeletal** formulae of **S** **T** and **U**.



(iii) Write an equation to represent the oxidation of **S** to **U** by acidified potassium dichromate(VI).

You should use [O] to represent the oxidising agent.

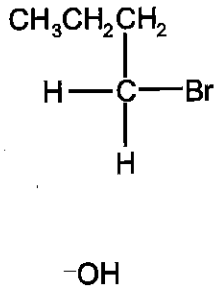
..... **[1]**

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2. MAR 17/P22/Q3/b

Complete the reaction scheme to show the mechanism of the reaction of 1-bromobutane with OH^-(aq) to produce **R**.

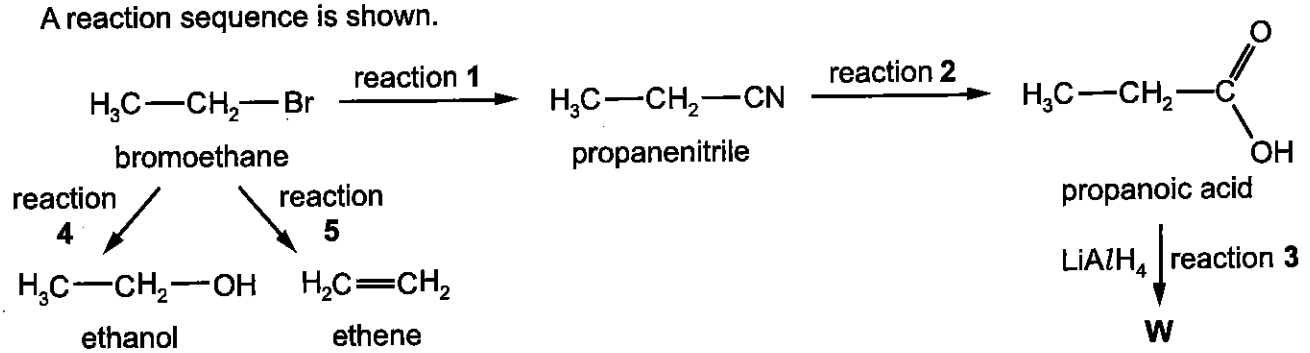
Include all necessary charges, dipoles, lone pairs and curly arrows and the structure of **R**.



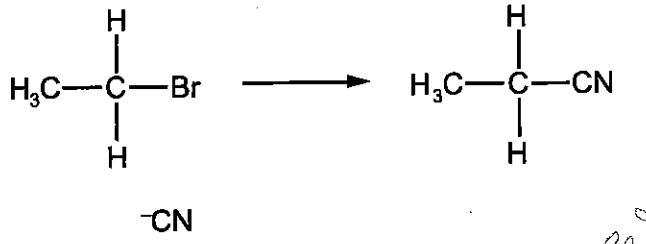
[3]

3. M/J 16/P21/Q5

A reaction sequence is shown.



(a) Complete the diagram to show the mechanism of reaction **1**. Include all necessary charges, partial charges, lone pairs and curly arrows.



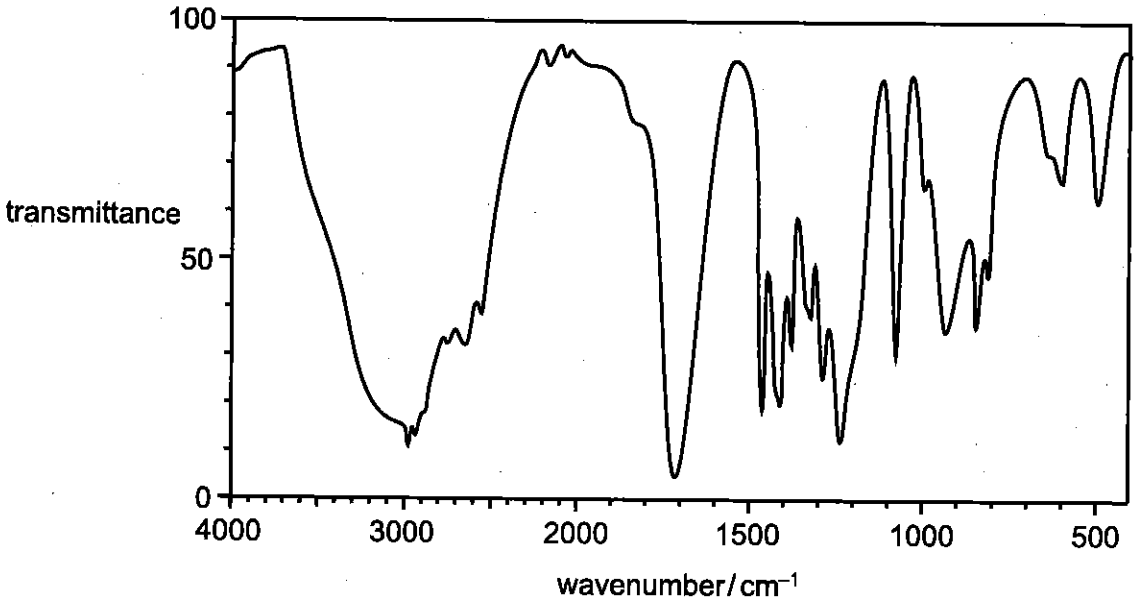
[2]

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(b) (i) Give the name of the type of reaction involved in reaction **3**.

..... [1]

The infra-red spectrum of the propanoic acid produced by reaction **2** is shown.



(ii) Describe and explain the main difference between the infra-red spectrum of **W** and that of propanoic acid.

.....

.....

[2]

(c) (i) Reactions **4** and **5** use the same reagent.

Give the reagent and conditions needed for reaction **4**.

reagent .....

conditions ..... [2]

(ii) Give the conditions needed for reaction **5**.

..... [1]

(d) Under appropriate conditions, ethanol and propanoic acid undergo a condensation reaction.

(i) State the condition necessary for the reaction.

..... [1]

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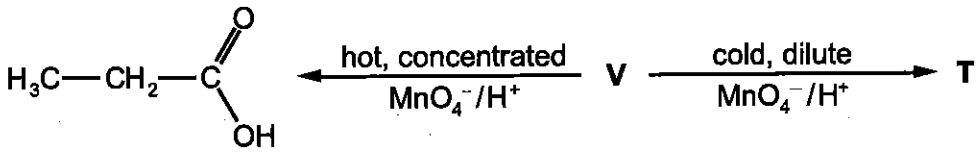
(ii) Draw the skeletal formula of the organic product of this reaction.

[1]

(iii) Name the organic product of this reaction.

..... [1]

(e) **V** reacts with acidified manganate(VII) ions in two different ways depending on the conditions, as shown in the reaction sequence below.



propanoic acid

V decolourises bromine water.

When the acidified manganate(VII) is hot and concentrated, propanoic acid is the only organic product.

When the acidified manganate(VII) is cold and dilute, the organic product is **T** which has two chiral centres.

(i) Give the structural formulae of **V** and **T**.

V ..... **T** .....

[2]

(ii) Identify the types of stereoisomerism shown by **V** and **T**.

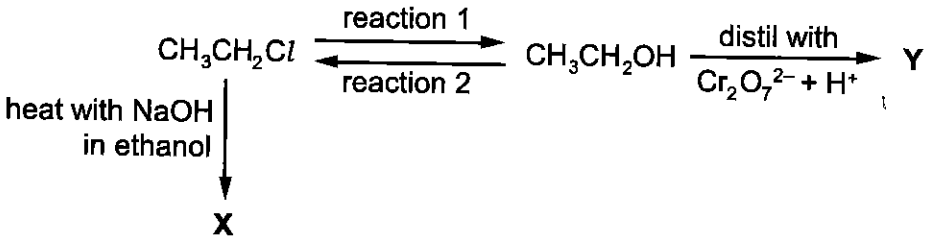
V ..... **T** .....

[2]

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4. O/N 15/P23/Q4, O/N 15/P21/Q4

Some reactions involving ethanol are shown.



(a) (i) Give an equation for reaction 2 including the reagent needed for the conversion.

..... **[2]**

(ii) State the reagent and conditions required for reaction 1.

..... **[2]**

(b) (i) Identify the organic product **X**.

..... **[1]**

(ii) Nitric acid is added to the products of reaction of CH_3CH_2Cl with NaOH in ethanol. Silver nitrate solution is then added to this mixture.

State what you would observe.

..... **[1]**

(iii) Write an ionic equation, including state symbols, for the reaction responsible for the observation in **(ii)**.

..... **[1]**

(c) (i) Identify the organic product **Y** which is distilled out of the reaction mixture.

..... **[1]**

(ii) Explain, in terms of the properties of and intermolecular forces in CH_3CH_2OH and **Y**, why the chosen conditions for the reaction ensure that **Y** is the product.

.....

.....

..... **[3]**

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5. M/J 15/P22/Q3

Ethane reacts with chlorine to form chloroethane.

$$C_2H_6(g) + Cl_2(g) \rightarrow C_2H_5Cl(g) + HCl(g)$$

(a) (i) Use bond energies from the *Data Booklet* to calculate the enthalpy change for this reaction. Include a sign in your answer.

enthalpy change = ... kJ mol^{-1} **[3]**

(ii) State the conditions needed for this reaction to occur.

..... **[1]**

(iii) Use a series of equations to describe the mechanism of this reaction including the names of each stage and an indication of how butane can be produced as a minor by-product.

.....

.....

.....

.....

.....

..... **[5]**

(b) Chloroethane can be converted back into ethane by a two-stage process via an intermediate compound, **X**.

$$C_2H_5Cl \xrightarrow{\text{reaction 1}} \mathbf{X} \xrightarrow{\text{reaction 2}} C_2H_6$$

(i) Give the name of **X**.

..... **[1]**

(ii) Suggest the reagent and conditions needed for reaction 1.

..... **[2]**

(iii) Suggest the reagent and conditions needed for reaction 2.

..... **[1]**

[13]

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6. M/J 14/P23/Q4/c,d,e,f

The halogens and their compounds have a wide variety of uses and the chemical and physical properties of the elements show regular patterns related to their positions in Group VII.

(a) (i) Give the structures of the four structural isomers of C_4H_9Br **and** identify each as primary, secondary or tertiary.

....

....

[4]

(ii) Name the isomer of C_4H_9Br that contains a chiral centre and draw the three-dimensional structures of the two optical isomers.

name .....

structures

[3]

(b) Aqueous silver nitrate solution was added to separate tubes containing chloroethane, bromoethane and iodoethane. The tubes were heated in a water bath.

A yellow precipitate appeared first in the tube containing iodoethane, followed by a cream precipitate in the tube containing bromoethane and finally a white precipitate appeared in the tube containing chloroethane.

Explain these observations.

.....

.....

.....

.....

.....

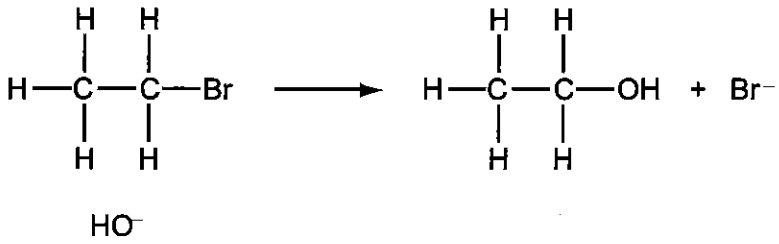
..... [2]

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(c) (i) Give the full name of the mechanism for the reaction between aqueous sodium hydroxide and bromoethane.

..... [2]

(ii) Complete the diagram below to represent this mechanism. Include all necessary curly arrows, partial charges and lone pairs.



[2]

(d) In the past, CFCs such as CF_3Cl were widely used as refrigerants.

(i) State a property of CFCs which makes them suitable for use as refrigerants.

..... [1]

(ii) State the damaging effect of CFCs in the upper atmosphere.

.....

Explain your answer.

.....

.....

.....

[2]

[4]

7. M/J 13/P22/Q1/c

(a) Chloropropanols such as 1,3-dichloropropan-2-ol (1,3-DCP) are present in some foods.

$ClCH_2CH(OH)CH_2Cl$

1,3-DCP

(i) What will be produced when 1,3-DCP is reacted separately with the following reagents under suitable conditions?
In each case give the **structural** formula.

concentrated sulfuric acid

an excess of ammonia

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(ii) Describe as fully as you can what type of reaction occurs with ammonia.

.....

8. O/N 10/P23/Q4

Although few halogenoalkanes exist naturally, such compounds are important as intermediates in organic reactions and as solvents.

B has the following composition by mass: C, 29.3%; H, 5.7%; Br, 65.0%.
B is 123.

(a) Calculate the molecular formula of **B**.

[3]

Halogenoalkanes such as bromoethane, C_2H_5Br, have two different reactions with sodium hydroxide, NaOH, depending on the conditions used.

(b) (i) When hot aqueous NaOH is used, the C_2H_5Br is hydrolysed to ethanol, C_2H_5OH.

Describe the mechanism of this reaction. In your answer, show any relevant charges, dipoles, lone pairs of electrons and movement of electron pairs by curly arrows.

(ii) What will be formed when C_2H_5Br is reacted with NaOH under different conditions?

.....

(iii) What are the conditions used?

.....

(iv) What type of reaction is this?

..... **[7]**

When 1,4-dichlorobutane, $ClCH_2CH_2CH_2CH_2Cl$, is reacted with NaOH, two different reactions can occur, depending on the conditions used.

(c) (i) Draw the **displayed** formula of the product formed when 1,4-dichlorobutane is reacted with hot aqueous NaOH as in **(b)(i)**.

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(ii) Draw the **skeletal** formula of the product formed when 1,4-dichlorobutane is reacted with NaOH in the way you have described in **(b)(ii)** and **(b)(iii)**.

[2]

9. O/N 10/P23/Q5

A student placed separate small samples of 1-chlorobutane, 1-bromobutane and, 1-iodobutane, in three separate test-tubes. To each test-tube, 1 cm^3 of ethanol was added, followed by 1 cm^3 of aqueous silver nitrate, $AgNO_3$. The tubes were then carefully shaken, placed in a test-tube rack and observed for 30 minutes.

A precipitate was formed in each test-tube but **not** at the same time; the fastest taking about two minutes to become opaque and the slowest about 20 minutes. [2]

(a) What is the identity of the precipitate formed when 1-chlorobutane is used?

..... **[1]**

(b) What will be the colour of this precipitate?

..... **[1]**

(c) Which of the three halogenoalkanes will produce a precipitate in about two minutes?

..... **[1]**

(d) Use appropriate data from the *Data Booklet* to explain why this reaction takes place most quickly of the three.

.....

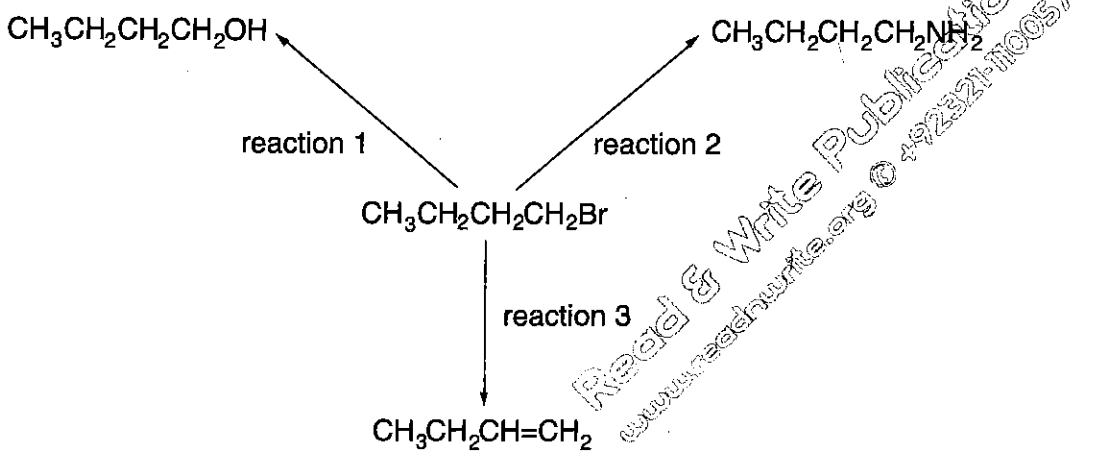
.....

..... **[2]**

10. O/N 10/P22/Q4

Halogenoalkanes have many chemical uses, particularly as intermediates in organic reactions.

Three reactions of 1-bromobutane, $CH_3CH_2CH_2CH_2Br$, are shown below.



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(a) For **each** reaction, state the reagent and solvent used.

reaction 1 reagent .....

solvent .....

reaction 2 reagent .....

solvent .....

reaction 3 reagent .....

solvent ..... **[6]**

(b) When 1-iodobutane, $CH_3CH_2CH_2CH_2I$, is reacted under the same conditions as those used in reaction 1, butan-1-ol is formed.

What difference, if any, would there be in the rate of this reaction compared to the reaction of 1-bromobutane?

Use appropriate data from the *Data Booklet* to explain your answer.

.....

.....

.....

..... **[3]**

Dichlorodifluoromethane, CCl_2F_2, is an example of a chlorofluorocarbon (CFC) that was formerly used as an aerosol propellant. In September 2007, at the Montreal summit, approximately 200 countries agreed to phase out the use of CFCs by 2020.

(c) State two properties of CFCs that made them suitable as aerosol propellants.

1. .....

2. ..... **[2]**

(d) When CFCs are present in the upper atmosphere, homolytic fission takes place in the presence of ultraviolet light.

(i) What is meant by the term *homolytic fission*?

.....

.....

(ii) Suggest an equation for the homolytic fission of CCl_2F_2.

..... **[2]**

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(e) The most common replacements for CFCs as aerosol propellants are hydrocarbons such as propane and butane.

Suggest **one** disadvantage of these compounds as aerosol propellants.

.....

[1]

11. M/J 10/P21/Q2/d

(a) Two reactions involving aqueous NaOH are given below.

$CH_3CHBrCH_3 + NaOH \rightarrow CH_3CH(OH)CH_3 + NaBr$ **reaction 1**

$HCl + NaOH \rightarrow NaCl + H_2O$ **reaction 2**

In order for **reaction 1** to occur, the reagents must be heated together for some time. On the other hand, **reaction 2** is almost instantaneous at room temperature.

Suggest brief explanations why the rates of these two reactions are very different.

reaction 1 .....

.....

.....

reaction 2 .....

.....

..... [4]

12. M/J 10/P23/Q4/a,b,c

Organic reactions involve substances which may be

atoms, *molecules*, *ions* or *free radicals*.

We also apply the terms

electrophilic, *nucleophilic*, *addition*, *elimination* and *substitution*

to organic reactions.

Consider the following reactions.

$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ reaction 1

$CH_3CH_2OH \rightarrow CH_2{=}CH_2 + H_2O$ reaction 2

$CH_3I + OH^- \rightarrow CH_3OH + I^-$ reaction 3

$CH_3COCH_3 + HCN \rightarrow CH_3C(OH)(CN)CH_3$ reaction 4

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(a) Using the terms mentioned above, state as clearly as you can the nature of each of the following reactions.

reaction 1 .....

reaction 2 ..... [2]

(b) By considering the four reactions above, suggest a formula for **each** of the following substances.
In **each** case, state which reaction you are considering.

(i) **one** substance that is an addition product

reaction..... addition product

(ii) **one** substance that is a leaving group

reaction..... leaving group

(iii) **one** substance that behaves as an electrophile

reaction..... electrophile [3]

(c) What is meant by the term *nucleophile*?

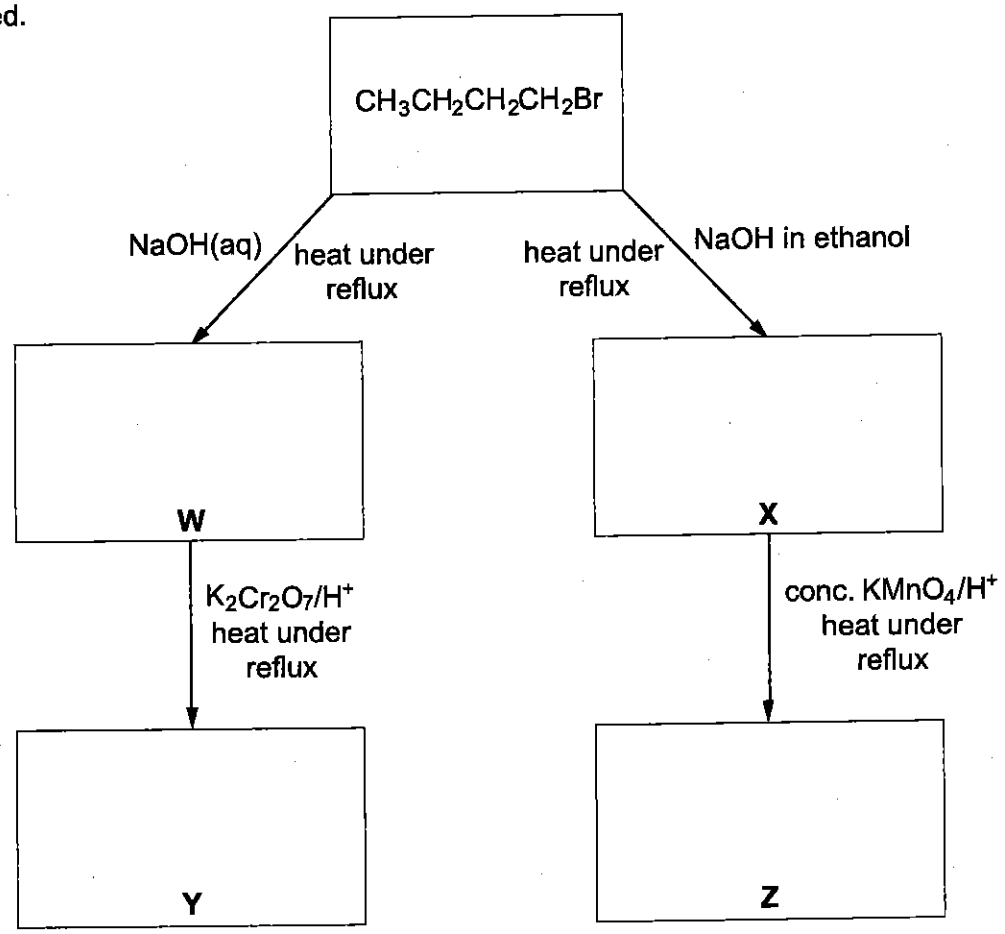
.....

..... [1]

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13. O/N 09/P22/Q4

(a) Complete the following reaction scheme which starts with 1-bromobutane.
In **each empty** box, write the **structural formula** of the organic compound that would be formed.



[4]

(b) One of the compounds **W**, **X**, **Y** or **Z** can be polymerised.

(i) Identify this compound by its letter.

.....

(ii) Draw a section of the polymer chain formed by this compound.

Show **two** repeat units.

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[2]

[6]

14. O/N 09/P22/Q3

One method of making 1-bromobutane in the laboratory is described below.

Stage 1	Place 35 g of powdered sodium bromide, $30\,cm^3$ of water, and $25\,cm^3$ (20 g) of butan-1-ol, in a $250\,cm^3$ two necked flask fitted with a tap funnel and reflux condenser.
Stage 2	Concentrated sulfuric acid ($25\,cm^3$) is then placed in the tap funnel and added drop by drop to the reagents in the flask, keeping the contents well shaken and cooled occasionally in an ice-water bath.

(a) The overall reaction may be considered to take place in two stages. In the first stage the inorganic reagents react together to form HBr. In the second stage, the organic reagent reacts with the HBr that is formed in the first stage.

Write an equation for **each** of these stages.

stage I .....

stage II ..... **[2]**

(b) In this preparation, by using the amounts given above, **one** of the reagents, sodium bromide or butan-1-ol, will be present in an excess.

Use your equations in **(a)** and the data above to determine, by calculation, which reagent is in an excess.

[2]

(c) In a laboratory preparation of 1-bromobutane, when 15.4 g of butan-1-ol was used, 22.5 g of 1-bromobutane was obtained after purification.

Calculate the yield of 1-bromobutane as a percentage of the theoretical maximum yield.

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[2]

(d) When the concentrated sulfuric acid is added to the reaction mixture (stage 2), unless the temperature is controlled carefully, the acid may react with either of the original reactants (sodium bromide or butan-1-ol) to give at least two by-products, one of which is inorganic and the other organic.

What inorganic and organic by-products may be formed?

In **each** case, identify **one** by-product and state the role of the concentrated sulfuric acid in the formation of this by-product.

inorganic by-product.....

role of conc. H_2SO_4 .....

organic by-product .....

role of conc. H_2SO_4 ..... **[4]**

15. M/J 08/P2/Q4/a,b

Two types of isomerism found in organic compounds are structural isomerism and *cis-trans* isomerism.

(a) Draw displayed formulae for

(i) **two** structural isomers of $C_2H_4Br_2$,

D	E

(ii) the *cis*- and the *trans*- isomers of $C_2H_2Br_2$.

cis	*trans*

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[4]

(b) (i) The *cis*- isomer of $C_2H_2Br_2$ can be converted into **one** of the structural isomers of $C_2H_4Br_2$. State the reagent(s) and conditions you would use to do this.

.....

.....

(ii) Which of your structural isomers, **D** or **E**, would be formed? Explain your answer.

isomer formed is .....

reason ..... **[3]**

[7]

16. M/J 07/P2/Q4/a,b

Commercial paint and varnish removers contain a mixture of dichloromethane, CH_2Cl_2, and methanol, CH_3OH.

(a) What would be observed when the following reactions are carried out?
In each case, give the name or formula of the reaction product which is responsible for the observation you have made.

(i) CH_2Cl_2 is reacted with NaOH(aq) and $AgNO_3$(aq) and the mixture left to stand.

observation .....

product responsible .....

(ii) CH_3OH is mixed with PCl_5.

observation .....

product responsible .....

(iii) CH_3OH is reacted with sodium.

observation .....

product responsible .....

[6]

(b) When CH_2Cl_2 is heated under reflux with an excess of NaOH(aq), a compound **W** is formed.

W has the following composition by mass: C, 40.0%; H, 6.7%; O, 53.3%.

Use this information and the *Data Booklet* to show that the empirical formula of **W** is CH_2O.

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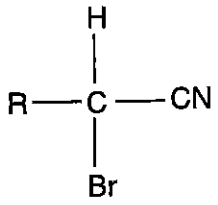
[2]

17. M/J 07/P2/Q1/d,e

This question is shifted in Unit 14 -- question No. 35

18. M/J 05/P2/Q4

(a) Compound **G**, in which R– represents the rest of the molecule, was made for use as a tear gas in World War 2.



compound **G**

Compound **G** was made by the following sequence of reactions.

$$R\text{–}CH_3 \xrightarrow{\text{stage I}} R\text{–}CH_2Cl \xrightarrow{\text{stage II}} R\text{–}CH_2CN \xrightarrow{\text{stage III}} R\text{–}CHBrCN$$

(i) For stage I **and** for stage II, state the reagent(s) and condition(s) used to carry out **each** change.

stage I reagent(s) .....

condition(s) .....

stage II reagent(s) .....

condition(s) .....

(ii) Suggest the reagent(s) and condition(s) necessary to carry out stage III.

reagent(s) .....

condition(s) ..... [6]

Compound **G** was not actually used in World War 2 and stocks of it had to be destroyed safely. The following sequence of reactions was used in this process.

$$R\text{–}CHBrCN \xrightarrow{\text{stage IV}} R\text{–}CHBrCO_2H \xrightarrow{\text{stage V}} R\text{–}CH(OH)CO_2H$$

$$R\text{–}CH(OH)CO_2H \xrightarrow{\text{stage VI}} R\text{–}CH_2CO_2H$$

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(b) For stage IV **and** for stage V state the reagent(s) and condition(s) necessary to bring about **each** reaction.

stage IV reagent(s) .....

condition(s) .....

stage V reagent(s) .....

condition(s) ..... [4]

(c) The full sequence of stages I to VI involves some compounds which contain chiral centres.

(i) Explain what is meant by the term *chiral centre*.

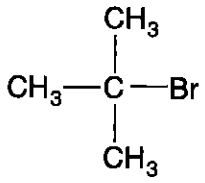
.....

.....

(ii) Draw displayed formulae for the isomers of **one** compound in the full sequence of stages I to VI which you consider to be chiral.

[3]

19. O/N 03/P2/Q5



$CH_3CH_2CH_2CH_2Br$

1-bromobutane

2-bromo-2-methylpropane

(a) 1-Bromobutane reacts with **aqueous** sodium hydroxide to form butan-1-ol.

(i) Give a balanced equation for this reaction.

.....

(ii) Name the type of reaction. .....

(iii) Describe the mechanism of this reaction.

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[5]

(b) 1-Bromobutane and 2-bromo-2-methylpropane both react with an **ethanolic (alcoholic** solution of sodium hydroxide to form alkenes.

(i) Name the type of reaction. .....

(ii) Identify, by means of the structural formula, the alkene formed from

I 1-bromobutane,

II 2-bromo-2-methylpropane.

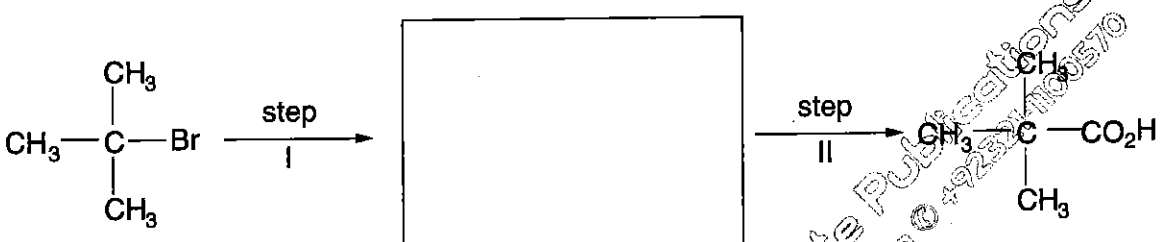
(iii) Hot, concentrated manganate(VII) ions break the double bond in alkenes. Each of the two alkenes in **(b)(ii)** gives CO_2 and H_2O from the terminal group, but the rest of the molecule remains as an organic oxidation product. Suggest the formula of each of these products.

from I .....

from II .....

[5]

(c) Complete the reaction sequence giving the intermediate, the reagents and the conditions for the synthesis of 2,2-dimethylpropanoic acid.



Step I: reagent .....

conditions .....

Step II: reagent .....

conditions .....

[3]

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20. M/J 02/P2/Q6/a,b

Chlorofluorocarbons, CFCs, are small alkane molecules in which some of the hydrogen atoms have been replaced by atoms of chlorine and fluorine.

(a) **(i)** State **two** uses of CFCs.

.....

.....

(ii) What property of CFCs causes them to be useful?

..... **[2]**

(b) A typical CFC is CHF_2CHClF.

(i) Which covalent bond in this CFC is the weakest?

.....

(ii) Why does this CFCpresent an environmental concern?

.....

.....

.....

..... **[3]**

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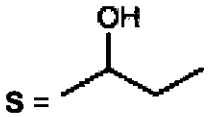
Answers Section

1. MAR 17/P22/Q3/c(iii,iv,v)

(a) (i) positive inductive effect of more alkyl groups/ more alkyl groups donate electron density **1**

secondary carbocation / secondary intermediate is more stable (than primary) **1**

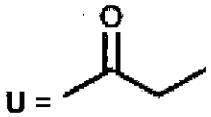
(ii) **1**

S = 

1

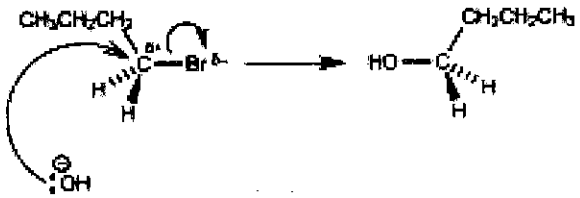
T = 

1

U = 

(iii) CH $_3$CHOHCH$_2$CH$_3$ + [O] → CH$_3$COCH$_2$CH$_3$ + H$_2$O **1**

2. MAR 17/P22/Q3/b

 **3**

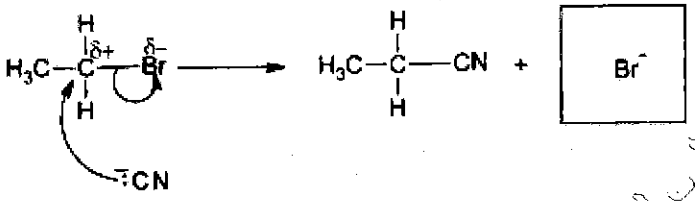
lone pair on O **AND** curly arrow from O to C of C–Br **1**

dipole on C–Br **AND** curly arrow from C–Br to Br **1**

product (butan-1-ol) **1**

3. M/J 16/P21/Q5

(a)



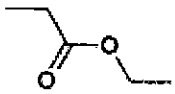
[2]

M1 = lone pair on C of CN− AND curly arrow from lone pair to C of C–Br [1]

M2 = correct dipole on C Br curly arrow from C Br bond to Br AND Br$^-$ [1]

(b) (i) reduction [1] [1]

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(ii)	disappearance of peak/ dip /trough/ absorption at 1680–1730	[1]		
	due to (loss of) C=O	[1]		
	OR			[2]
	peak at 3200–3650	[1]		
	due to (alcohol) O—H (formation)	[1]		
(c) (i)	sodium/potassium hydroxide	[1]		
	aqueous	[1]		[2]
(ii)	ethanol	[1]		[1]
(d) (i)	(conc) H^+ /(conc) acid / (conc) H_2SO_4 /(conc) H_3PO_4	[1]		[1]
(ii)		[1]		[1]
(iii)	ethyl propanoate	[1]		[1]
(e) (i)	V = $CH_3CH_2CH{=}CHCH_2CH_3$ / $CH_3CH_2CH{=}CHCH_2CH_3$	[1]		
	T = $CH_3CH_2CH(OH)CH(OH)CH_2CH_3$	[1]		[2]
(ii)	V = geometric(al) / *cis-trans* / *E–Z*	[1]		
	T = optical	[1]		[2]
				[15]

4. O/N 15/P23/Q4, O/N 15/P21/Q4

(a) (i)	$CH_3CH_2OH + HCl \rightarrow CH_3CH_2Cl + H_2O$			
	or			
	$CH_3CH_2OH + PCl_5 \rightarrow CH_3CH_2Cl + HCl + POCl_3$	[1+1]		[2]
	or			
	$CH_3CH_2OH + SOCl_2 \rightarrow CH_3CH_2Cl + HCl + SO_2$			
(ii)	NaOH / KOH	[1]		
	warm /heat/reflux AND aqueous	[1]		[2]
(b) (i)	$CH_2{=}CH_2$ / ethane / C_2H_4 / CH_2CH_2	[1]		[1]
(ii)	White ppt/solid/suspension	[1]		[1]
(iii)	$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$	[1]		[1]
(c) (i)	CH_3CHO/ethanal	[1]		[1]
(ii)	CH_3CH_2OH higher bpt than CH_3CHO ora	[1]		
	due to hydrogen bonding in ethanol / stronger IMFs	[1]		[3]
	prevents further oxidation owtte	[1]		
				[11]

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5. M/J 15/P22/Q3

(a) (i) Bond breaking = C*l*-C*l* = 242
C-H = 410 = 652 kJ [1]

Bond forming = C-C*l* = 340
H-C*l* = 431 = 771 kJ [1]

Enthalpy change = 652 – 771 = –119 [1] [3]

(ii) UV / High T / sunlight [1] [1]

(iii) Initiation
$Cl_2 \rightarrow 2Cl\bullet$ [1]

Propagation
$C_2H_6 + Cl\bullet \rightarrow \bullet C_2H_5 + HCl$ [1]
$\bullet C_2H_5 + Cl_2 \rightarrow C_2H_5Cl + Cl\bullet$ [1]

Termination
$\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_4H_{10}$ [1]

All three names correctly assigned [1] [5]

(b) (i) ethene [1] [1]

(ii) KOH / NaOH [1]

ethanolic **AND** heat / reflux [1] [2]

(iii) H_2 **AND** Pt or Ni (catalyst) [1] [1]

[13]

6. M/J 14/P23/Q4/c,d,e,f

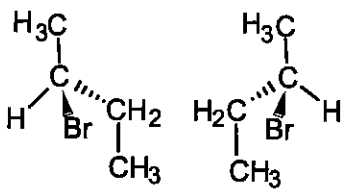
(a) (i) $CH_3CH_2CH_2CH_2Br$ primary (1)

$CH_3CH_2CHBrCH_3$ secondary (1)

$(CH_3)_2CHCH_2Br$ primary (1)

$(CH_3)_3CBr$ tertiary (1) [4]

(ii) 2-bromobutane **(1)**



(1+1) **[3]**

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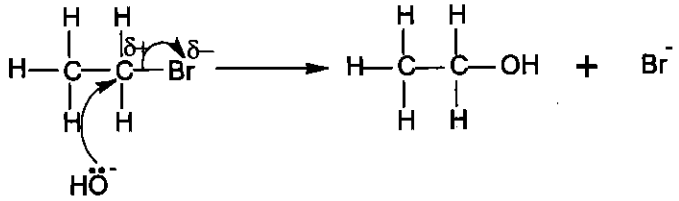
(b) halide ions liberated (by hydrolysis of halogenoalkanes)form precipitate with Ag^+ **(1)**

OR $Ag^+ + X^- \rightarrow AgX$

order due to decreasing bond strength (C I<C Br<C C*l*) **(1)** **[2]**

(c) **(i)** nucleophilic substitution **(2)** **[2]**

(ii)



M1 = curly arrow from lone pair on OH^-;
M2 for curly arrow from C-Br bond to Br **AND** dipole (2) [2]

(d) **(i)** inert or volatile owtte (1) [1]

(ii) destroy ozone (1)

(in stratosphere) C–C*l* bond broken by UV / free radicals produced (1) [2]

7. M/J 13/P22/Q1/c

(a) **(i)** **with concentrated sulfuric acid**
$ClCH_2CH{=}CHCl$ (1)

with ammonia
$H_2NCH_2CH(OH)CH_2NH_2$ (1)

(ii) nucleophilic substitution (1) (1) [4]

[11]

8. O/N 10/P23/Q4

(a) C : H : Br $= \frac{29.3}{12} : \frac{5.7}{1} : \frac{65.0}{79.9}$ (1)

$= 2.44 : 5.7 : 0.81$

$= 3 : 7 : 1$ (1)

$C_3H_7Br = (3 \times 12) + (7 \times 1) + 79.9 = 122.9$

use of 122.9 or 123 to prove

molecular formula must be C_3H_7Br (1) [3]

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(b) (i) mechanism must be S_N2

dipole on C-Br bond **or**
central C atom shown with δ+ (1)

attack on C atom by lone pair of OH^-
not from negative charge (1)

transition state formed **with** negative charge shown (1)

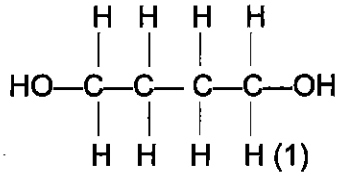
Br^- leaves/NaBr formed (1)

(ii) C_2H_4/ethane (1)

(iii) ethanol/C_2H_5OH (1)

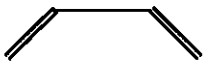
(iv) elimination (1) **[7]**

(c) (i)



(1)

(ii) **must** be skeletal



or



(1) **[2]**

[12]

9. O/N 10/P23/Q5

(a) AgC*l*/silver chloride (1) **[1]**

(b) white (1) **[1]**

(c) 1-iodobutane (1) **[1]**

(d) C-I bond is weaker/longer than the other C-halogen bonds (1)

C-I bond energy is 240 kJ mol^{-1}
or covalent radius of I is 0.133 nm (1) **[2]**

[5]

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10. O/N 10/P22/Q4

(a) reaction 1 — reagent — NaOH/KOH (1)

solvent — H_2O/water/aqueous (1)

reaction 2 — reagent — NH_3/ammonia (1)

solvent — ethanol/C_2H_5OH/alcohol (1)

reaction 3 — reagent — NaOH/KOH (1)

solvent — ethanol/C_2H_5OH/alcohol (1) [6]

(b) with $CH_3CH_2CH_2CH_2I$ rate would be faster (1)

C-I bond is weaker than C-Br bond (1)

C-I bond energy is 240 kJ mol^{-1}, C-Br bond energy is 280 kJ mol^{-1}
data **must** be quoted for this mark (1) **[3]**

(c) non-toxic non-flammable

volatile/low bp unreactive (any 2) **[2]**

(d) **(i)** when a covalent bond breaks the two electrons in the bond are shared between the two atoms (1)

(ii) $CCl_2F_2 \rightarrow CClF_2 + Cl$ (as minimum)

allow $CCl_2F + F$ (1) **[2]**

(e) they are flammable (1) **[1]**

[14]

11. M/J 10/P21/Q2/d

(a) **reaction 1**
has greater E_a (1)
because energy is needed to break covalent bonds (1)
reaction 2
has lower E_a
or actual reaction is $H^+ + OH^- \rightarrow H_2O$
or reaction involves ions (1)
opposite charges attract (1) **[4]**

[12]

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12. M/J 10/P23/Q4/a,b,c

(a)reaction1 free radical substitution (1)

reaction 2 elimination (1) **[2]**

(b) (i) in reaction 4 $CH_3C(OH)(CN)CH_3$ (1)

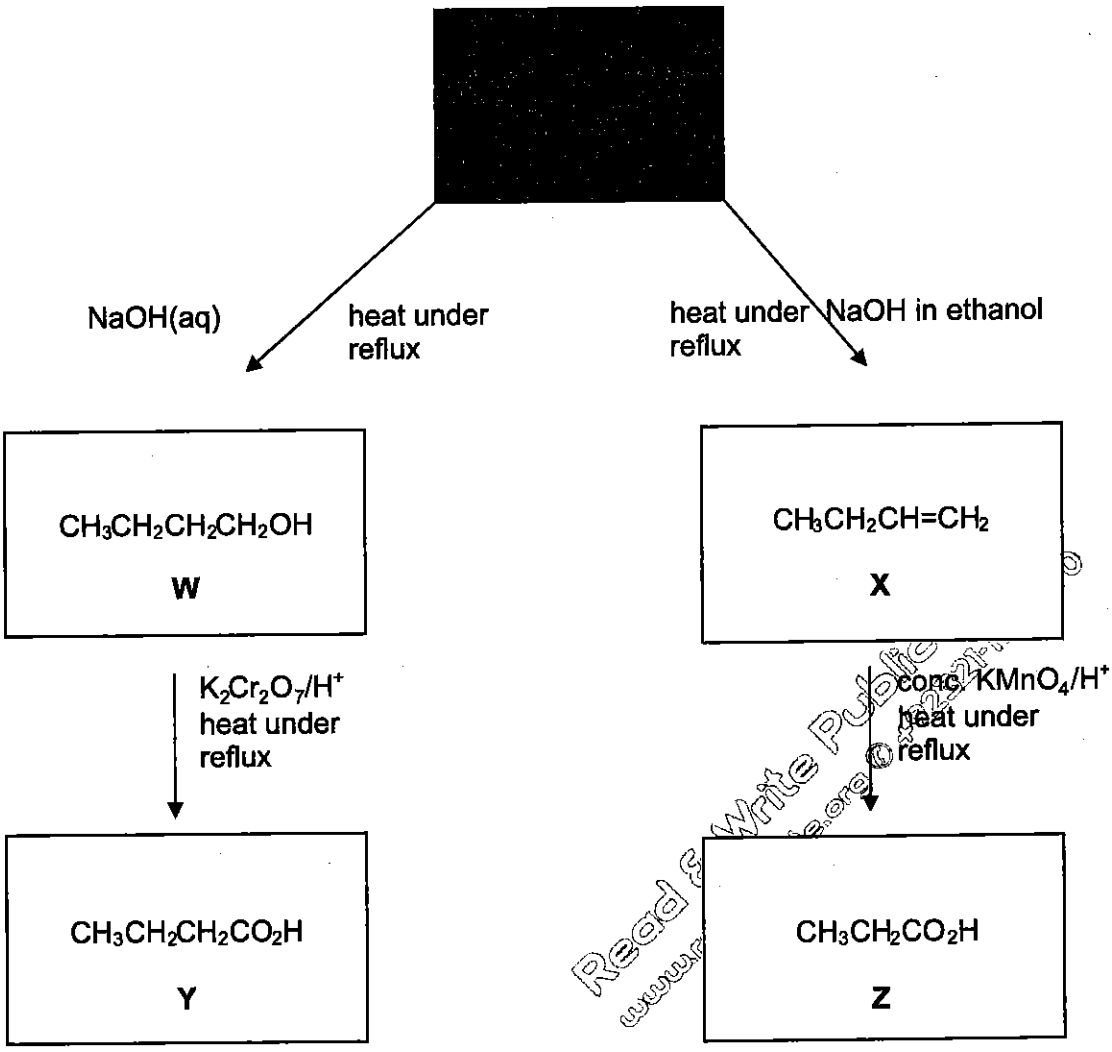
(ii) in reaction 3 I^- (1)

(iii) in reaction 3 CH_3I
or in reaction 4 CH_3COCH_3 (1) **[3]**

(c) a species which has a lone pair of electrons
or which reacts with an electron deficient ($\delta+$) centre in a molecule (1) **[1]**

13. O/N 09/P22/Q4

(a)

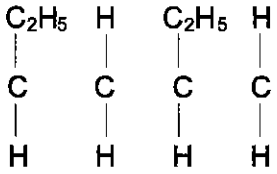


(4 × 1) **[4]**

(b) (i) X

allow ecf on any alkene above **(1)**

(ii)



allow ecf on any alkene above **(1)** **[2]**

14. O/N 09/P22/Q3 **[6]**

(a) stage I $NaBr + H_2SO_4 \rightarrow NaHSO_4 + HBr$

allow $2NaBr + H_2SO_4 \rightarrow Na_2SO_4 + 2HBr$ **(1)**

stage II $C_4H_9OH + HBr \rightarrow C_4H_9Br + H_2O$ **(1)** **[2]**

(b) $n(NaBr) = n(HBr) = \frac{35}{103} = 0.34$ **(1)**

$n(C_4H_9OH) = \frac{20}{74} = 0.27$ **(1)**

NaBr/HBr is in an excess – **no mark just for this answer** **[2]**

(c) method 1, using mass

$C_4H_9OH \equiv C_4H_9Br$

if yield is 100%,

74 g $C_4H_9OH \rightarrow$ 137 g C_4H_9Br

15.4 g C_4H_9OH would produce $\frac{137 \times 15.4}{74}$ = 28.5 g C_4H_9Br **(1)**

% yield = $\frac{22.5 \times 100}{28.5}$ = 78.9 **(1)**

or methods using moles

method 2

$n(C_4H_9OH) = \frac{15.4}{74} = 0.208$

for 100% yield $n(C_4H_9Br)$ would be 0.208 × 137 = 28.5g **(1)**

% yield = $\frac{22.5 \times 100}{28.5}$ = 78.9 **(1)**

method 3

$n(C_4H_9OH) = \frac{15.4}{74} = 0.208$ mol

for 100% yield $n(C_4H_9Br)$ would be 0.208 mol

actual $n(C_4H_9Br) = \frac{22.5}{137} = 0.164$ mol **(1)**

% yield = $\frac{0.164 \times 100}{0.208}$ = 78.8 **(1)** **[2]**

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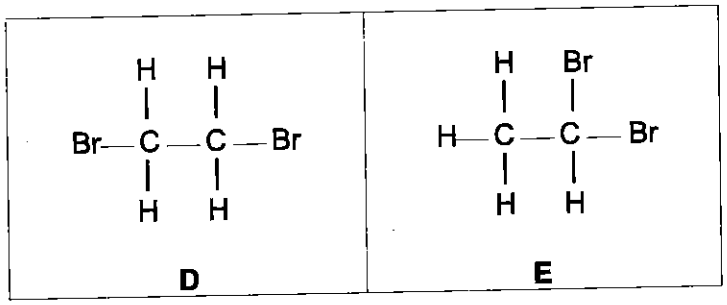
(d) inorganic by-product
Br_2/bromine **or** sulfur dioxide/SO_2 **(1)**
conc. H_2SO_4 behaves as an oxidising agent **(1)**

organic by-product
but-1-ene/$CH_3CH_2CH{=}CH_2$ **(1)**
allow butane and $C_4H_9OC_4H_9$
conc. H_2SO_4 behaves as a dehydrating agent **(1)** **[4]**

[10]

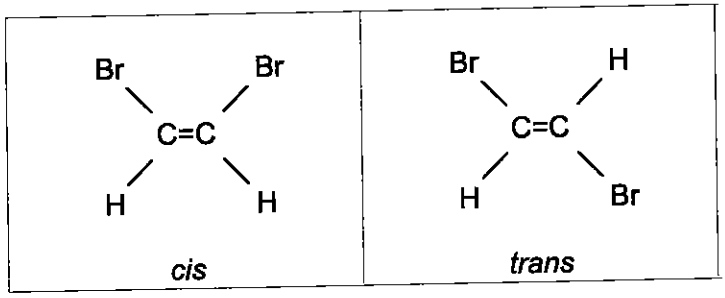
15. M/J 08/P2/Q4/a,b

(a) (i)



(1) (1)

(ii)



(1) (1) **[4]**

(b) (i) hydrogen (1)

nickel catalyst – allow platinum or palladium (1)

(ii) isomer formed **must** be 1,2-dibromoethane (**D** above)

because

cis isomer has one Br atom on **each** carbon atom (1)

mark is for the reason but wrong isomer is penalised **[3]**

[7]

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16. M/J 07/P2/Q4/a,b

(a) **(i)** white ppt. [1]
$AgCl$ [1]

(ii) white/steamy/misty fumes [1]
HCl [1]

(iii) colourless gas evolved *or* Na dissolves [1]
H_2 *or* CH_3ONa [1] **[6]**

(b) $C:H:O = \frac{40}{2} : \frac{6.7}{1} : \frac{53.3}{16}$ [1]

= 3.33 : 6.7 : 3.33 [1]

= 1 : 2 : 1 **[2]**

17. M/J 07/P2/Q1/d,e

This question answer is shifted in Unit 14 -- answer No. 35

18. M/J 05/P2/Q4

(a) **(i)** stage I Cl_2/chlorine (1)
uvl/sunlight (1)

stage II KCN (1)
heat in ethanol (1)

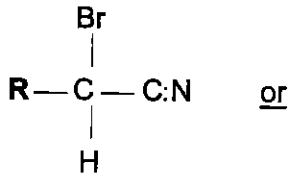
(ii) stage III Br_2 (1)
uvl/sunlight (1) **[6]**

(b) stage IV $H_2SO_4(aq)/HCl(aq)$ or
NaOH(aq) followed by H^+ (1)
heat/reflux (1)

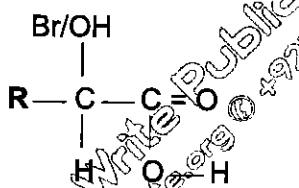
stage V NaOH(aq) (1)
heat (1) **[4]**

(c) **(i)** a carbon atom in a molecule attached to four different atoms or groups of atoms (1)

(ii)



or



correct cpd correctly displayed (1)
one correct isomer shown as 3D (1)
both isomers shown in
mirror object/mirror image arrangement (1) **[4]**

[13]

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19. O/N 03/P2/Q5

(a) (i) $CH_3CH_2CH_2CH_2Br + NaOH \rightarrow$ **or** OH^-

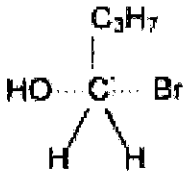
$CH_3CH_2CH_2CH_2OH + NaBr$ **or** Br^- **(1)**

(ii) nucleophilic substitution **(1)**

(iii) presence of $C^{\delta+} - Br^{\delta-}$ dipole **(1)**

attack of OH^- on $C^{\delta+}$ **(1)**

formation of intermediate



(1)

loss of Br^- **(1)** **(3)**

may all be in a mechanism **[5]**

(b) (i) elimination/dehydrobromination **(1)**

(ii) I $CH_3CH_2CH = CH_2$ **(1)**

II $CH_3C(CH_3) = CH_2$ **(1)**

(iii) I $CH_3CH_2CO_2H$ **(1)**

II CH_3COCH_3 **(1)** **[5]**

(c) $(CH_3)_3CBr \xrightarrow[\text{reflux}]{KCN/\text{ethanol}} (CH_3)_3CCN \xrightarrow[\text{reflux}]{\text{dil } H^+} (CH_3)_3CCO_2H$

(1) (1) (1) **[3]**

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20. M/J 02/P2/Q6/a,b

(a)(i)	Two of anaesthetics, refrigerants, (coolants) flame retardants, (fire extinguishers) plastics. solvents aerosols	1
	Chemical inertness low b.p/volatility	1
(b)(i)	C – Cl (1)	1
(ii)	U.V light breaks bonds and gives (free) radicals (1) these lead to chain reactions (1) which damages ozone layer (1) Any two points	2

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UNIT 16

Hydroxy Compounds

A-Level
Chemistry Paper 2
Topical Workbook

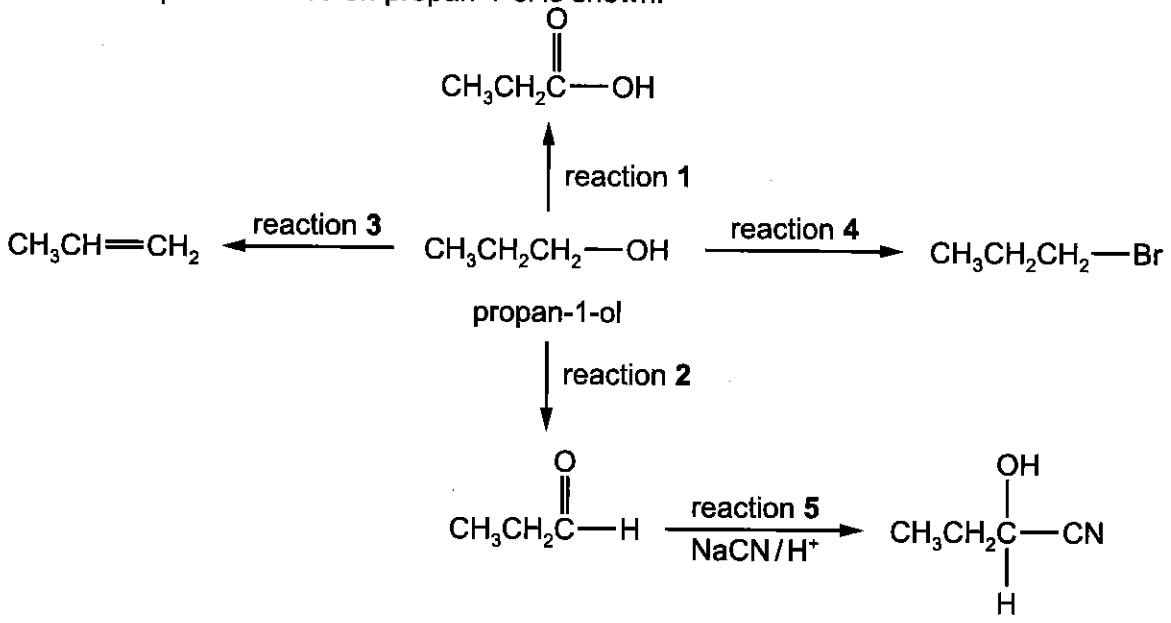
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Unit 16: Hydroxy Compounds

1. M/J 16/P22/Q5/a,b

A reaction sequence based on propan-1-ol is shown.



(a) Reactions **1** and **2** can both be carried out using the same reagents.

(i) Identify suitable reagents for reactions **1** and **2**.

.....

..... [1]

(ii) State and explain how the reaction should be carried out to ensure that reaction **2** rather than reaction **1** occurs.

.....

.....

.....

..... [2]

(b) Identify the necessary reagents and conditions for each of reactions **3** and **4**.

reaction **3** .....

.....

reaction **4** .....

.....

[2]

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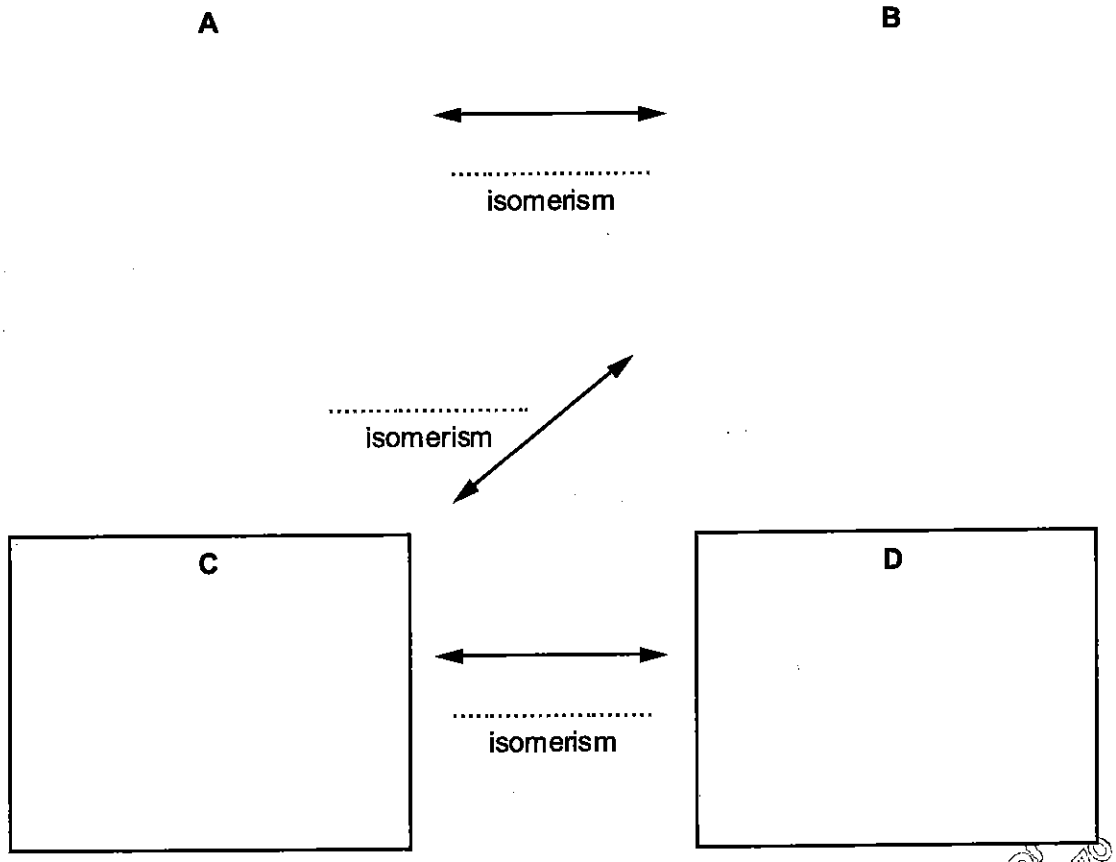
2. M/J 15/P21/Q4

There are four alcohols, **A**, **B**, **C** and **D**, which are structural somers with the molecular formula $C_4H_{10}O$.

Alcohol **A** does not react w th acidified potassium dichromate(VI) solution but **B**, **C** and **D** do.

All four alcohols react with hot, concentrated sulfuric ac d to form products with the molecular formula C_4H_8. **A**, **C** and **D** each give a single product in this reaction. **B** gives a mixture of two structural isomers, one of which shows stereoisomerism.

(a) Give the **skeletal** formula for each of the four alcohols and complete the diagram with the names of the types of structural isomerism shown by each linked pair of compounds.



[7]

(b) (i) Give the names of the two structural isomers produced by the reaction of **B** with hot, concentrated sulfuric acid

....

[2]

(ii) State which of these two isomers shows stereo somerism. Explain why this molecule s capable of showing stereoisomerism.

.....

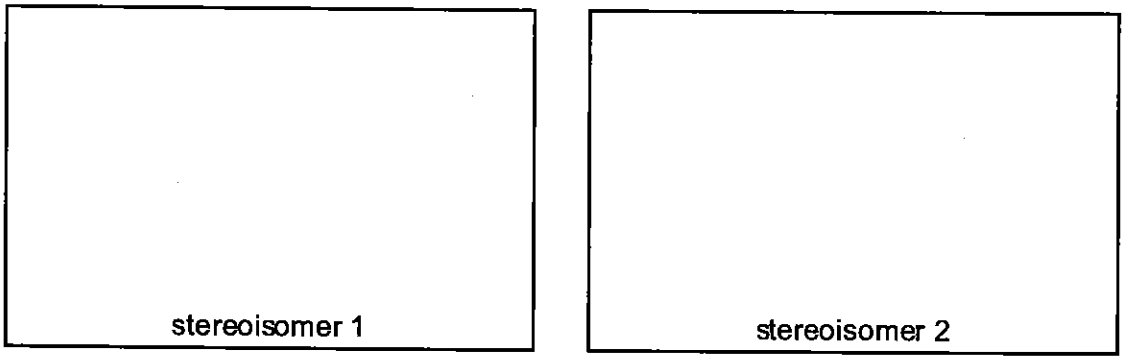
.....

.....

..... [2]

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(iii) Draw **displayed** formulae to show the two stereoisomers.



[2]

[13]

3. O/N 13/P23/Q5

The molecular formula C_4H_9OH represents four different alcohols, **W**, **X**, **Y** and **Z**.

W	X	Y	Z
$CH_3CH_2CH_2CH_2OH$	$CH_3CH_2CH(OH)CH_3$	$(CH_3)_2CHCH_2OH$	$(CH_3)_3COH$

(a) Draw the **skeletal formula** of **Z**. **[1]**

(b) Acidified potassium dichromate(VI) is used as an oxidising agent in organic chemistry.
Give the **structural formula** of the organic product formed when **each** above is heated under reflux with acidified potassium dichromate(VI).
If you believe that no reaction occurs, write 'no reaction' in the box.

W	
X	
Y	
Z	

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[4]

(c) One of the alcohols, **W**, **X**, **Y** or **Z**, can be dehydrated to give more than one organic product.
Identify this alcohol and give the structural formulae of **two** of the products.

alcohol	
product 1	
product 2	

[2]

[7]

4. M/J 13/P22/Q4/a,b

Crotyl alcohol, $CH_3CH{=}CHCH_2OH$, is a colourless liquid which is used as a solvent.

(a) In the boxes below, write the **structural formula** of the organic compound formed when crotyl alcohol is reacted separately with each reagent under suitable conditions.
If you think no reaction occurs, write 'NO REACTION' in the box.

A	Br_2 in an inert organic solvent	
B	PCl_5	
C	H_2 and Ni catalyst	
D	$NaBH_4$	
E	$K_2Cr_2O_7/H^+$ heat under reflux	

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[5]

(b) Draw the **displayed formula** of the organic compound formed when crotyl alcohol is reacted with cold, dilute acidified potassium manganate(VII).

[1]

5. M/J 13/P23/Q5

Compounds containing the allyl group, CH_2=$CHCH_2$–, have pungent smells and are found in onions and garlic.

Allyl alcohol, CH_2=$CHCH_2OH$, is a colourless liquid which is soluble in water.

(a) Allyl alcohol behaves as a primary alcohol and as an alkene.
Give the structural formula of the organic compound formed when allyl alcohol is reacted separately with each of the following reagents.

(i) acidified potassium dichromate(VI), heating under reflux

(ii) bromine in an inert organic solvent

(iii) cold, dilute, acidified potassium manganate(VII)

(iv) hot, concentrated, acidified potassium manganate(VII)

[5]

(b) Allyl alcohol undergoes the following reactions.

(i) When reacted with concentrated HCl at 100 °C, CH_2=$CHCH_2Cl$ is formed.

State as fully as you can what *type of reaction* this is.

.....

(ii) When reacted with MnO_2 at room temperature, CH_2=CHCHO is formed.

What *type of reaction* is this?

.....

[2]

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(c) Allyl alcohol can be converted into propanal in two steps.

$$CH_2{=}CHCH_2OH \xrightarrow{\text{step I}} CH_3CH_2CH_2OH \xrightarrow{\text{step II}} CH_3CH_2CHO$$

(i) What reagents and conditions would be used for **each** step?

step I

reagent(s) .....

condition(s) .....

step II

reagent(s) .....

(ii) Allyl alcohol and propanal are isomers.

condition(s) .....

What form of isomerism do they display?

.....

[5]

(d) Allyl alcohol may also be converted into propanal by using a ruthenium(IV) catalyst in water.

$$CH_2{=}CHCH_2OH \xrightarrow{\text{ruthenium(IV) catalyst}} CH_3CH_2CHO$$

Suggest what is unusual about this single step reaction.

.....

..... **[1]**

[13]

6. O/N 12/P21/Q4, O/N 12/P22/Q4

Many organic compounds, including alcohols, carbonyl compounds, carboxylic acids and esters, contain oxygen.

(a) The table below lists some oxygen-containing organic compounds and some common laboratory reagents.

(i) Complete the table as fully as you can.
If you think no reaction occurs, write 'no reaction' in the box for the structural formula(e).

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reaction	organic compound	reagent	structural formula(e) of organic product(s)
A	$(CH_3)_3COH$	$Cr_2O_7^{2-}/H^+$ heat under reflux	
B	CH_3CH_2CHO	Fehling's reagent warm	
C	$HCO_2CH(CH_3)_2$	NaOH(aq) warm	
D	$CH_2{=}CHCHO$	$NaBH_4$	
E	$(CH_3)_3COH$	$NaBH_4$	
F	$CH_3CH_2COCH_3$	MnO_4^-/H^+ heat under reflux	

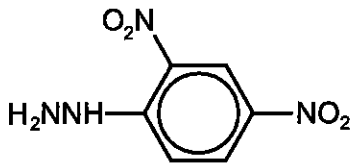
(ii) During some of the reactions in **(i)** a colour change occurs.
Complete the table below for any such reactions, stating the letter of the reaction and what the colour change is.

reaction	colour at the beginning of the reaction	colour at the end of the reaction

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(b) Some oxygen-containing compounds react with 2,4-dinitrophenylhydrazine.

[10]



2,4-dinitrophenylhydrazine

(i) Draw the structural formula of the organic compound formed when $HOCH_2CH_2CHO$ reacts with 2,4-dinitrophenylhydrazine reagent.

(ii) Suggest the colour of the organic product.

.....

[2]

[12]

7. M/J 12/P23/Q3/c,d

(a) DME and ethanol are isomers with the molecular formula C_2H_6O.

[10]

(i) Draw the displayed formula of DME and of ethanol.

DME	ethanol

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(ii) What type of isomerism do DME and ethanol show?

.....

[2]

(b) DME is a gas at room temperature while ethanol is a liquid.

(i) Which intermolecular force exists between ethanol molecules, which causes ethanol to be a liquid at room temperature?

.....

(ii) Draw a diagram that clearly shows this intermolecular force.

Your diagram should show any lone pairs or dipoles present that you consider to be important. You should represent at least two molecules in your diagram.

[4]

[12]

8. ON 11/P23/Q2/b

When 0.42 g of a gaseous hydrocarbon **A** is slowly passed over a large quantity of heated copper(II) oxide, CuO, **A** is completely oxidised.

The products are collected and it is found that 1.32 g of CO_2 and 0.54 g of H_2O are formed. Copper is the only other product of the reaction.

(a) Analysis of another organic compound, **B**, gave the following composition by mass: C, 64.86%; H, 13.50%, O, 21.64%.

(i) Use these values to calculate the empirical formula of **B**.

(ii) The empirical and molecular formulae of **B** are the same.

B is found to be chiral.

Draw displayed formulae of the two optical isomers of this compound, indicating with an asterisk (*) the chiral carbon atom.

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(iii) There are three other structural isomers of **B** which are not chiral but which contain the same functional group as **B**.

In the boxes below, draw the structural formulae of these isomers.

[7]

9. ON 11/P23/Q4

The structural formulae of six different compounds, **P – U**, are given below.

$CH_3CH=CHCH_2CH_3$	$CH_3CH_2COCH_2CH_3$	$CH_2=CHCH_2CH_2CH_3$
P	**Q**	**R**
$CH_3CH_2CH_2CH_2CH_2OH$	$HOCH_2CH_2CH(OH)CH_3$	$CH_3CH_2CH_2OCH_2CH_3$
S	**T**	**U**

(a) (i) What is the empirical formula of compound **T**?

.....

(ii) Draw the skeletal formula of compound **S**.

[2]

(b) (i) Compounds **S** and **U** are isomers.

What type of isomerism do they show?

.....

(ii) Two of the six formulae **P – U** can **each** be drawn in two forms which are known as stereoisomers.

Which two compounds have formulae that can be drawn in two forms?

What type of stereoisomerism does each show?

Identify each compound by its letter.

compound	type of stereoisomerism

[3]

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(c) Compound **S** can be converted into compound **R**.

(i) What type of reaction is this?

.....

(ii) What reagent would you use for this reaction?

.....

(iii) Write the structural formula of the compound formed when **T** undergoes the same reaction using an excess of the reagent you have used in **(c)(ii)**.

..... [3]

(d) Compound **P** may be converted into compound **Q** in a two-step reaction.

$$\underset{\mathbf{P}}{CH_3CH{=}CHCH_2CH_3} \xrightarrow{\text{step 1}} \text{intermediate} \xrightarrow{\text{step 2}} \underset{\mathbf{Q}}{CH_3CH_2COCH_2CH_3}$$

(i) What is the structural formula of the intermediate compound formed in this sequence?

(ii) Outline how step 1 may be carried out to give this intermediate compound.

.....

.....

.....

(iii) What reagent would be used for step 2?

..... [4]

[12]

10. ON 11/P23/Q5

Each of the three organic compounds, **V**, **W**, and **X**, has the empirical formula CH_2O.
The number of carbon atoms in each of their molecules is shown in the table.

compound	number of C atoms
V	1
W	2
X	3

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V gives a brick red precipitate when warmed with Fehling's reagent; **W** and **X** do not.

W is a fruity smelling liquid.

In **X**, the carbon atoms are bonded directly to one another.

X gives an effervescence when shaken with $Na_2CO_3(aq)$; **V** and **W** do not.

(a) Give the structural formula of **V**.

[1]

(b) **(i)** What functional group is present in **W**?

.....

(ii) Give the structural formula of **W**.

[2]

(c) When **X** is heated under reflux with acidified $K_2Cr_2O_7$, the product, **Y**, gives no reaction with 2,4-dinitrophenylhydrazine reagent.

(i) Give the structural formula of **X**.

(ii) Give the structural formula of **Y**, the compound formed from **X**.

[2]

(d) When **X** is warmed with a little concentrated sulfuric acid, a small amount of a cyclic compound, **Z**, is formed.

Z has the molecular formula $C_6H_8O_4$.

(i) Suggest a displayed formula for **Z**.

[2]

(ii) What type of reaction occurs when **Z** is formed from **X**?

.....

[7]

11. M/J 11/P21/Q2/b

(a) The boiling point of ethanol, C_2H_5OH, is higher than that of C_2H_5SH. Suggest a reason for this difference.

.....

..... [1]

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12. M/J 11/P23/Q5

Fermentation of sugars by bacteria or moulds produces many different organic compounds.

One compound present in fermented molasses is 2-ethyl-3-methylbutanoic acid which gives a distinctive aroma to rum.

$(CH_3)_2CHCH(C_2H_5)CO_2H$

2-ethyl-3-methylbutanoic acid

(a) (i) What is the molecular formula of 2-ethyl-3-methylbutanoic acid?

(ii) How many chiral carbon atoms are present in a molecule of 2-ethyl-3-methylbutanoic acid? If none write 'none'.

.....

[2]

A sample of 2-ethyl-3-methylbutanoic acid may be prepared in a school or college laboratory by the oxidation of 2-ethyl-3-methylbutan-1-ol, $(CH_3)_2CHCH(C_2H_5)CH_2OH$.

(b) (i) State the reagent(s) that would be used for this oxidation.
Describe what colour change would be seen.

reagent(s) .....

colour change from ..... to .....

This reaction is carried out by heating the reacting chemicals together.

(ii) What could be the main organic impurity present in the sample of the acid?

Explain your answer.

.....

.....

.....

(iii) State whether a distillation apparatus or a reflux apparatus should be used.

.....

.....

..... **[6]**

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(c) A structural isomer of 2-ethyl-3-methylbutan-1-ol is 2-ethyl-3-methylbutan-2-ol, $(CH_3)_2CHC(OH)(C_2H_5)CH_3$.

What colour change would be seen if this were heated with the reagents you have given in **(b)(i)**?
Explain your answer as clearly as you can.

.....

.....

..... **[3]**

An isomer of 2-ethyl-3-methylbutanoic acid which is an ethyl ester is a very strong smelling compound which is found in some wines.

(d) This ethyl ester contains a branched hydrocarbon chain and is chiral.

Draw the displayed formula of this ethyl ester.

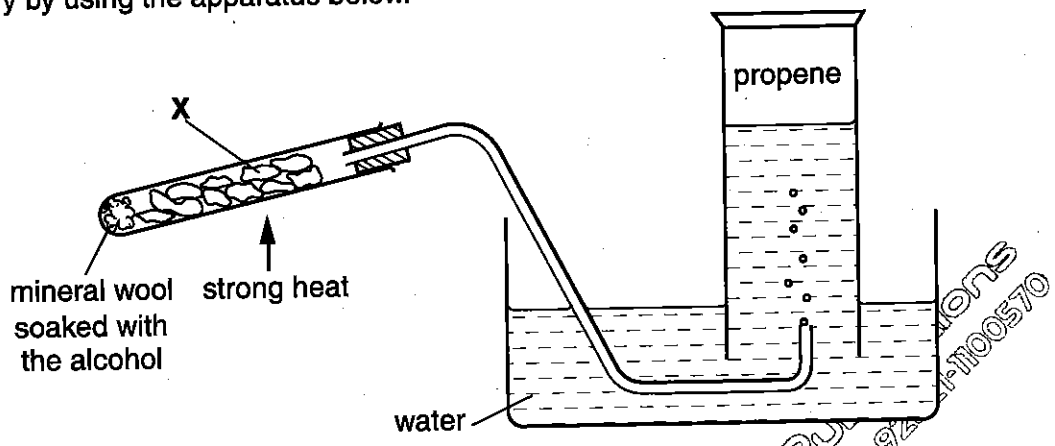
Identify the chiral carbon atom with an asterisk (*).

[3]

[14]

13. M/J 10/P22/Q5

Alkenes such as propene can be readily prepared from alcohols in a school or college laboratory by using the apparatus below.



(a) (i) Give the **name** of an alcohol that can be used in this apparatus to prepare propene.

.....

(ii) Draw the **skeletal** formula of the alcohol you have named in **(i)**.

(iii) What type of reaction occurs in this case?

..... **[3]**

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(b) **(i)** During the reaction, the material **X** becomes black in colour.
Suggest the identity of the black substance and suggest how it is produced during the reaction.

.....

.....

.....

(ii) At the end of the experiment, when no more propene is being produced, the delivery tube is removed from the water before the apparatus is allowed to cool.

Suggest why this done.

.....

.....

.....

(iii) The material labelled **X** can be broken crockery, broken brick or pumice.

Give the chemical formula of a compound that is present in one of these materials.

.....

(iv) State another reagent that could be used to produce propene from an alcohol.

..... **[5]**

(c) Give the structural formula of the organic product formed when propene reacts separately with **each** of the following substances.

(i) bromine

(ii) cold, dilute manganate(VII) ions

(iii) hot, concentrated manganate(VII) ions **[3]**

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(d) Propene may be polymerised.

(i) What is the essential condition for such a polymerisation?

.....

(ii) The disposal of waste poly(propene) is very difficult.
Give **one** important reason for this.

.....

.....

[2]

[13]

14. O/N 9/P21/Q4

The structural formulae of six different compounds, **A – F**, are given below.
Each compound contains four carbon atoms in its molecule.

$CH_3CH{=}CHCH_3$ **A**	$CH_3CH_2COCH_3$ **B**	$CH_2{=}CHCH_2CH_3$ **C**
$CH_3CH_2CH(OH)CH_3$ **D**	$HOCH_2CH_2CH_2CH_2OH$ **E**	$CH_3CH_2OCH_2CH_3$ **F**

(a) **(i)** What is the empirical formula of compound **E**? .....

(ii) Draw the skeletal formula of compound **D**.

(iii) Structural formulae do not show all of the isomers that may exist for a given molecular formula. Which **two** compounds **each** show **different** types of isomerism and what type of isomerism does each compound show? Identify each compound by its letter.

compound	type of isomerism

[4]

Compound **D** may be converted into compound **C**.

(b) **(i)** What type of reaction is this?

.....

(ii) What reagent would you use for this reaction?

.....

(iii) What is formed when compound **E** undergoes the same reaction using an excess of the same reagent?

.....

[3]

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Compound **A** may be converted into compound **B** in a two-stage reaction.

$$CH_3CH{=}CHCH_3 \xrightarrow{\text{stage I}} \text{intermediate} \xrightarrow{\text{stage II}} CH_3CH_2COCH_3$$

(c) **(i)** What is the structural formula of the intermediate compound formed in this sequence?

(ii) Outline how stage I may be carried out to give this intermediate compound.

.....

.....

.....

(iii) What reagent would be used for stage II?

..... **[4]**

(d) Compounds **D** and **F** are isomers.

What type of isomerism do they show?

..... **[1]**

[12]

15. O/N 9/P22/Q5

The fermentation of starch or molasses using the bacterium *Clostridium acetobutylicum*, produces a mixture of propanone and butan-1-ol.

(a) Give the reagent(s) and state what would be observed when **one** test is carried out to confirm the presence of propanone in a mixture of propanone and butan-1-ol.

reagent(s) .....

observation ..... **[2]**

(b) What will be observed when a small piece of sodium metal is dropped into a dry sample of butan-1-ol? Write an equation for the reaction that takes place.

observation .....

equation ..... **[2]**

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(c) Draw the following formulae.

(i) the **structural** formula of pentan-1-ol

(ii) the **displayed** formula of pentan-2-ol

(iii) the **skeletal** formula of pentan-3-ol **[3]**

When one of the three pentanols in **(c)** is dehydrated, alkenes with **two** different structural formulae are formed.

(d) Identify this alcohol and give the structural formula of **each** alkene.

name of alcohol .....

alkene 1	alkene 2

[3]

A number of alcohols with molecular formula $C_5H_{12}O$ are branched chain compounds and may be considered as derivatives of butanol or propanol with alkyl side chains.

(e) **(i)** Draw the structural formula of the **derivative of propanol** that has the molecular formula $C_5H_{12}O$.

(ii) Draw the structural formula of the organic compound that will be present when the derivative of propanol you have given in (i) is heated under reflux with acidified potassium dichromate(VI).

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16. O/N 07/P2/Q5

Ethanoic acid, CH_3CO_2H, is formed as vinegar by the bacterial oxidation of ethanol present in wine and other solutions.

$$CH_3CH_2OH + 2[O] \rightarrow CH_3CO_2H + H_2O$$

Ethanoic acid can also be formed in the laboratory by the oxidation of ethanol.

(a) (i) What oxidising agent is used for this laboratory reaction?

.....

(ii) What colour change would be observed?

from ..... to ..... **[2]**

When ethanoic acid is prepared in this way in the laboratory, the reagents are heated under reflux for some time before the ethanoic acid is separated.

(b) (i) Why is the reaction carried out by heating under reflux?

.....

.....

(ii) What would be the main organic compound formed if, instead of heating under reflux, the reagents were heated together and the products immediately distilled off?

..... **[2]**

(c) Ethanoic acid is manufactured from methanol, CH_3OH, by reacting it with carbon monoxide in the presence of a catalyst containing rhodium metal and iodide ions.

$$CH_3OH + CO \rightarrow CH_3CO_2H$$

The reaction proceeds in a number of stages.

(i) One stage in this process is the reaction of methanol with hydrogen iodide.

.....

(ii) A later stage involves the conversion of an intermediate compound.

$$CH_3C(=O)I \rightarrow CH_3C(=O)OH$$

What type of reaction is this?

.....

[2]

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What organic compound is formed in this reaction?

(d) Methanol can be converted into ethanoic acid in the laboratory in a three-stage process.

$$CH_3OH \xrightarrow{\text{step I}} CH_3I \xrightarrow{\text{step II}} CH_3CN \xrightarrow{\text{step III}} CH_3CO_2H$$

What reagent(s) and conditions are used in each step of the conversion?

step I
reagent(s) .....

conditions .....

step II
reagent(s) .....

conditions .....

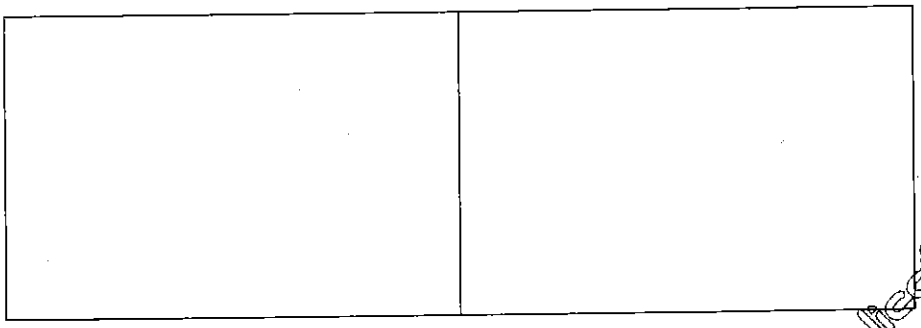
step III
reagent(s) .....

conditions ..... **[6]**

[12]

17. O/N 07/P2/Q4/c,d

(a) In the spaces below draw the structural formulae of **two** alcohols which would **each** produce pent-2-ene on dehydration.



(b) One of these alcohols exhibits optical isomerism. Draw the structural formulae of the two isomers of this alcohol. Your structures should clearly indicate the three-dimensional nature of the structures.

[2]

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18. M/J 07/P2/Q2/d

Alcohols may be classified into primary, secondary and tertiary. Some reactions are common to all three types of alcohol. In other cases, the same reagent gives different products depending on the nature of the alcohol.

(a) In the empty squares below give the structural formula of the organic compound formed in each of the reactions indicated.

If no reaction occurs, write 'no reaction' in the space.

alcohol / reagent(s) and conditions	$CH_3CH_2CH_2CH_2OH$	$CH_3CH_2CH(OH)CH_3$	$(CH_3)_3COH$
red phosphorus and iodine heat under reflux			
concentrated H_2SO_4 heat			
$Cr_2O_7^{2-}/H^+$ heat under reflux			

[5]

[11]

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19. M/J 06/P2/Q4, M/J 13/P23/Q5

Compounds containing the allyl group, $CH_2=CHCH_2-$, have pungent smells and are found in onions and garlic.
Allyl alcohol, $CH_2=CHCH_2OH$, is a colourless liquid which is soluble in water.

(a) Allyl alcohol behaves as an alkene and as a primary alcohol.
Give the structural formula of the organic compound formed when allyl alcohol is

(i) reacted with Br_2,

(ii) heated under reflux with an acidified solution of $Cr_2O_7^{2-}$ ions.

[2]

(b) When allyl alcohol is reacted with MnO_2 at room temperature, propenal, $CH_2=CHCHO$ is formed.

What type of reaction is this?

..... **[1]**

(c) Allyl alcohol may be converted into propanal, CH_3CH_2CHO, by using a ruthenium(IV) catalyst in water.

$$CH_2=CHCH_2OH \xrightarrow{\text{ruthenium(IV) catalyst}} CH_3CH_2CHO$$

The reactant and the product are isomers.
What form of isomerism do they display?

..... **[1]**

(d) Allyl alcohol can be converted into propanal in two steps **without** the use of a ruthenium(IV) catalyst.

$$CH_2=CHCH_2OH \xrightarrow{\text{step I}} CH_3CH_2CH_2OH \xrightarrow{\text{step II}} CH_3CH_2CHO$$

What reagents and conditions would be used for **each** step?

step I

reagent(s) .....

condition(s) .....

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step II

reagent(s) .....

condition(s) ..... **[4]**

(e) By considering your answers to **(b)** and **(d)**, suggest what is unusual about the single-step reaction in **(c)**.

.....

..... **[1]**

(f) Suggest the structural formula of the organic compound formed when allyl alcohol is

(i) reacted with cold, dilute MnO_4^- ions,

(ii) heated under reflux with acidified MnO_4^- ions.

[3]

[12]

20. O/N 05/P2/Q4

Alcohols are widely used as solvents and in the manufacture of esters.

Butan-1-ol, $C_4H_{10}O$, is an example of a primary alcohol.

(a) What is meant by the term *primary alcohol*?

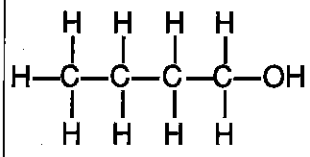
..... **[1]**

(b) There are three more alcohols with molecular formula $C_4H_{10}O$ that are **structural** isomers of butan-1-ol.

Complete the table below by drawing displayed formulae of **each** of these three compounds.

For **each** isomer, state whether it is a primary, secondary, or tertiary alcohol.

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primary			
butan-1-ol	isomer 2	isomer 3	isomer 4

[6]

(c) Butan-1-ol can be oxidised to a carboxylic acid by heating with an acidified solution of potassium dichromate(VI).

(i) What colour change would be seen during this reaction?

from ..... to .....

(ii) State which of the isomers you have drawn in **(b)** could also be oxidised to form a carboxylic acid.

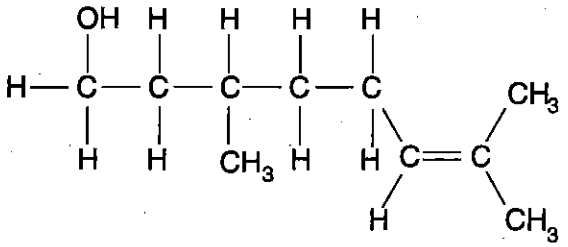
.....

[3]

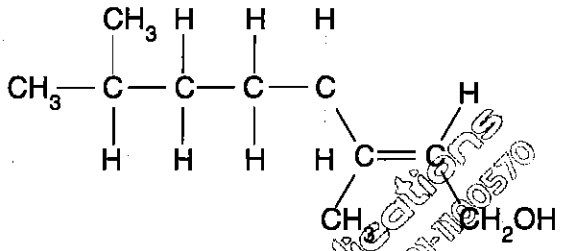
[10]

21. O/N 04/P2/Q4

Some perfumes and scents of flowers and fruit contain compounds which are structural isomers. Two such examples are citronellol and geraniol.



citronellol



geraniol

(a) Confirm that citronellol and geraniol are isomers by calculating their molecular formula and their relative molecular mass, M_r.

(i) Molecular formula .....

(ii) M_r ..... [2]

(b) Name two functional groups present in **both** molecules.

(i) .....

(ii) ..... [3]

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Citronellol and geraniol also show stereo isomerism.

(c) On the diagram of the structure of citronellol above, draw a circle around a chiral carbon atom. [1]

(d) **(i)** Draw the other *cis-trans* isomer of geraniol. [In parts **(d)** and **(f)** use R – to represent a part of the molecule.]

(ii) Explain why geraniol has no optical isomers.

.....

..... [2]

(e) State what you would expect to see if citronellol was reacted with aqueous bromine.

.....

.....[1]

(f) Draw structures of the organic products when geraniol reacts with each of the following reagents.

(i) an excess of $H^+ / Cr_2O_7^{2-}$ under reflux

(ii) ethanoic acid in the presence of an acidic catalyst

(iii) hydrogen bromide, HBr

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[4]

[13]

22. O/N 02/P2/Q5

Samples of the following compounds were labelled **A** to **E** as shown.

A $CH_3CH_2CH_2OH$

B $CH_3CH_2CH(OH)CH_3$

C CH_3CHO

D CH_3COCH_3

E $CH_3CH{=}CHCH_3$

Complete the table below by inserting the letter (or letters) of the compounds that correspond to each test.

reagent	observation	letter(s)
acidified potassium dichromate(VI)	green colour obtained on boiling	
acidified potassium manganate(VII)	ethanoic acid obtained on boiling	
hydrogen in the presence of a platinum catalyst	hydrogen absorbed	
Fehling's reagent	brown-red precipitate obtained on boiling	
2,4-dinitrophenylhydrazine	orange precipitate	
bromine in an inert solvent	solution decolourised	

[9]

23. O/N 02/P2/Q6

Pentan-1-ol, $C_5H_{11}OH$, is important in the synthesis of organic compounds.

(a) Give the structural formula of another primary alcohol which is an isomer of pentan-1-ol.

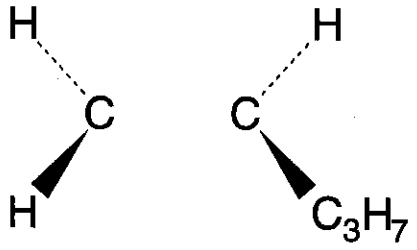
(b) **(i)** Write a balanced equation for the preparation of 1-bromopentane from pentan-1-ol.

(ii) This preparation gives a yield of 60%. Calculate the mass of pentan-1-ol required to produce 15.0 g of 1-bromopentane.

[1]

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(c) Dehydration of pentan-1-ol produces pent-1-ene. Sketch on the diagram below the orbital overlap between the two carbon atoms. Label the bonds. [3]



[2]

(d) The two compounds below are among many secreted by insects to attract members of the same species. Such compounds are used in traps to control insect populations. They need to be made synthetically.

For each synthesis outline how they could be prepared from pentan-1-ol, giving the necessary reagents and conditions.

(i) $CH_3(CH_2)_3CO_2H$

(ii) $CH_3CO_2(CH_2)_4CH_3$

[4]

[10]

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Answers Section

1. M/J 16/P22/Q5/a,b

(a) (i) acidified / H^+

AND

potassium / sodium dichromate [1] [1]

(ii) distillation (rather than reflux) [1]

(ensures aldehyde escapes) to avoid further oxidation/ to avoid forming acid / as reflux causes further oxidation [1] [2]

(b) react on 3 – (conc) H_2SO_4 / (conc) H_3PO_4 or Al_2O_3 / pumice / porcelain / porous pot / ceramic

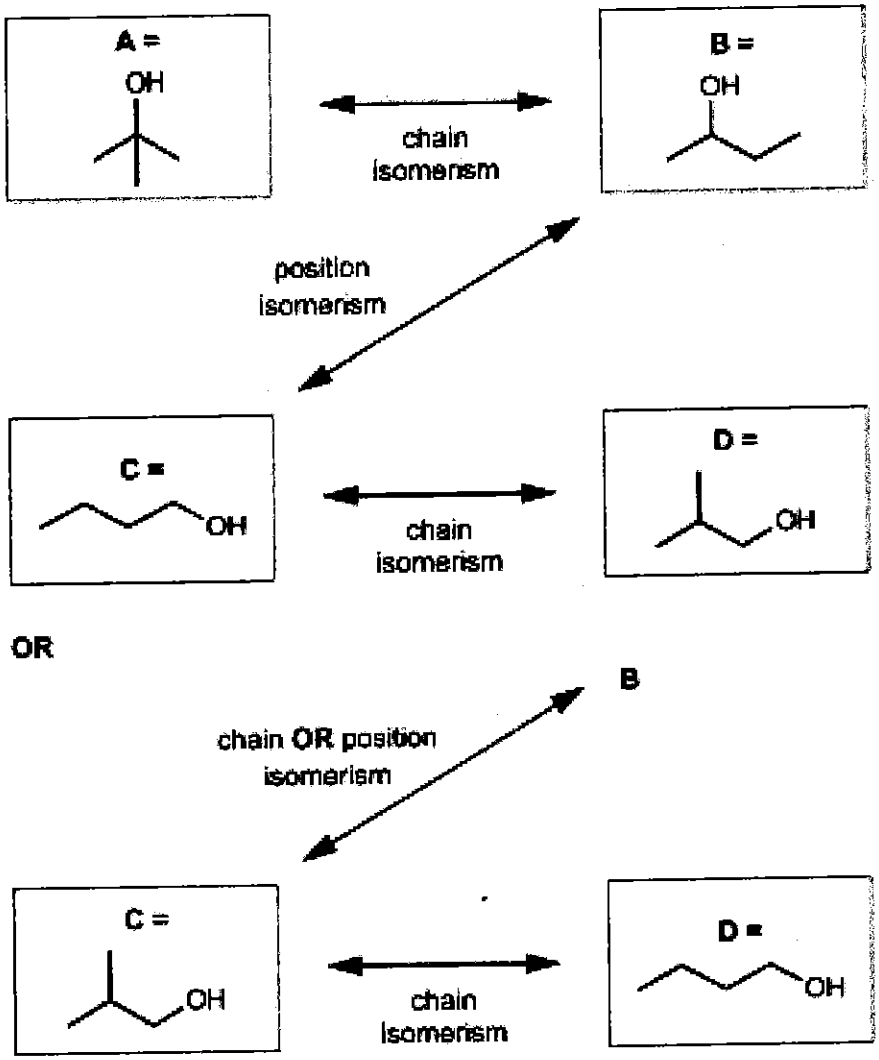
AND heat

react on 4 – KBr / NaBr with (conc) H_2SO_4 or (red)P and Br_2 / PBr_3 [1]

AND heat [1] [2]

2. M/J 15/P21/Q4

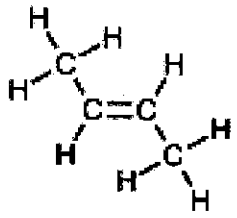
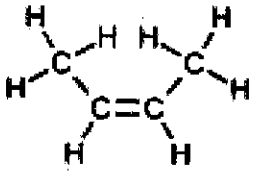
(a)



[1] [1] [1] [1] [1] [1] [1] [7]

(b) (i) but-1-ene / 1-butene [1]
but-2-ene / 2-butene [1] [2]

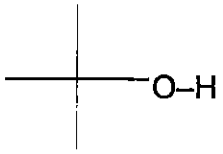
(ii) but-2-ene **AND** two different groups on each carbon (of C=C) [1]
double bond means no free rotation [1] [2]

(iii)   [1+1]

and (either way round) [2]

[13]

3. O/N 13/P23/Q5

(a) 

(1) [1]

(b)

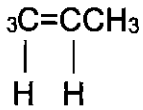
W	$CH_3CH_2CH_2CO_2H$
X	$CH_3CH_2COCH_3$
Y	$(CH_3)_2CHCO_2H$
Z	no reaction

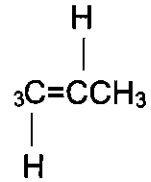
(4 × 1) [4]

(c) alcohol is **X** (no mark for this)

products are

$CH_3CH_2CH=CH_2$





(any two) [2]

[7]

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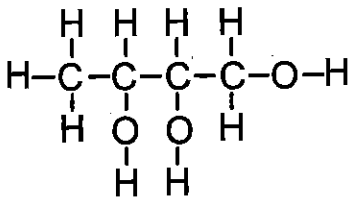
4. M/J 13/P22/Q4/a,b

(a)

A	Br_2 in an inert organic solvent	$CH_3CHBrCHBrCH_2OH$
B	PCl_5	$CH_3CH{=}CHCH_2Cl$
C	H_2 and Ni catalyst	$CH_3CH_2CH_2CH_2OH$
D	$NaBH_4$	NO REACTION
E	$K_2Cr_2O_7/H^+$, heat under reflux	$CH_3CH{=}CHCO_2H$

give one mark for each correct answer **(5 × 1) [5]**

(b)



(1) [1]

5. M/J 13/P23/Q5

(a)(i) **$CH_2{=}CHCO_2H$** **(1)**

(ii) $BrCH_2CHBrCH_2OH$ **(1)**

(iii) product is $HOCH_2CH(OH)CH_2OH$

correct addition across >C=C< **(1)**

original $-CH_2OH$ remains **(1)**

(iv) HO_2CCO_2H **(1) [5]**

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(b) (i) nucleophilic substitution **(1)**

(ii) oxidation **(1) [2]**

(c) (i) **step I**

H_2 **(1)**

heat with Ni catalyst **(1)**

step II

acidified $K_2Cr_2O_7$ **(1)**

heat **or** distil off product **(1)**

(ii) structural isomerism
or
functional group isomerism **(1) [5]**

(d) **both** oxidation **and** reduction have occurred **or**
disproportionation has taken place **(1) [1]**

[13]

6. O/N 12/P21/Q4, O/N 12/P22/Q4

(a) (i)

reaction	organic compound	reagent	structural formulae of organic products
A	$(CH_3)_3COH$	$Cr_2O_7^{2-}/H^+$ heat under reflux	no reaction
B	CH_3CH_2CHO	Fehling's reagent warm	$CH_3CH_2CO_2H$ **or** $CH_3CH_2CO_2^-$
C	$HCO_2CH(CH_3)_2$	NaOH(aq) warm	HCO_2Na **or** HCO_2^- $(CH_3)_2CHOH$
D	$CH_2=CHCHO$	$NaBH_4$	$CH_2=CHCH_2OH$
E	$(CH_3)_3COH$	$NaBH_4$	no reaction
F	$CH_3CH_2COCH_3$	MnO_4^-/H^+ heat under reflux	no reaction

each correct answer gets (1) **(7 × 1)**

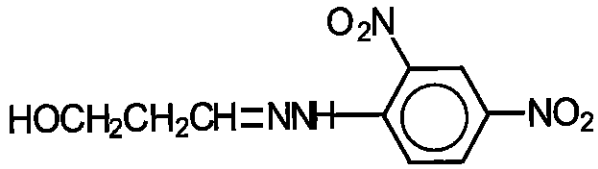
(ii)

reaction	colour at the beginning of the reaction	colour at the end of the reaction
B	blue	brick red

each correct answer gets 1 **(1 +1 + 1) [10]**

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(b) (i)



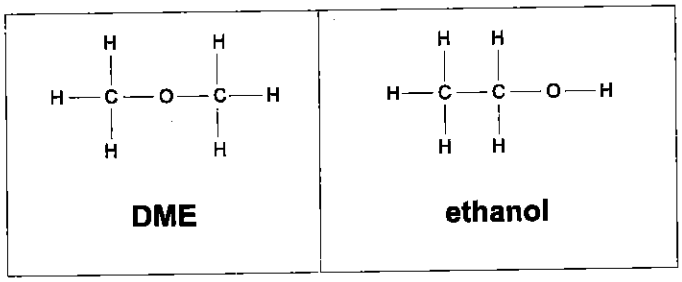
(1)

(ii) red **or** orange **(1) [2]**

[12]

7. M/J 12/P23/Q3/c,d

(a) (i)



both correct **(1)**

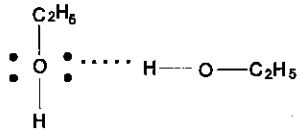
(ii) structural isomerism **or** functional group isomerism **(1) [2]**

(b) (i) hydrogen bonds **(1)**

(ii) lone pair on O atom of C_2H_5OH **(1)**

correct dipole $O^{\delta-}—H^{\delta+}$ on bond in one molecule of ethanol **(1)**

hydrogen bond shown between lone pair of an O atom and a hydrogen atom, i.e.



(1) [4]

[12]

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8. ON 11/P23/Q2/b

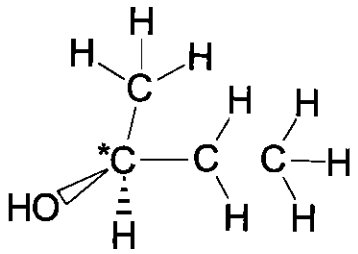
(a) (i) C : H : O = $\frac{64.86}{12} : \frac{13.50}{1} : \frac{21.64}{16}$ **(1)**

= 5.41: 13.50 : 1.35

= 4 : 10 : 1

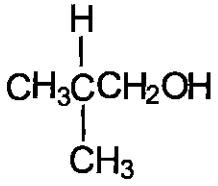
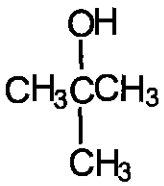
gives $C_4H_{10}O$ **(1)**

(ii)



correct compound **and** correct chiral C* **(1)**
correct mirror object/ mirror image relationship in 3D **(1)**

(iii)

$CH_3CH_2CH_2CH_2OH$		
(1)	**(1)**	**(1)**

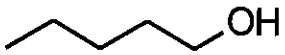
[7]

[12]

9. ON 11/P23/Q4

(a) (i) C_2H_5O **(1)**

(ii)



(1) **[2]**

(b) (i) functional group isomerism
or structural isomerism **(1)**

do **not** allow 'functional isomerism' or positional isomerism

(ii)

compound	type of isomerism
P	*cis-trans* **or** geometrical
T	optical

(1 + 1) **[3]**

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(c) (i) dehydration/elimination **(1)**

(ii) conc. H_2SO_4 / P_4O_{10} / Al_2O_3 / H_3PO_4 / pumice **(1)**

(iii) $CH_2=CHCH=CH_2$

allow $CH_2=C=CHCH_3$ **(1) [3]**

(d) (i) **$CH_3CH_2CH(OH)CH_2CH_3$** **(1)**

(ii) steam with H_3PO_4 catalyst **or**
conc. H_2SO_4 then water **(1 + 1)**

only allow condition mark if reagent mark has been given

(iii) $Cr_2O_7^{2-}/H^+$ **or**
MnO_4^-/H^+ **(1) [4]**

[12]

10. ON 11/P23/Q5

(a) **V** is HCHO **(1) [1]**

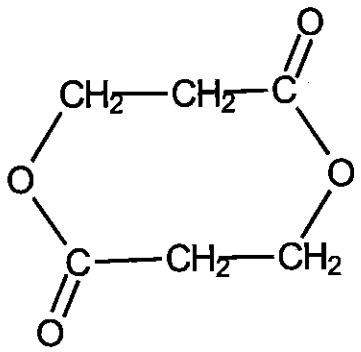
(b) (i) ester **(1)**

(ii) **W** is HCO_2CH_3 **(1) [2]**

(c) (i) **X** is $HOCH_2CH_2CO_2H$ **(1)**

(ii) **Y** is $HO_2CCH_2CO_2H$ **(1) [2]**

(d) (i) **Z** is



(1)

(ii) esterification **or**
dehydration **or**
or
condensation **(1) [2]**

[7]

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11. M/J 11/P21/Q2/b

(a) ethanol has hydrogen bonding, ethanethiol does not **(1)** **[1]**

12. M/J 11/P23/Q5

(a) (i) $C_7H_{14}O_2$ **(1)**

(ii) one **(1)** **[2]**

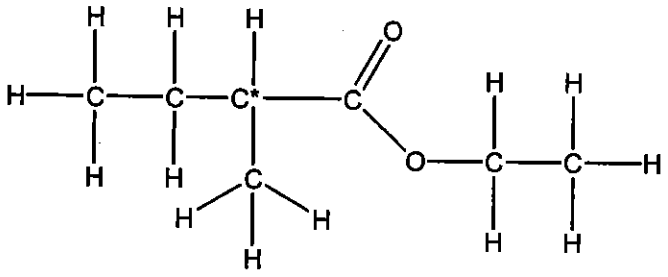
(b) (i) $Cr_2O_7^{2-}/H^+$ **(1)**
from orange **(1)**
to green **(1)**

(ii) 2-ethyl-3-methylbutanal/$(CH_3)_2CHCH(C_2H_5)CHO$/the corresponding aldehyde **(1)**
partial oxidation of alcohol will produce aldehyde **(1)**

(iii) reflux **because**
the alcohol must be fully oxidised **(1)** **[6]**

(c) none **(1)**
alcohol is tertiary **(1)**
cannot be oxidised **(1)** **[2]**

(d)



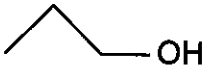
correct structure **(1)**
fully displayed $-CO_2C_2H_5$ group (allow ecf on wrong esters) **(1)**
correct chiral C atom (allow ecf on wrong esters) **(1)** **[3]**

[14]

13. M/J 10/P22/Q5

(a) (i) propan-1-ol **or** propan-2-ol (1)

(ii)



or



(1)

(iii) dehydration **or** elimination (1) **[3]**

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(b) (i) carbon **(1)**
by decomposition/cracking of the alcohol **(1)**

(ii) to avoid 'sucking back' of water into the hot tube **(1)**

(iii) SiO_2 **(1)**

(iv) conc. H_2SO_4 **or** P_4O_{10} **or** Al_2O_3 **or** H_3PO_4 (1) [5]

(c) (i) $CH_3CHBrCH_2Br$ (1)

(ii) $CH_3CH(OH)CH_2OH$ (1)

(iii) CH_3CO_2H (1) [3]

(d) (i) (very) high pressure **or** Ziegler-Natta catalyst (1)

(ii) does not biodegrade **or** gives harmful combustion products (1) **[2]**

[13]

14. O/N 9/P21/Q4

(a) (i) C_2H_5O **(1)**

(ii)  **(1)**

(iii)

compound	type of isomerism
A	*cis-trans* **or** geometrical
D	optical

allow one mark if **both A and D** are correctly identified but in **both** cases, the type of isomerism is incorrect **(1 + 1)** [4]

(b) (i) dehydration/elimination **(1)**

(ii) conc. H_2SO_4/P_4O_{10}/Al_2O_3/pumice etc. **(1)**

(iii) CH_2=CHCH=CH_2/butadiene/buta-1,3-diene **(1)** **[13]**

(c) (i) $CH_3CH_2CH(OH)CH_3$ **(1)**

(ii) steam with H_3PO_4 catalyst **or** conc. H_2SO_4 then water **(1 + 1)**

(iii) $Cr_2O_7^{2-}/H^+$ **(1)** **[4]**

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(d) functional group isomerism
or structural isomerism
not positional isomerism **(1)** **[1]**

[12]

15. O/N 9/P22/Q5

(a) 2,4-dinitrophenylhydrazine **or** aqueous alkaline iodine **(1)**

↓ ↓

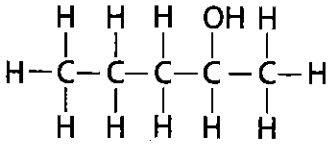
yellow-orange-red ppt. yellow ppt. **(1)** **[2]**

(b) colourless gas evolved **or** Na dissolves **(1)**

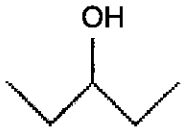
$C_4H_9OH + Na \rightarrow C_4H_9ONa + \frac{1}{2}H_2$ **(1)** **[2]**

(c) (i) $CH_3CH_2CH_2CH_2CH_2OH$ **(1)**

(ii)



(iii)



(1) **[3]**

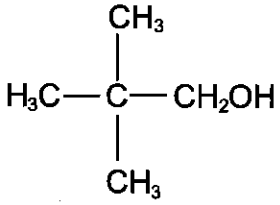
(d) (i) pentan-2-ol **(1)**

(ii)

$CH_3CH_2CH=CHCH_3$	$CH_3CH_2CH_2CH=CH_2$
product 1	product 2

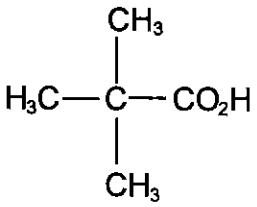
(1 + 1) **[3]**

(e) (i)



or $CH_3C(CH_3)_2CH_2OH$ **(1)**

(ii)



or $CH_3C(CH_3)_2CO_2H$

allow ecf on **(e)(i)** **(1)** **[2]**

[12]

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16. O/N 7/P2/Q5

(a) (i) $Cr_2O_7^{2-}/H^+$ allow MnO_4^-/H^+ **(1)**

(ii) from orange to **or** purple to colourless

green **or** green/blue **(1)** **[2]**

(b) (i) to ensure complete oxidation of $-CH_2OH$

or to keep reactants in the reaction flask **(1)**

(ii) CH_3CHO/ethanal **(1)** **[2]**

(c) (i) CH_3I/iodomethane **(1)**

(ii) nucleophilic substitution **or** hydrolysis **(1)** **[2]**

(d) **step I**

red P + I_2 **or** HI(aq) **or** KBr/conc H_3PO_4 **or** PI_3 **(1)**

heat **but** room temperature for PI_3 **(1)**

step II

KCN in aqueous ethanol **(1)**

in aqueous ethanol, heat under reflux **(1)**

allow aqueous ethanol in either place

step III

aqueous mineral acid (**not** nitric acid)

or NaOH(aq) then aqueous mineral acid **(1)**

heat **(1)** **[6]**

[12]

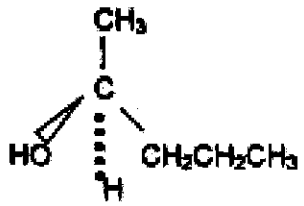
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17. O/N 7/P2/Q4/c,d

(a) $CH_3CH(OH)CH_2CH_2CH_3$ **(1)**

$CH_3CH_2CH(OH)CH_2CH_3$ (1) [2]

(b)



correct compound **(1)**

correct mirror object/mirror image relationship in 3D **(1)** **[2]**

18. M/J 7/P2/Q2/d

(a)

alcohol / reagent(s) and conditions	$CH_3CH_2CH_2CH_2OH$	$CH_3CH_2CH(OH)CH_3$	$(CH_3)_3COH$
red phosphorus and iodine heat under reflux	X	$CH_3CH_2\underset{\displaystyle I}{\underset{\vert}{C}}HCH_3$ [1]	X
concentrated H_2SO_4 heat	X	X	$CH_3—\underset{\displaystyle CH_3}{\underset{\vert}{C}}=CH_2$ [1]
$Cr_2O_7^{2-}/H^+$ heat under reflux	$CH_3CH_2CH_2CO_2H$ [1]	$CH_3CH_2COCH_3$ [1]	no reaction [1]

[5]

[11]

19. M/J 6/P2/Q4, M/J 13/P23/Q5

(a) (i) $BrCH_2CHBrCH_2OH$ **(1)**

(ii) $CH_2=CHCO_2H$ **(1)** **[2]**

(b) oxidation **(1)** **[1]**

(c) structural **or** functional group isomerism **(1)** **[1]**

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(d) **step I**

$CH_2=CHCH_2OH \rightarrow CH_3CH_2CH_2OH$

H_2 **(1)**

Ni catalyst and heat **or** Pt at room temperature **(1)**

step II $CH_3CH_2CH_2OH \rightarrow CH_3CH_2CHO$

acidified dichromate(VI) **(1)**

heat **not** under reflux
or distil off aldehyde as it is formed **(1)**
for both steps, conditions mark is only awarded if correct reagent is given **[4]**

(e) **both** oxidation and reduction have occurred **(1)** **[1]**

(f) (i) $HOCH_2CHOHCH_2OH$ formed

$CH_2=CH-$ forms $HOCH_2CHOH^-$ **(1)**

$^-CH_2OH$ is unchanged **(1)**

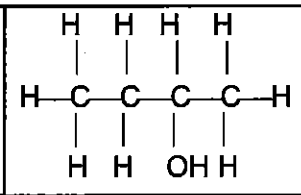
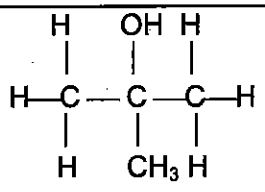
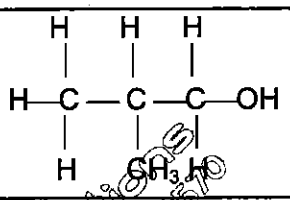
(ii) HO_2CCO_2H **(1)** **[3]**

[12]

20. O/N 5/P2/Q4

(a) a compound which contains the $-CH_2OH$ group **(1)** **[1]**

(b)

given in qu.			
primary	secondary	tertiary	primary
butan-1-ol	isomer 2	isomer 3	isomer 4

each correct structure **(3 x 1)**

each correct label **(3 x 1)** **[6]**

(c) **(i)** from orange **(1)**

to green **(1)**

(ii) correct primary alcohol **(1)** **[3]**

[10]

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21. O/N 4/P2/Q4

(a) (i) $C_{10}H_{20}O$ (1)

(ii) 156

allow e.c.f. on **(a) (i)** (1) **[2]**

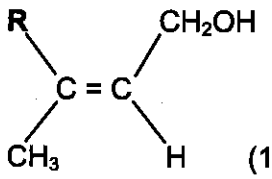
(b) (i) primary (1)

alcohol (1)

(ii) alkene (1) **[3]**

(c) carbon atom number 6 circled (1) **[1]**

(d) (i)

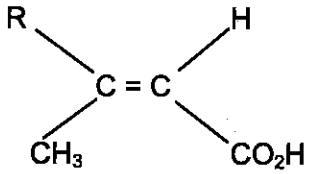


(1)

(ii) it does not have chiral C atom (1) **[2]**

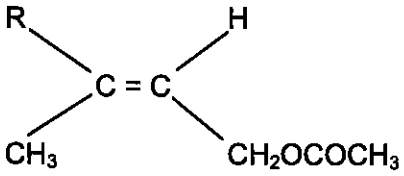
(e) bromine is decolourised (1) **[1]**

(f) (i)



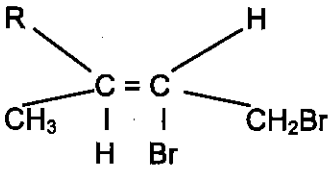
(1)

(ii)

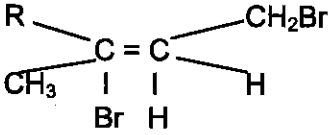


(1)

(iii)



or



correct addition of HBr (1)

substitution of $-CH_2OH$ by Br (1) **[4]**

[13]

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22. O/N 2/P2/Q5

$H^+/Cr_2O_7^{2-}$	A, B, C
H^+/MnO_4^-	C, E
H_2/Pt	E
Cu^{2+} (Fehling)	C
2,4-DNP	C, D
Br_2	E

1 each

Each wrong answer in a box invalidates a correct answer

[9]

23. O/N 2/P2/Q6

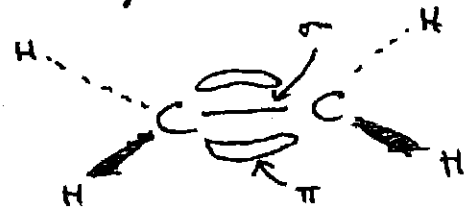
6 (a) CH_3 / C_2H_5 $CH-CH_2OH$ etc (1) [1]

(b)(i) $C_5H_{11}OH + HBr \longrightarrow C_5H_{11}Br + H_2O$ (1)

(ii) 88 g alcohol required for 151 g bromide (1)

$\therefore \frac{88}{151} \times \frac{100}{60} \times 15$ g required for 15 g bromide (60% yield)

$= 14.57$ g allow 14.5 to 14.6 g (1) [3]

(c) 

a neat drawing of a double bond (1)

σ and π labels (1) [2]

(d)(i) $C_5H_{11}OH \xrightarrow[\text{reflux (1)}]{H^+/Cr_2O_7^{2-}\ (1)} C_4H_9CO_2H$

accept H^+/MnO_4^- or OH^-/MnO_4^-

(ii) CH_3CO_2H (1) $+ HOC_5H_{11} \longrightarrow CH_3CO.OC_5H_{11} [+ H_2O]$ [4]

conc H_2SO_4 + heat/reflux (1)

condition mark is only awarded when the reagent is correct

[Total: 10]

[10]

UNIT 17

Carbonyl Compounds

A-Level
Chemistry Paper 2
Topical Workbook

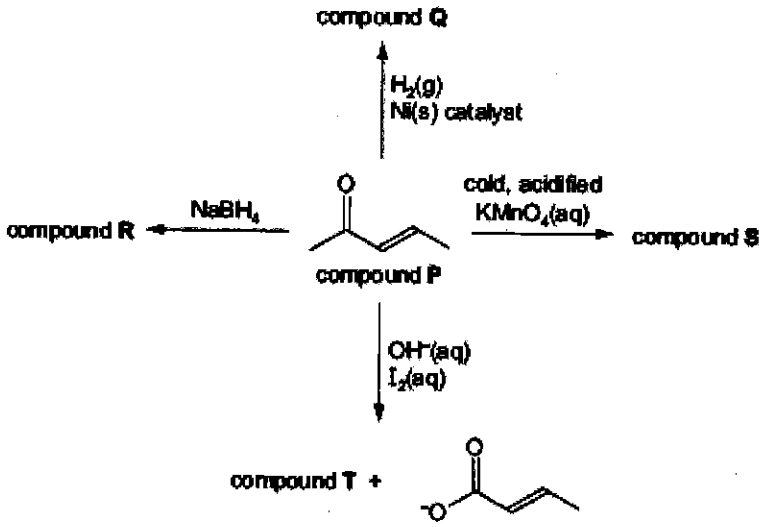
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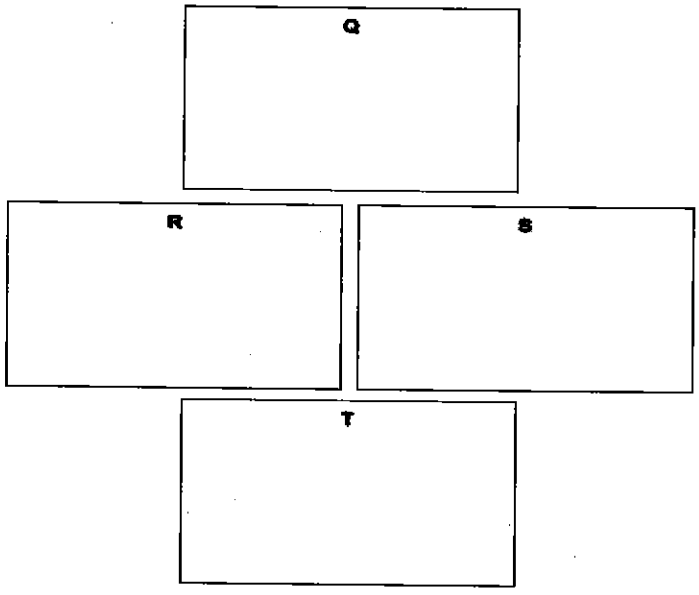
Unit 17: Carbonyl Compounds

1. MAR 16/P22/Q5

Some reactions of compound P, C_5H_8O, are shown.



(a) (i) Give the structures for organic compounds Q, R, S and T.



[4]

(ii) Give the systematic name of compound P.

.....

[1]

(iii) What would you observe when compound P is reacted with 2,4-dinitrophenylhydrazine (2,4-DNPH)?

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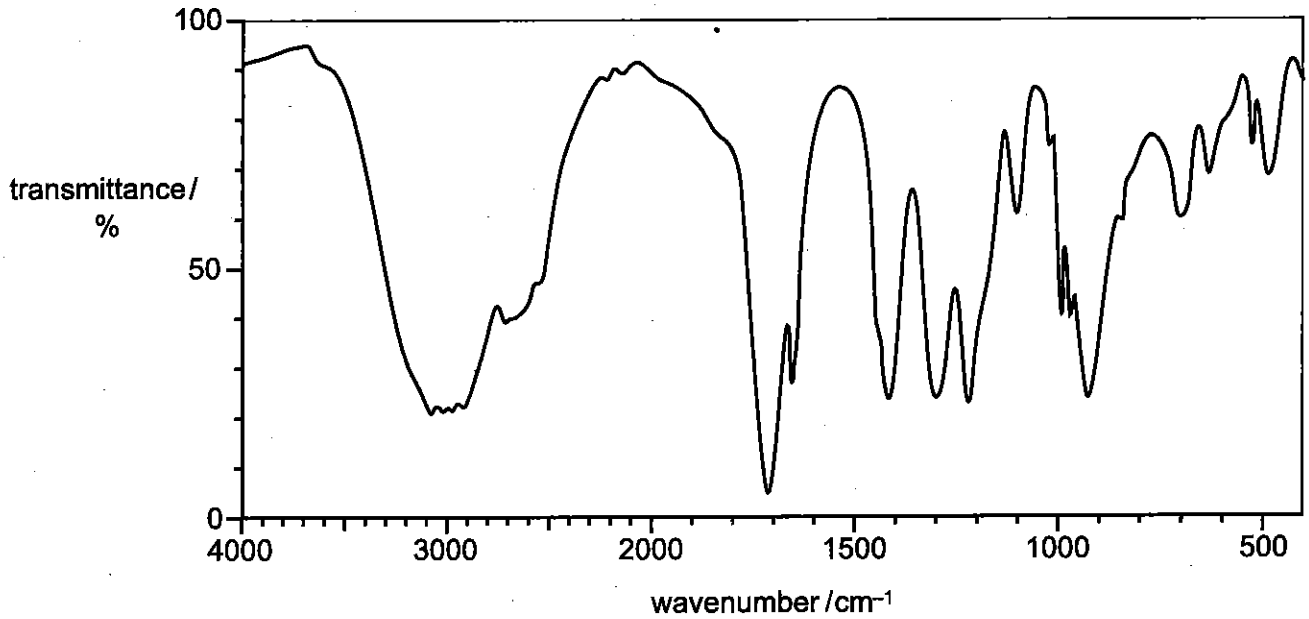
[1]

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(b) Compound U contains a chiral centre and has the same molecular formula as compound P, C_5H_8O.

- Compound U readily decolourises a sample of bromine water.
- Compound U does not show cis-trans isomerism.
- When compound U is heated under reflux in the presence of excess acidified potassium dichromate(VI), the organic product gives the infra-red spectrum shown.

infra-red spectrum of **product**



Use the information given to suggest a structure for compound U.
Explain your answer.

[4]

[10]

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2. MAR 16/P22/Q3/d

(a) The reaction of hydrogen cyanide with propanone is an important first step in many organic syntheses.

(i) Give the full name of the mechanism of this reaction.

.....[1]

(ii) Complete the diagram to show the mechanism of the reaction of hydrogen cyanide with propanone.
Draw the structure of the intermediate and the product of the reaction.
Include all relevant charges, partial charges, curly arrows and lone pairs.



[5]

3. M/J 16/P23/Q4

Acetoin, $CH_3COCH(OH)CH_3$, and diacetyl, $CH_3COCOCH_3$, are two of the compounds that give butter its characteristic flavour. Their skeletal formulae are shown.



acetoin diacetyl

(a) Give the systematic name for acetoin.

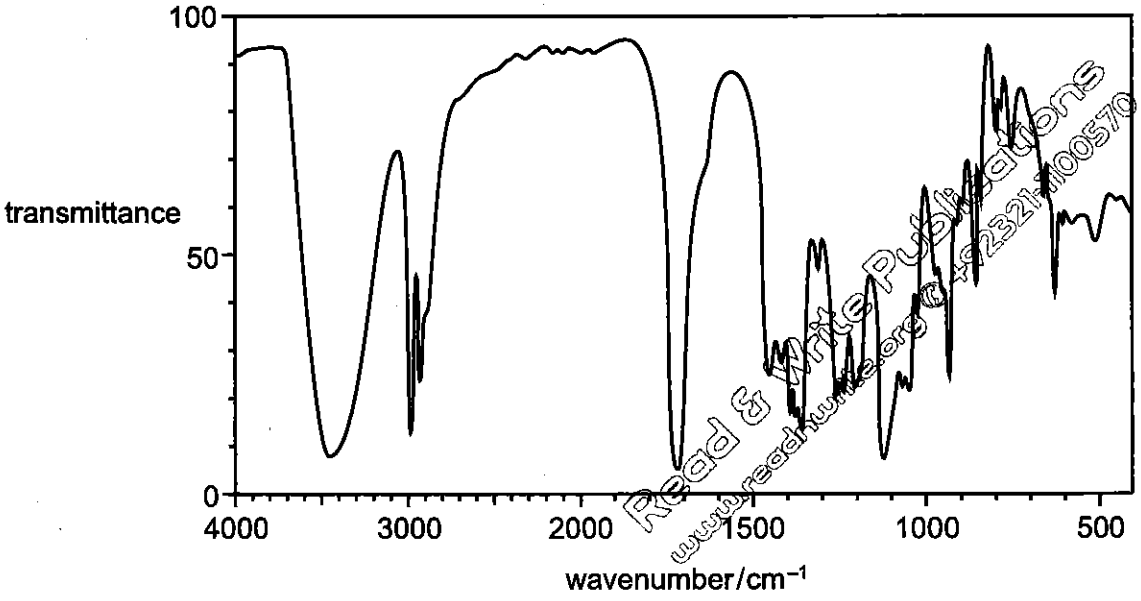
..... **[1]**

(b) Identify the reagents and conditions necessary for the conversion of acetoin into diacetyl.

.....

..... **[2]**

(c) The infra-red spectrum for acetoin is shown.



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(i) Explain the main features of this spectrum, with reference to the peaks with wavenumbers greater than 1500 cm^{-1}.

.....

.....

.....

.....

..... [3]

(ii) State and explain how the infra-red spectrum for diacetyl would differ from the infra-red spectrum for acetoin.

.....

.....

..... [2]

(d) If a sample of acetoin is reacted with concentrated sulfuric acid, a single product is formed that does not exhibit stereoisomerism.

However, if a sample of acetoin is reacted with HBr, a mixture of a pair of stereoisomers is produced.

(i) Give the structural formula of the product of the reaction of acetoin with concentrated sulfuric acid.

..... [1]

(ii) Explain why the product in (i) does not exhibit stereoisomerism.

.....

.....

..... [2]

(iii) Explain why the product of reaction of acetoin with HBr does exhibit stereoisomerism.

.....

.....

..... [1]

(iv) Draw the two stereoisomers from (iii) using the conventional representation.

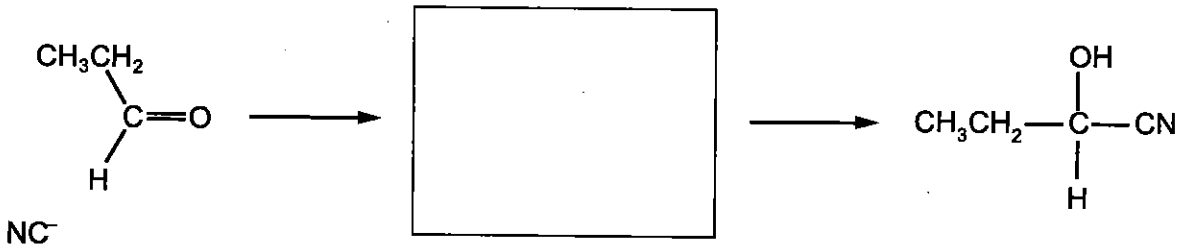
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[2]

[14]

4. M/J 16/P22/Q5/c

(a) (i) Complete the reaction mechanism for reaction 5. Include all relevant lone pairs, curly arrows, charges and partial charges.



[4]

The product of reaction 5 exhibits stereoisomerism.

(ii) Draw the two stereoisomers in the conventional way.

[2]

(iii) Suggest why a mixture of the two stereoisomers is formed by reaction 5.

.....

.....

..... **[2]**

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5. M/J 15/P23/Q3

A, B, C, D, E and F are all structural isomers with the molecular formula C_4H_8O.

(a) A, B and C all give an orange precipitate when treated with 2,4-DNPH but only A and B give a brick-red precipitate when warmed with Fehling's solution.

(i) Draw the skeletal formulae of A, B and C.

A	B	C

[3]

(ii) Name the type of structural isomerism shown by A and B.

..... **[1]**

(iii) State what you would see when a sample of A is warmed with Tollens' reagent.

..... **[1]**

(b) D, E and F all decolourise bromine and effervesce slowly with sodium metal.

E shows geometrical isomerism. Only D has a branched chain.

None of these isomers contains an oxygen atom bonded to a carbon atom involved in π bonding.

None of these isomers contains a chiral centre.

(i) Give the structures of D, E and F. Show the two stereoisomers of E and label the stereoisomerism shown.

D		
E		E
F		

[5]

(ii) Identify the gas produced during the reaction of each of these isomers with sodium metal.

..... [1]

(c) Another compound, G, C_3H_6O, contains the same functional group as A.
Give equations for the reactions of G with each of acidifi ed potassium dichromate(VI) and sodium tetrahydridoborate, $NaBH_4$, using [O] or [H] as appropriate.

(i) reaction with acidifi ed potassium dichromate(VI)

C_3H_6O + ... → ..... [1]

(ii) reaction with $NaBH_4$

C_3H_6O + ... → ..... [1]

[13]

6. M/J 15/P22/Q4

There are seven structural isomers with the molecular formula $C_5H_{10}O$ that are carbonyl compounds. Four of these are aldehydes.

These four aldehydes, A, B, C and D, have the following properties.

Aldehyde A has a straight chain while B, C and D are branched.

Aldehyde B is the only one of the four isomers with a chiral centre and it exists as a pair of optical isomers.

Aldehyde C has two methyl groups in its structure but D has three.

(a) (i) Give the structure of each of the four isomers.

A

B

C

D

[4]

(ii) Draw the three-dimensional structures of the two optical isomers of B.

[2]

(b) (i) Describe a chemical test that would allow you to distinguish between any of the four isomers A to D and any of the other three structural isomers of $C_5H_{10}O$, that are carbonyl compounds.

In your answer you should describe any necessary reagents and conditions as well as explaining what you would see in each case.

.....

.....

.....

.....

..... **[3]**

(ii) Describe a test that would give the same result with all seven carbonyl isomers of $C_5H_{10}O$.

.....

.....

..... **[2]**

[11]

7. M/J 15/P21/Q3

Ethanal reacts with hydrogen cyanide, in the presence of a small amount of NaCN, as shown.

$$CH_3CHO + HCN \rightarrow CH_3CH(OH)CN$$

(a) Use bond energies from the Data Booklet to calculate the enthalpy change for this reaction. Include a sign with your answer.

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enthalpy change = ... kJ mol^{-1} **[3]**

(b) The product of this reaction shows stereoisomerism as it contains a chiral centre. This reaction produces an equimolar mixture of two optical isomers.

(i) Explain the meanings of the terms stereoisomerism and chiral centre.

stereoisomerism .....

.....

.....

chiral centre .....

.....

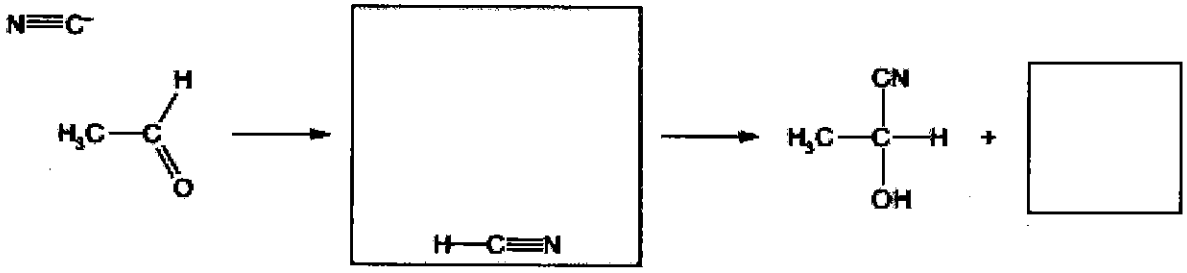
[2]

(ii) Suggest why the two optical isomers are produced in equal amounts by this reaction.

.....

..... **[1]**

(c) (i) Complete the diagram to show the mechanism of this reaction. Include all necessary charges, partial charges, lone pairs and curly arrows and show the structure of the intermediate.



[5]

(ii) With reference to your mechanism in (i), explain the role of the NaCN in this reaction.

.....

..... **[1]**

[12]

8. M/J 13/P23/Q4

Compound Q, heptan-2-one, is found in some blue cheeses.

$CH_3(CH_2)_4COCH_3$

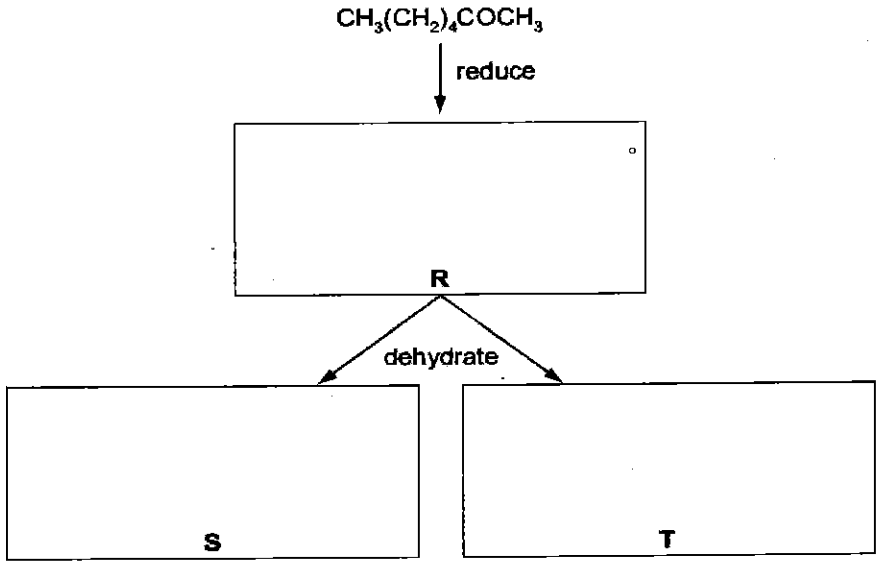
compound Q

(a) Compound Q may be reduced to R.

Compound R may be dehydrated to give two different products, S and T.

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(i) In the boxes below, draw the structural formulae of R, S, and T.



(ii) State the reagents that would be used for each of these reactions in a school or college laboratory.

reduction .....

dehydration .....

[5]

(b) In the boxes below, write the structural formula of the organic compound formed when Q is reacted separately with each reagent under suitable conditions.
If you think no reaction occurs, write 'NO REACTION' in the box.

Tollens' reagent	
HCN	
$K_2Cr_2O_7 / H^+$	

[3]

(c) The first stage of cheese making is to produce 2-hydroxypropanoic acid (lactic acid) from milk.

$CH_3CH(OH)CO_2H$
lactic acid

Other than the use of a pH indicator, what reagent could you use to confi rm the presence of some lactic acid in a sample of heptan-2-one?
State what observation you would make.

reagent .....

observation ..... [2]

[10]

9. M/J 13/P22/Q4/d,e

(a) Crotyl alcohol is obtained from crotonaldehyde, $CH_3CH=CHCHO$.

(i) Describe one test that would confi rm the presence of a small amount of unreacted crotonaldehyde in the crotyl alcohol.

Give the name of the reagent used and state what you would see.

reagent .....

observation .....

(ii) What type of reaction is the conversion of crotonaldehyde into crotyl alcohol?

.....

[3]

(b) Compound P, another unsaturated compound, is found in some blue cheeses.
The percentage composition by mass of compound P is C: 73.7%; H: 12.3%; O: 14.0%.
Calculate the empirical formula of compound P.

[2]

[13]

10. M/J 13/P22/Q5/c,d,e

A sample of Q was hydrolysed by heating with aqueous sulfuric acid.

The resulting mixture was heated under refl ux with acidifi ed potassium dichromate(VI) to give a single organic product, R.

The product, R, was collected and subjected to the following tests.

A sample of R gave no reaction with Tollens' reagent.

A second sample of R gave no reaction with 2,4-dinitrophenylhydrazine reagent.

A third sample of R gave an effervescence with sodium carbonate.

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(a) (i) What does the result of the test with Tollens' reagent show about R?

.....

(ii) What does the result of the test with 2,4-dinitrophenylhydrazine reagent show about R?

.....

(iii) What functional group does the result of the test with sodium carbonate show to be present in R?

.....

[3]

(b) (i) What is the identity of the single organic compound, R?

.....

(ii) Which of your structures, W, X, Y or Z, represents the ester, Q?

.....

[2]

(c) Which, if any, of your esters, W, X, Y or Z, is chiral?

.....

..... **[1]**

11. M/J 13/P21/Q5

Crotonaldehyde, $CH_3CH=CHCHO$, occurs in soybean oils.

(a) In the boxes below, write the structural formula of the organic compound formed when crotonaldehyde is reacted separately with each reagent under suitable conditions.

If you think no reaction occurs, write 'NO REACTION' in the box.

reaction	reagent	product
A	Br_2 in an inert organic solvent	
B	PCl_3	
C	H_2 and Ni catalyst	
D	$NaBH_4$	
E	$K_2Cr_2O_7/H^+$	

[5]

(b) Crotonaldehyde exists in more than one stereoisomeric form.
Draw the displayed formulae of the stereoisomers of crotonaldehyde.
Label each isomer.

[3]

(c) Draw the skeletal formula of crotonaldehyde.

[1]

(d) The product of reaction E in the table opposite will react with a solution containing acidifi ed manganate(VII) ions.
Draw the structural formulae of the organic products when the reagent is

(i) cold, dilute;

(ii) hot, concentrated.

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[3]

[12]

12. O/N 12/P23/Q5

The molecular formula C_4H_8O can represent a number of compounds which have different functional groups and which show different types of isomerism.

Compounds H, J and K each have the molecular formula C_4H_8O.

In each of the molecules of H, J and K,

- the carbon chain is unbranched and the molecule is not cyclic,
- no oxygen atom is attached to any carbon atom which is involved in π bonding.

When compound H is reacted with sodium metal, a colourless fl ammable gas is produced. Both J and K give an orange-red precipitate when reacted with 2,4-dinitrophenylhydrazine reagent but only K reacts with Fehling 's solution.

(a) (i) Suggest possible structural formulae for H, J and K.

Three structural formulae are possible for H but only one for J and one for K.

H	J	K

In addition to being structural isomers of each other, some of the possible structures forH, J or K show cis-trans isomerism or are chiral.

(ii) Draw the displayed formulae of those isomers which show cis-trans isomerism.

(iii) Draw the displayed formulae of those isomers which are chiral, indicating in each case the chiral carbon atom with an asterisk (*).

[8]

[8]

13. O/N 12/P21/Q5/b

(a) The molecule of X has the following features.

- The carbon chain is unbranched and the molecule is not cyclic.
- No oxygen atom is attached to any carbon atom which is involved in π bonding. No
- carbon atom has more than one oxygen atom joined to it.

There are five possible isomers of X which fit these data. Four of these isomers exist as two pairs of stereoisomers.

(i) Draw displayed formulae of each of these two pairs.

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pair 1		
pair 2		

(ii) These four isomers of X show two types of stereoisomerism.
State which type of isomerism each pair shows.

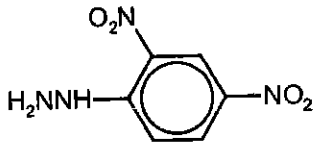
pair 1 .....

pair 2 .....

[6]

14. O/N 12/P22/Q4/b

(a) Some oxygen-containing compounds react with 2,4-dinitrophenylhydrazine.



2,4-dinitrophenylhydrazine

(i) Draw the structural formula of the organic compound formed when $HOCH_2CH_2CHO$ reacts with 2,4-dinitrophenylhydrazine reagent.

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(ii) Suggest the colour of the organic product.

.....

[2]

15. O/N 12/P22/Q5/a

(a) Compound X has the molecular formula $C_4H_8O_2$.

(i) Treatment of X with sodium metal produces a colourless flammable gas.
What does this result tell you about the functional groups that could be present in X?

.....

.....

(ii) There is no reaction when X is treated with sodium hydrogencarbonate, $NaHCO_3$.
What does this result tell you about the functional groups that could be present in X?

.....

.....

(iii) When X is shaken with aqueous bromine the orange colour disappears.
What does this result tell you about the functional groups that could be present in X?

.....

.....

[3]

16. M/J 12/P22/Q4/c,d

(a) Treatment of G with 2,4-dinitrophenylhydrazine reagent produces an orange solid.
When G is warmed with Fehling's reagent, no reaction occurs.

(i) What functional group do these reactions show to be present in G?
Draw the displayed formula of this functional group.

(ii) Use your answers to (b)(i) and (c)(i) to deduce the structural formula of G.

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[2]

(b) Compound G can be both oxidised and reduced.

(i) When G is heated under reflux with acidified $K_2Cr_2O_7$, compound H is formed. Give the structural formula of compound H.

(ii) When G is reacted with $NaBH_4$ under suitable conditions, compound J is formed. Give the structural formula of compound J.

[2]

17. M/J 12/P21/Q5

Organic compounds which contain oxygen may contain alcohol, aldehyde, carboxylic acid, ester or ketone functional groups. The functional groups may be identifi ed by their reactions with specifi c reagents.

Compound X has the empirical formula CH_2O and Mr of 90.

(a) There is no reaction when X is treated with $NaHCO_3$.
What functional group does this test show to be not present in X?

..... **[1]**

(b) When 0.600 g of X is reacted with an excess of Na, 160 cm^3 of H_2, measured at room temperature and pressure, is produced.

(i) What functional group does this reaction show to be present in X?

.....

(ii) Use the data to calculate the amount, in moles, of hydrogen atoms produced from 0.600 g of X.

(iii) Hence, show that each molecule of X contains two of the functional groups you have given in (i).

[4]

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(c) When X is warmed with Fehling's reagent, a brick red precipitate is formed.
Treatment of X with 2,4-dinitrophenylhydrazine reagent produces an orange solid.

(i) What functional group do these reactions show to be present in X?
Draw the displayed formula of this functional group.

(ii) Use your answers to (b)(i), (b)(ii) and (c)(i) to deduce the structural formula of X.

(iii) What is the structural formula of the organic product of the reaction of X with Fehling's reagent?

[3]

(d) Compound X can be both oxidised and reduced.

(i) Give the structural formula of the compound formed when X is reacted with $NaBH_4$ under suitable conditions.

(ii) Give the structural formula of the compound formed when X is heated under reflux with acidifi ed $K_2Cr_2O_7$.

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[2]

[10]

18. O/N 11/P22/Q5/a,c

Astronomers using modern telescopes of various types have found many molecules in the dust clouds in space. Many of these molecules are those of organic compounds and astronomers constantly look for evidence that amino acids such as aminoethanoic acid, $H_2NCH_2CO_2H$, are present.

One molecule that has been found in the dust clouds is hydroxyethanal, $HOCH_2CHO$.

(a) Hydroxyethanal contains two functional groups.

(i) Name, as fully as you can, each of the functional groups present in hydroxyethanal.

1 .....

2 .....

(ii) For each functional group, identify a reagent that will react with this group and not react with the other functional group present.
In each case, describe what would be observed when this reaction is carried out.

functional group 1 reagent .....

observation.....

functional group 2 reagent .....

observation..... **[7]**

In a school or college laboratory, it is possible to convert a sample of hydroxyethanal into aminoethanoic acid in a three-step process.

$$HOCH_2CHO \xrightarrow{\text{step 1}} X \xrightarrow{\text{step 2}} Y \xrightarrow{\text{step 3}} H_2NCH_2CO_2H$$

By considering the possible reactions of the functional groups present in hydroxyethanal, you are to deduce a possible route for this conversion.

(b) (i) In the boxes below, draw the structural formulae of your suggested intermediates X and Y.

X	Y

(ii) State the reagents for each of the three steps you have chosen.

step 1.....

step 2.....

step 3.....

[5]

19. M/J 11/P21/Q4

Ketones are widely used as solvents and as intermediates in the chemical industry.

Ketones contain the reactive keto group, $\diagdown\!\!\diagup C{=}O$.

(a) Propanone, CH_3COCH_3, undergoes a reaction with hydrogen cyanide, HCN.

(i) What type of reaction is this?

.....

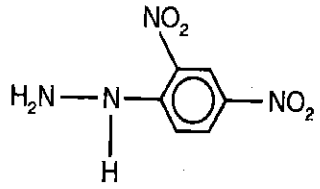
(ii) What reagents are used?

.....

(iii) Draw a diagram to show the dipole present in the propanone molecule.

[3]

(b) Propanone reacts with 2,4-dinitrophenylhydrazine reagent.

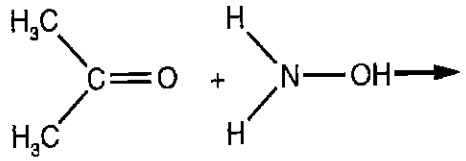


2,4-dinitrophenylhydrazine

(i) Construct a balanced equation for the reaction between propanone and 2,4-dinitrophenylhydrazine.

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(ii) A similar type of reaction occurs between propanone and hydroxylamine, NH_2OH. Draw the displayed formula of the organic product of this reaction.



[3]

[6]

20. O/N 10/P23/Q3

Astronomers using modern spectroscopic techniques of various types have found evidence of many molecules, ions and free radicals in the dust clouds in Space. Many of the species concerned have also been produced in laboratories on Earth.

Two such species are the dicarbon monoxide molecule, C_2O, and the amino free radical, NH_2.

(a) (i) Dicarbon monoxide can be produced in a laboratory and analysis of it shows that the sequence of atoms in this molecule is carbon-carbon-oxygen and there are no unpaired electrons, but one of the atoms is only surrounded by six electrons. Draw a 'dot-and-cross' diagram of C_2O and suggest the shape of the molecule.

shape .....

(ii) What is meant by the term free radical ?

.....

.....

(iii) Explain why NH_2 is described as a 'free radical' .

.....

..... **[5]**

Two derivatives of ethene which have been detected in dust clouds in space are acrylonitrile (2-propenenitrile), CH_2=CHCN, and vinyl alcohol (ethenol), CH_2=CHOH.

(b) Like ethene, acrylonitrile can be polymerised. The resulting polymer can be used to make carbon fibres.

(i) Draw the structural formula of the polymer made from acrylonitrile, showing two repeat units.

(ii) What type of polymerisation is this reaction?

..... **[2]**

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Vinyl alcohol cannot be polymerised in the same way as acrylonitrile because it will readily isomerise into another common organic compound, Z.

(c) (i) Suggest the structural formula of the organic compound Z.

(ii) Suggest the structural formula of another isomer of vinyl alcohol which has a cyclic (ring) structure.

[2]

Acrolein (2-propenal), CH_2=CHCHO, has also been found in Space.

(d) Give the structural formulae of the organic compounds formed when acrolein is reacted separately with each of the following reagents.

reagent	product
Br_2 in an inert solvent	
NaCN + dilute H_2SO_4	
Tollens' reagent	
$NaBH_4$	

[4]

[13]

21. M/J 10/P22/Q4/e

(a) On mild oxidation, the alcohol G gives a compound H which forms a silver mirror with Tollens' reagent.

(i) What functional group does the reaction with Tollens' reagent show to be present in compound H? Give the name of this group.

.....

(ii) What type of alcohol is G?

.....

(iii) What could be the structural formula of the alcohol G?

[3]

22. O/N 09/P21/Q5

Three organic compounds, **G**, **H**, and **J**, each have the empirical formula CH_2O.
The numbers of carbon atoms in their molecules are shown in the table.

compound	number of C atoms
G	1
H	2
J	3

In H and in **J**, the carbon atoms are bonded directly to one another.
G gives a silver mirror when treated with Tollens' reagent.
H and **J** each give a brisk effervescence with $Na_2CO_3(aq)$.

(a) Identify **G**.

..... **[1]**

(b) (i) What functional group is common to both **H** and **J**?

.....

(ii) Identify **H**.

.....

(iii) Identify **J**.

..... **[3]**

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(c) When **J** is heated under reflux with acidified $K_2Cr_2O_7$, the product, **K**, gives a red-orange precipitate with 2,4-dinitrophenylhydrazine reagent.
Draw the structural formula of **K**, the compound formed from **J**.

[1]

(d) When **J** is warmed with concentrated sulfuric acid, a cyclic compound, **L**, is formed.
L has the molecular formula $C_6H_8O_4$.

(i) Suggest a displayed formula for **L**.

(ii) What type of reaction occurs when **L** is formed from **J**?

..... **[2]**

[7]

23. M/J 09/P22/Q5

Ethanal, CH_3CHO, can be converted into compound U by the following sequence.

$$2\,CH_3CHO \xrightarrow{\text{step I}} \underset{\mathbf{T}}{C_4H_8O_2} \xrightarrow{\text{step II}} \underset{\mathbf{U},\ C_4H_6O}{CH_3CH{=}CHCHO}$$

(a) When T is formed in step I, no other compound is produced.
Suggest a structural formula for T which contains one –OH group in its molecule.

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[1]

(b) Compound **U** has two functional groups.

You are to name one functional group present in **U** and show how you would identify it. Put your answers in the table.

functional group in U	reagent used in test	what would be seen

[3]

(c) **U** is formed from **T** in step II.

Use your answers to (**a**) and (**b**) to suggest

(i) what type of reaction occurs in step II,

.....

(ii) a reagent for step II.

..... **[2]**

(d) Compound **U** can be converted into $CH_3CH=CHCH_2OH$.

What reagent(s) and solvent are normally used in a laboratory to reduce a >C=O group without reducing a >C=C< group present in the same molecule?

reagent(s) .....

solvent ..... **[2]**

U has three structural isomers.

(e) Draw the displayed formulae of **two** structural isomers of **U** that each contain the same functional groups as **U**.

[2]

(f) When a mixture of ethanal and propanal is reacted under the same conditions as in step I above, a similar reaction occurs with the formation of compound S, $C_5H_{10}O_2$.

$$CH_3CHO + CH_3CH_2CHO \rightarrow C_5H_{10}O_2$$

Suggest a structural formula for S.

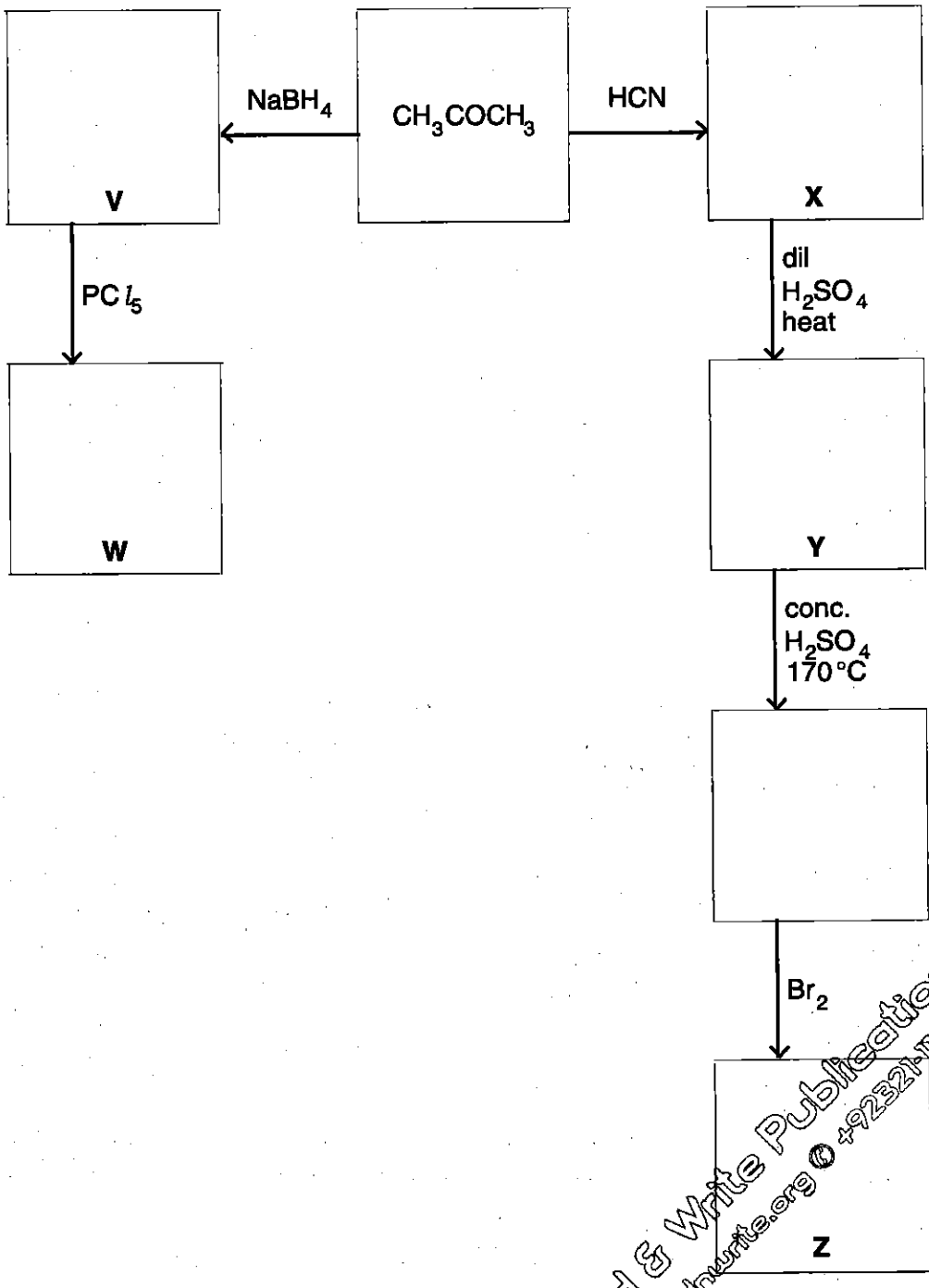
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[1]

[11]

24. M/J 09/P22/Q4

(a) Complete the following reaction scheme which starts with propanone.
In each empty box, write the structural formula of the organic compound that would be formed.



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[6]

(b) One of the compounds V, W, X, Y or Z is chiral.

(i) Identify this compound by its letter.

.....

(ii) Draw displayed formulae of the two optical isomers of this compound. Indicate with an asterisk (*) the chiral carbon atom.

[3]

(c) Write the structural formula for the organic compound formed when, under suitable conditions,

(i) compound Y reacts with compound V,

(ii) compound Y reacts with compound Z.

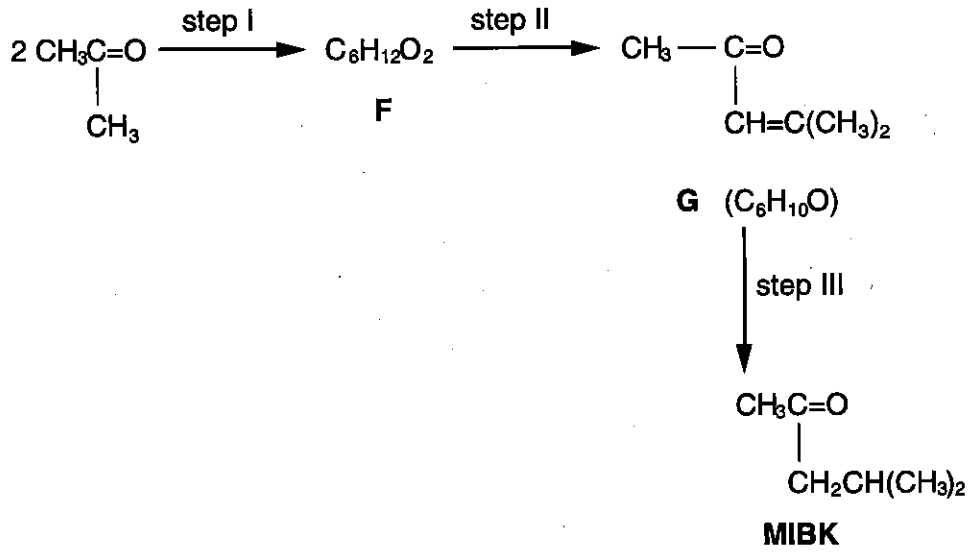
[2]

[11]

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25. M/J 09/P21/Q5

Propanone, CH_3COCH_3, an important industrial solvent, can be converted into another industrially important solvent, MIBK, by the following sequence.



(a) When F is formed in step I no other compound is produced.
Suggest a structural formula for F, which contains one – OH group.

[1]

(b) Compound G has two functional groups.
Name one functional group present in G and show how you would identify it. Put your answers in the table.

functional group in **G**	reagent used in test	what would be seen

[3]

(c) G is formed from F in step II.
Use your answers to (a) and (b) to suggest

(i) what type of reaction occurs in step II,

.....

(ii) a reagent for step II.

..... **[2]**

(d) The production of MIBK from G in step III involves the hydrogenation of the >C=C< group and is carried out catalytically. A mixture of compounds is formed because the >C=O group is also reduced.

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What reagent(s) and solvent are normally used in a laboratory to reduce a >C=O group without reducing a >C=C< group present in the same molecule?

reagent(s) .....

solvent ..... **[2]**

G has a number of structural isomers.

(e) Draw the displayed formulae of a pair of structural isomers of G which contain the CH_3CO- group and which exhibit cis-trans isomerism.

Label each structure cis or trans and give your reasoning.

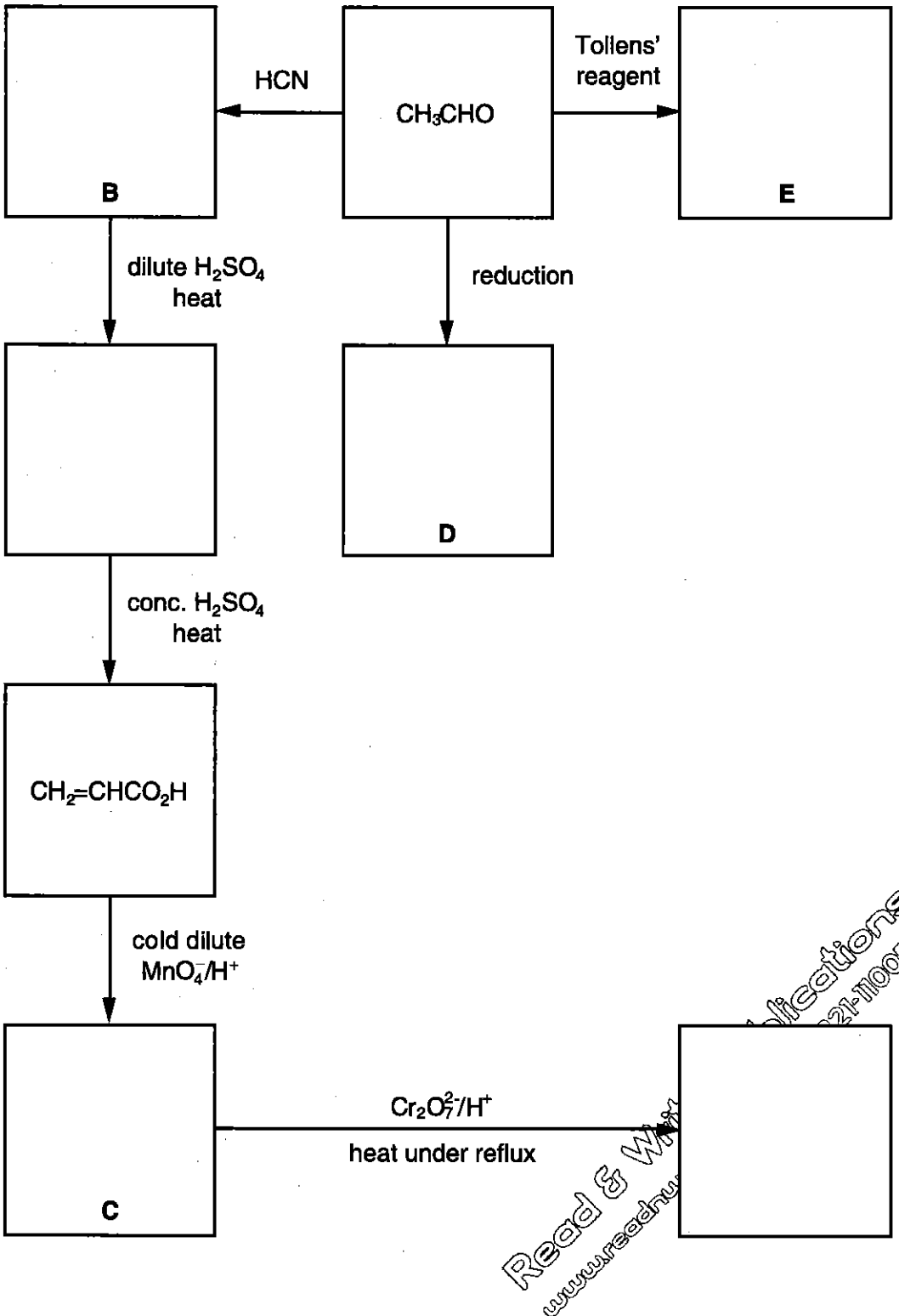
[3]

[11]

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26. M/J 09/P21/Q4

(a) Complete the following reaction scheme which starts with ethanal.
In each empty box, write the structural formula of the organic compound that would be formed.



[6]

(b) Write the structural formula for the organic compound formed when, under suitable conditions,

(i) compound **C** reacts with compound **D**,

(ii) compound **C** reacts with compound **E**.

[2]

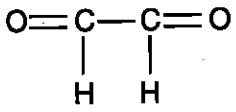
(c) Compound **B** is chiral. Draw displayed formulae of the two optical isomers of compound **B**, indicating with an asterisk (*) the chiral carbon atom.

[3]

[11]

27. M/J 08/P2/Q5

Ethanedial (glyoxal) is used in the production of fabrics which have permanent creases.



ethanedial

Ethanedial undergoes many of the reactions of aldehydes.

(a) Ethanedial reacts with Tollens' reagent.

(i) What would you see if you carried out this reaction?

.....

(ii) What is the structural formula of the organic compound formed?

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[2]

(b) Ethanedial reacts with hydrogen cyanide, HCN, to give compound **F**.

(i) What is the structural formula of **F**?

(ii) What type of reaction is this?

.....

(iii) What is the structural formula of the compound formed when **F** is heated with an aqueous mineral acid such as dilute sulphuric acid?

[3]

(c) Ethanedial can be oxidised and reduced.

(i) What is the structural formula of the organic compound formed when ethanedial is heated under reflux with an excess of acidified potassium dichromate(VI)?

(ii) What is the structural formula of the compound formed when ethanedial is reduced?

(iii) What reagent would be used for this reduction?

.....

[3]

(d) When ethanedial is reacted with NaOH and the product treated with a mineral acid such as dilute sulphuric acid, the following reaction sequence takes place.

I $CHOCHO + NaOH \rightarrow HOCH_2CO_2Na$

II $HOCH_2CO_2Na + H^+ \rightarrow HOCH_2CO_2H + Na^+$

What type of reaction is the overall change?

..... **[1]**

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(e) An isomer of ethanedial exists which reacts with sodium metal to give hydrogen.

Suggest the displayed formula of this isomer.

[2]

[11]

28. O/N 05/P2/Q5

Compound **Z**, an organic compound with **three** functional groups, has the molecular formula $C_4H_6O_2$. The functional groups can be confirmed by the following tests.

(a) Test for the first functional group.

Z decolourises aqueous bromine.

What functional group is shown to be present in **Z** by this test?

..... [1]

(b) Tests for the second functional group.

Z reacts with sodium to give hydrogen and a solid compound of formula $C_4H_5O_2Na$.

When **Z** is heated with ethanoic acid and a few drops of concentrated sulphuric acid, a sweet smelling liquid of molecular formula $C_6H_8O_3$ is formed.

What functional group is shown to be present in **Z** by these tests?

..... [1]

(c) Tests for the third functional group.

A few drops of **Z** form a yellow/orange precipitate when added to 2,4-dinitrophenylhydrazine reagent.

When a few drops of **Z** are warmed with Tollens' reagent, a silver mirror is formed.

What functional group is shown to be present in **Z** by these tests?

..... [1]

(d) Z does **not** show *cis-trans* isomerism.

Draw the displayed formula of **Z**.

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[2]

In parts **(e)** and **(f)** you may use R– to represent the part of the molecule that does not react.

(e) What is the organic compound formed by the reactions of **Z** in **each** of the tests in **(b)**?

with sodium

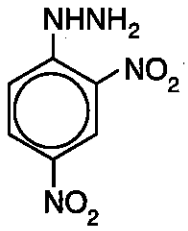
with ethanoic acid

[2]

(f) Draw the structure of the organic compound formed by **Z** in **each** of the tests in **(c)**.

with Tollens' reagent

with 2,4-dinitrophenylhydrazine,



[2]

(g) But-2-enoic acid is an isomer of **Z** which shows *cis-trans* isomerism.

Draw a displayed formula of the *cis* isomer of this acid.

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[2]

[11]

29. M/J 05/P2/Q5

A student obtained the following results when analysing an organic compound, **H**.

test		observation
test 1	relative molecular mass	72
test 2	% composition by mass	C, 66.7%; H, 11.1%; O, 22.2%
test 3	reactions with $Br_2(aq)$	Br_2 decolourised
test 4	reaction with Na(s)	$H_2(g)$ evolved
test 5	reaction with warm $Cr_2O_7^{2-}/H^+$	green colour observed

The student allowed test 5 to go to completion and then investigated the **product** of test 5 with the following result.

test 6	reaction with 2,4-dinitrophenylhydrazine	no reaction

(a) Calculate the molecular formula of **H**.

[2]

(b) What can be deduced about the nature of **H** by the following tests?

(i) test 3 .....

(ii) test 4 .....

[2]

(c) (i) What functional group would have given a positive result in test 6?

.....

(ii) What functional group is shown to be present in **H** by tests 5 and 6?

.....

[2]

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(d) On testing a sample of **H**, the student found that it was not chiral.

H did, however, show *cis-trans* isomerism.

How does *cis-trans* isomerism arise in an organic molecule?

.....

.....

.....[2]

(e) Use all of the information above to draw labelled, displayed formulae of the stereoisomers of compound **H**.

[2]
[10]

30. O/N 04/P2/Q5

2-Hydroxypropanoic acid (lactic acid), $CH_3CH(OH)CO_2H$, can be prepared in a two-stage synthesis from ethanal, CH_3CHO.

(a) In the first stage, ethanal reacts with hydrogen cyanide, HCN, in the presence of an NaCN catalyst to produce a cyanohydrin.

(i) Write an equation for the reaction of ethanal and HCN, giving the displayed formula of the product.

(ii) State what type of reaction this is.

.....

(iii) Describe the mechanism of this reaction.

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[5]

(b) In the second stage, the product from **(a)** is converted into lactic acid.

(i) Write the equation for this stage.

.....

(ii) State what type of reaction this is.

.....[2]

(c) In this synthesis 4.40 g of ethanal were used and at the end 5.40 g of lactic acid were obtained.

Calculate the percentage yield of lactic acid.

[3]
[10]

31. M/J 03/P2/Q6

A compound, **A**, has the following composition by mass.

C, 66.7%; H, 11.1%; O, 22.2%.

It has an M_r of 72.

(a) Calculate the molecular formula of **A**.

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[2]

(b) **A** reacts with 2,4-dinitrophenylhydrazine but not with Fehling's or Tollens' reagents.

(i) State what you would see when **A** reacts with the 2,4-dinitrophenylhydrazine reagent.

.....

(ii) State what functional group is present in **A**. .....

(iii) Identify **A** either by name or by its structural formula.

..... **[3]**

(c) **A** can be reduced to compound **B**.

For this reaction

(i) state a suitable reducing agent, ...

(II) name the functional group in **B** (two words are required),

.....

(iii) give the structural formula of **B**.

[3]

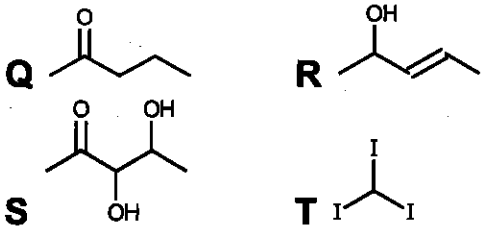
[8]

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Answers Section

1. MAR 16/P22/Q5

(a) (i)

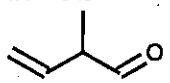


[1] [1] [1] [1] [4]

(ii) pent-3-en(e)-2-one [1]
OR [1]
3-penten-2-one

(iii) red / orange / yellow precipitate / solid [1] [1]

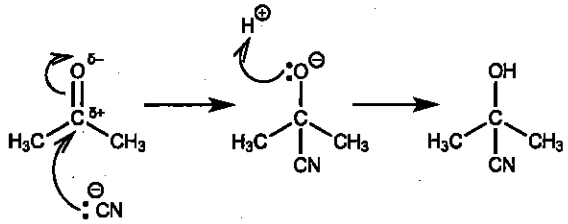
(b) *This question was discounted.*
M1 = decolourises bromine / 1500–1600 cm^{-1} = alkene [1]
M2 = absorption at 1700 cm^{-1} is C=O
AND
(very) broad absorption at 2500–3000 cm^{-1} is O—H = carboxylic acid [1]
M3 = no cis-trans so terminal alkene [4]
OR
chiral so contains a carbon atom with 4 different groups attached [1]
M4 = **U** is



2. MAR 16/P22/Q3/d

(d) (i) nucleophilic addition [1] [1]

(ii)



[5]

correct dipole on carbonyl [1]
curly arrow from lone pair on CN^- AND from C=O to O [1]
correct intermediate [1]
curly arrow from lone pair on O^- to H^+ [1]
correct product [1]

3. M/J 16/P23/Q4

(a) 3-hydroxybutan(-2-)one [1] [1]

(b) H_2 / $Cr_2O_7^{2-}$ or names [1] [2]
heat / reflux / warm [1]

(c) (i) absorption at 1670–1740 C (=) O [1] [3]
absorption at 2850–3000 C (-) H [1]
absorption at 3200–3650 O (-) H [1]

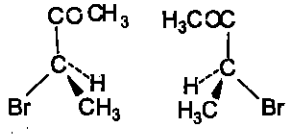
(ii) no absorption at 3200–3650 [1] [2]
O-H disappears / no O-H bond in diacetyl [1]

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(d) **(i)** $CH_3COCH(=)CH_2$ [1] [1]

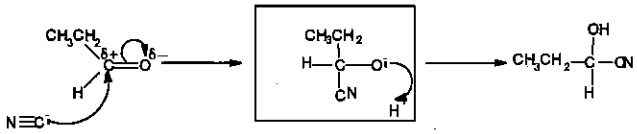
(ii) one of the double-bonded C atoms/ first C has 2H atoms attached **ora** [1] [2]
so no cis-trans /*E-Z*/ geometric(al) isomerism possible
OR
no chiral C [1]
so mirror images superimposable /molecule not asymmetric

(iii) asymmetric/ chiral C atom / carbon with four different groups /atoms attached [1] [1]

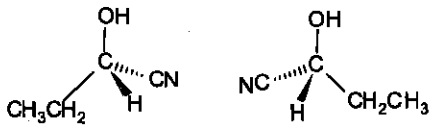
(iv)  [1+1] [2]

[14]

4. M/J 16/P22/Q5/c

(a) **(I)** 

M1 = lone pair on C of CN^- AND curly arrow from lone pair to carbonyl carbon [1]
M2 = dipole on C=O AND curly arrow to O from = [1]
M3 = intermediate with negative charge [1]
M4 = lone pair and curly arrow to H^+ [1] [4]

(ii)  [1+1]

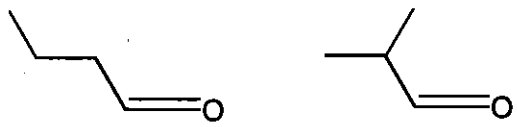
[2]

(iii) attack/attach from either side / above or below/ from two directions because the carbonyl/ molecule is planar/ trigonal /flat/ because of the shape of the molecule [1] [1]

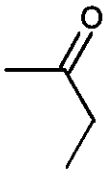
OR
product is chiral /has a chiral carbon/ has a carbon attached to four different groups /has a chiral centre/ is asymmetric
(equal) chance of forming either (of the two optical isomers)/ mechanism doesn't distinguish between the two (optical isomers)/ able to form either/chance of forming / able to form 50:50

OR
because the carbonyl /molecule is planar/trigonal /flat OR
because of the shape of the molecule (equal) chance of forming either (of the two optical isomers)/mechanism doesn't distinguish between the two (optical isomers)/ able to form either/chance of forming/ able to form 50:50 [2]

5. M/J 15/P23/Q3

(a) **(i)** **A/B** =  [1]

[1]

C = 

[1]

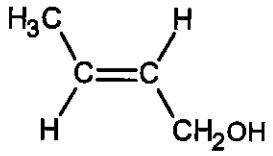
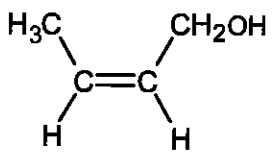
[3]

(ii) Chain [1] [1]

(iii) Silver mirror/ppt/solid (black/grey) [1] [1]

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(b) (i)

D $CH_2=C(CH_3)CH_2OH$		[1]
E  trans **OR** *E*	**E**  cis **OR** *Z*	[1+1] [1] [1]
F $H_2C=CHCH_2CH_2OH$		

[5]

(ii) Hydrogen [1] **[1]**

(c) (i) $C_3H_6O + [O] \rightarrow C_3H_6O_2$ [1] **[1]**

(ii) $C_3H_6O + 2[H] \rightarrow C_3H_8O$ [1] **[1]**

[13]

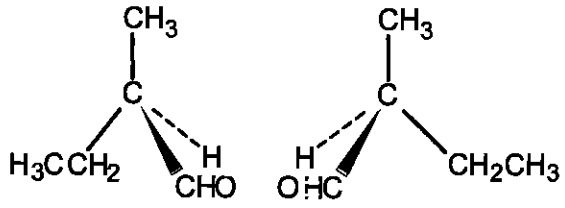
6. M/J 15/P22/Q4

(a) (i) **A** = $CH_3CH_2CH_2CH_2CHO$ [1]

B = $CH_3CH_2CH(CH_3)CHO$ [1]

C = $(CH_3)_2CHCH_2CHO$ [1]

D = $(CH_3)_3CCHO$ [1] **[4]**

(ii)  [1+1] **[2]**

(b) (i) Fehling's / Benedict's **OR** Tollens' **OR** dichromate **OR** manganate [1]
Warm / heat [1]
Fehling's / Benedict's = (Brick)-red ppt
Tollens' = silver / mirror **OR** grey/black precipitate
Dichromate = orange to green
Manganate = purple to colourless
with the aldehyde / A-D [1] **[3]**

(ii) (2,4-)DNP(H) / Brady's reagent [1]
Orange / yellow / red-orange / yellow-orange ppt [1] **[2]**

[11]

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7. M/J 15/P21/Q3

(a) Bond breaking = C=O = 740
C–H = 410 = 1150 kJ [1]

Bond forming = C–C = 350
C–O = 360
O–H = 460 = 1170 kJ [1]

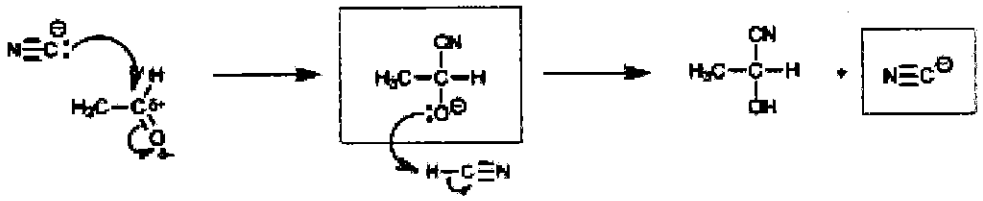
Enthalpy change = 1150 – 1170 = **–20** kJ mol^{-1} [1] **[3]**

(b) (i) Stereoisomerism = (molecules with the same molecular formula and) same structural formula but different spatial arrangements of atoms [1]

Chiral centre = atom with four different atoms/groups attached [1] **[2]**

(ii) (Planar) carbonyl so (equal chance of nucleophile) attacking either side [1] **[1]**

(c) (i)



M1 = lone pair **AND** curly arrow from lone pair to carbonyl C [1]

M2 = partial charges on C=O **AND** curly arrow from bond (=) to $O^{\delta-}$ [1]

M3 = structure of intermediate including charge [1]

M4 = lone pair **AND** two correct curly arrows (from lone pair to H **AND** from H—C to C) [1]

M5 = CN^- [1] **[5]**

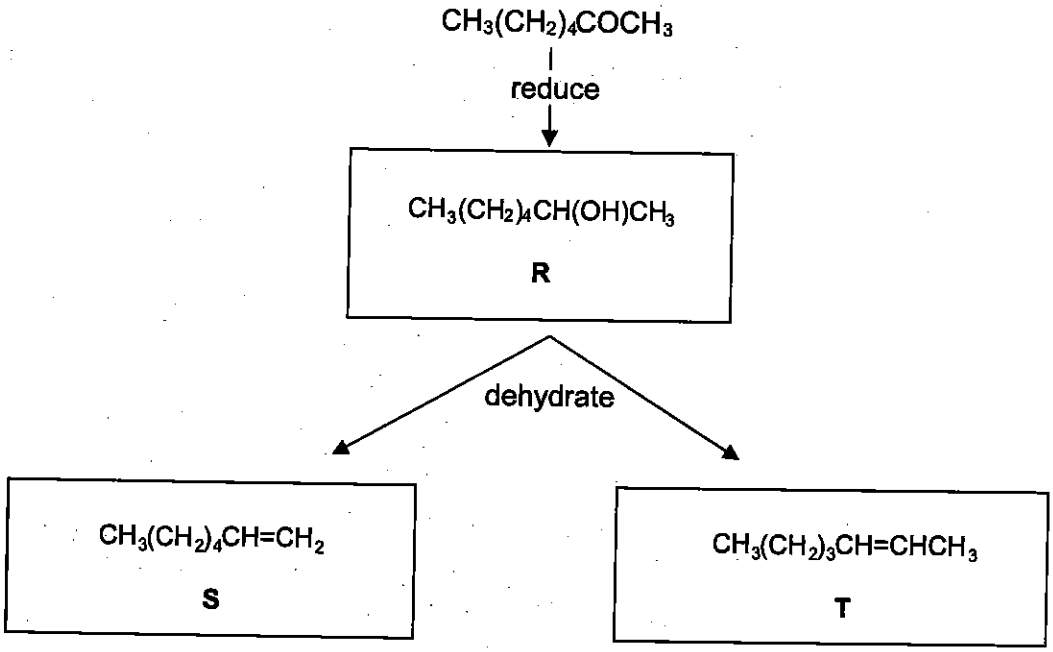
(ii) (CN^- regenerated so) catalyst [1] **[1]**

[12]

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8. M/J 13/P23/Q4

(a) (i)



one mark for each correct compound, **R**, **S** and **T**

allow correct *cis* **and** *trans* versions of compound **T** for 2 marks (3 × 1)

(ii) reduction

$NaBH_4$ **or** $LiAlH_4$ **or** H_2/Ni **or** Na/C_2H_5OH (1)

dehydration

P_4O_{10}/P_2O_5 **or** H_3PO_4 **or** conc. H_2SO_4 **or** Al_2O_3 (1) **[5]**

(b)

Tollens' reagent	NO REACTION
HCN	$CH_3(CH_2)_4C(OH)CH_3$ | CN
$K_2Cr_2O_7/H^+$	NO REACTION

one mark for each correct answer (3 × 1) **[3]**

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(c) Na_2CO_3 **or** $NaHCO_3$ effervescence/colourless gas
or
Na colourless gas
or
PCl_3/PCl_5 etc. steamy fumes
or
C_2H_5OH/conc. H_2SO_4 sweet smell of ester
or
$K_2Cr_2O_7/H^+$ orange solution becomes green

correct reagent (1)
correct observation (1) **[2]**

[10]

9. M/J 13/P22/Q4/d,e

(a) (i)

reagent	**observation**
2,4-dinitrophenylhydrazine	red/orange ppt.
Tollens' reagent	silver mirror **or** grey ppt. **or** black ppt.
Fehling's reagent	brick red ppt.

correct reagent (1)
observation (1)

(ii) reduction **or** nucleophilic addiction (1) **[3]**

(b) $C : H : O = \frac{73.7}{12} : \frac{12.3}{1} : \frac{14.0}{16}$

$= 6.14 : 12.3 : 0.875$ (1)
$= 7.01 : 14.1 : 1$

gives $C_7H_{14}O$
formula must be given (1) **[2]**

10. M/J 13/P22/Q5/c,d,e

(a) (i) —CHO **or** aldehyde absent (1)
(ii) >CO **or** carbonyl absent (1)
(iii) $—CO_2H$ **or** carboxylic acid present (1) **[3]**

(b) (i) CH_3CO_2H **or** ethanoic acid (1)
(ii) **Y** above (1) **[2]**

(c) none – no chiral carbon atoms present (1) **[1]**

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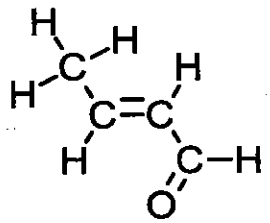
11. M/J 13/P21/Q5

(a)

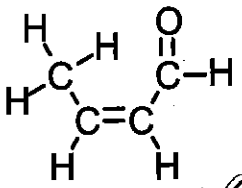
reaction	reagent	product
A	Br_2 in an inert organic solvent	$CH_3CHBrCHBrCHO$
B	PCl_3	NO REACTION
C	H_2 and Ni catalyst	$CH_3CH_2CH_2CH_2OH$
D	$NaBH_4$	$CH_3CH=CHCH_2OH$
E	$K_2Cr_2O_7/H^+$	$CH_3CH=CHCO_2H$

one mark for each correct answer **[5]**

(b)



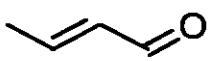
trans **or** E



cis **or** Z

two correct structures (1)
both correctly labelled (1)
correctly displayed -CHO group (1) **[3]**

(c)



(1) **[1]**

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(d) (i) $CH_3CH(OH)CH(OH)CO_2H$ (1)

(ii) CH_3CO_2H (1)
HO_2CCO_2H (1) **[3]**

allow ecf on candidate's answer to E in **(a)** **[12]**

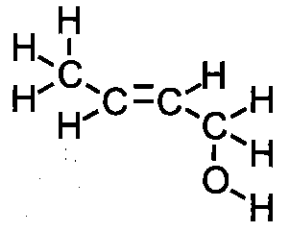
12. O/N 12/P23/Q5

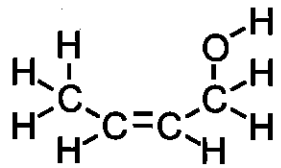
(a) (i)

H	**J**	**K**
$CH_2=CHCH_2CH_2OH$	$CH_3CH_2COCH_3$	$CH_3CH_2CH_2CHO$
$CH_3CH=CHCH_2OH$		
$CH_2=CHCH(OH)CH_3$		

each correct answer gets 1 (5 x 1)

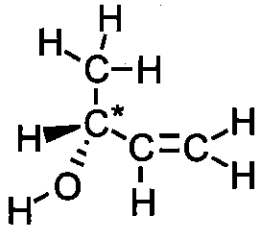
(ii)





(1)

(iii)



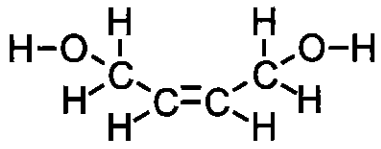
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[8]

[8]

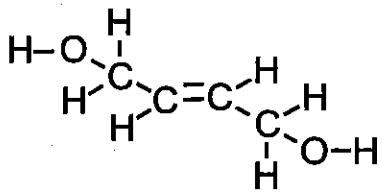
13. O/N 12/P21/Q5/b

(a) (i)



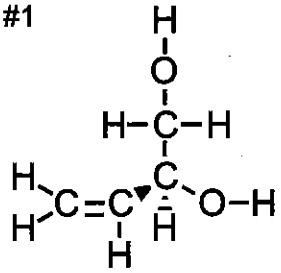
each correct structure gets (1) (4 × 1)

(ii) pair 1 geometrical **or** *cis-trans* **or** *E*/*Z* isomerism (1)

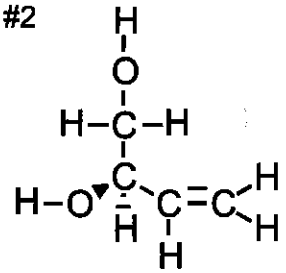


pair 2 optical isomerism – accept chiral compounds (1) **[6]**

#1

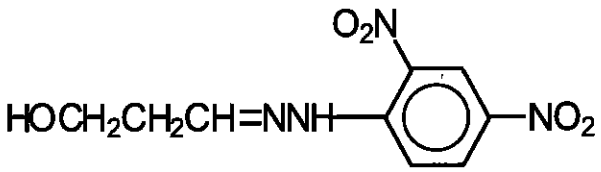


#2



14. O/N 12/P22/Q4/b

(a) (i)



(1)

(ii) red **or** orange (1) **[2]**

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15. O/N 12/P22/Q5/a

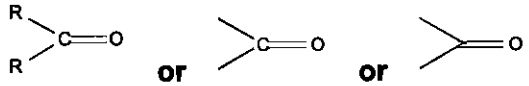
(a) (i) carboxylic acid **or** alcohol present **or**
carboxylic acid **and** alcohol present
not acid **or** carboxyl **or** hydroxyl (1)

(ii) carboxylic acid **not** present **or**
only alcohol present (1)

(iii) alkene **or** >C=C< present (1) **[3]**

16. M/J 12/P22/Q4/c,d

(a) (i)



and **'ketone'** (1)

(ii) **G** is $HOCH_2COCH_2OH$ as the minimum (1)
allow the *gem* diol $CH_3COCH(OH)_2$ **[2]**

(b) (i) **H** is HO_2CCOCO_2H as the minimum (1)

(ii) **J** is $HOCH_2CH(OH)CH_2OH$ as the minimum (1) **[2]**

17. M/J 12/P21/Q5

(a) carboxylic acid **or** $-CO_2H$ **or** $-COOH$ (1) **[1]**

(b) (i) alcohol (1)

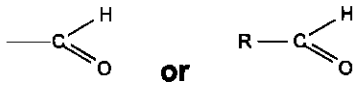
(ii) $n(H_2) = \frac{160}{24000} = 6.67 \times 10^{-3}$ mol (1)

n(H atoms) $= 2 \times 6.67 \times 10^{-3}$ mol $= 1.33 \times 10^{-2}$ mol (1)

(iii) $n(\mathbf{X}) = \frac{0.600}{90} = 6.67 \times 10^{-3}$ mol

$n(\mathbf{X}) : n$(H atoms) $= 6.67 \times 10^{-3} : 1.33 \times 10^{-2}$
$= 1 : 2$
since each –OH group produces one H atom
there are two –OH groups (1) **[4]**

(c) (i)



(1)

(ii) $HOCH_2CH(OH)CHO$ as the minimum
allow the *gem* diols $(HO)_2CHCH_2CHO$ **or** $CH_3C(OH)_2CHO$ (1)

(iii) $HOCH_2CH(OH)CO_2H$ or $HOCH_2CH(OH)CO_2^-$ (1) **[3]**

(d) (i) $HOCH_2CH(OH)CH_2OH$ (1)

(ii) HO_2CCOCO_2H (1) **[2]**

[10]

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18. O/N 11/P22/Q5/a,c

(a) (i) 1 primary (1)
alcohol **not** hydroxyl (1)

2 aldehyde **not** carbonyl (1)

(ii)

test 1			
reagent	Na	$PCl_3/PCl_5/PBr_3$	RCO_2H/H^+
observation	gas/H_2/effervescence/ fizzing	HCl/HBr steamy fumes	fruity smell
test 2			
reagent	Tollens' reagent	Fehling's reagent	2,4-dinitro-phenylhydrazine
observation	Ag mirror/silver/ black ppt	brick-red ppt red ppt	orange/red/yellow ppt/solid

only award the observation mark if reagent is correct (4) **[7]**

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(b)

route	starting compound	**first reagent**	intermediate **X**	**second reagent**	intermediate **Y**	**third reagent**	final compound
A/1	$HOCH_2CHO$	PCl_3 PCl_5 $SOCl_2$ etc.	$ClCH_2CHO$	$K_2Cr_2O_7/H^+$ $KMnO_4/H^+$ $KMnO_4/OH^-$ Tollens' or Fehling's reagents	$ClCH_2CO_2H$	NH_3	$H_2NCH_2CO_2H$
A/2	$HOCH_2CHO$	HBr P/Br_2 etc.	$BrCH_2CHO$	$K_2Cr_2O_7/H^+$ $KMnO_4/H^+$ $KMnO_4/OH^-$ Tollens' or Fehling's reagents	$BrCH_2CO_2H$	NH_3	$H_2NCH_2CO_2H$
B/1	$HOCH_2CHO$	PCl_3 PCl_5 $SOCl_2$ etc.	$ClCH_2CHO$	NH_3	H_2NCH_2CHO	$K_2Cr_2O_7/H^+$ $KMnO_4/H^+$ $KMnO_4/OH^-$ Tollens' or Fehling's reagents	$H_2NCH_2CO_2H$
B/2	$HOCH_2CHO$	HBr P/Br_2 etc.	$BrCH_2CHO$	NH_3	H_2NCH_2CHO	$K_2Cr_2O_7/H^+$ $KMnO_4/H^+$ $KMnO_4/OH^-$ Tollens' or Fehling's reagents	$H_2NCH_2CO_2H$
C	$HOCH_2CHO$	Tollens' or Fehling's reagents	$HOCH_2CO_2H$	KBr/conc. H_2SO_4	$BrCH_2CO_2H$	NH_3	$H_2NCH_2CO_2H$
mark		(1)	(1)	(1)	(1)	(1)	

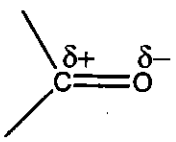
[5]

19. M/J 11/P21/Q4

(a) (i) nucleophilic addition
both words are necessary (1)

(ii) NaCN and H_2SO_4 **or**
HCN plus CN^-
do not allow HCN on its own (1)

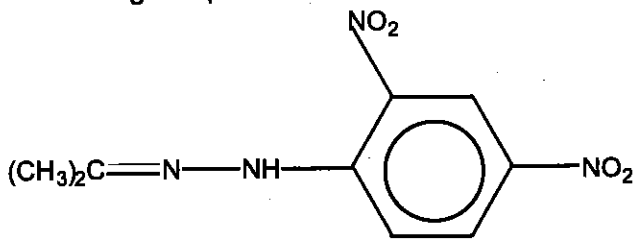
(iii) correct δ+ **and** δ-, i.e.



(1) **[3]**

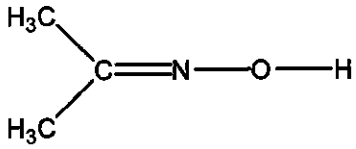
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(b) (i) correct organic product



H_2O formed/ equation balanced (1) **[2]**

(ii)



(1) **[1]**

[6]

20. O/N 10/P23/Q3

(a) (i) order of atoms **must** be C-C-O

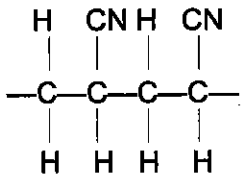
(1)

linear (1)

(ii) a molecule or atom with an unpaired electron **or**
a species formed by the homolytic fission of a covalent bond (1)

(iii) molecule has 2 bond pairs and one lone pair (1)
and one unpaired electron (1)
these may be shown in a diagram **[5]**

(b) (i)

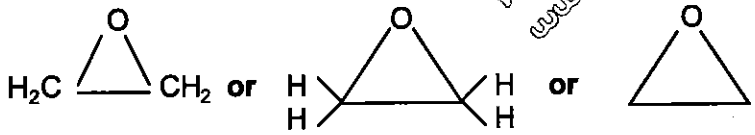


allow the structural formula $—CH_2CH(CN)CH_2CH(CN)—$ (1)

(ii) addition (1) **[2]**

(c) (i) CH_3CHO (1)

(ii)



(1) **[2]**

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(d)

reagent	product
Br_2 in an inert solvent	$BrCH_2CHBrCHO$
NaCN + dil. H_2SO_4	$CH_2=CHCH(OH)CN$ allow $CH_2=CHCH(OH)CO_2H$
Tollens' reagent	$CH_2=CHCO_2H$ **or** $CH_2=CHCO_2^-$
$NaBH_4$	$CH_2=CHCH_2OH$

(4 × 1) [4]

[13]

21. M/J 10/P22/Q4/e

(a) (i) aldehyde (1)

(ii) must be a primary alcohol (1)

(iii) CH_3OH **or** CH_3CH_2OH **or** $CH_3CH_2CH_2OH$ (1) [3]

22. O/N 09/P21/Q5

(a) **G** is HCHO/methanal (1) [1]

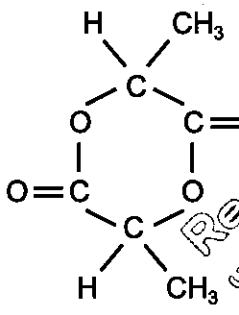
(b) (i) carboxylic acid/carboxyl/$-CO_2H$
not acid (1)

(ii) **H** is CH_3CO_2H/ethanoic acid (1)

(iii) **J** is $CH_3CH(OH)CO_2H$/2-hydroxypropanoic acid
allow $HOCH_2CH_2CO_2H$/3-hydroxypropanoic acid (1) [3]

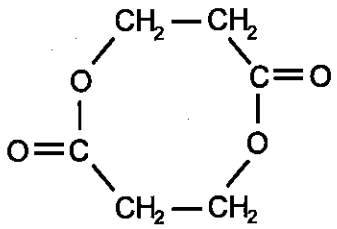
(c) **K** is CH_3COCO_2H (1) [1]

(d) (i) **L** is



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allow as ecf on $HOCH_2CH_2CO_2H$/3-hydroxypropanoic acid



(1)

(ii) esterification
allow elimination/dehydration/condensation (1) **[2]**

[7]

23. M/J 09/P22/Q5

(a) $CH_3CH(OH)CH_2CHO$ (by addition of one molecule of CH_3CHO across the >C=O bond of another)

or

$CH_3CH_2CH(OH)CHO$ (by working backwards from **U** and adding one molecule of H_2O across the C=C bond 'the other way') (1) **[1]**

(b)

functional group in **U**	reagent used in test	what would be seen
alkene	Br_2 **or** $KMnO_4$(aq)	decolourised
.....	.....	.....
or carbonyl not ketone	**or** 2,4-dinitro-phenylhydrazine/ Brady's reagent	**or** yellow/orange/red colour or ppt.
.....	.....	.....
or aldehyde	**or** Tollens' reagent	**or** silver ppt./mirror black colour
	or	**or**
	Fehling's solution	brick red ppt.
(1)	(1)	(1)

[3]

(c) (i) dehydration/elimination (1)

(ii) Al_2O_3/P_4O_{10}/conc. H_2SO_4/conc. H_3PO_4 (1) **[2]**

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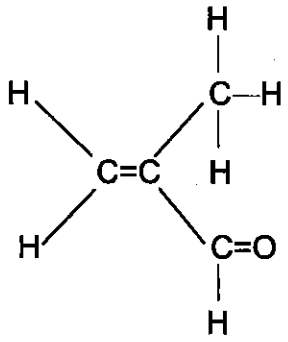
(d) $NaBH_4$ **or** $LiAlH_4$ (1)

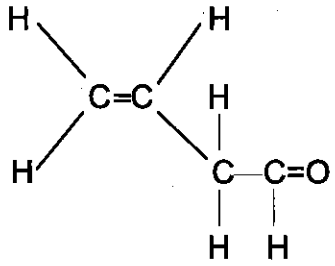
in water **or** methanol **or** ethanol **or** mixture of water and alcohol **or** in **dry** ether (1)

not ether

Solvent mark is only to be awarded if reagent is correct. **[2]**

(e)





two structures (1) + (1) **[2]**

(f) $CH_3CH_2CH(OH)CH_2CHO$

or

$CH_3CH(OH)CH(CH_3)CHO$

allow

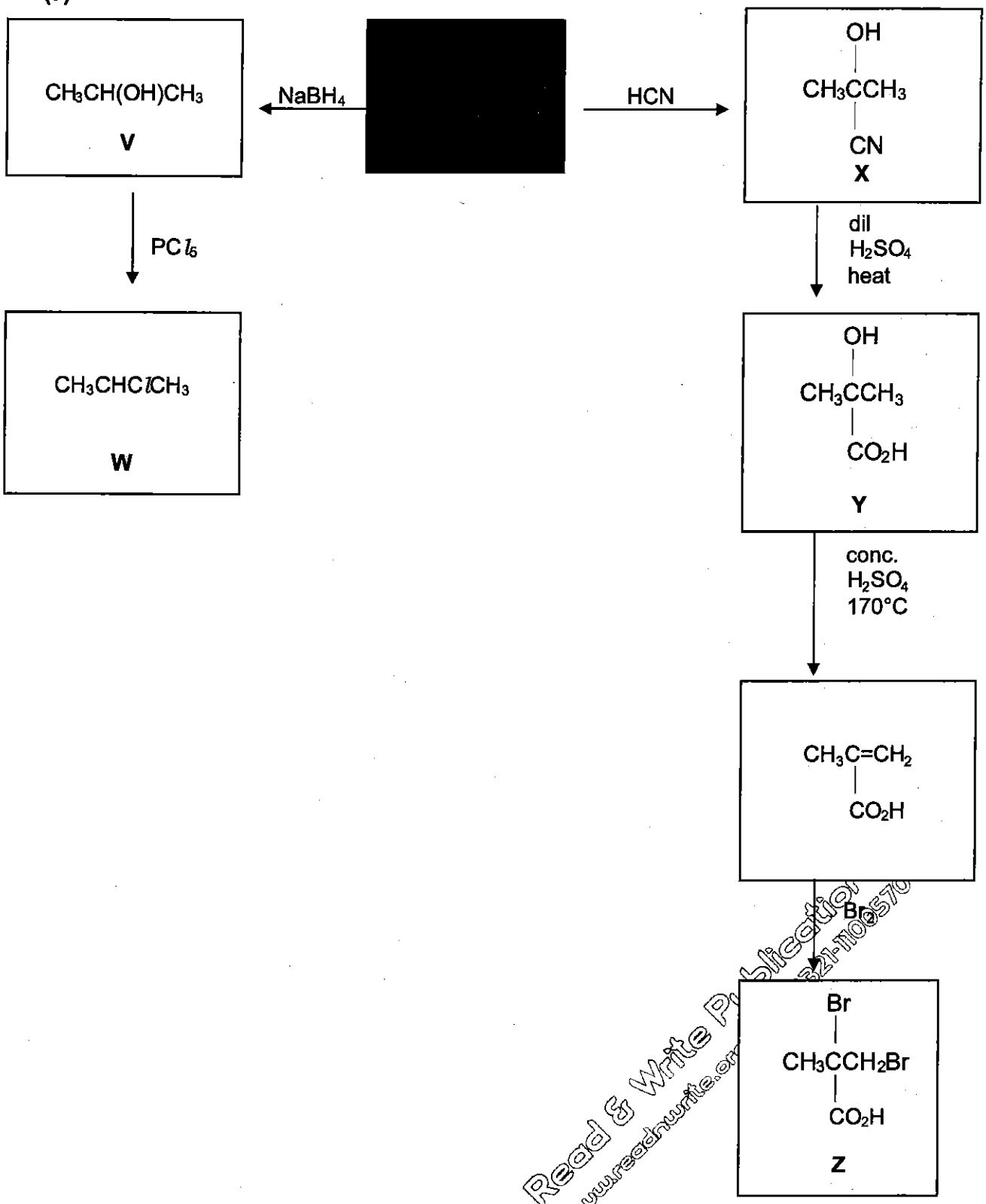
$CH_3CH(OH)CH_2CH_2CHO$ (1) **[1]**

[11]

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24. M/J 09/P22/Q4

(a)



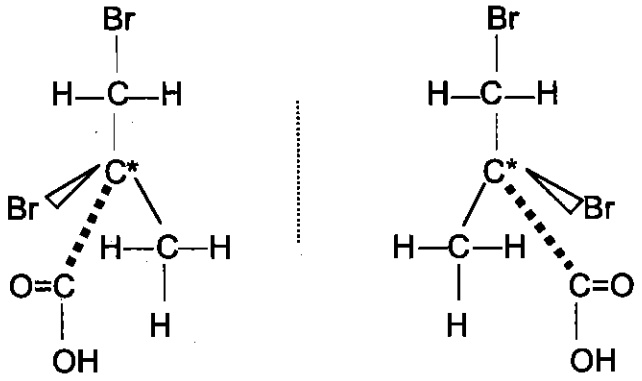
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(each correct structure gets 1 mark) [6]

(b) (i) Z

allow ecf on candidate's **Z**
or other **chiral** compound (1)

(ii)



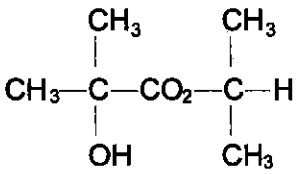
chiral centre clearly shown by * (1)

one structure drawn fully displayed

especially $-CO_2H$ group (1)

mirror object/mirror image pair correctly drawn in 3D (1) **[4]**

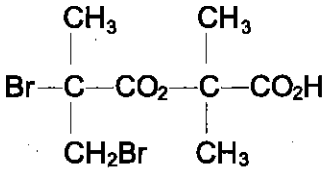
(c) (i) Y + V



or $(CH_3)_2C(OH)CO_2CH(CH_3)_2$

allow ecf on **candidate's Y** and/or **V** (1)

(ii) Y + Z



or $CH_3C(CH_2Br)BrCO_2C(CH_3)_2CO_2H$

allow ecf on **candidate's Y** and/or **Z** (1) **[2]**

[11]

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25. M/J 09/P21/Q5

(a) $CH_3COCH_2C(CH_3)_2$ **or** (by addition of one molecule of $(CH_3)_2CO$ across the >C=O bond of another)



$CH_3COCHCH(CH_3)_2$ (by working backwards from **G** and adding one molecule of H_2O across the C=C bond)



(1) **[1]**

(b)

functional group in **G**	reagent used in test	what would be seen
alkene	Br_2 **or** $KMnO_4(aq)$	decolourised
.....	.....	.....
or carbonyl	**or** 2,4-dinitro-phenylhydrazine/ Brady's reagent	**or** yellow/orange/red colour or ppt.
(1)	(1)	(1)

[3]

(c) (i) dehydration/elimination (1)

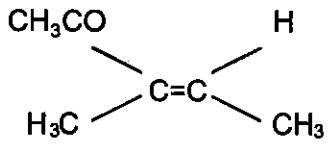
(ii) Al_2O_3 / P_4O_{10} / conc. H_2SO_4/ conc.H_3PO_4 (1) **[2]**

(d) $NaBH_4$ **or** $LiAlH_4$ (1)

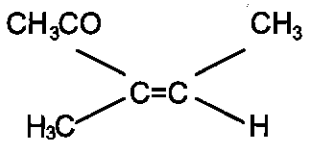
in water **or** methanol/ethanol **or** mixture of alcohol and water **or** in **dry** ether (1) **[2]**

not ether
Solvent mark is only awarded if reagent is correct.

(e)



*cis**

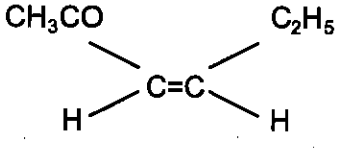


*trans***

* allow this to be called Z

** allow this to be called E

or



*cis**



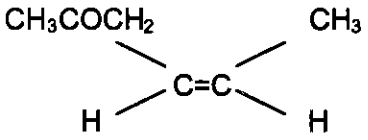
*trans***

* allow this to be called Z

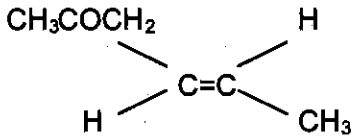
** allow this to be called E

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or



cis or Z



trans or E

two structures (1)
correct *cis* and *trans* (1)
explanation (1) **[3]**

For *cis* and *trans* answers, the explanation should be in terms of the methyl groups (first pair of isomers) or hydrogen atoms (second and third pairs of isomers) being on the same or opposite sides relative to the C=C bond.

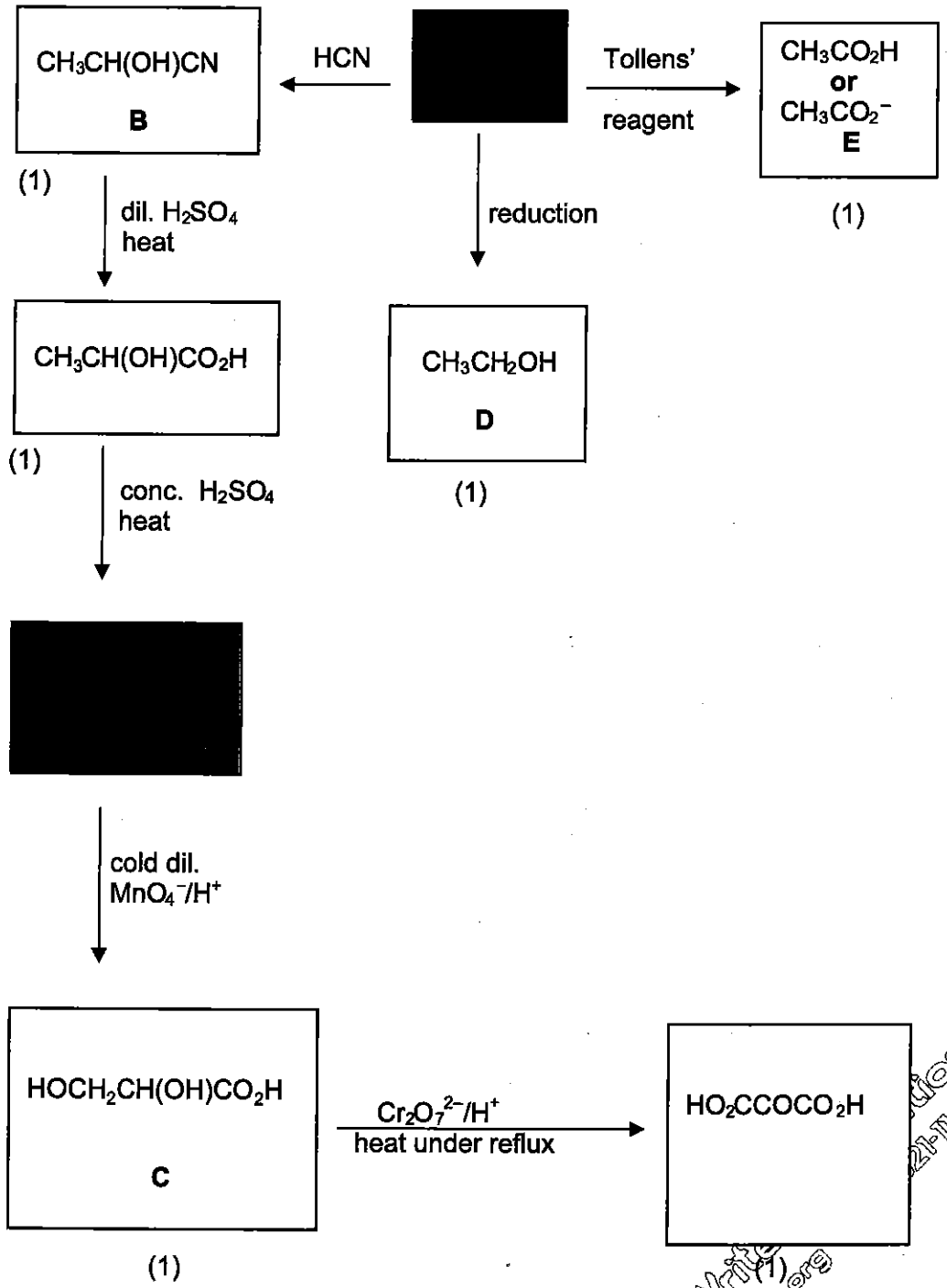
For E/Z answers, the explanation will need to involve the relative sizes of the CH_3C- group and the CH_3- group. This really only affects the first pair of isomers.

[11]

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26. M/J 09/P21/Q4

(a)

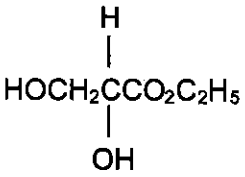


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one mark for each correct structure **[6]**

(b) C + D

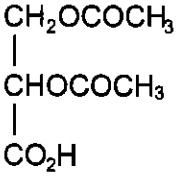
$HOCH_2CH(OH)CO_2C_2H_5$ as minimum or



(1)

Allow e.c.f on candidate's **C** and/or **D**.

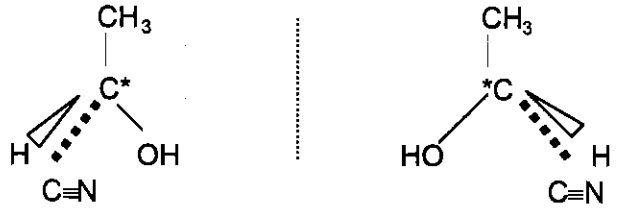
C + E



Allow either monoester. (1) **[2]**

Allow e.c.f on candidate's **C** and/or **E**.

(c)

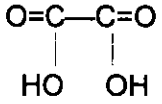


correct chiral carbon atom indicated (1)
one structure drawn fully displayed with C≡N (1)
mirror object/mirror image pair correctly drawn in 3D (1) **[3]**

[11]

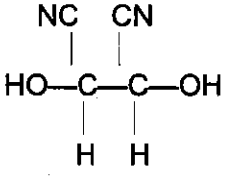
27. M/J 08/P2/Q5

(a) (i) silver or black ppt. (1)

(ii)  **or** HO_2CCO_2H (1)

allow anion

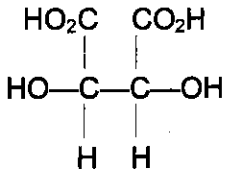
[2]

(b) (i)  **or** NCCH(OH)CH(OH)CN (1)

allow NCCH(OH)CHO

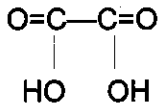
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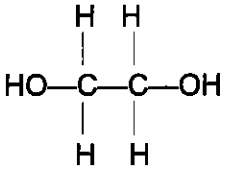
(ii) nucleophilic addition (1)

(iii)  **or** $HO_2CCH(OH)CH(OH)CO_2H$ (1)

allow $HO_2CCH(OH)CHO$ (ecf)

[3]

(c) (i)  **or** HO_2CCO_2H (1)

(ii)  **or** HOH_2CCH_2OH (1)

allow HOH_2CCHO

(iii) $NaBH_4$ **or** $LiAlH_4$ **or** H_2/Ni (1) [3]

(d) both oxidation **and** reduction **allow** disproportionation (1) **[1]**

(e) HO—C≡C—OH – candidate's compound must be $C_2H_2O_2$

-OH present (1)

C≡C present (1) [2]

[11]

28. O/N 05/P2/Q5

(a) C=C (1) **[1]**

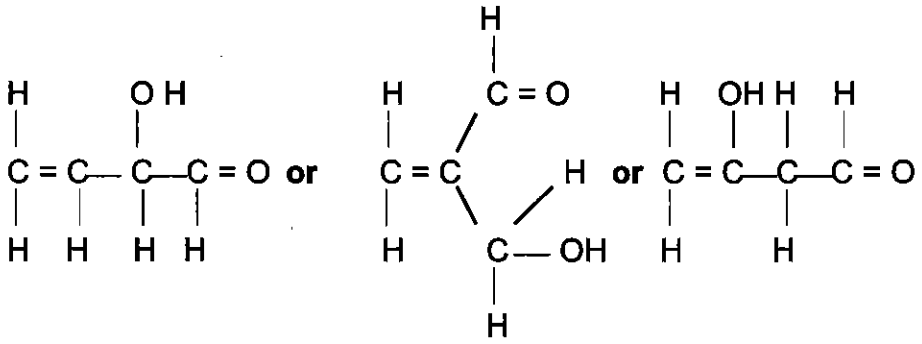
(b) alcohol (1)

(ignore any reference to primary or secondary) **[1]**

(c) aldehyde (1) **[1]**

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(d)



fully correct structure is worth 2 (2)

CH_2 = present in wrong structure gets (1) **[2]**

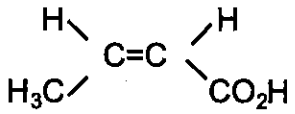
(e) RONa **or** R^+ ONa^- (1)

RO_2CCH_3 (1) **[2]**

(f) RCO_2H (1)

$RCH{=}NNHC_6H_3(NO_2)_2$ as the minimum (1) **[2]**

(g)



correct acid (1)

correctly shown as *cis* (1) **[2]**

[11]

29. M/J 05/P2/Q5

(a) C:H:O = $\frac{66.7}{12} : \frac{11.1}{1} : \frac{22.2}{16}$ **(1)**

= 5.56 : 11.1 : 1.39

= 4 : 8 : 1

C_4H_8O = 72 molecular formula = C_4H_8O **(1)** **[2]**

(b) (i) presence of C=C/alkene/unsaturated **(1)**

(ii) -OH group (in $-CO_2H$ <u>or</u> -OH) present **(1)** **[2]**

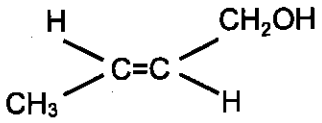
(c) (i) aldehyde/ketone/carbonyl **(1)**

(ii) primary alcohol **(1)** **[2]**

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(d) restricted rotation about a C = C bond (1)
two different groups on each side of C = C (1) **[2]**

(e)



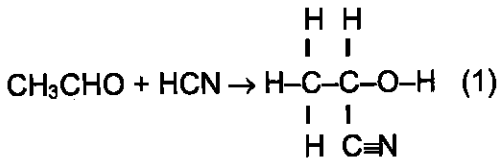
one fully correct structure (1)
two fully correct structures with correctly labelled cis-trans (1)

allow **(1)** for correctly labelled cis-trans structures that are C_4H_8O but incorrect **[2]**

[11]

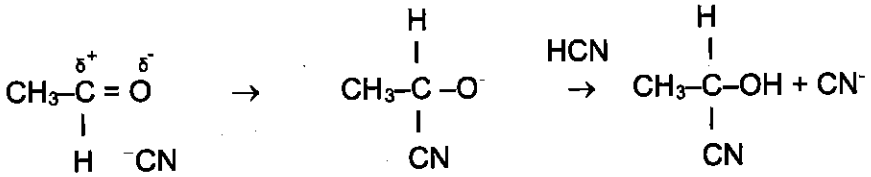
30. O/N 04/P2/Q5

(a) (i)



(ii) nucleophilic addition (1)

(iii)



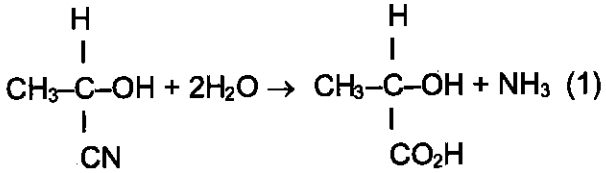
C = O dipole correctly shown (1)

attack on $C^{\delta+}$ by CN^- (1)

correct intermediate/correct curly arrow on C = O (1)

CN^- regenerated (1) **[5]**

(b) (i)



(ii) hydrolysis (1) **[2]**

(c) $CH_3CHO \rightarrow CH_3CH(OH)CO_2H$

44 90 **both** M_r values correct (1)

4.40 g → 9.00 g

% yield = $\frac{5.40 \times 100}{9.00}$ expression (1)

= 60% value (1) **[3]**

[10]

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31. M/J 03/P2/Q6

(a) $\frac{66.7}{12}$ $\frac{11.1}{1}$ $\frac{22.2}{16}$

= 5.5 = 11.1 = 1.3875

Divide by 1.3875

C_4H_8O (1) 48 + 8 + 16 = 72 hence C_4H_8O (1) **[2]**

(b) (i) orange ppt (1) red to yellow/crystals or solid

(ii) ketone (1)

(iii) $CH_3CH_2COCH_3$ or butanone (1) **[3]**

(c) (i) $NaBH_4$ allow $NaAlH_4$ (Li Al H_4) (1) H_2/Ni or Pt

(ii) secondary alcohol (1)

(iii) $CH_3CH_2CHOHCH_3$ (1)
[Allow ecf marks if **(b) (iii)** is butanal] **[3]**

[8]

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UNIT 18

Carboxylic Acids and Derivatives

A-Level
Chemistry Paper 2
Topical Workbook

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Unit 18: Carboxylic Acids and Derivatives

1. MAR 17/P22/Q3/d(ii)

$CH_3(CH_2)_3CO_2H$ is a colourless liquid with an unpleasant odour.

It reacts with methanol in the presence of an acid catalyst to produce an organic product **V**, which has a pleasant fruity smell.

(a) (i) A student analysed $CH_3(CH_2)_3CO_2H$, methanol and **V** using infra-red spectroscopy. The spectra were returned to the student without labels.

Identify which of the infra-red spectra, X, Y or Z, corresponds to **V**.

compound	$CH_3(CH_2)_3CO_2H$	methanol	**V**
spectrum			

Explain your answer with reference to relevant features of the **three** spectra in the region above 1500 cm^{-1}.

.....

.....

.....

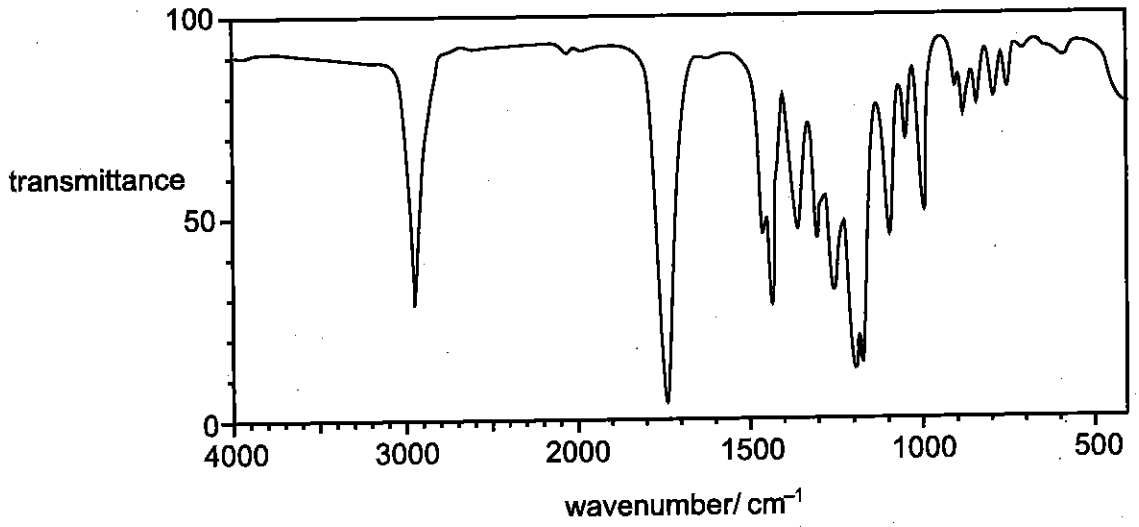
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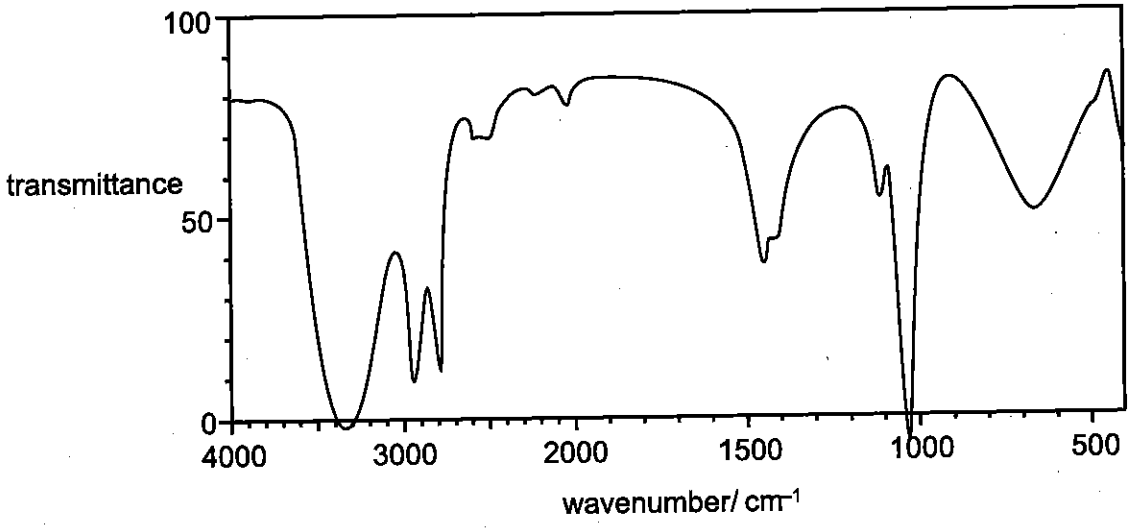
..... **[4]**

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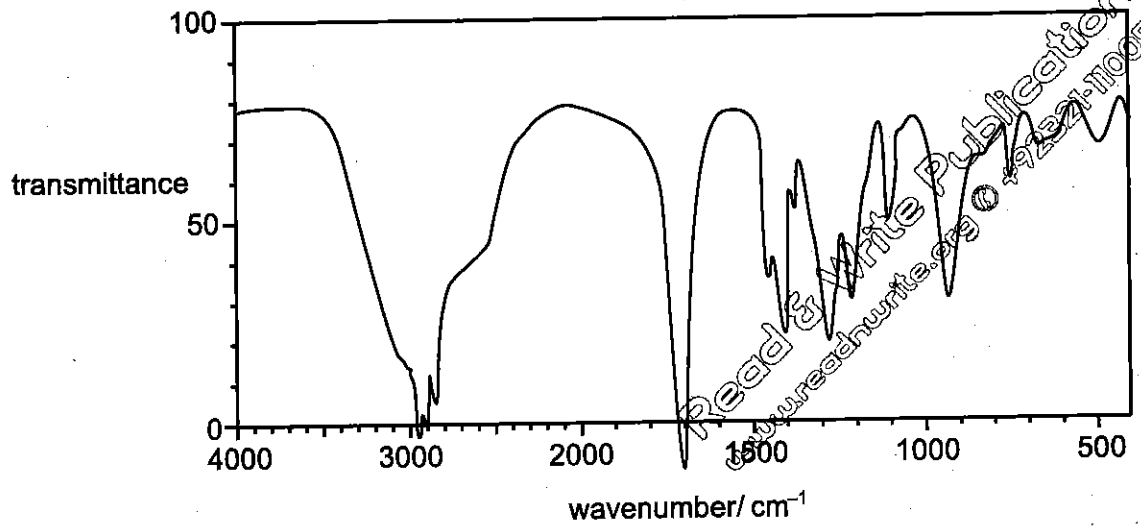
infra-red spectrum X



infra-red spectrum Y



infra-red spectrum Z



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[21]

2. M/J 16/P22/Q4

This question is about molecules with molecular formula $C_4H_8O_2$.

(a) Give the structural formulae of the pair of **chain** isomers with the formula $C_4H_8O_2$ that are carboxylic acids.

[2]

(b) (i) Give the structural formulae of a pair of **positional** isomers with the formula $C_4H_8O_2$ that are esters.

[2]

(ii) Give the reagents and conditions needed to produce one of your esters in **(i)**.

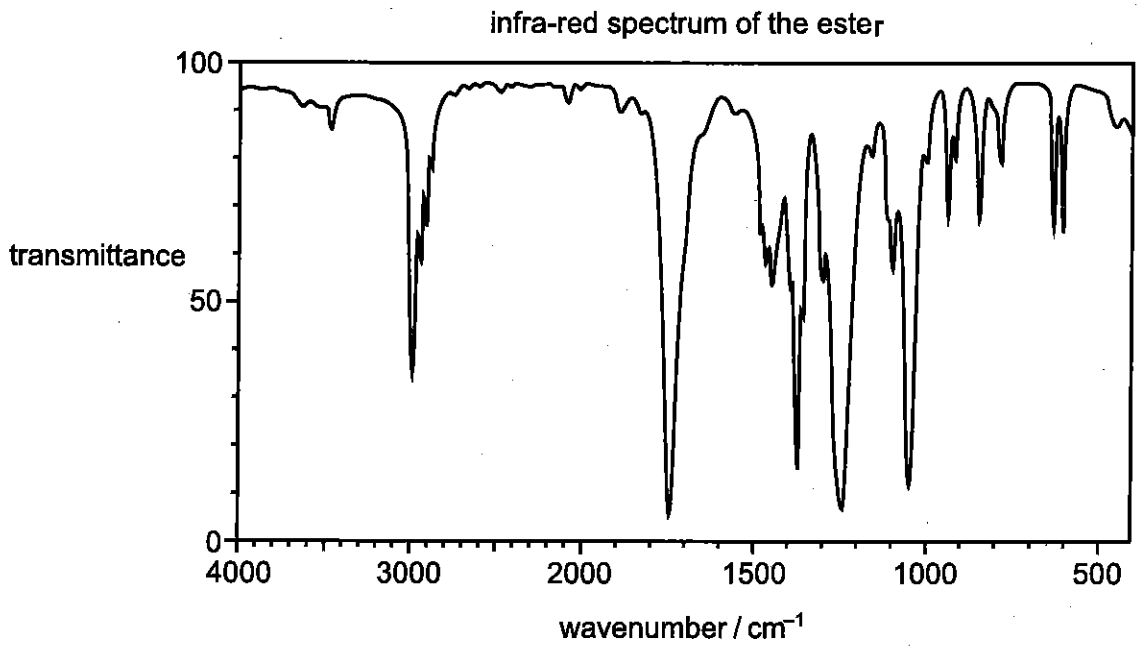
.....

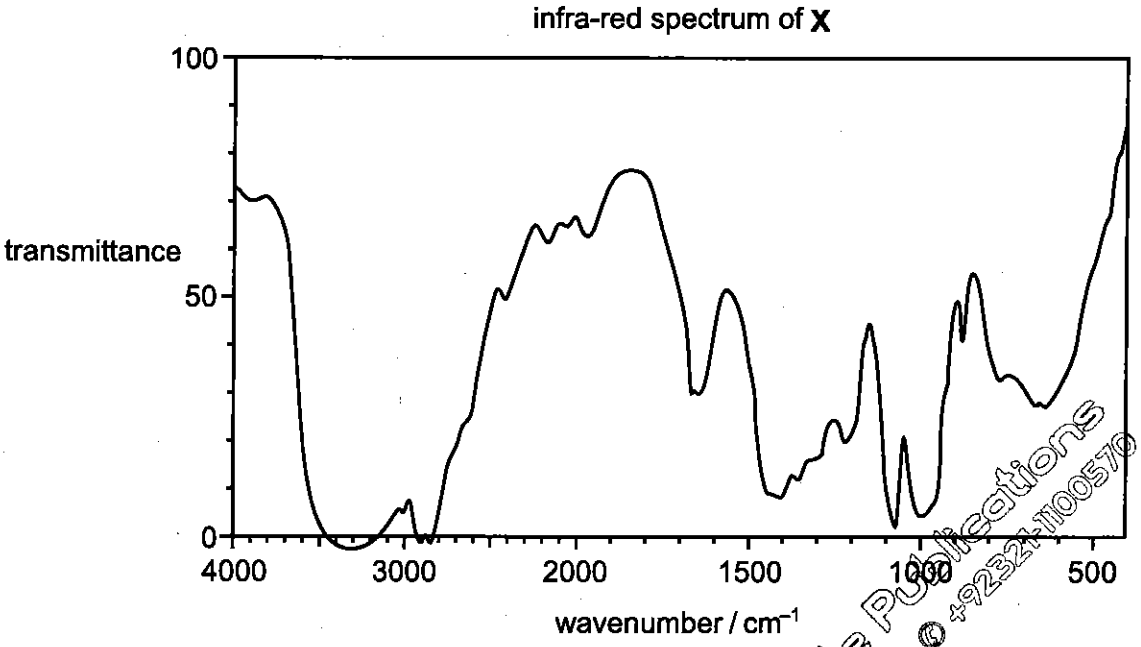
..... **[2]**

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(c) The infra-red spectra of one of the esters and of another isomer, **X**, are shown.

X decolourises bromine water and is not an ester or an acid.





Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm^{-1}

.....

.....

.....

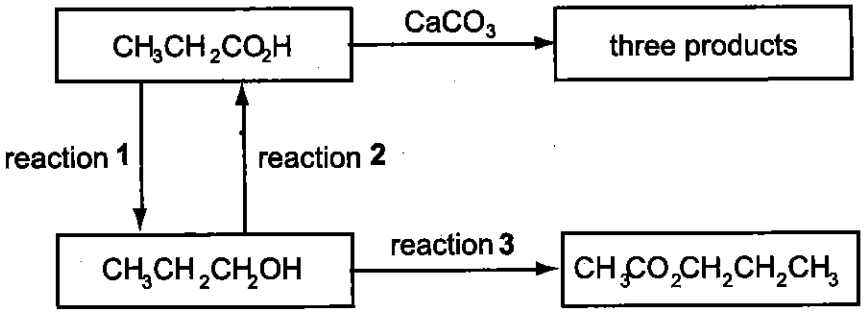
[3]

..... [9]

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3. O/N 14/P21/Q4

A series of reactions based on propanoic acid is shown.



(a) Write an equation for reaction **1**, using [H] to represent the reducing agent.

..... **[2]**

(b) (i) What type of reaction is reaction **2**?

..... **[1]**

(ii) Suggest a suitable reagent and conditions for reaction **2**.

..... **[2]**

(c) Write an equation for the reaction of propanoic acid with calcium carbonate, $CaCO_3$.

..... **[2]**

(d) (i) Suggest a suitable reagent and conditions for reaction **3**.

.....

..... **[2]**

(ii) Identify the **other** product of reaction **3**.

..... **[1]**

[10]

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4. O/N 13/P22/Q4, O/N 13/P21/Q4

Compound **R** is a weak diprotic (dibasic) acid which is very soluble in water.

(a) A solution of **R** was prepared which contained 1.25g of **R** in 250 cm^3 of solution. When 25.0 cm^3 of this solution was titrated with 0.100 $moldm^{-3}$ NaOH, 21.6 cm^3 of the alkali were needed for complete reaction.

(i) Using the formula H_2X to represent **R**, construct a balanced equation for the reaction between H_2X and NaOH.

.....

(ii) Use the data above to calculate the amount, in moles, of OH^- ions used in the titration.

(iii) Use your answers to **(i)** and **(ii)** to calculate the amount, in moles, of **R** present in 25.0 cm^3 of solution.

(iv) Calculate the amount, in moles, of **R** present in 250 cm^3 of solution.

(v) Calculate M_r of **R**.

[5]

(b) Three possible structures for **R** are shown below.

S	T	U
$HO_2CCH{=}CHCO_2H$	$HO_2CCH(OH)CH_2CO_2H$	$HO_2CCH(OH)CH(OH)CO_2H$

(i) Calculate the M_r of each of these acids.

M_r of **S** = ... M_r of **T** = ... M_r of **U** = ...

(ii) Deduce which of the structures, **S**, **T** or **U**, correctly represents the structure of the acid, **R**.

R is represented by .....

[2]

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It is possible to convert **S**, **T**, or **U** into one another.

(c) State the reagent(s) and essential conditions that would be used for the following conversions.

S into **T**

.....

S into **U**

.....

T into **S**

..... **[5]**

(d) Give the structural formula of the organic product formed in **each** of the following reactions.

T reacting with an excess of Na

U reacting with an excess of Na_2CO_3

[2]

(e) The acid **S** shows stereoisomerism. Draw structures to show this isomerism. Label each isomer.

[2]

(f) When one of the isomers of **S** is heated at 110 °C in the absence of air, a cyclic compound **V**, with molecular formula $C_4H_2O_3$, is formed.
The other isomer of **S** does not react at this temperature.

Suggest the displayed formula of **V**

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[2]

[18]

5. O/N 13/P23/Q4

Compound **Q** is a viscous liquid which is very soluble in water.
The M_r of **Q** is 90.0.

Three possible structures for **Q** are shown below.

R	S	T
$HOCH_2CH_2CO_2H$	$HOCH_2CO_2CH_3$	$HCO_2CH_2CH_2OH$

(a) (i) What type of isomerism do **R**, **S** and **T** show?

.....

(ii) What oxygen-containing functional groups are present in **R**, **S** and **T**?
Give their **full names**.

R ..... and .....

S ..... and .....

T ..... and .....

(iii) Which functional group(s) in **(ii)** will react with sodium carbonate?

.....

(iv) Which functional group(s) in **(ii)** will react with sodium metal?

.....

[6]

(b) When 0.002 mol of **Q** is reacted with an excess of solid sodium carbonate, Na_2CO_3, 24 cm^3 of carbon dioxide, measured at room temperature and pressure, is produced.

(i) Calculate the amount, in moles, of carbon dioxide produced in this reaction.

(ii) Hence calculate the amount, in moles, of carbon dioxide produced by 1 mol of **Q**.

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[2]

When 0.002 mol of **Q** is reacted with an excess of metallic sodium, 48 cm^3 of hydrogen, measured at room temperature and pressure, is produced.

(c) (i) Calculate the amount, in moles, of hydrogen molecules produced in this reaction.

(ii) Hence calculate the amount, in moles, of hydrogen molecules produced by 1 mol of **Q**.

[2]

(d) Use your answers to **(b)** and **(c)** to deduce which structure, **R**, **S** or **T**, corresponds to the structure of **Q** and write balanced equations for the reactions that occurred.

identity of **Q** is .....

equation for reaction with sodium carbonate

.....

equation for reaction with sodium metal

..... **[5]**

[15]

6. M/J 13/P22/Q5/a,b

A student reacted together an alcohol and a carboxylic acid under appropriate conditions to produce an ester.
A sweet smelling organic liquid, **Q**, with the empirical formula C_2H_4O was produced.
The M_r of **Q** was found by experiment to be 87.5.

(a) What is the molecular formula of **Q**?

..... **[1]**

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(b) In the boxes below, draw the structural formulae of **four** isomers with this formula that are esters.

W	**X**
Y	**Z**

[4]

7. M/J 12/P22/Q3

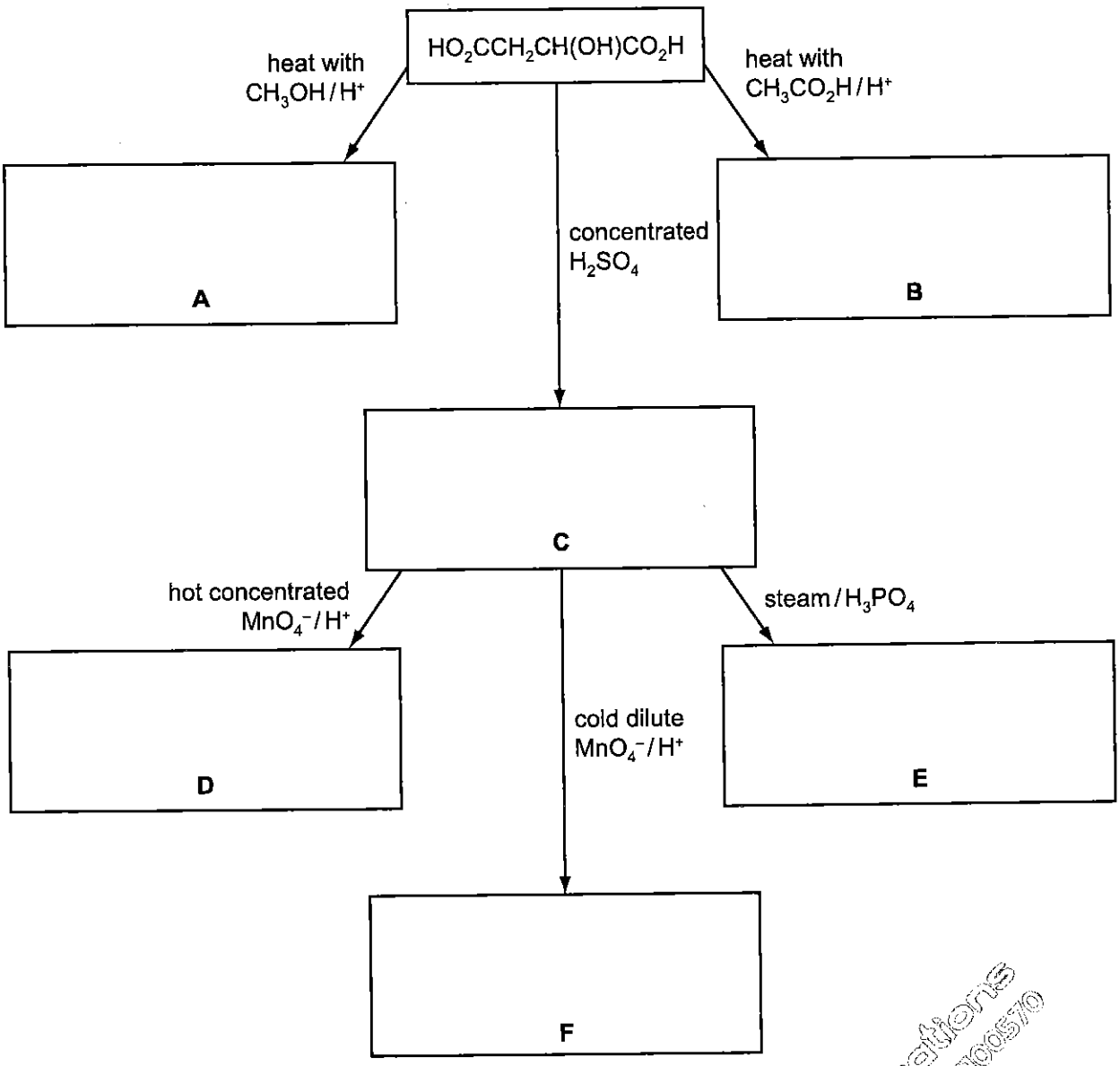
Food additives are substances added to food to preserve the flavour or to improve its taste and appearance.

European Union legislation requires most additives used in foods to be labelled clearly in the list of ingredients, either by name or by an 'E number'. E296 is malic acid which occurs in unripe fruit.

Malic acid has the structural formula $HO_2CCH_2CH(OH)CO_2H$.

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(a) Some reactions of malic acid are shown below.
In the boxes below, give the **structural** formulae of organic compounds **A** to **F**.



[6]

(b) What *type of reaction* is **each** of the following conversions?

malic acid into **C** .....

C into **D** .....

C into **E** .....

[3]

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(c) Suggest **one** major commercial use of compounds such as **A** or **B**.

..... [1]

(d) **(i)** Malic acid is chiral.
Draw fully displayed formulae of the two optical isomers of malic acid.
Indicate with an asterisk (*) the chiral carbon atom.

(ii) Compound **C** also shows stereoisomerism.
Draw the skeletal formulae of **each** of the stereoisomers of **C**. Label **each** isomer.

[6]

(e) The food additive E330 is another organic compound which occurs naturally in fruit.
E330 has the following composition by mass: C, 37.5 %; H, 4.17%; O, 58.3 %.
Calculate the empirical formula of E330.

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[3]

[19]

8. M/J 12/P22/Q4/a

Oxygen-containing organic compounds may contain a number of different functional groups including alcohol, aldehyde, carboxylic acid, ester or ketone functional groups. These functional groups may be identified by their reactions with specific reagents.

(a) On treating compounds containing each of these functional groups with the reagents below, only five reactions occur. Complete the table by placing a tick (✓) in each box where you believe a reaction will occur. You should place **no more** than five ticks in the table.

reagent	alcohol R_2CHOH	aldehyde RCHO	carboxylic acid RCO_2H	ester RCO_2R'	ketone RCOR'
$NaHCO_3$					
Na					
$Cr_2O_7^{2-}/H^+$					

[5]

9. M/J 12/P23/Q5

Many naturally occurring organic compounds contain oxygen. Such compounds may contain alcohol, aldehyde, carboxylic acid, ester or ketone functional groups. These functional groups may be identified by their reactions with specific reagents.

Compound **F** is a white solid which has the molecular formula $C_3H_6O_3$.

Compound **F** is soluble in water. Addition of $NaHCO_3$ to this solution produces a colourless gas, **G**, which turns lime water milky.

(a) (i) What is the identity of the gas **G**?

.....

(ii) What functional group does this test show to be present in **F**?

.....

[2]

(b) When **F** is heated with concentrated sulfuric acid, a colourless liquid **H** is produced. When cold dilute acidified $KMnO_4$ is shaken with **H**, the solution becomes colourless.

(i) What *type of reaction* occurs when **H** is formed from **F**?

.....

(ii) Use your answers to **(a)(ii)** and **(b)(i)** to deduce the structural formula of the colourless liquid **H**.

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[4]

(c) Compound **F** will react with sodium.

Calculate the volume of H_2, measured at room temperature and pressure, which will be produced when 0.600 g of **F** is reacted with an excess of Na.

[4]

(d) There are two structural isomers of **F** that give the reactions described in **(a)** and **(b)**.

(i) Suggest two structural formulae for these isomers.

J	**K**

(ii) Isomers **J** and **K** can both be oxidised.
What will be produced when **each** of the isomers **J** and **K** is heated under reflux with acidified $K_2Cr_2O_7$?

product from **J**	product from **K**

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[2]

[12]

10. O/N 11/P23/Q5

Each of the three organic compounds, **V**, **W**, and **X**, has the empirical formula CH_2O.
The number of carbon atoms in each of their molecules is shown in the table.

compound	number of C atoms
V	1
W	2
X	3

V gives a brick red precipitate when warmed with Fehling's reagent; **W** and **X** do not.

W is a fruity smelling liquid.

In **X**, the carbon atoms are bonded directly to one another.

X gives an effervescence when shaken with $Na_2CO_3(aq)$; **V** and **W** do not.

(a) Give the structural formula of **V**.

[1]

(b) **(i)** What functional group is present in **W**?

.....

(ii) Give the structural formula of **W**.

[2]

(c) When **X** is heated under reflux with acidified $K_2Cr_2O_7$, the product, **Y**, gives no reaction with 2,4-dinitrophenylhydrazine reagent.

(i) Give the structural formula of **X**.

(ii) Give the structural formula of **Y**, the compound formed from **X**

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[2]

(d) When **X** is warmed with a little concentrated sulfuric acid, a small amount of a cyclic compound, **Z**, is formed.

Z has the molecular formula $C_6H_8O_4$.

(i) Suggest a displayed formula for **Z**.

(ii) What type of reaction occurs when **Z** is formed from **X**?

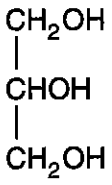
..... [2]

[7]

11. M/J 11/P22/Q5/a,b,c

Although there are many different types of food eaten around the world, animal fats and/or vegetable oils are commonly used in cooking.

Animal fats and vegetable oils are usually glyceryl esters, that is esters of glycerol, propane-1,2,3-triol.



Many animal fats contain esters of stearic acid, $CH_3(CH_2)_{16}CO_2H$.

Vegetable oils often contain esters of oleic acid, $CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2H$.

(a) Draw the structural formula of the glyceryl ester formed when one molecule of glycerol is completely esterified with stearic acid.

[1]

(b) What reagent(s) would you use, in a school or college laboratory, to obtain a small sample of oleic acid, $C_{17}H_{33}CO_2H$, from the glyceryl ester present in a vegetable oil?

..... [1]

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Oleic acid is the *cis* isomer and elaidic acid the *trans* isomer of

$$CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2H.$$

(c) By using this formula, draw the structural formula of elaidic acid, clearly showing the stereochemistry.

[1]

12. M/J 10/P22/Q4/c

(a) Compound **F**, is an ester with the molecular formula $C_4H_8O_2$.

F is one of four isomers, **S**, **T**, **U**, and **V**, that are all esters.

In the boxes below, the structural formula of **S** is given.

Draw the structural formulae of the other **three** isomers of **F** that are esters.

$HCO_2CH(CH_3)_2$ **S**	**T**	**U**	**V**

[3]

13. O/N 08/P2/Q5

An organic ester, **B**, has the empirical formula C_2H_4O. An experiment by a student in a college gave a value of 87.5 for M_r of **B**.

(a) What is the molecular formula of **B**?

[1]

.....

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(b) In the boxes below, draw the structural formulae of **four** isomers of **B** that are esters.

W	**X**
Y	**Z**

[4]

The student hydrolysed his sample of **B** by heating with aqueous mineral acid and then separating the alcohol, **C**, that was formed. He heated the alcohol **C** under reflux with acidified dichromate(VI) ions and collected the product **D**.

A sample of **D** gave an orange precipitate with 2,4-dinitrophenylhydrazine reagent. A second sample of **D** gave no reaction with Tollens' reagent.

(c) **(i)** What group does the reaction with 2,4-dinitrophenylhydrazine reagent show to be present in **D**?

.....

(ii) What does the result of the test with Tollens' reagent show about **D**?

.....

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(iii) What is the structural formula of the alcohol **C**?

(iv) Which of your esters, **W**, **X**, **Y**, or **Z** has the same structure as that of the ester **B**?

..... **[4]**

(d) Which, if any of your esters, **W**, **X**, **Y**, or **Z** is chiral? Explain your answer.

.....

..... **[1]**

[10]

14. O/N 06/P2/Q5

Lactic acid, 2-hydroxypropanoic acid, $CH_3CH(OH)CO_2H$, occurs in sour milk.

Glycollic acid, 2-hydroxyethanoic acid, $HOCH_2CO_2H$, occurs in sugar cane.

(a) Lactic acid may be synthesised from propene by the following sequence.

$$CH_3CH{=}CH_2 \xrightarrow{\text{step I}} CH_3CH(OH)CH_2OH \xrightarrow{\text{step II}} CH_3CH(OH)CO_2H$$

(i) What reagent(s) and condition(s) are used for step I?

reagent(s) .....

condition(s) .....

(ii) What type of reaction is step II?

.....

[3]

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(b) Glycollic acid may be synthesised from ethanoic acid by the following sequence.

$$CH_3CO_2H \xrightarrow{\text{step III}} ClCH_2CO_2H \xrightarrow{\text{step IV}} HOCH_2CO_2H$$

(i) Suggest the reagent(s) and condition(s) that are used for step III.

reagent(s) .....

condition(s) .....

(ii) What reagents and conditions are used in step IV?

reagent(s) .....

condition(s) .....

[4]

(c) Lactic acid and glycollic acid react differently when heated under reflux with acidified dichromate(VI) ions.

Draw the structural formula of the organic product in **each** case.

product from lactic acid product from glycollic acid

(d) Lactic acid is chiral. Draw displayed formulae of the two optical isomers of lactic acid clearly showing their three-dimensional structures. Indicate with an asterisk (*) the chiral carbon atom in each.

[2]

Glycollic acid and lactic acid each give the reactions of an alcohol group and of a carboxylic acid group. Each compound will react with the other to give an ester.

(e) When one molecule of glycollic acid reacts with one molecule of lactic acid, it is possible to form two different esters.

Draw the structure of **each** of these esters.

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[2]

Glycollic acid and lactic acid are reacted together to make the material for 'soluble stitches' (also known as 'soluble sutures') which are used in surgery.

In this material, many molecules of each acid have been reacted to form a long chain 'polyester' molecule which contains many ester groups.

This polyester is used in surgery to sew up wounds inside the body.

Over a period of time, the polyester undergoes a chemical reaction and breaks up to re-form the two individual hydroxy-acids.

(f) **(i)** This reaction occurs where the pH of the body is about pH5 to pH6. Suggest what type of chemical reaction causes the polyester material to break up.

.....

(ii) Suggest why the products of this reaction are soluble in water.

.....

.....

[2]

[15]

15. M/J 04/P2/Q4

Esters are compounds which provide the flavour of many fruits and the perfumes of many flowers.

(a) The ester $CH_3(CH_2)_2CO_2CH_3$ contributes to the aroma of apples.

(i) State the reagents and conditions needed for the hydrolysis of this ester.

.....

(ii) Write the equation for the hydrolysis of this ester.

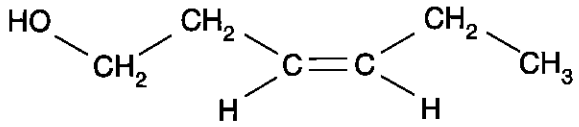
.....

(iii) Apart from their use as perfumes and food flavourings, state **one** major commercial use of esters.

..... **[3]**

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(b) Leaf alcohol is a stereoisomer that can form when insects such as caterpillars eat green leaves.



(i) Draw the other stereo-isomer of leaf alcohol.

(ii) Draw the structure for the ester formed when leaf alcohol reacts with ethanoic acid. Show **all** the bonds in the ester group.

[3]

(c) **(i)** Deduce the relative molecular mass, M_r, for leaf alcohol.

(ii) Leaf alcohol was reacted to form a product with an M_r value 18 units less.

Suggest a structure for this product and deduce the type of reaction that took place.

structure of product.

type of reaction ..... [3]

(d) Describe a simple chemical test to distinguish between leaf alcohol and your product in **(c)(ii)**.

test .....

observation ..... [2]

[11]

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16. M/J 03/P2/Q7

(a) (i) This question is about esters; esters occur naturally and are widely used.
In the boxes below, draw the structural formulae of any **three** different esters that have the molecular formula $C_5H_{10}O_2$.

(ii) Write an equation for the hydrolysis of **one** of these esters by hot, aqueous sodium hydroxide.

..... [4]

(b) State **two** general physical properties of esters.

(i) .....

(ii) ..... [2]

(c) State **two** commercial uses of esters.

(i) .....

(ii) ..... [2]

[8]

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Answers Section

1. MAR 17/P22/Q3/d(ii)

(a) (i) (compound **V** is) spectrum X [1]

spectra X and Z show a C=O (stretch) at 1730 (cm^{-1}) [1]

spectra Y and Z show O–H (stretches) above 2500 (cm^{-1}) [1]

V has a C=O (bond) and no O–H (bond) [1]

2. M/J 16/P22/Q4

(a) $CH_3CH_2CH_2COOH$ [1]

$(CH_3)_2CHCOOH$ / $CH_3CH(CH_3)COOH$ [1] [2]

(b) (i) Two from [1]
1. $CH_3CH_2COOCH_3$ 2. $CH_3COOCH_2CH_3$ 3. $HCOOCH_2CH_2CH_3$ [1] [2]

(ii) correct acid + alcohol for either ester [1]
1. methanol + propanoic acid
2. ethanol + ethanoic acid
3. propan-1-ol + methanoic acid

(conc)H_2SO_4 / (conc)H_3PO_4 AND heat / warm / reflux [1] [2]

(c) Peak at 1710–1750 (for ester) due to C(=)O [1]
Peak at 1500–1680 (for **X**) due to C(=)C / alkene [1]
Peak at 3200–3650 (for **X**) due to (alcohol) O(–)H [1] [3]

[9]

3. O/N 14/P21/Q4

(a) $CH_3CH_2CO_2H + 4[H] \rightarrow CH_3CH_2CH_2OH + H_2O$ [1+1] [2]

(b) (i) Oxidation [1] [1]

(ii) Sodium / potassium dichromate or correct formula [1]
H^+ / acidified and (heat under) reflux [1] [2]

(c) $2\ CH_3CH_2CO_2H + CaCO_3 \rightarrow (CH_3CH_2CO_2)_2Ca + H_2O + CO_2$ [1+1] [2]

(d) (i) CH_3CO_2H [1]

warm / hot / high temperature / heat / reflux **AND** concentrated sulfuric acid [1] [2]

(ii) water (or hydrogen chloride or ethanoic acid) [1] [1]

[10]

4. O/N 13/P22/Q4, O/N 13/P21/Q4

(a) (i) $H_2X + 2NaOH \rightarrow Na_2X + 2H_2O$ [1]

(ii) $n(OH^-) = \frac{21.6 \times 0.100}{1000} = 2.16 \times 10^{-3}$ mol [1]

(iii) $n(\mathbf{R}) = n(H_2X) = \frac{2.16 \times 10^{-3}}{2}$ [1]

$= 1.08 \times 10^{-3}$ mol in 25.0 cm^3

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(iv) $n(\mathbf{R}) = 1.08 \times 10^{-3} \times \frac{250}{25.0} = 0.0108$ mol in 250 cm^3 **[1]**

(v) 0.0108 mol of **R** = 1.25 g of **R**

1 mol of **R** = $\frac{1.25 \times 1}{0.0108} = 115.7 = 116$ g **[1]** **[5]**

(b) **(i)** M_r of **S** = 116
M_r of **T** = 134
M_r of **U** = 150 **all three** needed **[1]**

(ii) **S** **[1]** **[2]**

(c) **S** into **T**
conc. H_2SO_4 **followed by** H_2O
or H_3PO_4 **followed by** H_2O **or**
steam **and** H_3PO_4 catalyst **[1+1]**

S into **U**
$KMnO_4$ **[1]**
cold dilute acidified **or** cold dilute alkaline **[1]**

T into **S**
P_4O_{10} **or conc.** H_2SO_4 **or** conc. H_3PO_4 **or** Al_2O_3
and heat in each case **[1]** **[5]**

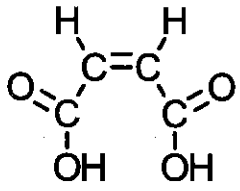
(d) **T** reacting with an excess of Na

$NaO_2CCH(ONa)CH_2CO_2Na$ **[1]**

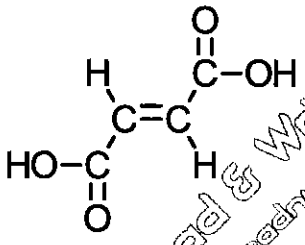
U reacting with an excess of Na_2CO_3

$NaO_2CCH(OH)CH(OH)CO_2Na$ **[1]** **[2]**

(e)



cis **or** Z

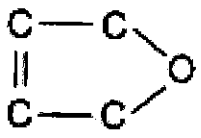


trans **or** E

two correct structures **[1]**
correct labels **[1]** **[2]**

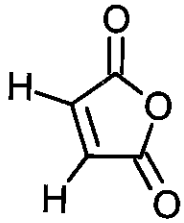
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(f) correct ring of C and O atoms, i.e.



[1]

correct compound, i.e.



(hydrogen atoms do not need to be shown) **[1] [2]**

[18]

5. O/N 13/P23/Q4

(a) (i) structural **or** functional group isomerism **[1]**

(ii) **R** primary alcohol **and** carboxylic acid – **not** 'acid' **[1]**
S primary alcohol **and** ester **[1]**
T primary alcohol **and** ester **[1]**

(iii) **with Na_2CO_3**
carboxylic acid **[1]**

(iv) **with Na**
alcohol **and** carboxylic acid **[1] [6]**

(b) (i) $n(CO_2) = \frac{24.0}{24000} = 0.001$ mol **[1]**

(ii) 0.002 mol of **Q** → 0.001 mol of CO_2
1 mol of **Q** → 0.5 mol of CO_2 **[1] [2]**

(c) (i) $n(H_2) = \frac{48.0}{24000} = 0.002$ mol **[1]**

(ii) 0.002 mol of **Q** → 0.002 mol of H_2
1 mol of **Q** → 1 mol of H_2 **[1] [2]**

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(d) **Q** is isomer **R** **[1]**

with sodium carbonate

$2HOCH_2CH_2CO_2H + Na_2CO_3 \rightarrow 2\ HOCH_2CH_2CO_2Na + H_2O + CO_2$

correct products **[1]**

balanced **[1]**

with sodium metal

$HOCH_2CH_2CO_2H + 2Na \rightarrow NaOCH_2CH_2CO_2Na + H_2$

correct products **[1]**

balanced **[1]** **[5]**

[15]

6. M/J 13/P22/Q5/a,b

(a) $C_4H_8O_2$ **[1]** **[1]**

(b)

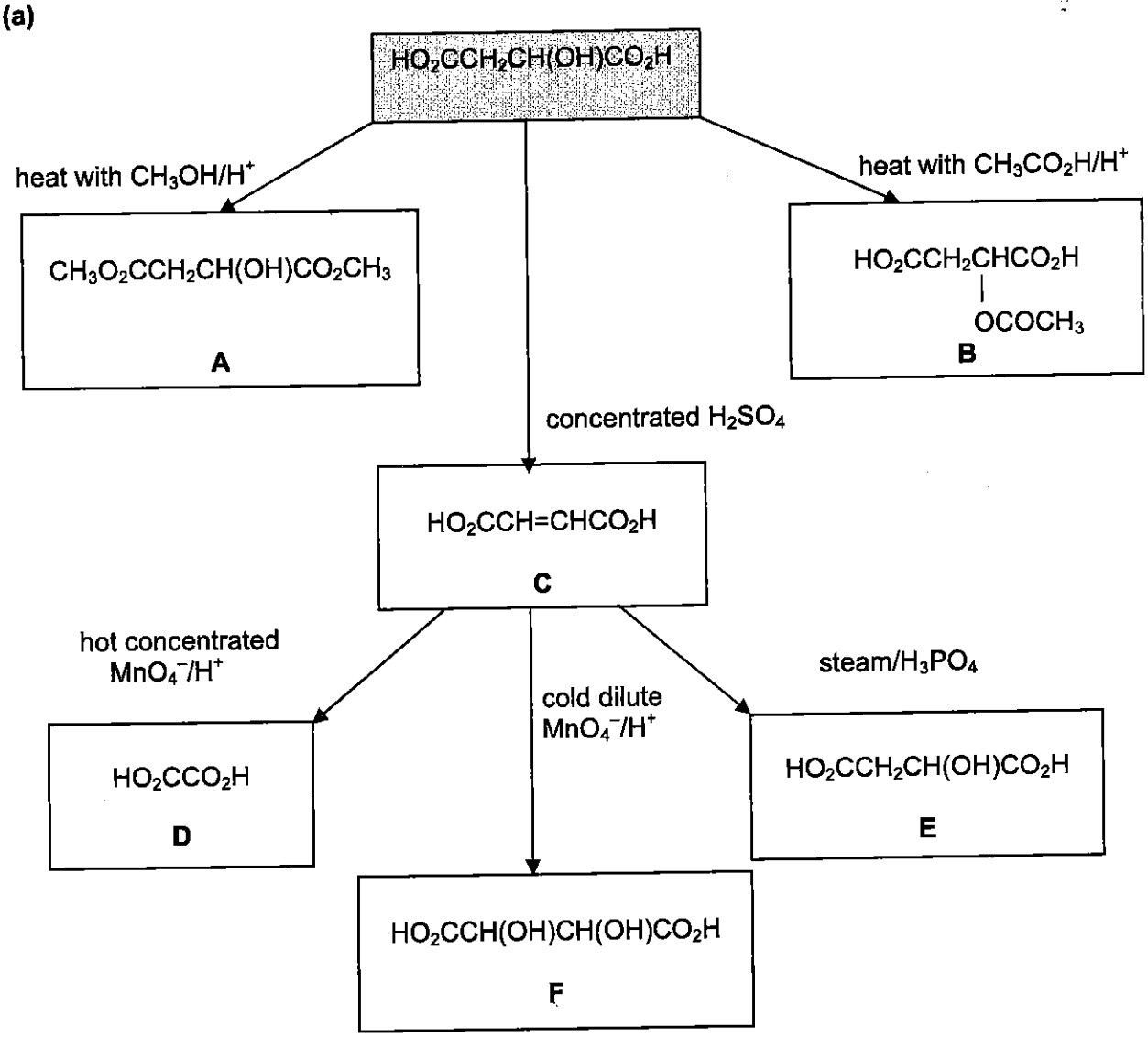
$HCO_2CH_2CH_2CH_3$ **W**	$HCO_2CH(CH_3)_2$ **X**
$CH_3CO_2CH_2CH_3$ **Y**	$CH_3CH_2CO_2CH_3$ **Z**

give one mark for each correct answer (4 × 1) [4]

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7. M/J 12/P22/Q3

(a)



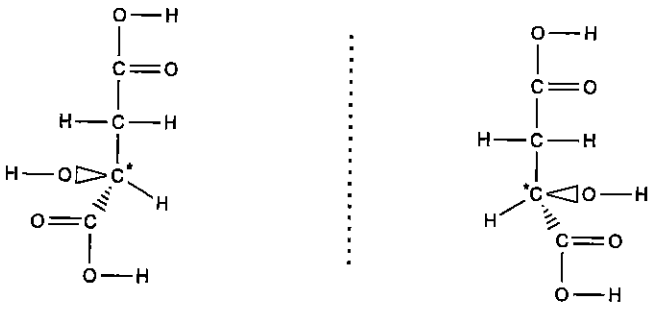
give one mark for each correct compound [6 x 1] [6]

(b) malic acid into **C** dehydration **or** elimination [1]
C into **D** oxidation [1]
C into **E** addition **or** hydration [1] [3]

(c) solvents **or** perfumes **or** flavourings [1] [1]

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(d) (i)



correct compound (malic acid) shown as a pair of enantiomers in 3D **[1]**
chiral carbon (*) atom correctly identified **[1]**
structure **fully** displayed **[1]**

(ii)



give one for each correct **skeletal formula** **[1 +1]**

correct *cis* (or Z) **and** *trans* (or E) labels **[1]** **[6]**

(e) $C : H : O = \frac{37.5}{12} : \frac{4.17}{1} : \frac{58.3}{16}$

$= 3.13 : 4.17 : 3.64$ **[1]**

$= 1 : 1.33 : 1.16$ **[1]**

$= 6 : 8 : 7$

empirical formula is $C_6H_8O_7$ **[1]** **[3]**

8 (a) **[19]**

reagent	R_2CHOH	RCHO	RCO_2H	RCO_2R'	RCOR'
$NaHCO_3$			✓		
Na	✓		✓		
$Cr_2O_7^{2-}/H^+$	✓	✓			

give one mark for each correct tick **[5 x1]** **[5]**

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9 (a) (i) CO_2/carbon dioxide **[1]**

(ii) carboxylic acid **or** $-CO_2H$ **or** $-COOH$ **[1]** **[2]**

(b) (i) dehydration **or** elimination [1]

(ii) **H** contains >C=C< bond [1]
H contains $-CO_2H$ group [1]
H is $CH_2=CHCO_2H$ [1] **[4]**

(c) $n(\mathbf{F}) = \frac{0.600}{90} = 6.67 \times 10^{-3}$ mol [1]

F contains one –OH group and one $-CO_2H$ group
hence one mole of **F** produces one mole of H_2 with Na [1]
$n(H_2) = 6.67 \times 10^{-3}$ mol [1]
vol. of $H_2 = 6.67 \times 10^{-3} \times 24000$ cm^3
$= 160$ cm^3 at room temperature and pressure [1] **[4]**

(d) (i)

$HOCH_2CH_2CO_2H$	$CH_3CH(OH)CO_2H$
J	**K**

one isomer correct [1]

(ii)

$HO_2CCH_2CO_2H$	CH_3COCO_2H
product from J	**product from K**

one oxidation product correct [1] **[2]**

[12]

10 (a) **V** is HCHO [1] **[1]**

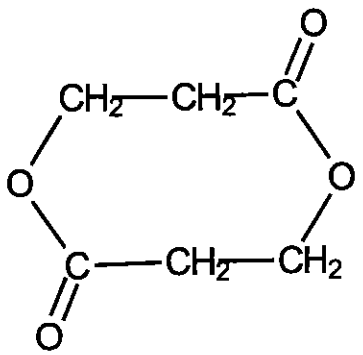
(b) (i) ester [1]

(ii) **W** is HCO_2CH_3 [1] **[2]**

(c) (i) **X** is $HOCH_2CH_2CO_2H$ [1]

(ii) **Y** is $HO_2CCH_2CO_2H$ [1] **[2]**

(d) (i) **Z** is



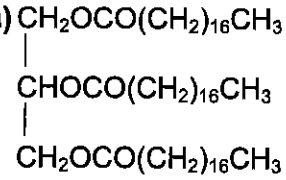
[1]

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(ii) esterification **or** dehydration **or** elimination **or** condensation **[1]** **[2]**

[7]

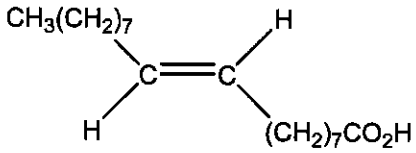
11 **(a)**



all three alcohol groups must be esterified **[1]** **[1]**

(b) dilute HC*l* **or** dilute H_2SO_4 **or** dilute mineral acid **or** NaOH(aq) **followed by** dilute acid **[1]** **[1]**

(c)



[1] **[1]**

12 **(a)** structures of **F** are

$HCO_2CH(CH_3)_2$ **S**	$HCO_2CH_2CH_2CH_3$ **T**	$CH_3CO_2CH_2CH_3$ **U**	$CH_3CH_2CO_2CH_3$ **V**

each correct structure is worth one mark **[3 x 1]** **[3]**

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13 **(a)** $C_4H_8O_2$ (1) **[3]**

(b)

$HCO_2CH(CH_3)_2$	$HCO_2CH_2CH_2CH_3$	$CH_3CO_2CH_2CH_3$ **or** $CH_3CO_2C_2H_5$	$CH_3CH_2CO_2CH_3$ **or** $C_2H_5CO_2CH_3$
W	**X**	**Y**	**Z**

each correct structure is worth (1) **[4]**

(c) **(i)** presence of >C=O group/carbonyl group (1)

(ii) –CHO group/aldehyde group is absent **or** ketone is present (1)

(iii) alcohol **C** is $(CH_3)_2CHOH$
allow e.c.f. on **(c)(i)** and **(ii)** (1)

(iv) correct identification of candidate's ester (**W** in this case)

allow e.c.f. on **(c)(iii)** (1) **[4]**

(d) none
no chiral centres are present in any of the four esters
allow e.c.f. on candidate's compounds in **(a)** (1) **[1]**

[10]

14 **Note** In parts **(a)** and **(b)** the conditions mark is only awarded if the reagent is correct.

(a) **(i)** manganate(VII) ions **[1]**

[1]

cold, dilute

(ii) oxidation **[1]**

(b) **(i)** **[1]**

chlorine

uvl **or** sunlight **[1]**

(ii) $NaOH(aq)/OH^-(aq)$ **[1]**

[1]

heat

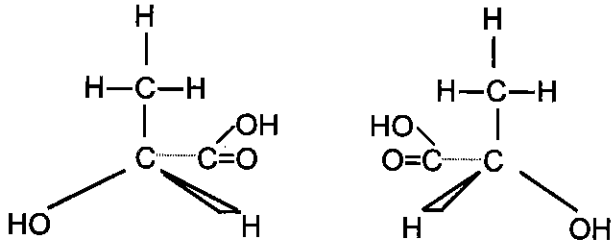
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Note: Throughout parts **(c)**, **(d)**, and **(e)** penalise **once** a wrongly drawn C–OH bond, e.g. OH-C.

(c) lactic acid → CH_3COCO_2H **[1]**

glycollic acid → HO_2CCO_2H **[1]**

(d) central C shown as chiral (C*) **[1]**



two correct three dimensional structures **[1]**

correctly displayed **[1]**

(e) $CH_3CH(OH)CO_2CH_2CO_2H$ **[1]**

$HOCH_2CO_2CH(CH_3)CO_2H$ **[1]**

(f) **(i)** hydrolysis **[1]**

(ii) hydrogen bonding **[1]**

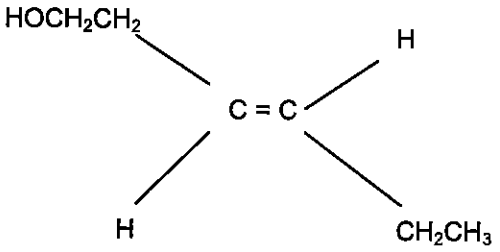
[10]

15 **(a)** **(i)** Acid or base, heating / reflux / warm **[1]**

(ii) $CH_3(CH_2)_2CO_2CH_3 + H_2O \longrightarrow CH_3(CH_2)_2CO_2H + CH_3OH$ **[1]**

(iii) Solvents (polyesters not in AS syllabus, but allow as plastics, textiles) **[1]**

(b) **(i)**

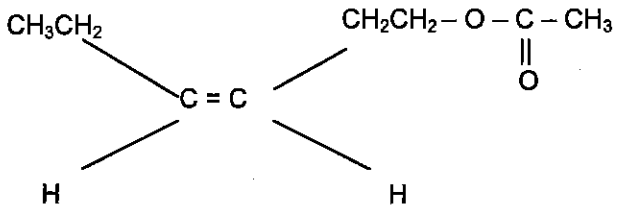


[1]

1 mark for this diagram

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(ii)



1 mark for ester link, 1 mark for rest of molecule **[3]**

(c) **(i)** $C_6H_{12}O$ 72 + 12 + 16 M_r = 100 **[1]**

$CH_2 = CH - CH = CH - CH_2CH_3$ **[1]**

dehydration / elimination **[1]**

(d) A test for an alcohol (both alcohol and the product are alkenes)

e.g. sodium	bubbles of gas
PCl_5	misty fumes
$H^+/ Cr_2O_7^{2-}$	orange turned green
conc. H_2SO_4 + carboxylic acid	ester smell

NOT Br_2 or H^+/MnO_4^- as it tests positive for both

1 mark for specified test
1 mark for the relevant observation **[2]**

[11]

16 (a) **(i)** e.g.
$CH_3CO_2C_3H_7$ $CH_3CO_2CH(CH_3)_2$ $CH_3CH_2CO_2C_2H_5$ $H\text{-}CO_2C_4H_9$
$C_3H_7CO_2CH_3$ + branches any three **[3]**

(ii) $RCO_2R' + NaOH \rightarrow RCO_2Na$ (1) + R'OH (1)
$\rightarrow RCO_2H$ + R'OH (1) only **[2]**

(b) **(i)** * volatile, or liquids (1) immiscible, with water (1) smell (1)
and (ii) any two **[2]**

(c) **(i)** solvents, perfumes, flavourings, lotions, olive or palm oils any two

and (ii) To make soap, to make Terylene **[2]**
NOT polyesters

[8]

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Yearly Past Paper

Past Paper

October / November 2017/P22
May / June 2018/P22
October / November 2018/P22
May / June 2019/P22

A-Level
Chemistry Paper 2
Topical Workbook

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October/November 2017 Paper-22

1 The elements sodium to sulfur react with chlorine. The melting points of some of the chlorides formed are shown.

chloride	NaCl	$MgCl_2$	$AlCl_3$	$SiCl_4$	PCl_3	SCl_2
melting point/K	1074	987	463	203	161	195

(a) Predict the shapes of $AlCl_3$ and PCl_3.
Draw diagrams to show the shapes, name the shapes and state the bond angles.

$AlCl_3$

shape .....

angle .....

PCl_3

shape .....

angle .....

[4]

(b) (i) Explain, in terms of structure and bonding, why the melting point of $SiCl_4$ is much lower than that of NaCl.

.....

.....

.....

.....

..... [3]

(ii) Explain why the melting point of $SiCl_4$ is higher than that of PCl_3.

.....

.....

..... [2]

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(iii) Draw the 'dot-and-cross' diagram of a molecule of $SiCl_4$.
Show outer electrons only.

[1]

[Total: 10]

2 At 450 K phosphorus(V) chloride, $PCl_5(g)$, decomposes to form phosphorus(III) chloride, $PCl_3(g)$, and chlorine, $Cl_2(g)$. A dynamic equilibrium is established as shown.

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

(a) The enthalpy change of formation of $PCl_3(g)$ under these conditions is given.

$$\Delta H_f\, PCl_3(g) = -320\,kJ\,mol^{-1}$$

Calculate the enthalpy change of formation of $PCl_5(g)$ under these conditions.

Include a sign with your answer.

enthalpy change = ... kJ mol^{-1} [1]

(b) **(i)** State and explain the effect of increasing temperature on the rate of decomposition of $PCl_5(g)$.

.....

.....

..... [2]

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(ii) State and explain the effect of increasing temperature on the percentage of $PCl_5(g)$ that decomposes.

.....

.....

..... [2]

(c) Explain the meaning of the term *dynamic equilibrium* and the conditions necessary for it to become established.

.....

.....

.....

..... [2]

(d) When 2.00 mol of $PCl_5(g)$ are decomposed at 450 K and 1.00×10^5 Pa the resulting equilibrium mixture contains 0.800 mol of $Cl_2(g)$.

(i) Calculate the partial pressure of phosphorus(V) chloride, $pPCl_5$, in this equilibrium mixture.

$pPCl_5$ = ... Pa [2]

(ii) Write the expression for the equilibrium constant, K_p, for the decomposition of $PCl_5(g)$.

K_p =

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[1]

(iii) The partial pressures of $PCl_3(g)$ and of $Cl_2(g)$ in this equilibrium mixture are both 2.86×10^4 Pa.

Calculate the value of K_p and state its units.

K_p = ...

units = ...

[2]

[Total: 12]

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3 The elements in Group 2 show trends in their properties that are typical of metals.
The elements in Group 17 show trends in their properties that are typical of non-metals.

(a) State and explain the trend in ionisation energy down Group 2.

.....

.....

..... [2]

(b) **(i)** State and explain the trend in melting point down Group 17.

.....

.....

..... [2]

(ii) The melting point decreases down Group 2.

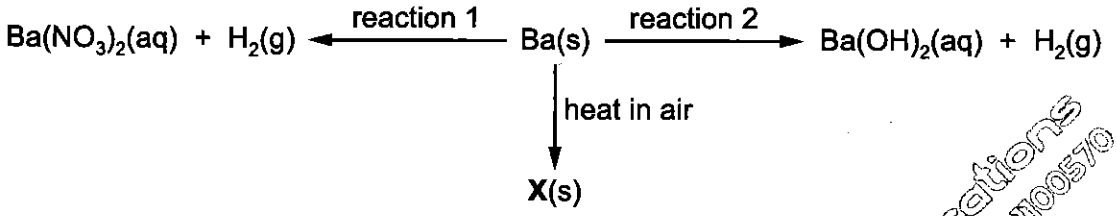
Explain this trend.

.....

.....

..... [2]

(c) Some reactions based on the Group 2 metal barium, Ba, are shown.



(i) State the reagent needed for each of reactions 1 and 2.

reaction 1 .....

reaction 2 .....
[2]

(ii) Name **X** and write an equation for its formation.

name .....

equation .....
[2]

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(iii) The $Ba(NO_3)_2(aq)$, produced by reaction 1, is heated to dryness. The anhydrous solid is then heated strongly and decomposes. Barium oxide is produced, together with two other products.

Identify the **two** other products of this decomposition reaction and state what would be observed.

.....

..... [2]

(iv) State what would be observed when excess $MgSO_4(aq)$ is added to the $Ba(OH)_2(aq)$ produced in reaction 2. Explain your answer.

.....

.....

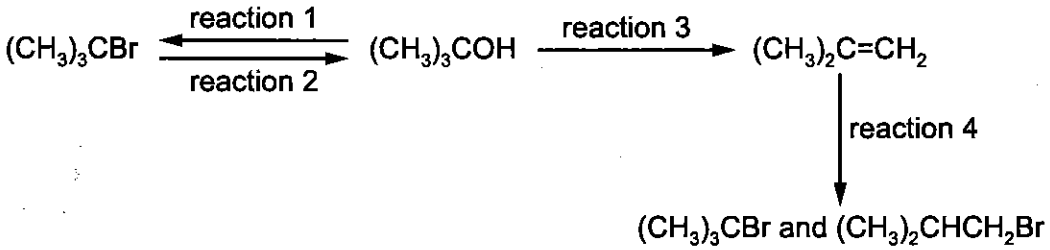
.....

..... [3]

[Total: 15]

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4 Some reactions are shown, based on methylpropan-2-ol, $(CH_3)_3COH$.



(a) For each of the reactions state the reagent(s), the particular conditions required, if any, and the type of reaction.
For the type of reaction choose from the list.
Each type may be used once, more than once or not at all.
Each reaction may be described by one or more than one type.

hydrolysis dehydration substitution

oxidation addition condensation

reaction	reagent(s) and conditions	type(s) of reaction
1		
2		
3		
4		

[5]

(b) Draw a diagram to show the S_N1 mechanism of reaction 2.
Include all necessary charges, dipoles, lone pairs and curly arrows.

[3]

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(c) 1-bromobutane is a structural isomer of the product of reaction 1.

(i) Define the term *structural isomer* and name the three different types of structural isomerism.

definition .....

.....

.....

.....

types of structural isomerism

1 .....

2 .....

3 .....

[4]

(ii) 1-bromobutane is treated with the same reagents as in reaction 2. Butan-1-ol is formed.

Identify the mechanism of this reaction.
Explain why this reaction proceeds via a different mechanism from that of reaction 2.

mechanism .....

explanation .....

.....

.....

.....

.....

[3]

(d) The product of reaction 3, methylpropene, does **not** show stereoisomerism.

(i) Give **two** reasons why methylpropene does **not** show stereoisomerism.

.....

.....

..... [2]

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(ii) Methylpropene can be polymerised to form a poly(alkene).

State the type of polymerisation and draw the repeat unit of the polymer formed from methylpropene.

type of polymerisation .....

repeat unit

[3]

(iii) State the difficulty associated with the disposal of poly(alkenes).

.....

..... [1]

(e) Name the two products of reaction 4.

name of $(CH_3)_3CBr$ .....

name of $(CH_3)_2CHCH_2Br$ .....

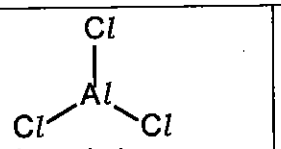
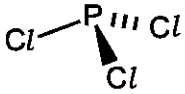
[2]

[Total: 23]

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Answers Section

1(a) 4

 trigonal planar 120°	 (trigonal) pyramid(al) 100–107°

3 marking points for each box: diagram, name and shape.
for each box:
all three correct = 2 marks
two correct = 1 mark

1(b)(i) $SiCl_4$ simple / molecular **AND** Van der Waals' / id-id forces / London / dispersion forces / IMFs 1

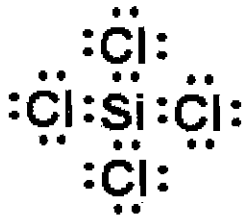
NaCl ionic **OR** giant 1

bonding (in NaCl) stronger (than forces in $SiCl_4$) owtte 1

1(b)(ii) $SiCl_4$ has more electrons ORA 1

stronger Van der Waals' / id-id forces / London / dispersion forces / IMFs 1

1(b)(iii) 1



2(a) −444 1

2(b)(i) (higher rate / rate increases) due to higher frequency of successful collisions 1

more molecules / particles with $E \geqslant E_a$ 1

2(b)(ii) (percentage decomposition of PCl_5) increases 1

(forward) reaction is endothermic 1

2(c) rates of forward and reverse / backward reactions are equal 1

closed / sealed system/container 1

2(d)(i) n_{TOTAL} = 1.20 + 0.80 + 0.80 OR 2.80 (mol) 1
OR mole fraction = 1.20 / 2.80 OR 0.429

$pPCl_5$ = 1 × 10^5 × (1.20 / 2.80) = 4.29 × 10^4 (Pa) 1

2(d)(ii) $K_p = \frac{pPCl_3 \times pCl_2}{pPCl_5}$ 1

2(d)(iii) 1.91 × 10^4 1

Pa 1

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3(a) (IE) <u>decreases / lower</u> because increasing **distance** of outer electron(s) from nucleus **1**
OR increasing distance of outer / valence shell from nucleus
OR increased **shielding** / screening (from inner shells)

reduces nuclear **attraction** (for electrons) **1**

3(b)(i) (Melting point) <u>increases / higher</u> because (molecules have an)

increasing (number of) electrons **1**

increasing strength / number / amount of IMFs / Van der Waals' / id–id / London / dispersion (forces) **1**

3(b)(ii) increased metallic / (cat)ionic radius / size **1**
OR decreasing (cat)ion charge-density

decreased attraction (of ions) for delocalised / outer electrons **1**

3(c)(i) reaction 1: HNO_3 or nitric((V)) acid **1**

reaction 2: water / H_2O **1**

3(c)(ii) barium oxide **1**

$2Ba + O_2 \rightarrow 2BaO$ **1**

3(c)(iii) NO_2 / nitrogen dioxide / nitrogen(IV) oxide **AND** O_2 / oxygen **1**

(red / yellow-)brown gas **OR** gas given off that relights glowing splint **1**

3(c)(iv) <u>white</u> ppt / solid / suspension **1**

of $BaSO_4$ / barium sulfate **OR** $Mg(OH)_2$ / magnesium hydroxide **1**

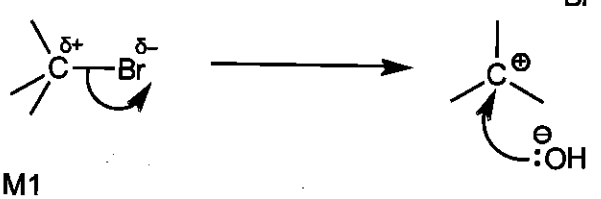
$BaSO_4$ is insoluble **OR** $Mg(OH)_2$ is insoluble / partially / slightly / sparingly soluble **1**

4(a) **5**

1	<u>c</u>oncentrated H_2SO_4 / H_3PO_4 **AND** NaBr **OR** (red) P / Br_2 **OR** HBr	substitution
2	aqueous / dilute NaOH / KOH	hydrolysis **OR** substitution
3	<u>c</u>oncentrated H_2SO_4 / H_3PO_4 **OR** Al_2O_3 / P_4O_{10} / pumice / porous pot / SiO_2	dehydration
4	(ethanolic) HBr	addition

4 marks for column 1 (one per row) *1 mark for col 2*

4(b) **3**



M1
correct dipole on $^{\delta+}C—Br^{\delta-}$ **AND** curly arrow from C—Br bond to Br

M2 correct intermediate with + charge

M3 curly arrow from lone pair on $\overset{\ominus}{:}OH$ to C^+ of carbocation

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4(c)(i) (different molecules) same molecular formula / same numbers of atoms of each (type of) element **1**

different structural formulae / displayed formulae **1**

chain / skeletal
functional group
position(al) / regioisomerism
two types correct = 1 mark, all three correct = 2 marks **2**

4(c)(ii) S_N / nucleophilic substitution **1**

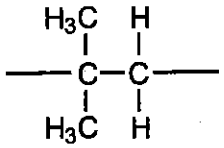
no (stable) (carbo)cation / intermediate is formed **1**

only one alkyl group / fewer alkyl / methyl groups (compared to reaction 2)
AND limited (+)I / inductive effect / less electron donating (effect) **1**

4(d)(i) mirror images are super(im)posable
OR not chiral / no chirality / no chiral/asymmetric carbon/centre / achiral **1**

one or both C/end of **double bond** has identical groups / 2 methyl groups / 2 H (atoms) **1**

4(d)(ii) addition **1**



marking points: **2**

- correct number of tetravalent carbon atoms in backbone, with extension bonds
- correct groups on backbone carbon atoms **and** only one repeat unit

4(d)(iii) not/non- biodegradable / harmful combustion products **1**

4(e) 2-bromo-2-methylpropane **1**

1-bromo-2-methylpropane **1**

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May/June 2018 Paper 22

1 Sodium and magnesium are the first two elements in the third period.

(a) Sodium and magnesium both react with cold water to produce the same type of product in solution. With sodium the solution is clear but with magnesium it appears cloudy.

(i) Write an equation for the reaction of magnesium with cold water.

..... **[1]**

(ii) Suggest why the solution is cloudy after the reaction of magnesium with cold water.

.....

..... **[1]**

(b) Group 2 elements, including magnesium, react with oxygen and with dilute acids. There are trends in both the physical and chemical properties of the elements and their compounds down the group. Reactivity generally increases from Mg to Ba.

(i) Explain why there is a general increase in reactivity from Mg to Ba.

.....

.....

..... **[2]**

(ii) Give **two** observations for the reaction of magnesium with oxygen. Write an equation for this reaction. Include state symbols.

.....

.....

equation ..... **[3]**

(iii) Write an equation for the reaction of magnesium with sulfuric acid.

..... **[1]**

(iv) Suggest why there is a general **decrease** in the melting points of the elements down Group 2.

.....

.....

.....

.....

..... **[3]**

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2 Ammonium iron(II) sulfate, $(NH_4)_2Fe(SO_4)_2$, has a relative formula mass, M_r, of 284.

(a) Define the term *relative formula mass*.

.....

.....

.....

..... **[2]**

(b) One of the cations in ammonium iron(II) sulfate is the ammonium ion, NH_4^+.

(i) Draw a 'dot-and-cross' diagram of an ammonium ion. Show outer shell electrons only.

Use × to show electrons from nitrogen.
Use • to show electrons from hydrogen.

[2]

(ii) Suggest the shape of an ammonium ion and predict the bond angle.

shape .....

bond angle .....
[2]

(c) In aqueous solution the ammonium ion acts as a weak Brønsted-Lowry acid.

(i) Explain the meaning of the term *weak Brønsted-Lowry acid*.

.....

.....

.....

..... **[2]**

(ii) Write an equation to show this behaviour of the ammonium ion in water. Include state symbols.

..... **[2]**

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(d) Mohr's salt, $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$, is the hydrated form of ammonium iron(II) sulfate.

x represents the number of moles of water in 1 mole of the salt.

A student wanted to determine the value of x. 0.784 g of the hydrated salt was dissolved water and this solution was acidified.

All of the solution was titrated with 0.0200 mol dm^{-3} potassium manganate(VII). 20.0 cm^3 of t potassium manganate(VII) solution was required for complete reaction with the Fe^{2+} ions.

(i) Use changes in oxidation numbers to balance the equation for the reaction taking place

$MnO_4^-(aq)$ + ...$Fe^{2+}(aq)$ + ...$H^+(aq)$ → .....$Mn^{2+}(aq)$ + ...$Fe^{3+}(aq)$ + ...$H_2O(l)$

(ii) State the role of the Fe^{2+} ions in this reaction.

Explain your answer.

.....

..... [

(iii) Calculate the amount, in moles, of manganate(VII) ions that reacted.

amount = ... mol [

(iv) Calculate the amount, in moles, of Fe^{2+} ions in the sample of the salt.

amount = ... mol [

(v) Calculate the relative formula mass of $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$.

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relative formula mass = ... [

(vi) Calculate the value of x.

x = ... [

3 Most vehicle fuels contain hydrocarbons obtained from crude oil.

(a) (i) State the name of the type of reaction that hydrocarbons undergo when being used as fuels.

..... [1]

(ii) Write an equation for the reaction of octane, C_8H_{18}, as a fuel, as in **(a)(i)**.

..... [2]

(b) The supply of material suitable for use as fuels directly from crude oil is **not** sufficient to meet demand. A process is carried out to make some of the larger hydrocarbon molecules more useful.

(i) Name this process.

..... [1]

As well as producing fuels, this process produces compounds suitable for use in the production of polymers. An example of such a compound is but-2-ene, $CH_3CH=CHCH_3$.

(ii) Draw the repeat unit of the polymer that is produced from but-2-ene.

[2]

(iii) Name the type of polymerisation that occurs during the production of the polymer in **(ii)**.

..... [1]

(c) Gases produced in internal combustion engines include carbon monoxide, oxides of nitrogen such as NO_2, and unburnt hydrocarbons.

These gases are removed from the exhaust before they can enter the atmosphere.

(i) State what is used to remove these gases from the exhaust.

..... [1]

(ii) Write **one** equation to show how both carbon monoxide, CO, and nitrogen dioxide, NO_2, are removed from the exhaust.

..... [1]

(iii) State the environmental consequence of allowing unburnt hydrocarbons to enter the atmosphere.

..... [1]

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(d) Vehicle fuels are treated to remove sulfur. If sulfur is present in a fuel when it is burned, SO_2 is produced and may be released into the atmosphere where it can form acid rain.

(i) Acid rain can contribute to breathing difficulties.

Identify **two** other consequences of acid rain in the atmosphere.

.....

.....

.....

..... **[2]**

(ii) NO_2 is involved in the production of acid rain from SO_2.

Give **two** equations which describe how acid rain is formed by the action of NO_2 with SO_2.

.....

..... **[2]**

(iii) NO_2 is described as a catalyst during this process.

Explain, with the use of an appropriate equation, why NO_2 is described as a catalyst.

.....

..... **[2]**

4 **W** is $CH_3COCH_2CH_3$.

(a) The reaction between **W** and alkaline aqueous iodine produces a yellow precipitate.

(i) Give the name of the compound formed as a yellow precipitate in this reaction.

..... **[1]**

(ii) Give the name of **W**.

..... **[1]**

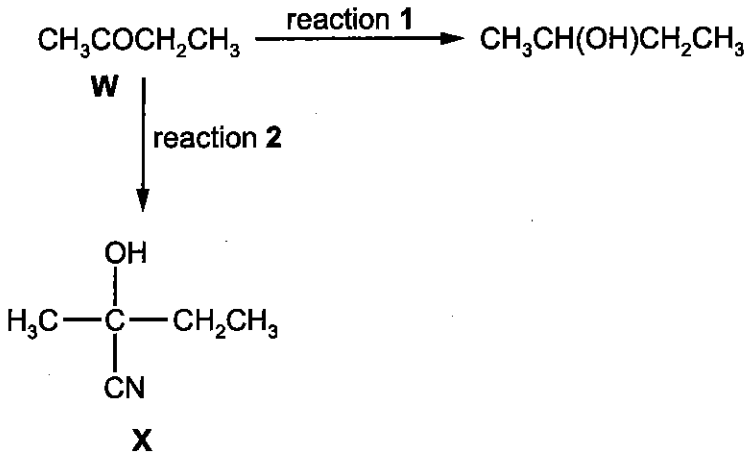
(b) There are two structural isomers of **W** that are also carbonyl compounds.

Draw the structures of these two isomers of **W**.

[2]

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Two reactions of **W** are shown.



(c) (i) Identify the type of reaction occurring in reaction **1**.

..... [1]

(ii) Identify the reagent for reaction **1**.

..... [1]

(d) Reaction **2** is carried out by adding a mixture of HCN and NaCN to **W**.
The product, **X**, is formed as a mixture of two isomers.

(i) Complete the mechanism for this reaction.

Include the structure of the intermediate formed and all necessary charges, dipoles, lone pairs and curly arrows.



[4]

(ii) State the name of the type of isomerism shown by **X**.

..... **[1]**

(iii) Explain fully why **X** shows this type of isomerism.

.....

.....

.....

..... **[2]**

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(e) If **X** is treated with ammonia and the product hydrolysed, a compound, **Y**, is obtained that contains 51.3% C, 9.40% H, 12.0% N and 27.3% O by mass.

(i) Show that the empirical formula of **Y** is $C_5H_{11}NO_2$.

[2]

(ii) The empirical formula of **Y** is $C_5H_{11}NO_2$ and the M_r of **Y** is 117.

Deduce the molecular formula of **Y**. You **must** explain your reasoning.

molecular formula = ...

.....

.....

[1]

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Answers Section

1 (a) (i) $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$ **1**

(ii) the product / $Mg(OH)_2$ sparingly soluble / slightly soluble / less soluble (than NaOH) **1**

(b) (i) *any two from:* **2**

- (from Mg to Ba) larger (atomic) radius / more shells / more shielding
- electron(s) are less tightly held (by nucleus) / less attracted (to nucleus)
- ionisation energy / ies decrease(s) / electron(s) lost (more) easily (down the group)
- lower activation energy (for the reactions down the group)

(ii) white light / white flame **1**

white smoke / white solid **1**

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$ **1**

(iii) $Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$ **1**

(iv) *any two from:* **2**

- increasing (cation) size / (cat)ionic radius increases / increasing size of atoms
- overall charge on (cation) is constant / (+)2 / decreasing charge density of (+2 charged cation)
- number of delocalised / outer / valence electrons (per atom) remains the same / 2
- increased shielding

decreasing (strength of) attraction between (cat)ion / nucleus / nuclear charge **AND** delocalised electron(s) **1**

2 (a) *option 1:* **2**

the mass of (all the atoms/ions in) a formula (unit) / molecule OR the (weighted) average / (weighted) mean mass of (all the atoms / ions in) the formula (unit) / molecule [1]

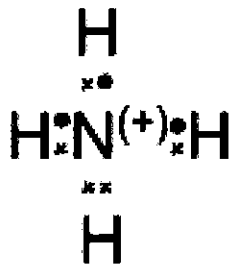
relative / compared to 1 /12 (the mass of an atom) of carbon–12 OR on a scale in which a carbon–12 (atom / isotope) has a (mass) of (exactly) 12 (units) [1]

option 2:

mass of one mol of a compound / formula (unit) / molecule [1]

relative compared to 1 / 12 (the mass) of 1 mol of C-12 OR in which one mol C-12 (atom / isotope) is (a mass of exactly) 12 g [1]

(b) (i)



4 shared pairs only (any symbols) (in NH_4) **1**

3 × dot-and-cross bonds AND 1 × 2 crosses (in NH_4) **1**

(ii) tetrahedral **1**

109–109.5° (inclusive) **1**

(c) (i) *in any order explain meaning of:* **2**

weak

partially ionises / incompletely dissociates (into ions)

Bronsted-Lowry acid

is a proton donor / H^+ (ion) donor / hydrogen ion donor

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(ii) $NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq \text{ or } g) + H_3O^+(aq)$
all correct species and balancing 1
correct state symbols 1

(d) (i) $MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$ 1

(ii) (Fe^{2+} is a) reducing agent / reductant 2
provides/donates electron(s) / loses electron(s) / increases its oxidation number / (Fe^{2+}) becomes Fe^{3+}

(iii) 4×10^{-4} / 0.0004 1

(iv) 2×10^{-3} / 0.002 1

(v) 392 1

(vi) 6 1

3 (a) (i) combustion 1

(ii) $C_8H_{18} + 12\frac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$
correct species 1
correct balancing 1

(b) (i) cracking 1

(ii) $-CH(CH_3)CH(CH_3)-$
OR



even number of C's in correct backbone with 'end bonds' AND no C=C 1
CH_3 and H on each of two C drawn for 1 repeat unit only AND all the carbons must be tetravalent 1

(iii) addition 1

(c) (i) catalytic converter / catalyst 1

(ii) $2CO + NO_2 \rightarrow 2CO_2 + \frac{1}{2}N_2$ 1

(iii) (photochemical) smog / fog / haze 1
OR
global dimming
any 2 from: 2
lowers pH / increases acidity of rivers / lakes / oceans / seas / soil
kills/harms fish OR harms / kills coral / plants / crops / trees
leaches (toxic) aluminium (ions / salts) from soil (into rivers / lakes)
leaches away soil nutrients
damages / weathers / erodes buildings / statues

(d) (i) $NO_2 + SO_2 \rightarrow NO + SO_3$ 1

(ii) $SO_3 + H_2O \rightarrow H_2SO_4$ 1

(iii) (it is) regenerated / not used up / undergoes temporary chemical change / recovered unchanged 1
$NO + \frac{1}{2}O_2 \rightarrow NO_2$ 1

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4 (a) (i) iodoform / tri-iodomethane **1**

(ii) butanone **1**

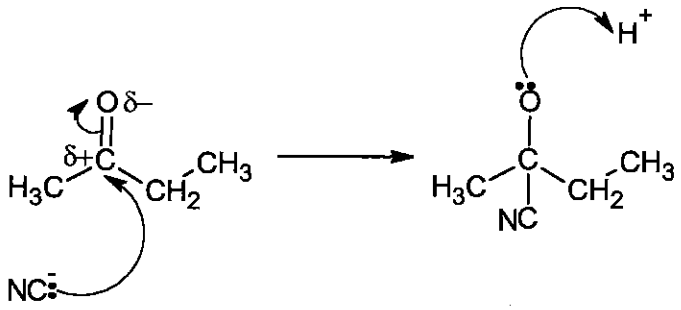
(b) $CH_3CH_2CH_2CHO$ **1**

$(CH_3)_2CHCHO$ **1**

(c) (i) reduction **1**

(ii) $NaBH_4$ / sodium borohydride **1**
OR
$LiAlH_4$ / lithium aluminium hydride

(d) (i)



lone pair on C of CN^- and curly arrow to C of C=O **1**

correct dipole on C=O and curly arrow from = to O **1**

correct intermediate anion **1**

curly arrow from lone pair on O to H^+ **1**

(ii) optical **1**

(iii) (X has a) chiral centre / asymmetric carbon atom **1**
OR
(X has a) C atom attached to four different groups / atoms / chains
non-super(im)posable mirror images **1**

(e) (i) *M1 is for the process of taking the % of each element and dividing by its relative atomic mass.* **2**

C	H	N	O
$\frac{51.3}{12}$	$\frac{9.40}{1}$	$\frac{12.0}{14}$	$\frac{27.3}{16}$

OR

4.28	9.40	0.857	1.71

M2 is for dividing the smallest %/A_r into each of the remaining values to produce the correct ratio.

$\frac{4.28}{0.857}$	$\frac{9.40}{0.857}$	$\frac{0.857}{0.857}$	$\frac{1.71}{0.857}$

OR

4.9942 : 10.9685 : 1 : 1.9953

(ii) $C_5H_{11}NO_2$ **AND** because the EFM = RFM **1**

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October/November 2018 Paper 22

1 The model of the nuclear atom was first proposed by Ernest Rutherford. He developed this model on the basis of results obtained from an experiment using gold metal foil.

(a) Complete the table with information for two of the particles in an atom of ^{197}Au.

particle	relative mass	relative charge	location within atom	total number in an atom of ^{197}Au
electron	0.0005	–1		79
neutron			nucleus	

[4]

(b) State the type of bonding in gold.

..... **[1]**

(c) A sample of gold found in the earth consists of only one isotope.

(i) Explain what is meant by the term *isotopes*.

.....

.....

..... **[2]**

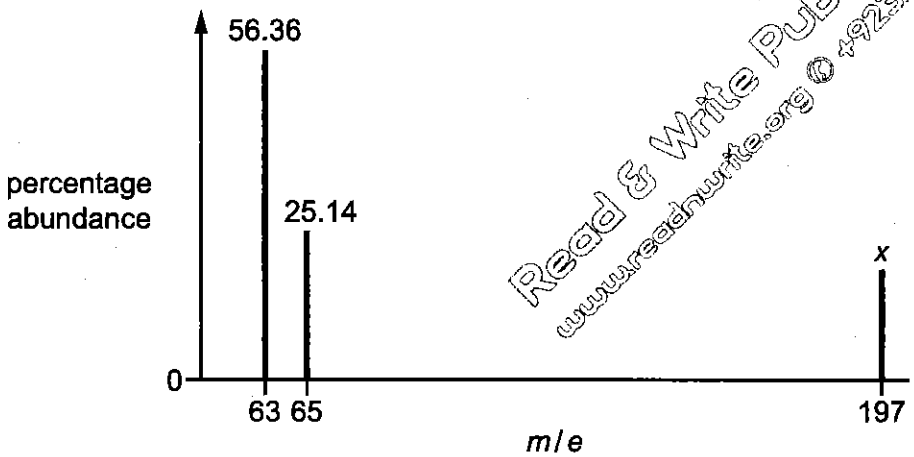
(ii) A different sample of gold contains more than one isotope.

Suggest why this different sample of gold has the same **chemical** properties as the sample found in the earth.

.....

..... **[1]**

(d) *Tumbaga* is an alloy of copper and gold. A sample of tumbaga was analysed. The mass spectrum of the sample is shown.



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(i) Calculate the percentage abundance of gold, x, in the sample of tumbaga.

x = ... % **[1]**

(ii) Calculate the relative atomic mass, A_r, of the copper present in this sample.
Give your answer to **two** decimal places.

A_r (Cu) = ... **[2]**

2 The table gives some data for elements in the third period and some of their compounds.

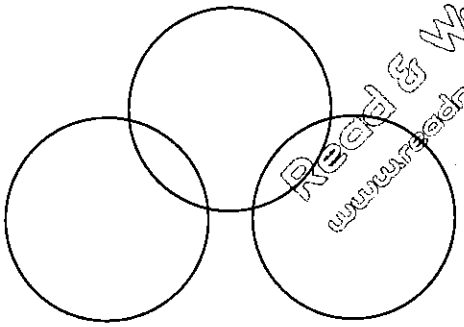
element	Na	Mg	Al	Si	P	S
type of bonding	metallic				covalent	covalent
formula of oxide					P_4O_{10}	SO_2
formula of chloride	NaCl	$MgCl_2$				SCl_2

(a) Complete the table to show the bonding in the elements, and the formulae of their oxides and chlorides. **[3]**

(b) SCl_2 is formed in the following reaction.

$$S_2Cl_2(l) + Cl_2(g) \rightleftharpoons 2SCl_2(l) \qquad \Delta H = -40.6\ kJ\ mol^{-1}$$

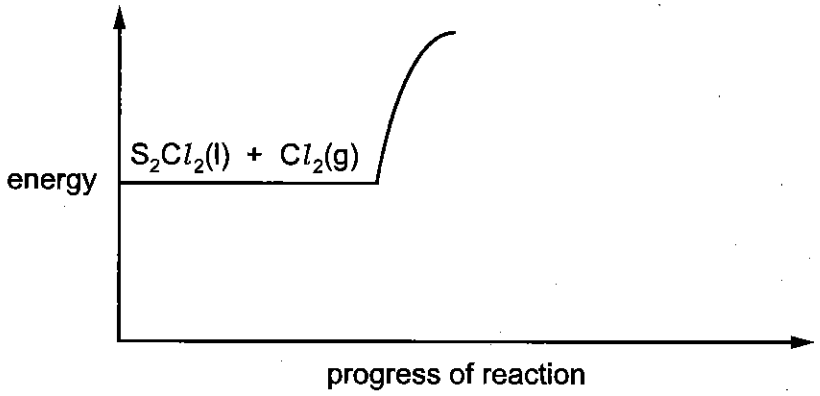
(i) Complete the 'dot-and-cross' diagram to show the bonding in a molecule of SCl_2. Show outer electrons only.



[1]

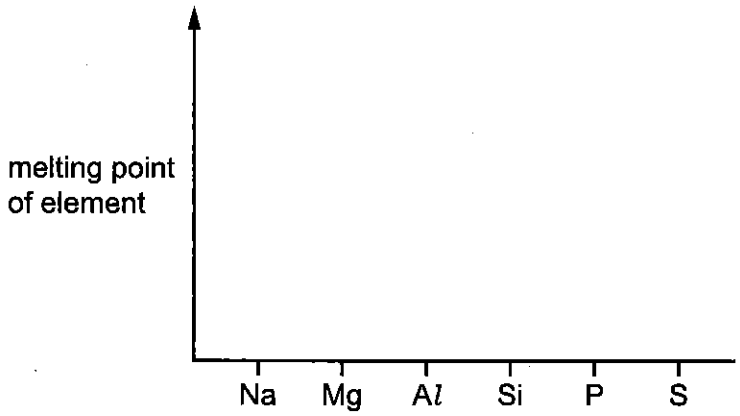
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(ii) Complete and fully label the reaction pathway diagram for the reaction between S_2Cl_2 and Cl_2. Include labels for activation energy, E_a, and enthalpy change of the forward reaction, ΔH.



[2]

(c) (i) On the axes, sketch the trend in melting point of the elements Na to S.



[1]

(ii) Give three statements to explain your sketch.

1 .....

.....

2 .....

.....

3 .....

.....

[3]

(d) Write an equation for the reaction of P_4O_{10} with water.

..... [1]

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(e) SO_2 can be released into the atmosphere when fossil fuels containing sulfur are burnt.

State and explain one environmental consequence of the release of SO_2 into the atmosphere.

.....

.....

.....

..... [2]

(f) The elements in the third period show a general increase in their first ionisation energies from left to right.

Identify **two** pairs of successive elements in the third period that do **not** agree with this statement.

For each pair, explain why the change in ionisation energy does **not** agree with this statement.

Use of the Data Booklet may help you to answer this question.

pair 1 .....

explanation .....

.....

.....

.....

.....

pair 2 .....

explanation .....

.....

.....

.....

.....

[4]

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3 Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example CHF_3.

(a) The equation shows a reaction to produce CHF_3.

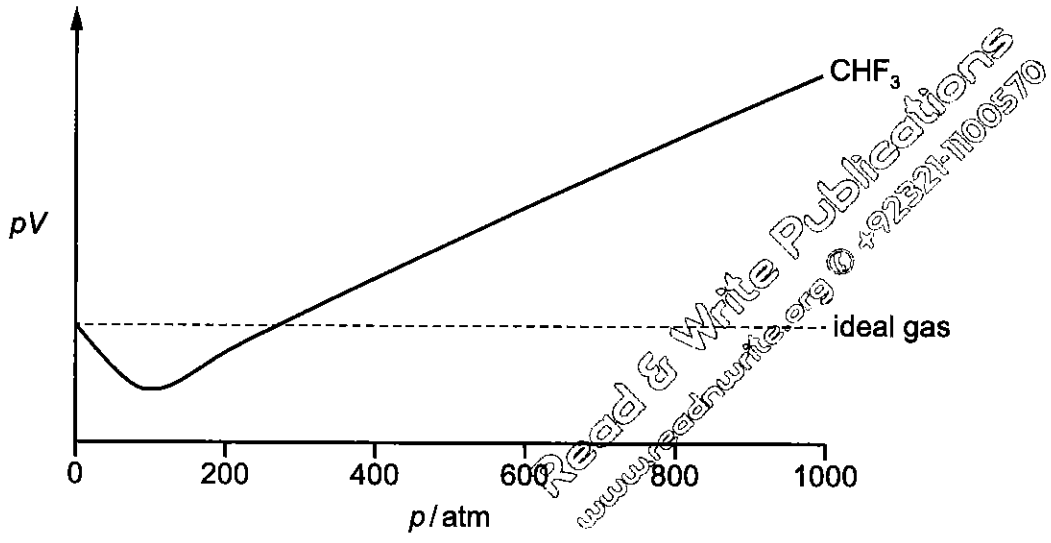
$$CHI_3(s) + 3AgF(s) \rightarrow CHF_3(g) + 3AgI(s)$$

Use the data to calculate the enthalpy change of reaction, ΔH_r, for this formation of CHF_3.

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$CHI_3(s)$	–182.1
$CHF_3(g)$	–692.9
AgF(s)	–204.6
AgI(s)	–61.8

enthalpy change of reaction, ΔH_r = ... kJ mol^{-1} **[3]**

(b) The graph shows the relationship between pV and p at a given temperature for CHF_3 and an ideal gas.



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(i) CHF_3 is not an ideal gas.

State **three** basic assumptions that scientists make about the properties of ideal gases.

1 .....

2 .....

3 ..... **[3]**

(ii) Explain why CHF_3 deviates from the properties of an ideal gas at pressures greater than 300 atm.

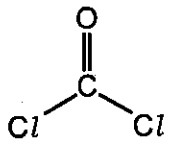
.....

.....

.....

..... **[2]**

(c) A different trihalomethane, $CHCl_3$, reacts with O_2 to produce carbonyl dichloride. $HCl(g)$ is also released as a product of this reaction.

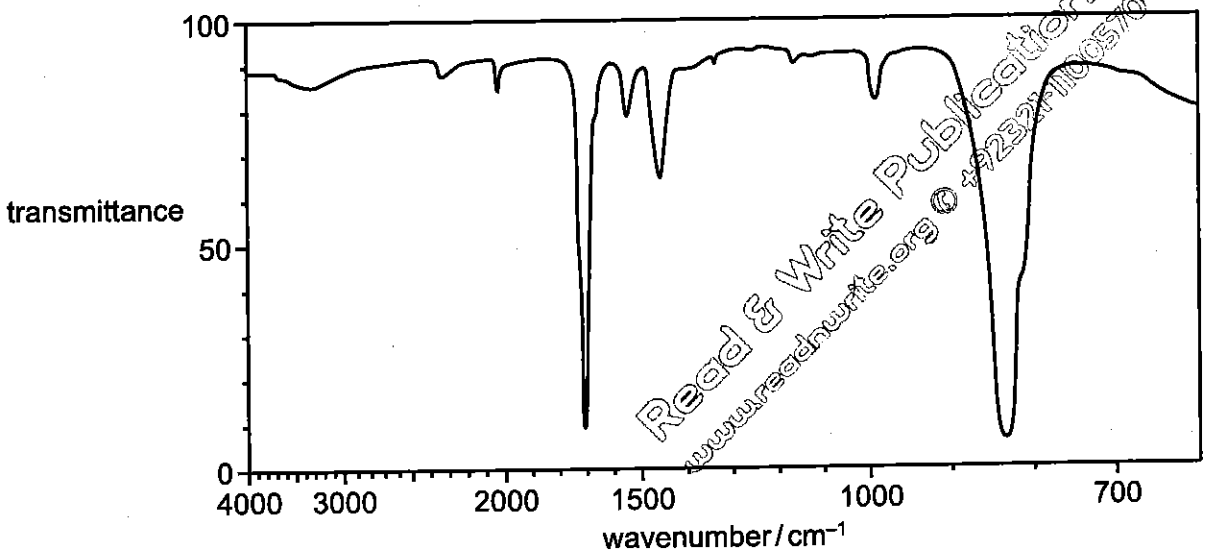


carbonyl dichloride

(i) Write an equation for this reaction of $CHCl_3$ with O_2.

..... [1]

(ii) The conversion of $CHCl_3$ to carbonyl dichloride can be monitored by infra-red spectroscopy. The infra-red spectrum of carbonyl dichloride is shown.



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On the infra-red spectrum of carbonyl dichloride identify with an **X** the absorption that would **not** be present in an infra-red spectrum of $CHCl_3$.

Explain your answer.

.....

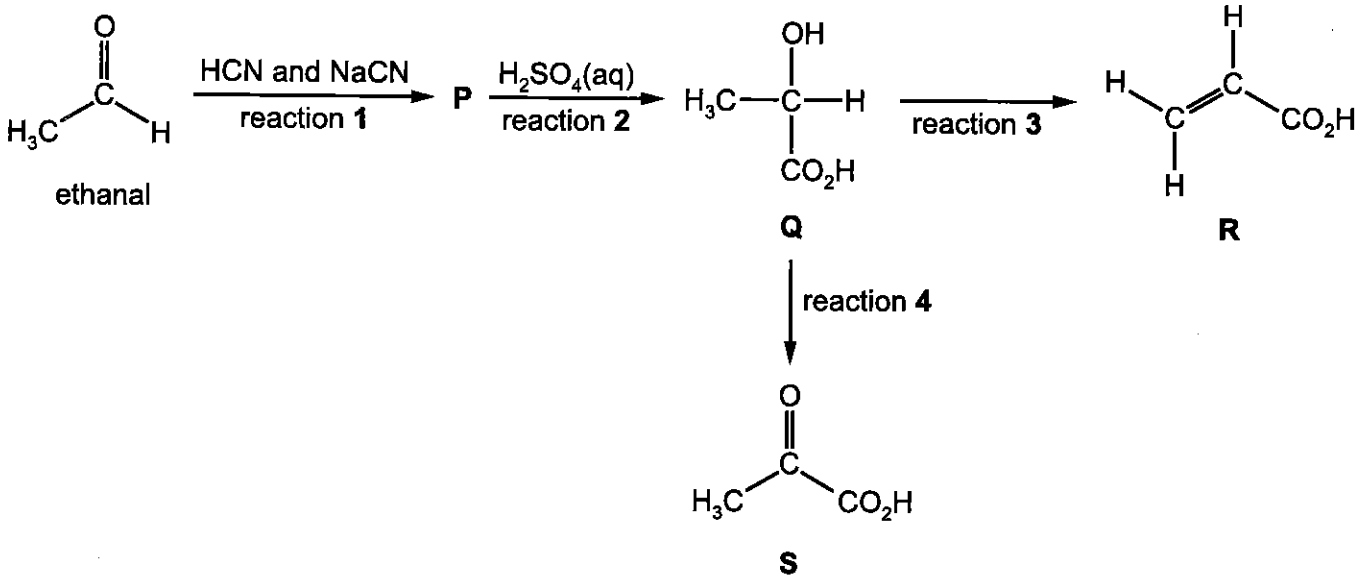
..... [2]

(iii) Suggest another difference between the infra-red spectra of $CHCl_3$ and carbonyl dichloride.

.....

..... [1]

4 The diagram shows a reaction sequence starting from ethanal.



(a) (i) Draw the **displayed** formula of **P**.

(ii) Name the type of chemical reaction that occurs in reaction 3.

[1]

..... [1]

(iii) Write an equation to represent reaction 4.
Use [O] to represent the oxidising agent.

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..... [1]

(iv) State the reagents and conditions for reaction **4**.

..... [1]

(b) Compound **Q** is formed as a mixture of two optical isomers.

(i) Explain what is meant by the term *optical isomers*.

.....

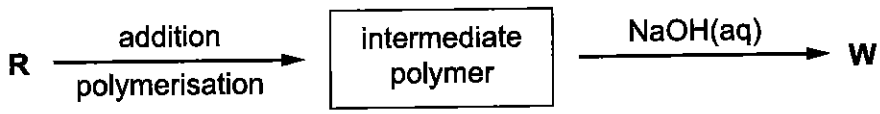
.....

..... [1]

(ii) Draw the **two** optical isomers of **Q**, showing clearly their three-dimensional structures.

[2]

(c) **R** can be used to make a polymer, **W**, in two steps.



Draw one repeat unit of **W**.

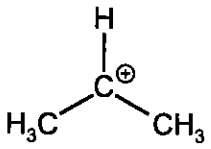
[3]

(d) Compound **Z**, $H_2C{=}CHCH_3$, is produced from **R**.

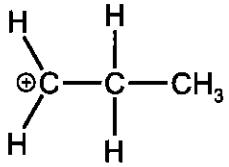
Z can be used in a two-step process to produce 2-aminopropane.

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(i) In the first step, **Z** reacts with HBr to form two products. The structure of the product depends on which intermediate is formed, intermediate **I** or intermediate **II**.



intermediate **I**



intermediate **II**

Explain why intermediate **I** is more likely to form than intermediate **II**.

.....

.....

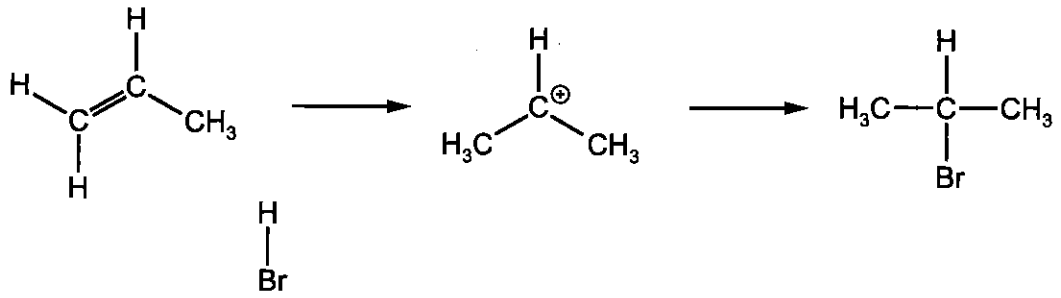
.....

..... [2]

(ii) When intermediate **I** forms, the product of the first step is **T**.

Complete the diagram to show the mechanism for the conversion of **Z** to **T**.
Include all relevant charges, partial charges, curly arrows and lone pairs.

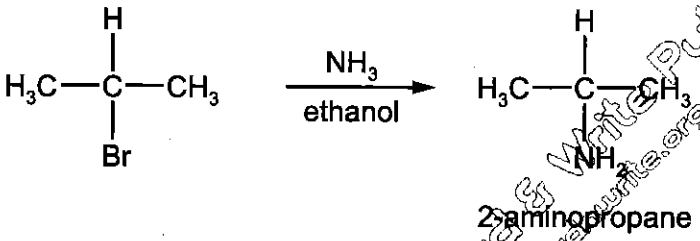
Z **T**



[3]

(iii) **T** can then be converted to 2-aminopropane.

T



2-aminopropane

Name the mechanism for this conversion.

..... [1]

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(e) (i) Compound **S**, CH_3COCO_2H, can be reduced by $LiAlH_4$.

Complete the equation using structural formulae to represent this reaction.
Use [H] to represent the reducing agent.

CH_3COCO_2H + ... [2]

Other reducing agents containing Group 1 metal cations include $LiBH_4$, $NaBH_4$ and KBH_4.
The strength of the reducing agent depends on the size of its cation.

(ii) Give the electronic configuration of the Na^+ cation.

$1s^2$ ..... [1]

(iii) Suggest why ionic radius increases down Group 1.

.....

.....

..... [1]

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Answers Section

1 (a)

particle	relative mass	relative charge	location	total number in an atom of $^{197}_{79}Au$
electron	0.0005	−1	**shell(s)** [1]	79
neutron	**1.(001)** [1]	**0** [1]	nucleus	**118** [1]

(b) metallic **4**

(c) (i) **M1** (atoms of the same element) with the same proton / atomic number [1] **2**
M2 (but) different number of neutrons/mass number [1]

(ii) same number of electrons/electronic structure **1**

(d) (i) (100 – 56.36 – 25.14) = 18.5(0)

(ii) **M1** correct use of ^{63}Cu and ^{65}Cu and their % abundance [1] **2**
M2 ÷ (56.36 + 25.14) **AND** answer correct to two decimal places [1]

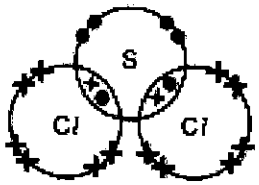
2 (a)

Na	Mg	Al	Si	P
metallic	metallic	metallic	covalent	covalent
Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}
$NaCl$	$MgCl_2$	$AlCl_3$	$SiCl_4$	PCl_5

3

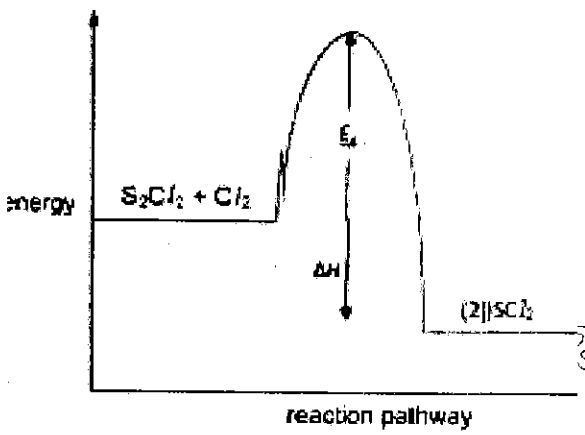
[1] for each correct row

(b) (i)



1

(ii)



2

M1 profile for exothermic reaction [1]
M2 identification of ΔH and E_a [1]

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(c) (i) graph rises to maximum for Si, then falls ntification of 1

(ii) **Max. 3 from:** 3
- increasing strength of metallic bond; Na < Mg < Al
  OR
  stronger attraction between delocalised electrons and (positive) ion so melting point of Na < Mg < Al
- Si is giant covalent **AND** it has the highest melting point due to breaking / presence of strong (covalent) bonds
  OR
  Si requires the most energy because the covalent bonds in Si are stronger than metallic bonds (in Na / Mg / Al)
- P and S have weak(er) intermolecular forces / induced dipoles / van der Waals forces (than covalent / so have low(er) melting points
- $S_{(8)}$ has stronger / more intermolecular forces / van der Waals forces / induced dipoles than $P_{(4)}$ so melting point of $S_{(8)}$ is higher

(d) $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$ 1

(e) **M1** acid rain [1] 2
M2 any of the following [1]
- lowers pH / increases acidity of rivers / lakes / oceans / water supplies / seas / soil / ground water
- kills / harms / damages fish / coral / aquatic life / plants / crops / trees or deforestation
- leaches (toxic) aluminium (ions / salts) from soil (into rivers/lakes)
- leaches away soil nutrients / soil unfit for agriculture
- damages / weathers / erodes / destroys buildings / statues
- causes breathing difficulties

(f) **M1** process of 'first ionisation energy' involves the loss/removal of an electron [1] 4
M2 Mg and Al **AND** S and P (in either order) [1]
M3 For Al **3p** (orbital / sub-level / sub-shell) is higher in energy / further from the nucleus / more shielded (than Mg) [1] ora
M4 For S the pair of electrons in the (3)p-orbital repel [1] ora

3 (a) $\Delta H_r = (-692.9)+3(-61.8)- (-182.1) -3(-204.6)$ 3
$= -82.4$ (kJ mol^{-1})
M1 $\Delta H_r = x(-692.9) + y(-61.8) - v(-182.1) - w(-204.6)$ where x y v and w are integers ≥ 1 [1]
M2 use of correct stoichiometry where $x = 1$ $y = 3$ $v = 1$ and $w = 3$ [1]
M3 –82.4 [1]

(b) (i) 1 mark for each bullet, max 3 3
- particles / molecules have (mass but) negligible size / volume (compared to total volume of gas / container)
- no / negligible forces / interactions between particles / molecules
- collision between particles / molecules are elastic
- gas obeys (all) basic gas laws

(ii) **M1** particles / molecules are (so) close [1] 2
M2 particle / molecule size becomes significant [1]
OR
repulsive forces between particle / molecules become significant

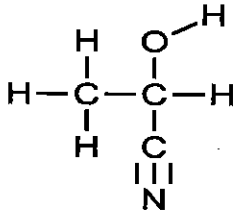
(c) (i) $CHCl_3 + \frac{1}{2}O_2 \rightarrow COCl_2 + HCl$ 1

(ii) **M1 X** marked on peak at 1670–1740 cm^{-1} [1] 2
M2 $CHCl_3$ has no C=O [1]

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(iii) (It / $CHCl_3$ has a) peak at 2850–2950 (cm^{-1})
OR
carbonyl dichloride spectrum has no peak 2850–2950 (cm^{-1})

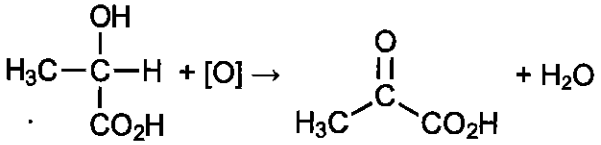
3 (a) (i)



1

(ii) dehydration 1

(iii)

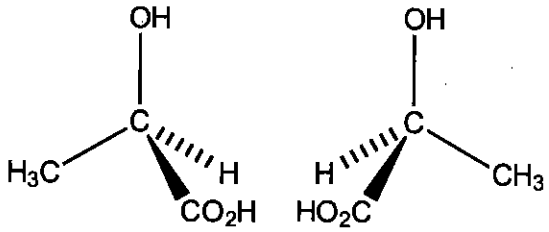


1

(iv) $Na_2Cr_2O_7$ / $K_2Cr_2O_7$ **AND** (dilute) H_2SO_4 / $H^+(aq)$ / acidified 1

(b) (i) (Molecules that are) non-super(im)posable mirror images 1

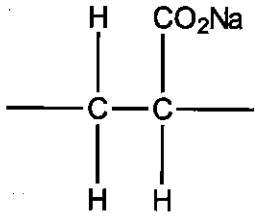
(ii)



2

M1 correct 3-d drawing of one isomer of Q [1]
M2 correct pair of 3-d structures of the optical isomers of Q [1]

(c)

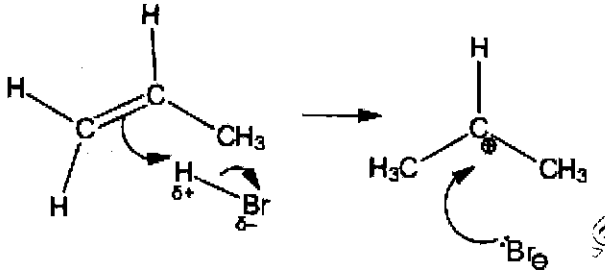


3

OR
$-CH_2CH(CO_2Na)-$

(d) (i) **M1** I experiences a (greater positive) inductive effect due to more alkyl groups 2
OR I contains more electron donating alkyl groups (than II) [1]
M2 which stabilises the charge / reduces the charge (on the ion/intermediate)
OR
spreads the charge across the ion / molecule / intermediate [1]

(ii)



3

M1 curly arrow from double bond to H of H—Br [1]
M2 curly arrow from H—Br bond to Br **AND** correct dipole on H—Br [1]
M3 curly arrow from lone pair on Br^- to C^+ [1]

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(iii) nucleophilic substitution **1**

(e) (i) $CH_3COCO_2H + 6[H] \rightarrow CH_3CHOHCH_2OH + H_2O$ **2**

M1 correct organic product $CH_3CHOHCH_2OH$ [1]

M2 [H] present as reactant with H_2O as product and balancing [1]

(ii) $1s^2\ 2s^2\ 2p^6\ (3s^0)$ **1**

(iii) Ions/elements have more shells/ energy levels (as the group is descended) **1**

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May/June 2019 Paper 22

1 Methylpropane, $(CH_3)_2CHCH_3$, is an isomer of butane, $CH_3(CH_2)_2CH_3$.

(a) (i) Explain why methylpropane and butane are a pair of isomers.

.....

..... **[2]**

(ii) Identify the type of isomerism shown by methylpropane and butane.

..... **[1]**

(b) When a sample of butane is heated to 373 K, in the presence of a catalyst, and allowed to reach equilibrium the following reaction occurs.

$$CH_3(CH_2)_2CH_3(g) \rightleftharpoons (CH_3)_2CHCH_3(g) \qquad \Delta H = -8.0\,kJ\,mol^{-1}$$

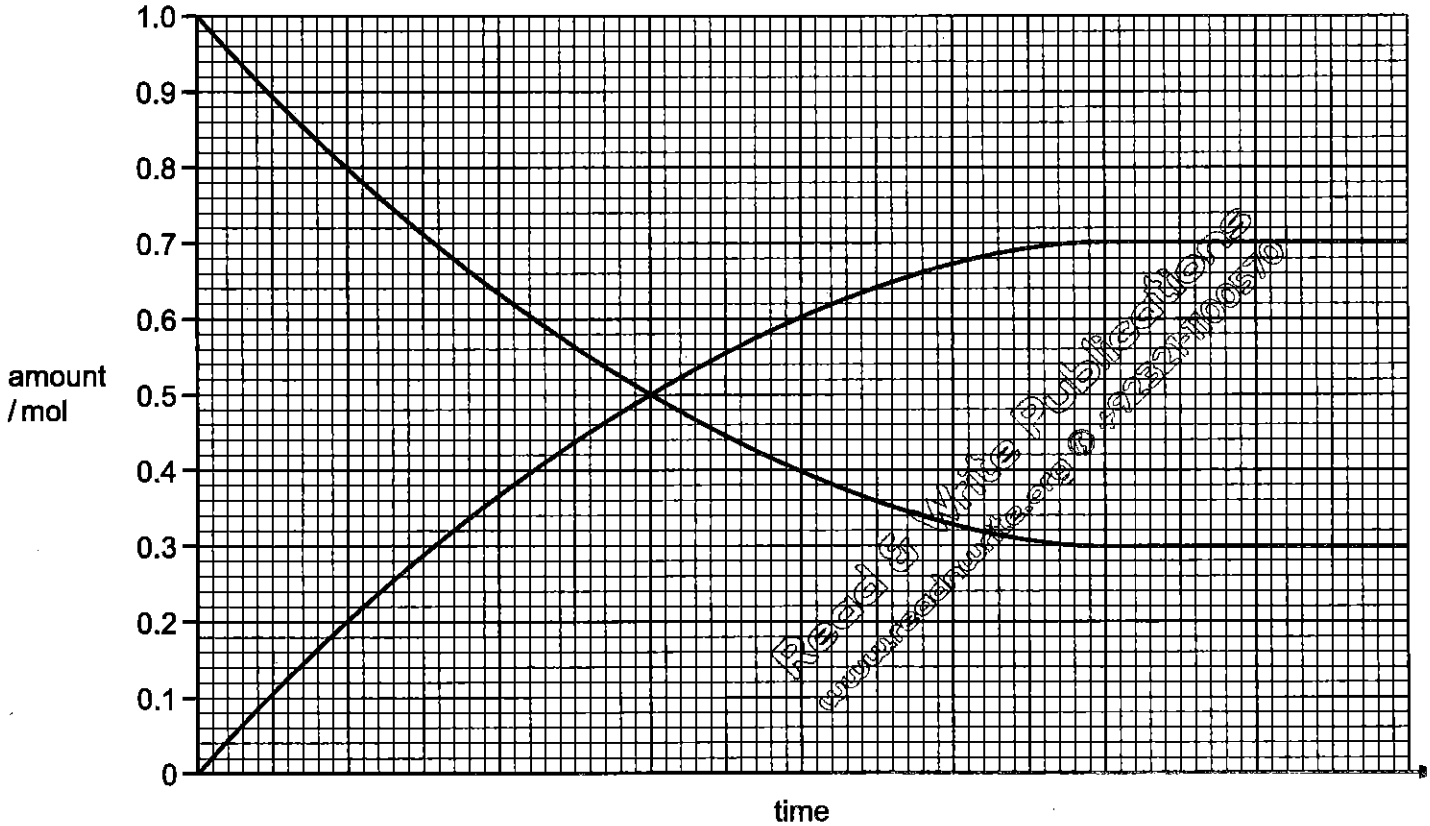
State and explain the effect on the composition of this equilibrium mixture when the temperature is increased to 473 K.

.....

.....

..... **[2]**

(c) 1 mole of butane gas was added to a 1 dm^3 closed system, at a constant temperature and pressure. The amount of butane and methylpropane was measured at regular time intervals.



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(i) Label the graph with a *t* to show the time taken to reach dynamic equilibrium. [1]

(ii) Use the graph to find the concentration of butane and methylpropane in the mixture at equilibrium.

concentration of butane = ... $mol\,dm^{-3}$

concentration of methylpropane = ... $mol\,dm^{-3}$ [1]

(iii) Write an expression for K_c for this reaction.

[1]

(iv) Calculate a value for K_c and state its units.

K_c = ... units = ... [2]

2 Group 17 elements are commonly referred to as the halogens.

(a) State and explain the trend in volatility of chlorine, bromine and iodine down the group.

.....

.....

.....

..... [3]

Hydrogen gas reacts with the different halogens under different conditions.

(b) (i) State the conditions required for chlorine to react with hydrogen at room temperature.

..... [1]

(ii) On heating, iodine reacts with hydrogen in a reversible reaction.

Give the equation for this reaction. Include state symbols.

..... [2]

(c) Hydrogen chloride reacts with water.

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

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(i) In this reaction, one of the reactants behaves as a Brønsted-Lowry acid.
What is meant by the term *Brønsted-Lowry acid*?

.....

..... [1]

(ii) Identify the reactant behaving as an acid and its conjugate base.

acid .....

conjugate base .....
[1]

(iii) Name the type of bond formed between H^+ and H_2O to make H_3O^+.

..... [1]

(iv) For H_3O^+, predict its shape and the H–O–H bond angle.

shape .....

bond angle .....
[2]

3 Period 3 elements react with chlorine gas, $Cl_2(g)$, to form chlorides.

(a) The table shows the differences in observations which occur when two Period 3 chlorides are added to water.

Period 3 chloride	observations when added to water	pH of solution formed with water
NaCl	White solid disappears. Colourless solution made.	7
$SiCl_4$	Pale yellow solution forms. Bubbles form and the test-tube feels hot. White precipitate forms.	1–2

(i) Write an equation for the reaction occurring when $SiCl_4$ is added to cold water. Include state symbols.

..... [1]

(ii) Name the type of reaction occurring when $SiCl_4$ is added to water.
Ignore the exothermic/endothermic nature of the reaction.

..... [1]

(iii) Explain, in terms of bonding, why NaCl and $SiCl_4$ behave differently when added to water.

.....

.....

..... [2]

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(iv) Explain, in terms of electronegativity, why the bonding in NaCl is different from the bonding in $SiCl_4$.

.....

.....

.....

..... **[3]**

(b) $Cl_2(g)$ dissolves in cold water and reacts with it.

$$Cl_2 + H_2O \rightarrow HCl + HClO$$

(i) Identify the oxidation number of chlorine in each of the chlorine-containing species in this reaction.

chlorine-containing species	Cl_2	HCl	HClO
oxidation number of chlorine			

[2]

(ii) Name the type of reaction occurring.

..... **[1]**

(iii) Explain why chlorine is used in the purification of water.

.....

..... **[1]**

(c) A mixture of HCl and HClO is added to cold dilute NaOH. One of the products behaves as a bleach.

Suggest the equation for the reaction occurring.

..... **[2]**

4 There are many different types of aliphatic and aromatic hydrocarbons.

(a) Name a naturally occurring source of aliphatic and aromatic hydrocarbons and outline how different hydrocarbons are separated from this source.

name of source .....

outline of separation of hydrocarbons .....

.....

[2]

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(b) When alkanes are heated to high temperatures, in the absence of air, the molecules can break into smaller molecules.

(i) Identify the type of reaction occurring.

..... **[1]**

(ii) Write an equation which describes the reaction occurring when heptane, C_7H_{16}, is heated in the absence of air, to form hexane, butane and ethene only.

..... **[1]**

(c) The equation for the complete combustion of ethene is shown.

$$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$$

Calculate the volume, in dm^3, of carbon dioxide formed in the complete combustion of 1.00 g of ethene at room temperature and pressure.

volume of CO_2 = ... dm^3 **[3]**

(d) The table compares the reactivity of alkanes and alkenes with chlorine.

	alkanes	alkenes
name of the type of reaction with chlorine	substitution	addition and substitution
name of the type of reacting species	free radical	electrophile and free radical

(i) During the first stage in the substitution reaction chlorine forms chlorine free radicals.

Explain what is meant by the term *free radical*.

..... **[1]**

(ii) Name and explain the type of bond breaking which occurs to form chlorine free radicals.

.....

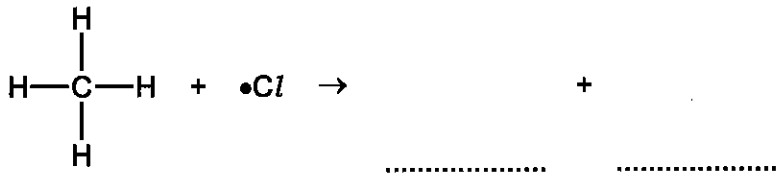
..... **[2]**

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(iii) Name the stage of the reaction mechanism which occurs when a methane molecule reacts with a chlorine free radical.

..... [1]

(iv) Complete the equation for the reaction which occurs when a methane molecule reacts with a chlorine free radical.



....

[1]

(v) Carbon atoms can form σ and π bonds within hydrocarbon molecules.

Explain the following statement with reference to σ and π bonds.

Alkenes react with electrophiles but alkanes do not.

.....

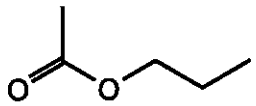
.....

.....

..... [2]

5 Many naturally occurring esters are used as flavourings in food.

(a) The structure of ester **V** is shown.



V

(i) Name **V**.

..... [1]

V reacts with a reagent to form a salt of a carboxylic acid and an alcohol.

(ii) Identify a reagent that could be used in this reaction.

..... [1]

(iii) Draw the displayed formula of the alcohol made during this reaction.

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[1]

(iv) State one other possible use for **V**, apart from as a food flavouring.

..... **[1]**

(b) Ester **W** is made up of 54.5% carbon, 9.1% hydrogen and 36.4% oxygen.

(i) Calculate the empirical formula of **W**.

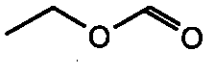
[3]

(ii) State what additional information is required to determine the molecular formula of **W**.

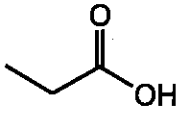
..... **[1]**

(c) Compounds **X**, **Y** and **Z** are shown. They all have the same molecular formula.

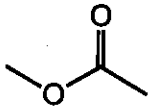
X



Y



Z



(i) Deduce the molecular formula of **X**, **Y** and **Z**.

..... **[1]**

(ii) In three experiments, sodium is added to separate samples of **X**, **Y** and **Z**.

Complete the table to show the observations for each of these three experiments. Ignore any temperature changes which may occur.

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experiment	observations
Na + **X**	
Na + **Y**	
Na + **Z**	

[2]

(d) Sodium carbonate solution reacts with methanoic acid.

Write the equation for this reaction.

..... **[1]**

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Answers Section

1 **(a) (i)** C_4H_{10} / same molecular formula **1**

OR

same number of carbon (atoms) and hydrogen (atoms)

different structural formula **1**

OR

description of different structural formula which does not imply stereoisomerism

(ii) structural / chain **1**

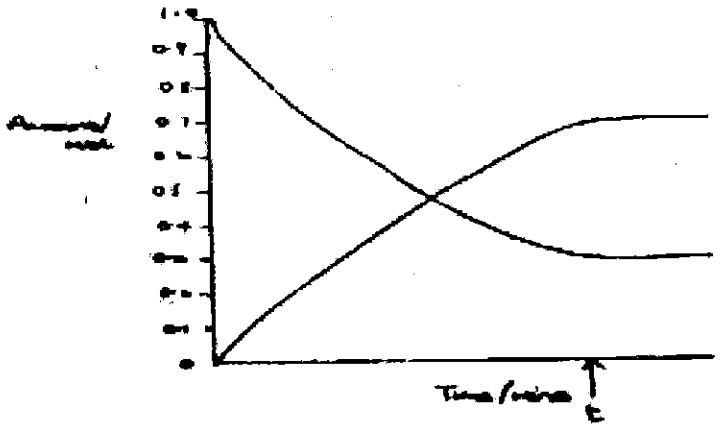
(b) (forward reaction is) exothermic reaction **1**

the proportion of methylpropane / product decreases **1**

OR

the proportion of butane / reactant increases

(c) (i) *t* shown on graph which corresponds to start of the horizontal part of both curves. **1**



(ii) concentration of butane = 0.3 mol dm^{-3} **1**

AND

concentration of methylpropane = 0.7 mol dm^{-3}

(iii) [methylpropane] / [butane] **1**

OR

$[(CH_3)_2CHCH_3] / [CH_3(CH_2)_2CH_3]$

(iv) **M1** *value for* K_c **1**

$$K_c = \frac{\text{value of methylpropane in (ii)}}{\text{value of butane in (ii)}} = 0.7 / 0.3 = 2.3 \text{ (3)}$$

M2 *units consistent with expression used in* M1 **1**

no units / dimensionless / none

2 **(a)** *trend in volatility down the group* **1**

decrease (in volatility)

identification of specific IMF increasing **1**

increasing (strength of) induced dipole (id) (interactions between molecules)

explanation in terms of electrons **1**

increasing number of electrons

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(b) (i) *Conditions for reaction with Cl_2 at room temperature* 1
ultra-violet / uv

(ii) $I_2(g/s) + H_2(g) \rightleftharpoons 2HI(g)$ 1
M1 correctly balanced equation
M2 correct state symbols AND use of equilibrium sign 1

(c) (i) proton / H^+ donor 1
(ii) acid HCl AND conjugate base Cl^- 1
(iii) co-ordinate / dative (covalent) 1
(iv) (triangular / trigonal) pyramid(al) 1
(v) $107^{(0)}$ 1

3 (a) (i) $SiCl_4(l) + 2H_2O(l) \rightarrow SiO_2(s) + 4HCl(aq/g)$ 1
(state symbols required)

(ii) hydrolysis 1

(iii) $NaCl$ – ionic 1
$SiCl_4$ – covalent 1

(iv) **M1** statement correctly comparing the **difference** in electronegativity between Si and Cl AND Na and Cl 1
OR
Na is less electronegative that Si *ORA*
M2 $NaCl$ transfer of electrons 1
M3 $SiCl_4$ shared (pair of) electrons 1

(b) (i) 2

Chlorine containing species	Cl_2	HCl	$HOCl$
Oxidation number of chlorine	0	–1	(+)1

Award 2 marks for 3 correct oxidation numbers
Award 1 Mark for 2 correct oxidation numbers

(ii) disproportionation 1

(iii) kills micro-organisms 1

(c) $2NaOH + HCl + HClO \rightarrow NaCl + NaClO + 2H_2O$ 2
M1 Identifies the product $NaClO$
M2 Correctly balances the equation
OR
The overall equation may be seen as:
$NaOH + HCl \rightarrow NaCl + H_2O$ **AND** $NaOH + HClO \rightarrow NaClO + H_2O$

4 (a) name of source crude oil / petroleum 1
outline of separation of hydrocarbons 1
(separation of molecules according to) different boiling points

(b) (i) cracking 1

(ii) $2C_7H_{16} \rightarrow C_4H_{10} + C_6H_{14} + 2C_2H_4$ 1

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(c)

	method 1	*method 2*	
M1	1 / 28 (= 0.035714)	1 : 88 / 28 (= 3.14286)	1
M2	2 × M1 (= 1 / 14 = 0.07143)	M1 / 44 (= 0.071429)	1
M3	M2 × 24 = 1.7 dm^3	M2 × 24 = 1.7 dm^3	1

(d) (i) unpaired electron(s) 1

(ii) homolytic (fission) 1

one electron goes to each chlorine / atom 1

OR

pair of electrons is shared out (equally between the two atoms)

(iii) propagation 1

(iv) $CH_4 + (\bullet)Cl \rightarrow (\bullet)CH_3 + HCl$ **OR** $CH_4 + (\bullet)Cl \rightarrow HCl + CH_3(\bullet)$ 1

(v) ***M1*** *identify bond types in alkanes and alkenes* 1

bonds in alkanes are (all) sigma / σ

AND

alkenes have (C = C made of) sigma AND pi / σ AND π

M2 *electrons in π (of the C = C) are responsible for the reaction* 1

electrophiles are attracted to / attack to electrons in **pi / π**

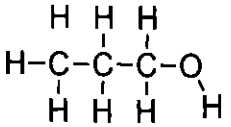
OR

electrophiles react with **pi / π**

5 (a) (i) (n–)propyl ethanoate 1

(ii) NaOH / sodium hydroxide 1

(iii) 1



(iv) perfume / solvent 1

(b) (i)

	C	H	O	
M1 *divide by A_r*	54.5 / 12	9.1 / 1	36.4 / 16	1
M2 *divide by smallest number*	4.54 / 2.275 (= 2 OR 1.99)	9.1 / 2.275(=4)	2.275 / 2.275 (=1)	1

M3 *empirical formula based on correctly rounded values of M2* 1

C_2H_4O

(ii) (relative) molecular mass / M_r 1

(c) (i) $C_3H_6O_2$ 1

(ii) X and Z – no reaction / no (visible) change 1

Y – effervesces 1

(d) $2HCO_2H + Na_2CO_3 \rightarrow 2HCO_2Na + CO_2 + H_2O$ 1

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October/November 2019 Paper 22

1 In the Periodic Table, the p block contains elements whose outer electrons are found in the p subshell.

(a) Elements in the p block show a general increase in first ionisation energy as the atomic number increases.

(i) Draw the shape of a p orbital.

[1]

(ii) Write an equation to show the first ionisation energy of silicon.

..... [1]

(iii) Explain why there is a general increase in first ionisation energies of the elements across Period 3.

.....

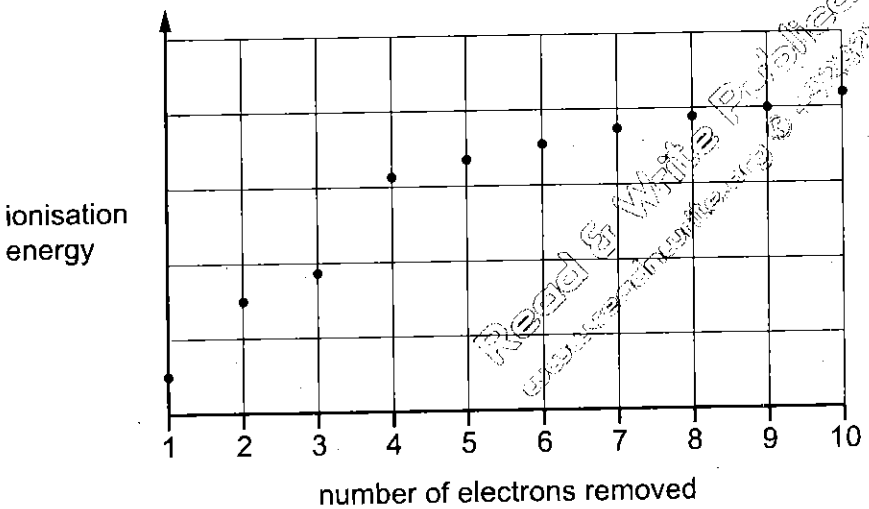
.....

.....

..... [2]

(iv) Element **A** is in the p block.

The graph shows the successive ionisation energies for the removal of the first ten electrons of **A**.



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State and explain the group of the Periodic Table that element **A** belongs to.

group number .....

explanation .....

.....

.....

[2]

(b) Silicon is found in many compounds in the Earth's crust. Silicon has only three naturally occurring isotopes, ^{28}Si, ^{29}Si and ^{30}Si.

(i) The table shows data for ^{28}Si, ^{29}Si and ^{30}Si.

	^{28}Si	^{29}Si	^{30}Si
relative isotopic mass	28.0	29.0	30.0

A sample of silicon contains 92.2% ^{28}Si. The total percentage abundance of ^{29}Si and ^{30}Si in the sample is 7.8%.

The relative atomic mass, A_r, of silicon in the sample is 28.09.

Calculate the percentage abundance of ^{30}Si.

Give your answer to **one** decimal place.

percentage abundance of ^{30}Si = ... %

[3]

(ii) Silicon reacts with nitrogen gas to form Si_3N_4.

Si_3N_4 is a solid with a melting point of 1900 °C. It is insoluble in water and does not conduct electricity when molten.

Suggest the type of bonding in **and** structure of Si_3N_4. Explain your answer.

.....

.....

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.....

.....

..... [3]

(c) Sulfur-containing compounds, such as C_2H_5SH, are found in fossil fuels, and produce SO_2 when they are burned.

(i) Write the equation to show the complete combustion of C_2H_5SH.

..... [1]

(ii) State why the presence of SO_2 in the atmosphere has environmental consequences. Describe **one** of the consequences on the environment.

.....

.....

..... [2]

(d) SO_2 can react with ozone, O_3, to form SO_3 in two different reactions.

(i) In one reaction, SO_2 reacts with O_3 until a dynamic equilibrium is established.

$$SO_2(g) + O_3(g) \rightleftharpoons SO_3(g) + O_2(g)$$

State and explain the effect of an increase in pressure on the composition of the equilibrium mixture.

.....

.....

..... [2]

(ii) In the other reaction, a different equilibrium is established at 300 K as shown.

$$3SO_2(g) + O_3(g) \rightleftharpoons 3SO_3(g) \qquad \Delta H = +462.3\,kJ\,mol^{-1}$$

Suggest a temperature needed to increase the yield of SO_3 at equilibrium.

Explain your answer.

.....

.....

..... [2]

[Total: 19]

2 Oxygen is the most abundant element in the Earth's crust. It reacts with other elements to form stable compounds, ions and molecules.

(a) Complete the table to give the formulae and acid/base behaviour of some of the oxides of the Period 3 elements.

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element	sodium	aluminium	silicon	phosphorus	sulfur
formula of oxide	Na_2O				SO_3
acid/base behaviour		amphoteric			

[2]

(b) Group 2 elements form stable hydroxides, with general formula $M(OH)_2$, where M is the Group 2 element.

(i) Beryllium hydroxide, $Be(OH)_2$, is an amphoteric compound that shows similar chemical reactions to aluminium oxide.

State the meaning of the term *amphoteric*.

.....

..... [1]

(ii) Write an **ionic** equation for the reaction of magnesium hydroxide, $Mg(OH)_2$, with hydrochloric acid.

..... [1]

(iii) Two methods of preparing strontium hydroxide are shown.

strontium $\xrightarrow[\text{reaction 1}]{H_2O}$ strontium hydroxide $\xleftarrow[\text{reaction 2}]{H_2O}$ strontium oxide

State **one** difference between the observations you would make for reaction **1** and reaction **2**.

.....

.....

..... [1]

(iv) State how the solubility of the Group 2 hydroxides changes down the group.

..... [1]

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(c) Sodium peroxide, Na_2O_2, reacts with CO_2.

$$Na_2O_2(s) + CO_2(g) \rightarrow Na_2CO_3(s) + \tfrac{1}{2}O_2(g)$$

The partial pressure of $CO_2(g)$ in a 0.500 dm^3 sample of air is 5.37 kPa at 20 °C.

(i) Calculate the amount, in moles, of $CO_2(g)$ present in the sample of air at 20 °C.

amount of $CO_2(g)$ = ... mol [2]

(ii) Calculate the mass of $Na_2O_2(s)$ that would react fully with the amount of $CO_2(g)$ calculated in **(i)**.

mass of $Na_2O_2(s)$ = ... g [1]

(iii) The peroxide ion, O_2^{2-}, has a single covalent bond between the two oxygen atoms. Each oxygen atom carries a negative charge.

Draw a 'dot-and-cross' diagram for the peroxide ion. Show outer electrons only.

[2]

[Total: 11]

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3 A series of reactions for phosphorus and its compounds is shown.

$$P \xrightarrow[\text{reaction 1}]{\text{excess } Cl_2} PCl_5 \xrightarrow[\text{reaction 2}]{H_2O} H_3PO_4 \xrightarrow[\text{reaction 3}]{NH_3} (NH_4^+)(H_2PO_4^-)$$

(a) (i) State what you would observe in reaction **1**.

.....

..... [1]

(ii) State the type of reaction that occurs in reaction **2**.

..... [1]

(iii) H_3PO_4 can be produced by direct reaction of phosphorus with nitric acid.

$$P + 5HNO_3 \rightarrow H_2O + 5NO_2 + H_3PO_4$$

Use oxidation numbers to show that this reaction is a redox reaction.

.....

.....

..... [2]

(b) Reaction **3** is a neutralisation reaction in which NH_3 acts as a base.

(i) Explain how NH_3 acts as a base in reaction **3**.

.....

..... [1]

(ii) Draw the three-dimensional shape of the ammonium ion, NH_4^+. Give the bond angle.

bond angle = ... ° [1]

(iii) State the industrial importance of compounds such as $(NH_4^+)(H_2PO_4^-)$.

..... [1]

(c) PCl_5 can be used to convert alcohols to halogenoalkanes.

(i) Write an equation for the reaction of C_2H_5OH with PCl_5 to form C_2H_5Cl.

..... [1]

(ii) State the type of reaction in **(i)**.

..... [1]

(iii) Halogenoalkanes can also be prepared by reacting alcohols with hydrogen halides, such as HCl and HI.

- HCl is prepared using NaCl and concentrated H_2SO_4.
- HI is prepared by reacting NaI with concentrated H_3PO_4.

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Suggest why HI is **not** prepared by the reaction of NaI with concentrated H_2SO_4.

.....

.....

..... [2]

(iv) The rate of the hydrolysis reaction of halogenoalkanes with NaOH(aq) is dependent on the halogen that is bonded to carbon.

State and explain the order of reactivity when NaOH(aq) reacts separately with C_2H_5Cl, C_2H_5Br and C_2H_5I.

.....

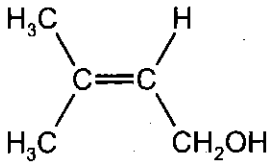
.....

..... [2]

[Total: 13]

4 Prenol is a naturally occurring organic molecule found in many fruits. It contains both an alkene and an alcohol functional group.

prenol

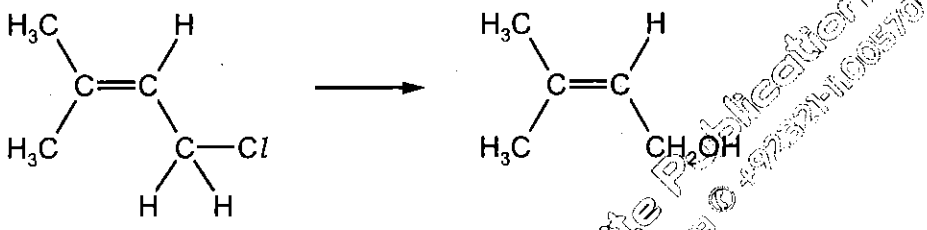


(a) Prenol can be formed by the reaction of **G** with NaOH(aq).

Complete the diagram to show the mechanism of the reaction between **G** and NaOH(aq) to form prenol.

Include all relevant charges, partial charges, lone pairs and curly arrows.

G prenol



[2]

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(b) Prenol reacts with steam to form a mixture of three isomers, **J**, **K** and **L**, of molecular formula $C_5H_{12}O_2$.

(i) When **J** is heated with excess acidified potassium dichromate(VI) it forms an organic product which shows no reaction with 2,4-DNPH.

Draw the structure of **J**.

[1]

K and **L** are stereoisomers with molecular formula $C_5H_{12}O_2$.

K and **L** both react when heated with excess acidified potassium dichromate(VI) to form **M**, $C_5H_8O_3$.

M forms an orange precipitate on reaction with 2,4-DNPH.

(ii) Give the structural formula of **K** and **L**.

..... [1]

(iii) Name the type of stereoisomerism shown by **K** and **L**.

..... [1]

(iv) Give the balanced equation to represent the reaction of **K**, $C_5H_{12}O_2$, with acidified potassium dichromate(VI) to form **M**, $C_5H_8O_3$.

Use [O] to represent an atom of oxygen provided by the oxidising agent.

..... [1]

(c) (i) Prenol contains an alkene functional group.

Describe a chemical test to confirm the presence of an alkene functional group. Give the result of the test.

.....

..... [1]

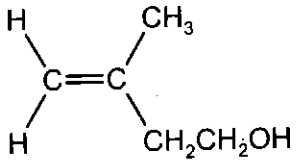
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(ii) Prenol can be polymerised to form poly(prenol).
Draw **one** repeat unit of poly(prenol).

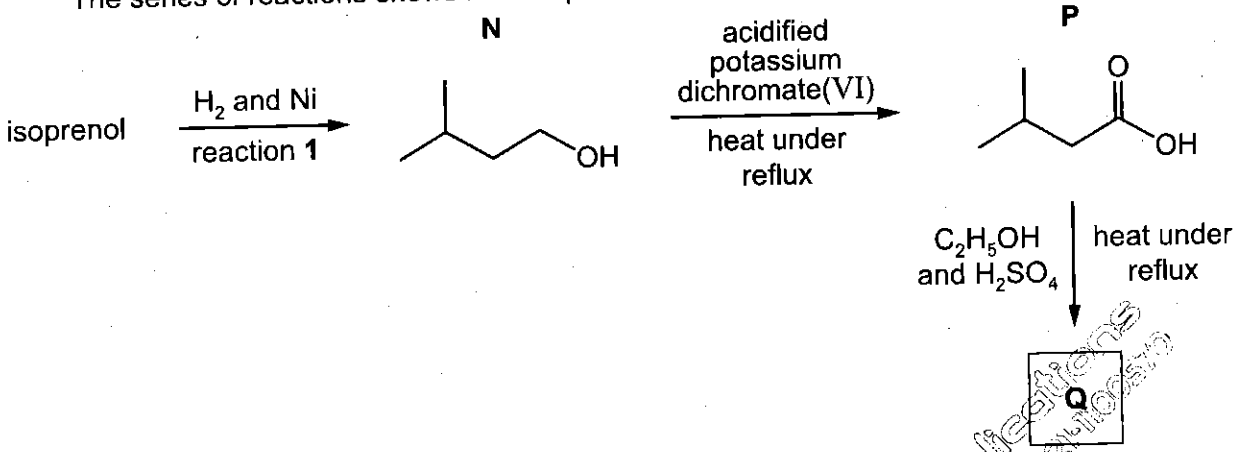
[1]

(d) Isoprenol is a structural isomer of prenol.

isoprenol



The series of reactions shows how isoprenol can be used to form **Q**, a sweet-smelling liquid.



(i) Give the name of **N**.

..... [1]

(ii) Isoprenol is a liquid.
Ni acts as a catalyst for reaction **1**.
Identify the type of catalysis shown by Ni in reaction **1**.

..... [1]

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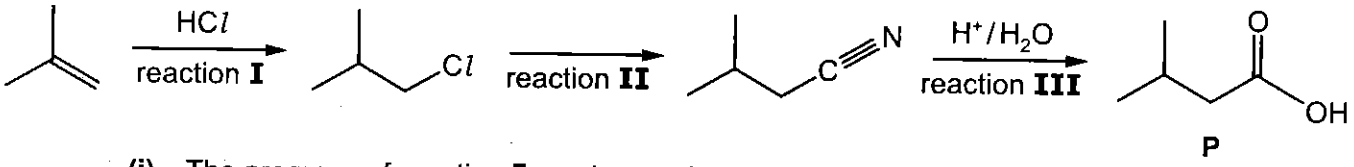
(iii) Draw the **skeletal** formula of **Q** and suggest one commercial use of **Q**.

Q

commercial use .....

[2]

(e) **P** can be produced as shown.



P

(i) The progress of reaction **I** can be monitored using infra-red spectroscopy.

One absorption that can be used to monitor the progress of this reaction is that of C–C*l* at 730 cm^{-1}.

Identify another absorption that can be used to monitor the progress of this reaction. In your answer, you should refer to the specific bond and its corresponding absorption range in wavenumbers.

.....

..... [1]

(ii) State the reagent(s) needed for reaction **II**.

..... [1]

(iii) Name the type of reaction that occurs in reaction **III**.

..... [1]

(iv) The yield of reaction **I** is very low.

Explain why.

.....

.....

..... [2]

[Total: 17]

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Answers Section

1 (a) (i)  1

(ii) $Si(g) \rightarrow Si^{+}(g) + e^{-}$ 1

(iii) **M1:** similar shielding AND increase in proton number/atomic number / nuclear charge 2
M2: increased nuclear attraction

(iv) **M1:** 3 **OR** 13 2
M2: large(r) *increase* between third and fourth ionisation energies **OR** large(r) *increase* after third electron removed

(b) (i) **M1:** 3

$$\frac{(92.2 \quad 28) + (^{29}Si \quad 29) + (^{30}Si \quad 30)}{100} = 28.09$$

M2: (x =) 6.6 **OR** 28.09 = 28.078 + x (where x = abundance of Si-29)
M3: *7.8 – M2 calculated correctly to one decimal place (or more)*
(=) 1.2%

(ii) **M1** giant (molecule) 3
M2 strong covalent bonds (between atoms / particles)
M3 no mobile charged particles / carriers

(c) (i) $C_2H_5SH + 4\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O + SO_2$ 1

(ii) **M1:** (causes) acid rain OR reacts/dissolves with (rain)water (vapour) to form (sulfuric / sulfurous) acid **2**
M2: one point from the following list.
- ∞ lowers pH / increases acidity of rivers / lakes / oceans / water supplies / seas / soil / ground water
- ∞ kills/harms / damages fish
- ∞ kills / harms / damages plants / damages coral / aquatic life / plants / crops / trees or deforestation
- ∞ leaches (toxic) aluminium (ions / salts) from soil (into rivers / lakes)
- ∞ leaches away soil nutrients / soil unfit for agriculture
- ∞ damages / weathers / erodes / destroys buildings / statues

(d) (i) **M1:** no effect / none 2
M2: equal mol(es) (*of gas*) on both sides (of equilibrium / equation) owtte

(ii) **M1:** (forward reaction is) endothermic 2
M2: Any temperature higher than 300 K

2 (a) 2

Na_2O	Al_2O_3	SiO_2	P_4O_{10} / P_4O_6 / P_2O_3 / P_2O_5	SO_3
basic	amphoteric	acidic	acidic	acidic

M1: all formulae correct
M2: all acid / base behaviour correctly stated

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(b) (i) reacts with both acid and base 1

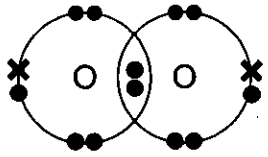
(ii) $OH^- + H^+ \rightarrow H_2O$ 1

(iii) reaction with strontium / reaction 1 will effervesce / fizz / bubble 1
OR
no fizzes / bubbles / effervescence with SrO

(iv) increases 1

(c) (i) **M1:** correct conversion of quantities 2
$V = 5(.00) \quad 10^{-4}\,(m^3)$
$T = 293\,(K)$
$p = 5.37(0) \quad 10^3\,(Pa)$
M2: calculation to find n using n = PV / RT
$(n) = 1.1 \quad 10^{-3}\,(mol)$

(ii) (i) $78 = 0.0860$ g 1

(iii) 

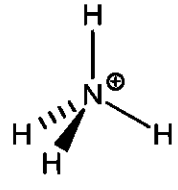
2
M1: bonding pair between the two O
M2: total of 14 electrons distributed equally between the two O

3 (a) (i) green gas fades 1
OR
white solid / white powder / white smoke / white fumes

(ii) hydrolysis 1

(iii) ∞ P goes from 0 to (+)5 / (+)V 2
∞ P is oxidised
∞ N goes from (+)5 / (+)V to (+)4 / (+)IV
∞ N is reduced
Award one mark for two correct bullet points, award two marks for all four correct.

(b) (i) accepts a proton / H^+ 1
OR
donates a (lone) pair of e^-

(ii) *3-D shape **AND** bond angle* 1


AND $109\frac{1}{2}$(°)

(iii) fertilisers 1

(c) (i) $C_2H_5OH + PCl_5 \rightarrow C_2H_5Cl + POCl_3 + HCl$ 1

(ii) substitution 1

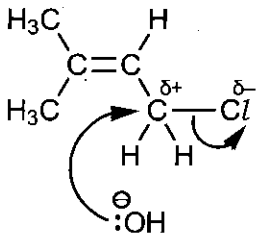
(iii) EITHER 2
M1: HI / I^- is a strong(er) reducing agent (than HCl / Cl^-)
M2: HI / I^- is oxidised (to iodine but the chloride is not)
OR
M1: H_2SO_4 is a (strong enough) oxidising agent (to react with HI / I^- here)
M2: HI / I^- forms iodine

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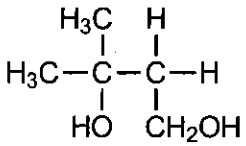
OR

M1: phosphoric acid is a weak / not an oxidising agent
M2: (so) does not react with iodide (where M2 is dependent on M1 here)

(iv) **M1:** C_2H_5I reacts fastest AND C_2H_5Cl reacts slowest **OR** $C_2H_5Cl < C_2H_5Br < C_2H_5I$ **2**
M2: C—I bond is the weak(est) AND C—Cl bond strong(est)

(a)  **2**

M1: curly arrow from lone pair on O of OH^- to C of C—Cl
M2: correct dipole on C—Cl **AND** curly arrow from C—Cl bond to $Cl^{\delta-}$

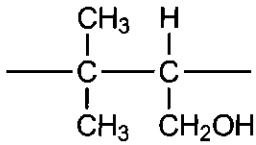
(b) (i)  **1**

(ii) $(CH_3)_2CHCH(OH)CH_2OH$ **1**

(iii) optical (isomerism) **1**

(iv) $C_5H_{12}O_2 + 3[O] \rightarrow C_5H_8O_3 + 2H_2O$ **1**

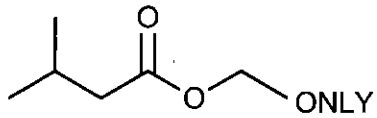
(c) (i) Add bromine water / $Br_2(aq)$ **AND** turns (from orange / brown to) colourless **1**

(ii)  **1**

(d) (i) 3-methylbutan-1-ol **1**

(ii) heterogeneous **1**

(iii) **M1:** skeletal formula of Q **2**



M2: one commercial use of Q (ethyl isovalerate / ethyl 3methylbutyrate)
solvents / perfumes / flavourings

(e) (i) 1500–1680 (cm^{-1}) **AND** C=C **1**

(ii) potassium cyanide / KCN / sodium cyanide / NaCN **1**

(iii) (acidic) hydrolysis **1**

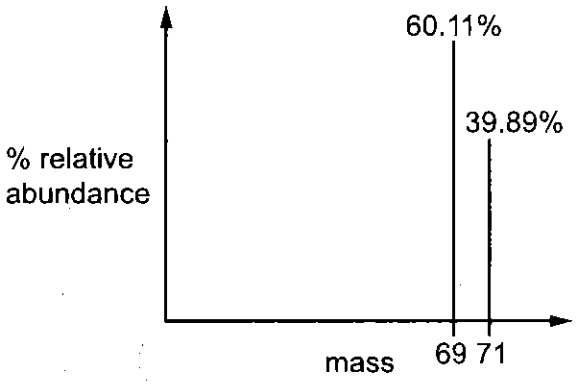
(iv) **M1:** recognise this reaction involves less stable intermediate **2**
1° (carbo)cation (intermediate) is less stable (than 3°)
M2: explain difference in reactivity in terms of positive inductive effect – comparative answer lower (positive) inductive effect / lower (+)I
OR
inductive effect of **less** alkyl groups

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May/June 2020 Paper 22

1 Gallium is an element in Group 13.

A sample of gallium is analysed using a mass spectrometer. The mass spectrum produced is shown.



(a) Explain what is meant by the term *relative atomic mass*.

.....

..... [2]

(b) Calculate the relative atomic mass of gallium in this sample. Give your answer to 4 significant figures.

Show your working.

relative atomic mass = ... [2]

(c) Complete the table which describes a gaseous atom of gallium.

isotope	nucleon number	total number of electrons in **lowest** energy level	type of orbital which contains the electron in the **highest** energy level
^{71}Ga			

[3]

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(d) When gallium is heated in excess chlorine, gallium trichloride, $GaCl_3$, is made.
Draw the shape of the gallium trichloride molecule and suggest the Cl–Ga–Cl bond angle.
shape of molecule

bond angle .....

[2]

(e) Gallium oxide, Ga_2O_3, and aluminium oxide react in the same way with HCl(aq) and with NaOH(aq).

(i) Suggest the equation for the reaction between Ga_2O_3 and HCl(aq).

..... [1]

(ii) Suggest an equation for the reaction between gallium oxide and NaOH(aq).

..... [2]

[Total: 12]

2 Nitric acid can be made in a 3-stage process.

Stage 1 Ammonia is oxidised by oxygen from the air, to form nitrogen monoxide and water. This reaction is carried out at 10–13 atmospheres pressure and 900 °C in the presence of a platinum catalyst.

Stage 2 Nitrogen monoxide reacts with more oxygen to form nitrogen dioxide.

$$2NO + O_2 \rightleftharpoons 2NO_2 \qquad \Delta H = -114\,kJ\,mol^{-1}$$

Stage 3 Nitrogen dioxide reacts with water to make nitric acid and nitrogen monoxide.

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

(a) Write an equation to show the reaction occurring in stage 1.

..... [1]

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(b) Draw a 'dot-and-cross' diagram to show the arrangement of outer electrons in a molecule ammonia.

(c) **(i)** In the boxes, give the oxidation numbers of nitrogen in the nitrogen-containing species the reaction in stage 3.

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

(ii) Explain why the reaction in stage 3 is described as a disproportionation reaction. Include reference to transfer of electrons in your answer.

.....

.....

.....

(d) The release of nitrogen monoxide into the atmosphere causes atmospheric pollution.

State and explain the effect of nitrogen monoxide gas in contact with moist air.

.....

.....

(e) The nitric acid made in stage 3 can then be reacted with ammonia to form ammonium nitra

Stage 3 $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

$NH_3 + HNO_3 \rightarrow NH_4NO_3$

Calculate the volume of nitrogen dioxide, measured at room temperature and press required to make 40 tonnes of ammonium nitrate.
[1 tonne = 1000 kg]

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Show your working.

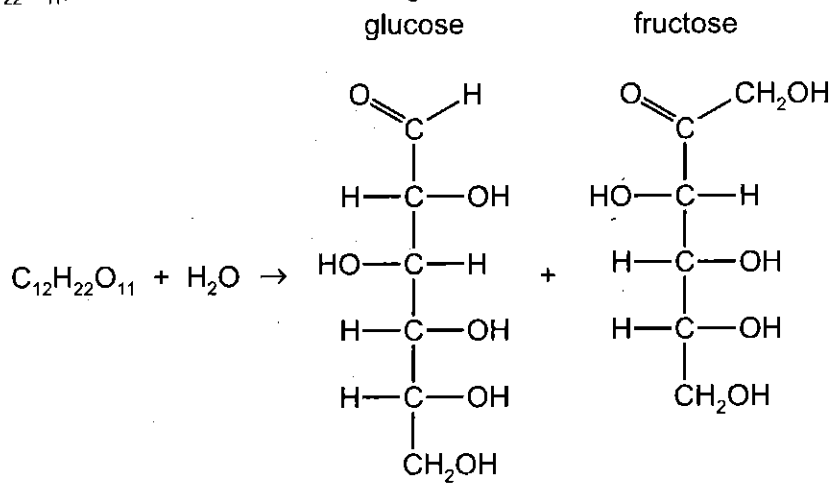
volume of nitrogen dioxide = ... [3]

(f) State **one** use of ammonium nitrate.

..... [1]

[Total: 12]

3 Sucrose, $C_{12}H_{22}O_{11}$, reacts with water to form glucose and fructose in reaction **A**.



reaction **A**

(a) Suggest a name for this type of reaction.

..... [1]

(b) Explain in detail, why glucose and fructose are a pair of structural isomers. Your answer should refer specifically to these two molecules.

.....

.....

..... [2]

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(c) Reaction **A** occurs faster in the presence of an enzyme. This is reaction **B**.

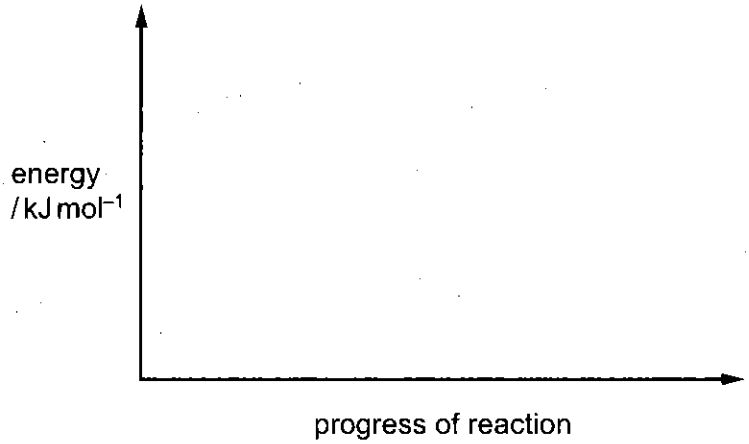
(i) The activation energy for reaction **B** is $+29\,kJ\,mol^{-1}$.
Predict a value for the activation energy of reaction **A**.

..... [1]

(ii) The enthalpy change for reaction **A** is $-14\,kJ\,mol^{-1}$.
Predict a value for the enthalpy change for reaction **B**.

..... [1]

(iii) Sketch a labelled energy level diagram for reaction **B**. Use relevant values from **(c)(i)** and **(c)(ii)**.



[2]

(d) 1.00 g of sucrose, $C_{12}H_{22}O_{11}$, is completely combusted. The heat energy produced is used to increase the temperature of 250 g of water inside a calorimeter from 25.0 °C to 40.7 °C.
These data can be used to calculate the enthalpy change of combustion of sucrose.

(i) Explain what is meant by the term *enthalpy change of combustion of sucrose*.

.....

.....

..... [2]

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(ii) Use the *Data Booklet* to calculate the enthalpy change, in kJ mol^{-1}, for the combustion of sucrose.
Assume that all of the heat energy produced is transferred to the water.
Show your working.

enthalpy change of combustion of sucrose = ... kJ mol^{-1}
[3]
[Total: 12]

4 (a) An unlabelled bottle contains a straight-chain halogenoalkane, **Q**. The molecular formula of **Q** is C_5H_{11}**X**, where **X** is a halogen; bromine, chlorine or iodine.
A test is carried out to identify the halogen present in **Q**.
A sample of **Q** is added to NaOH(aq) and warmed. Dilute nitric acid is then added followed by a few drops of aqueous silver nitrate. A cream precipitate is observed.

(i) Suggest the identity of **X**.

..... [1]

(ii) Write an ionic equation to describe the formation of the cream precipitate. Include state symbols.

..... [1]

(iii) Describe a further test which would confirm the identity of **X**.

test .....

expected result .....
[2]

(b) The reaction of **Q** with NaOH(aq) tends to proceed via an S_N2 mechanism.

(i) Suggest the structural formula of the straight-chain halogenoalkane **Q**.

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[1]

(ii) Explain why the reaction tends to proceed via an S_N2 mechanism rather than an S_N1 mechanism.

.....

.....

..... [2]

(c) Two different halogenoalkanes, **P** and **R**, both with the molecular formula C_4H_9Cl, are separately dissolved in ethanol and heated under reflux with sodium hydroxide.

The major organic product of each of these reactions is methylpropene.

(i) Name the type of reaction occurring.

..... [1]

(ii) Write an equation, using molecular formulae, to represent the reaction occurring.

..... [1]

(iii) Draw the skeletal formula of methylpropene.

[1]

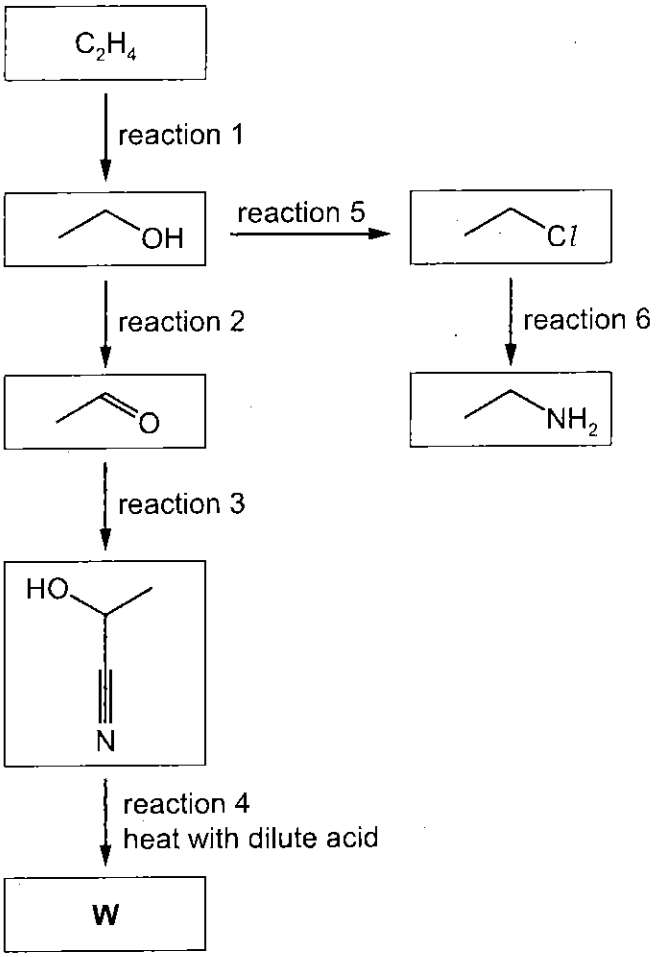
(iv) Give the names of **P** and **R**.

..... [2]

[Total: 12]

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5 The reaction sequence shows how ethene, C_2H_4, can be converted into other organic molecules.



(a) Complete the table to give
- the name of the reaction mechanisms of reactions 1 and 6
- the reagents and conditions required for reactions 1, 2 and 6.

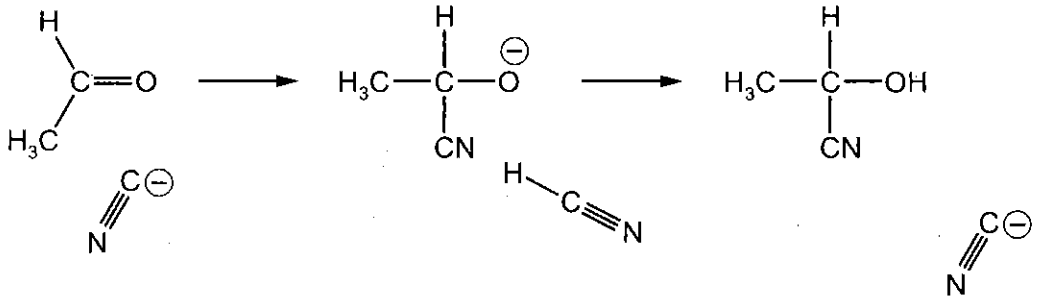
reaction	name of mechanism	**name** of reagents and conditions
1		
2		
6		

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[6]

(b) In reaction 3 the organic molecule reacts with HCN and a KCN catalyst.

(i) Complete the diagram to show the mechanism of the reaction occurring. Include all relevant dipoles, lone pairs and curly arrows in your answer.



[3]

(ii) Name the functional groups present in the product of reaction 3.

..... [2]

(c) Draw the structure of the organic molecule **W** formed in reaction 4.

[1]

[Total: 12]

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Answers Section

1 (a) EITHER **2**

M1 (weighted) average/mean mass of the isotope(s)/an atom(s)

M2 relative to 1/12 of the mass (of an atom) of ^{12}C (where an atom of ^{12}C is exactly12).

OR

M1 mass of one mol of atoms

M2 relative / compared to 1/12 (the mass) of 1 mol of C-12 OR

in which one mol C-12 (atom) has a mass of (exactly) 12 g

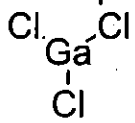
(b) **M1** 60.11/100 x 69 + 39.89/100x71 **2**
M2 69.80

(c)

isotope	nucleon number	total number of electrons in **lowest** energy level	type of orbital contains the electron in the **highest** energy level
^{71}Ga	**M1** 71	**M2** 2	**M3** p (-orbital)

3

(d) **M1** shape **2**



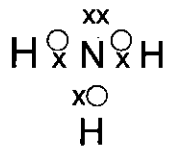
M2 bond angle 120(°)

(e) (i) $Ga_2O_3 + 6HCl \rightarrow 2GaCl_3 + 3H_2O$ **1**

(ii) **M1** *Identity of correct gallium containing product* **2**
$NaGa(OH)_4$ OR $NaGaO_2$
M2 *correctly balanced equation for reaction of Ga_2O_3 with NaOH(aq)*
EITHER
$Ga_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaGa(OH)_4$
OR
$Ga_2O_3 + 2NaOH \rightarrow 2NaGaO_2 + H_2O$

2 (a) $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$ **1**

(b) **1**



(c) (i) $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$ **2**

(+)4 (+)5 (+)2

3 correct oxidation numbers – 2 marks
2 correct oxidation numbers – 1 mark

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(c) **(ii)** *relates the term disproportionation to the reaction described*
M1 nitrogen /N (in nitrogen dioxide) is both gaining electrons and losing electrons during the reaction
M2 *refer to relevant transfer of electrons when NO_2 reacts to form HNO_3 and NO*
NO_2 to HNO_3 involves loss of electron(s)
AND
NO_2 to NO involves gain of electron(s)

(d) **M1** *state the effect of NO gas on contact with moist air* **2**
NO reacts with water **OR** NO reacts with oxygen and water.
M2 *consequence of M1 in terms of atmospheric pollution*
causing acid rain photochemical smog / ground level ozone OR destroy ozone layer

(e) **M1** *number of mol in sample of NH_4NO_3* **3**
40t NH_4NO_3 = 500 000 mol ammonium nitrate
M2 *ratio of mol NO_2: NH_4NO_3*
3/2 mol NO_2 :1 mol NH_4NO_3
M3 *volume of no mol NO_2 at rtp using 1 mol = 24dm^3*
18 000 000 dm^3 of NO_2

(f) fertilise r **1**

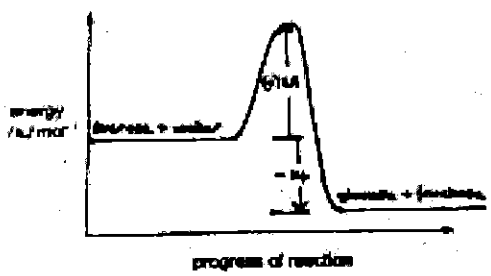
3 **(a)** hydrolysis **1**

(b) M1 both have molecular formula - $C_6H_{12}O_6$ **2**
M2 idea that in glucose and fructose there are the same number and type of atoms present but the atoms are arranged in a
different order ie one has a carbonyl group at the end of the chain/molecule and the other has a carbonyl group in the middle of the chain/molecule

(c) (i) value for the activation energy for the reaction ***A*** (no enzyme) compared to reaction ***B*** **1**
(with enzyme) value / range of values that are more (+) 29 kJ mol

(ii) value for the enthalpy change for reaction ***A*** (no enzyme) compared to reaction ***B*** **1**
(with enzyme)-14 kJ mol^{-1}

(iii) **M1** show the energy of the reactants > products AND label ΔH
using the predicted value given in **(ii)**
M2 show activation energy 'hump' AND label using the value given in **(i)**



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(d) (i) **M1** (enthalpy change) when 1 mole of sucrose **2**

M2 burns/combusts/reacts in excess air/oxygen

OR

completely burns/combusts/reacts in air/oxygen

(ii) **M1** *for finding amount of energy released per gram of sucrose using* **3**
ΔH /Q = mcΔT OR ΔH = – mcΔT
= (-)250x4.18x(40.7-25) = (-)16406.5 J per gram OR(-)16.4065 kJ / g
M2 *for finding amount (mol) sucrose in1g = 1/342 mol*
M3 *= M1 / (M2x1000)*
ΔH = - 5610 kJ mol^{-1} (3 sig figs) OR -5611 kJ mol^{-1} (4 sig figs)

4 (a) (i) Bromine / Br **1**

(ii) $Ag^+(aq) + X^-(aq) \rightarrow AgX(s)$ OR $Ag^+(aq) + Br^-(aq) \rightarrow AgBr(s)$ **1**

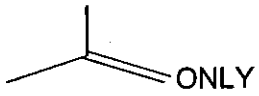
(iii) **M1** *reagent* **2**
Add (aqueous) ammonia
M2 *expected result*
EITHER (Dilute ammonia) – partial amount precipitate dissolves OR not much precipitate dissolves **OR** add concentrated ammonia – precipitate dissolves

(b) (i) $CH_3CH_2CH_2CH_2CH_2Br$ **1**

M1 primary/ 1° (carbo)cation formed is not very stable **2**
M2 EITHER (as) only one alkyl group exerting an inductive effect
OR only one alkyl group so the charge is (more) localised on the C+

4 (c) (i) elimination **1**

(ii) $C_4H_9Cl + NaOH \rightarrow C_4H_8 + NaCl + H_2O$

(iii)  ONLY **1**

(iv) **M1** 2-chloro(-2-)methylpropane **2**
M2 1-chloro(-2-)methylpropane
ALLOW in any order

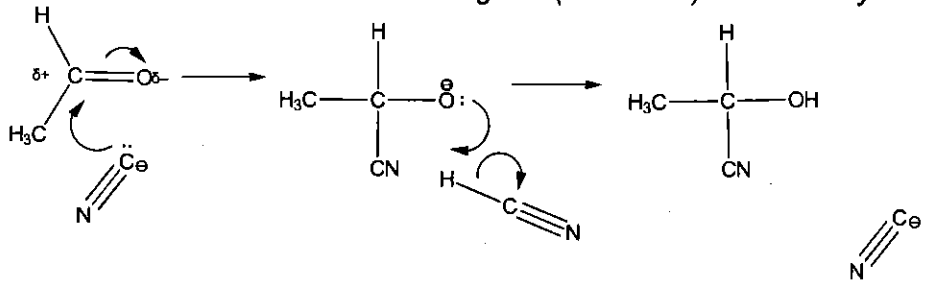
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5 (a)

Rxn.	name of mechanism	**Name** of reagents and conditions
1	**M1** electrophilic addition	**M2** steam **AND** concentrated phosphoric acid (catalyst)
2	[redacted]	***M3*** **&** ***M4*** *Two marks for name of reagent and both conditions.* *One mark for name of reagent and one conditions* acidified potassium dichromate ((VI)) *condition 1* warm *condition 2* distil NOT reflux
6	**M5** nucleophilic substitution	**M6** ammonia (alcoholic) AND heat in a sealed tube / heat under pressure

6

(b) (i) *mechanism for ethanal and HCN using CN^- (from KCN) as the catalyst* **3**



M1 arrow from lone pair of electrons on $:CN^-$ to C of C=O

M2 correct dipole on $C^{\delta+}=O^{\delta-}$ AND arrow from the double bond to or beyond the O of C=O

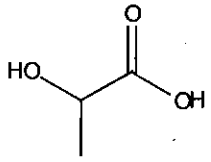
M3 arrow from lone pair of electrons on O of intermediate to H of HCN AND arrow from H-C bond to C of H-C≡N

(ii) ALLOW in any order **2**

M1 nitrile

M2 (secondary) alcohol

(iii) **1**



ALLOW any unambiguous structure

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