A Level

Article No. 232

Chemistry 9701

Paper-2

Topical Workbook with Mark Scheme
Updated Till – 2021

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

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A Level

Unit 1
ATOMS, MOLECULES AND STOICHIOMETRY

Chemistry Paper-2
Topical Workbook
Article Number: 232

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Unit 1: Atoms, Molecules And Stoichiometry

1. M/J 21/P23/Q3

Separate samples of **R**, **S**, **T** and **U** are added to cold water. The identity of each sample is unknown. However, each sample is known to be pure and can only be one of $Ba(OH)_2$, $NaCl$, P_4O_{10} or $SiCl_4$.

(a) (i) Use the observations in the table to identify each sample as one of $Ba(OH)_2$, $NaCl$, P_4O_{10} and $SiCl_4$. Write your answers in the table.

	state at room temperature	observations on addition of sample to water	identity of sample
R	solid	alkaline, colourless solution is produced, some white solid remains	
S	solid	white solid disappears, solution is neutral	
T	liquid	misty fumes produced, white solid is made in vigorous reaction	
U	solid	acidic, colourless solution produced in vigorous reaction	

[4]

(ii) Identify the formula of the white solid made when sample **T** reacts with water.

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

(iii) Name the solution formed when sample **U** reacts with water.

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

(b) Magnesium oxide and aluminium oxide have properties typical of ceramic materials.

(i) Name **one** physical property typical of ceramic materials.

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

(ii) Give the formula of another Period 3 oxide which behaves as a ceramic material.

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

(c) Tungsten oxide, W_xO_y, is used to give colour to ceramic materials.

A sample of W_xO_y contains 79.29% tungsten by mass.

Calculate the empirical formula of W_xO_y.

Show your working.

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empirical formula = ... **[3]**

2. **M/J 20/P21/Q2**

(a) The equation shown in **(a)(i)** describes the reaction which occurs when aqueous potassium iodide is added to aqueous copper(II) sulfate. A white precipitate of copper(I) iodide forms in a brown solution of iodine and potassium sulfate.

(i) Balance the equation and include state symbols.

.....$CuSO_4$(.....) + ...KI(.....) → .....CuI(.....) + ...I_2(.....) + ...K_2SO_4(.....) **[2]**

The table gives the oxidation numbers of iodine in the different species in the equation.

iodine-containing species	oxidation number of iodine
KI	–1
CuI	–1
I_2	0

(ii) Deduce the oxidation number of copper in $CuSO_4$ and CuI.

- oxidation number of copper in $CuSO_4$ .....
- oxidation number of copper in CuI ..... **[1]**

(iii) Describe the type of reaction shown by the equation in **(a)(i)**. Explain your answer in terms of electron transfer.

.....

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

(b) In the reaction described in **(a)(i)**, a student uses 17.43 g of $CuSO_4$•**y**H_2O. By further titration of the reaction products the student concludes that the total amount of $CuSO_4$ in the sample is 0.0982 mol.

Use the *Data Booklet* to complete the table to calculate the value of **y**, where **y** is an integer. Show your working.

mass of 0.0982 mol $CuSO_4$	..... g
amount of H_2O in 17.43 g of $CuSO_4$•**y**H_2O	..... mol H_2O
value of **y**	**y** = ...

[4]

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3. M/J 20/P23/Q2

(a) Explain what is meant by the term *relative isotopic mass.*

.....

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

(b) A sample of copper contains two isotopes, ^{63}Cu and ^{65}Cu. The relative atomic mass of the copper in this sample is 63.55.

Calculate the percentage abundance of each of these isotopes. Show your working.

percentage abundance of ^{63}Cu = ... %

percentage abundance of ^{65}Cu = ... %
[2]

(c) (i) Name the type of bonding within a sample of solid copper.

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

(ii) Draw a labelled diagram to show the bonding within a sample of solid copper.

[2]

(iii) State the electronic configuration of a copper atom.

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

(d) A student is provided with a sample of hydrated copper(II) sulfate, $CuSO_4 \cdot xH_2O$, and is asked to determine the value of x.
The student dissolves a sample of the hydrated copper(II) sulfate in water and adds it to an excess of aqueous potassium iodide to make a total volume of 250.0 cm^3 of solution.

$$2CuSO_4 + 4KI \rightarrow 2CuI + I_2 + K_2SO_4$$

The amount of iodine produced during this reaction is found by titrating a sample of this solution with sodium thiosulfate solution.

25.0 cm^3 of the iodine-containing solution requires 20.0 cm^3 of 0.10 mol dm^{-3} sodium thiosulfate solution.

$$I_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2I^-$$

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(i) Calculate the amount, in mol, of copper(II) sulfate present in the original sample of hydrated copper(II) sulfate.
Show your working.

amount of copper(II) sulfate = ... mol **[2]**

(ii) A total of 7.98 g of $CuSO_4$ is present in 10.68 g of $CuSO_4 \cdot xH_2O$.
Complete each row of the table to calculate the value of x, where x is an integer.
[M_r: $CuSO_4$,159.6]

amount of $CuSO_4$ in 10.68 g of $CuSO_4 \cdot xH_2O$	..... mol
amount of H_2O in 10.68 g of $CuSO_4 \cdot xH_2O$	..... mol
value of x	x = ...

[3]

4. O/N 19/P22/Q1
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.

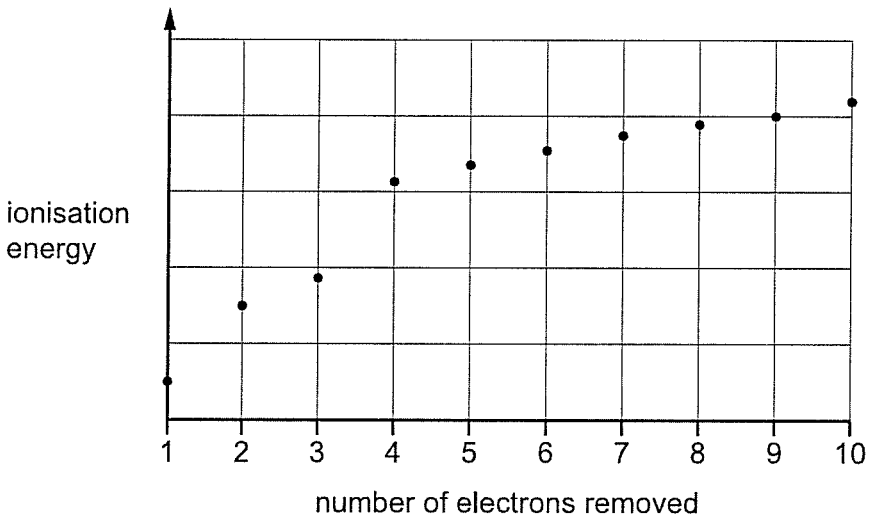
.....

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

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(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**.



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]

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(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.

.....

.....

..... **[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]**

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5. O/N 19/P22/Q2/c

(a) 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]

6. MAR 19/P22/Q2/a(i)

The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2, HC*l* and CaF_2.

	F_2	HC*l*	CaF_2
boiling point/K	85	188	2773
relative formula mass	38.0	36.5	78.1

(a) (i) State what is meant by the term *relative formula mass*.

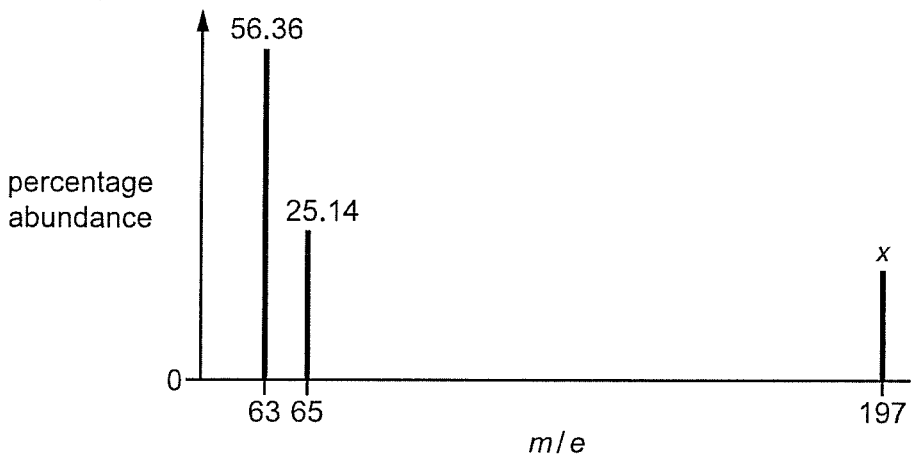
.....

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

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7. O/N 18/P22/Q1/d

(a) *Tumbaga* is an alloy of copper and gold. A sample of tumbaga was analysed. The mass spectrum of the sample is shown.



(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]

8. O/N 18 /P21/Q1/c(ii),(iii),(iv), O/N 18 /P23/Q1/c(ii),(iii),(iv)

(i) Complete the equation to show the roasting of iron pyrite in oxygen.

$4FeS_2$ + ... → $2Fe_2O_3$ + ... [2]

(ii) A sample of impure iron pyrite was roasted in oxygen. The composition of the mixture of solid products is shown.

solid product	mass/g
Fe_2O_3	33.18
Au	0.37

Calculate the mass of FeS_2 present in the sample of impure iron pyrite.
Assume that all the FeS_2 was converted to Fe_2O_3 during the roasting process.

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(M_r: FeS_2, 120.0; Fe_2O_3, 159.6)

mass of FeS_2 = ... g **[2]**

(iii) Use your answer to **(iii)** to calculate the percentage by mass of gold in this sample of impure iron pyrite. Assume that gold is the only impurity in this sample of impure iron pyrite.
Give your answer to **two** significant figures.
(If you were unable to calculate an answer to **(iii)**, use 55.00 g as the mass of FeS_2 in this calculation. This is **not** the correct answer.)

percentage by mass of gold = ... % **[1]**

9. M/J 18/P22/Q2/a,d

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

.....

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

(b) 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 in 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 this 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.

$MnO_4^-(aq)$ + ...$Fe^{2+}(aq)$ + ...$H^+(aq)$ → .....$Mn^{2+}(aq)$ + ...$Fe^{3+}(aq)$ + ...$H_2O(l)$

[1]

(ii) State the role of the Fe^{2+} ions in this reaction.
Explain your answer.

.....

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

(iii) Calculate the amount, in moles, of manganate(VII) ions that reacted.

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

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(iv) Calculate the amount, in moles, of Fe^{2+} ions in the sample of the salt.

amount ..... mol [1]

(v) Calculate the relative formula mass of $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$.

relative formula mass = ... [1]

(vi) Calculate the value of x.

x = ... [1]

10. 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]

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

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

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

.....

..... [2]

12. 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]

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

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

(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]**

13. 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, $H_2C_2O_4.xH_2O$, 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]**

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

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

(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]**

14. 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]**

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15. 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%

(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]

16. 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.

$$\text{.....(.....)} + \text{.....}HgCl_2(aq) \rightarrow SnCl_4(\text{.....}) + Hg_2Cl_2(\text{.....})$$

[2]

17. 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?

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

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(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]**

18. M/J 15/P22/Q1/a,b,c(ii)

(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]

(c) (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]

19. M/J 15/P21/Q1/a,b,c(i)

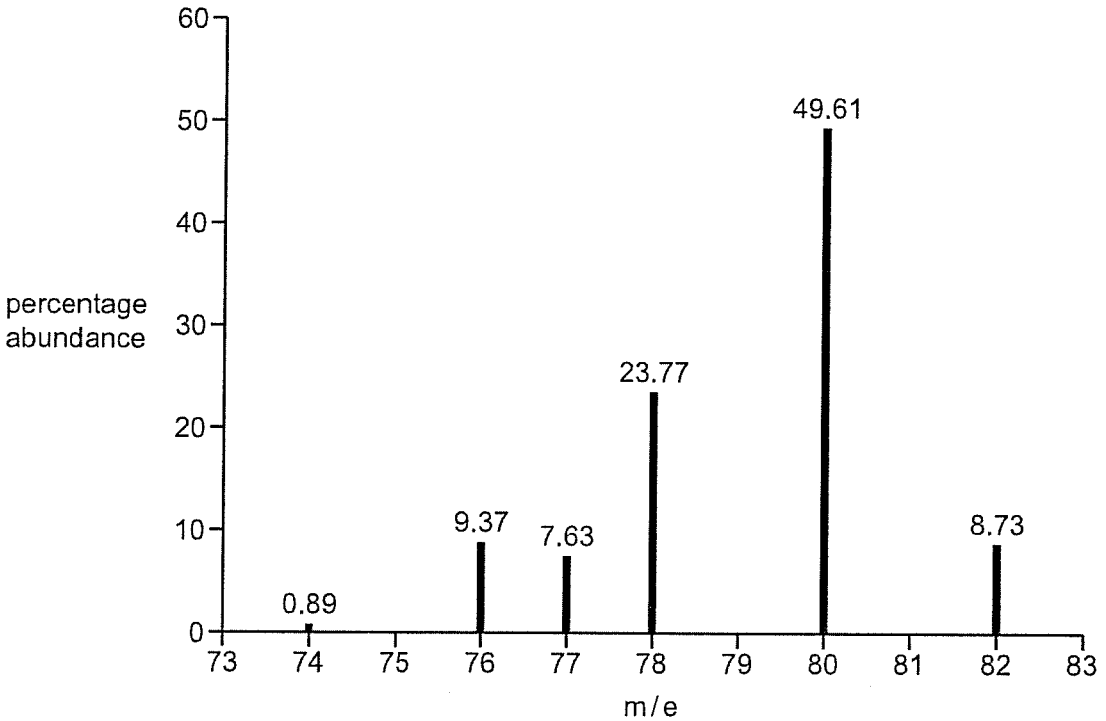
(a) Chemists recognise that atoms are made of three types of particle.
Complete the following table with their names and properties.

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**.

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

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

[2]

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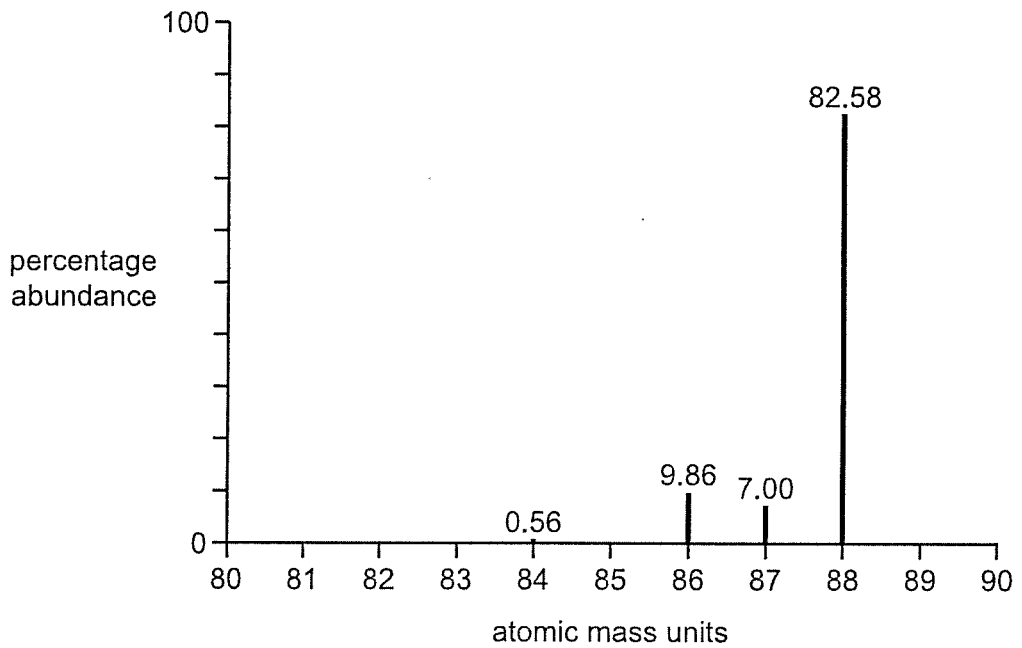
(c) The element tellurium, Te, reacts with chlorine to form a single solid product, with a relative formula mass of 270. The product contains 52.6% chlorine b ymass.

(i) Calculate the molecular formula of this chloride.

molecular formula ..... [3]

20. 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]

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(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]

(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]

21. 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]

22. 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.

[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]

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23. 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]

(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]

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24. 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 **Z**Cl_2. The percentage composition by mass of **Z**Cl_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]

25. 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.

(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]

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(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]

26. 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.

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

(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.

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(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.

(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]

27. 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*

.....

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$(NH_4)_2SO_4$ 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 $(NH_4)_2SO_4$.

(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]

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28. 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

(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.

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

[7]

29. 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.

(a) (i) Write a balanced equation for the reaction between Na_2CO_3 and HCl.

.....

(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.

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(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.

[6]

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

[2]

30. 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*.

.....

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(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.

(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.

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

[7]

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Answers Section

1. M/J 21/P23/Q3

(a) (i)

	state at room temp	observations on add'n of sample to water	identity of sample
R	solid	alkaline, colourless solution is made but some white solid remains	**M1** $Ba(OH)_2$ OR barium hydroxide
S	solid	white solid disappears, solution is neutral	**M2** $NaCl$ OR sodium chloride
T	liquid	misty fumes, white solid is made in vigorous reaction	**M3** $SiCl_4$ OR silicon(IV) chloride
U	solid	acidic, colourless solution is made in vigorous reaction	**M4** P_4O_{10} OR phosphorus(V) oxide

4

(ii) SiO_2 **1**

(iii) phosphoric acid / phosphoric(V)acid **1**

(b) (i) *any **one** physical property typical of ceramic materials from:* **1**
- strong / retain strength (over certain temperatures / conditions)
- non-conductors of electricity / electrical insulators
- high melting points

(ii) SiO_2 **1**

(c) *% of O* **1**
M1 100 – 79.29 (= 20.71)
M2 *express W and O as mol by / 183.8 and / 16 respectively* **1**
M3 *divide each by smallest number to give empirical formula* **1**
WO_3

2. M/J 20/P21/Q2

(a) (i) $2CuSO_4(aq) + 4KI(aq) \rightarrow 2CuI(s) + (1)I_2(aq) + 2K_2SO_4(aq)$ **2**
M1 correct balancing **M2** correct state symbols

(ii) Oxidation state of copper in $CuSO_4$ (+)2 **1**
AND
Oxidation state of copper in CuI (+)1

(iii) **M1** redox **1**
M2 iodide ions – lost electron(s) AND copper ions – gained electron(s) **1**

(b)

Mass of 0.0982mol $CuSO_4$ in 17.43g $CuSO_4.yH_2O$	**M1** *calculate M_r $CuSO_4$ using Ar from data booklet* 63.5 + 32.1 + 64.0 = 159.6 **M2** *use Mr to calculate mass of $CuSO_4$* (0.0982 × M1) =15.67272g
number of water in 17.43g of $CuSO_4$ **y**H_2O	**M3** *calculate the mass amount of water in sample AND use this value to calculate the amount of water present* (17.43-15.67)/18 = 0.097778 mol
value of **y**	**M4** *use the ratio of M2: 0.0982 to find y* (mol H_2O ÷ mol $CuSO_4$) = 1

4

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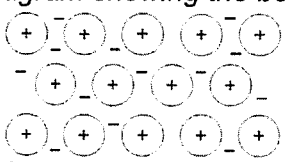
3. M/J 20/P23/Q2

(a) **EITHER** **2**
M1 mass of an atom / isotope
M2 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)
OR **M1** mass of one mol (of atoms) of an isotope
M2 relative / compared to 1/12 (the mass) of 1 mol of C-12 OR
in which one mol C-12 (atom / isotope) has a mass of (exactly) 12 g

(b) % abundance of ^{63}Cu = 72.5% **2**
% abundance of ^{65}Cu = 27.5%
M1 *correct algebraic expression AND correct calculation of x for one isotope*
% ab of ^{63}Cu = x $(x/100 \times 63) + ((1- x)/100 \times 65) = 63.55$ so x =72.5
OR
% ab of ^{65}Cu = x $(1- x)/100 \times 63) + x/100 \times 65) = 63.55$ so x = 27.5
M2 *calculation of abundance of other isotope by 100- x*

(c) (i) metallic **1**

(ii) *diagram showing the bonding in a sample of copper* **3**



M1 diagram shows regular arrangement of spheres labelled as positively charged ions / +2 or +1 / cations
M2 diagram shows surrounded by electrons and clearly labelled as 'delocalised electrons'

(iii) $(1s^2)\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^1$ **OR** $(1s^2)\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^{10}$ **1**

(d) (i) **M1** *calculate the number mol $S_2O_3^{2-}$ added* **2**
20/1000 x 0.10 = $2x10^{-3}$ = 0.002 (mol $S_2O_3^{2-}$)
M2 *calculate number mol $CuSO_4$ in 250cm^3*
(1mol $S_2O_3^{2-}$: 1 mol $CuSO_4$) = 0.002 mol $CuSO_4$ in 25cm^3
so 0.02 mol $CuSO_4$ in 250cm^3

(ii) **3**

M1 amount of $CuSO_4$ in 10.68 g of $CuSO_4 \cdot xH_2O$	7.98 / (159.6) = 0.05 (mol)
M2 amount of H_2O in 10.68 g of $CuSO_4 \cdot xH_2O$	(10.68 – 7.98) / 18 = 2.7 / 18 =) 0.15 (mol)
M3 value of **x**	(mol H_2O ÷ mol $CuSO_4$ =) 3

4. O/N 19/P22/Q1

(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

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(b) (i) **M1:** **3**

$$\frac{(92.2 \times 28) + (^{29}\text{Si} \times 29) + (^{30}\text{Si} \times 30)}{100} = 28.09$$

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

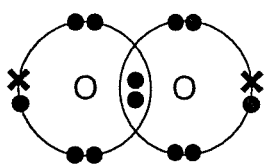
5. O/N 19/P22/Q2/c

(a) (i) **M1:** correct conversion of quantities **2**
$V = 5(.00) \times 10^{-4}$ (m^3)
T = 293 (K)
$p = 5.37(0) \times 10^3$ (Pa)

M2: calculation to find n using n = PV / RT
(n) = 1.1×10^{-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

6. MAR 19/P22/Q2/a(i)

(a) (i) **M1** **2**
① mass of a molecule
OR ② (weighted) average / mean mass of the molecules
OR ③ mass of one mole of molecules

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M2

① / ② compared to $\frac{1}{12}$ (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)

③ relative / compared to $\frac{1}{12}$ (the mass) of 1 mole of carbon-12

OR on a scale in which 1 mole of carbon-12 (atoms / isotope) has a mass of (exactly) 12 g

7. O/N 18/P22/Q1/d

(a) (i) (100 – 56.36 – 25.14) = 18.5(0) **1**

(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]

8. O/N 18 /P21/Q1/c(ii),(iii),(iv),O/N 18 /P23/Q1/c(ii),(iii),(iv)

(a) (i) balanced equation with $11O_2$ and $8SO_2$ **2**

M1: O_2 and SO_2

M2: 11 and 8

(ii) **M1** *is for process of calculating number of moles of* Fe_2O_3 **2**

33.18 ÷ 159.6 (= 0.2079 mol)

M2 *for correct use of stoichiometry and 120.0 with candidate's* ***M1***

M2 (0.2079) × 4 / 2 × 120.0 = 49.89 (g)

(iii) (0.37/(0.37+49.89)) = 0.74 **1**

9. M/J 18/P22/Q2/a,d

(a) *option 1:*

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] **2**

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) $MnO_4^- + \mathbf{5}Fe^{2+} + \mathbf{8}H^+ \rightarrow Mn^{2+} + \mathbf{5}Fe^{3+} + \mathbf{4}H_2O$ **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**

10. 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 **1**

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

OR

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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**

11. 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)

12. M/J 16/P23/Q1

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

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

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

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

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

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

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

(b) **(i)** covalent **[1]**
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]**
$FeCl_3 + 6H_2O \rightarrow [Fe(H_2O)_6OH]^{2+} + H^+ + 3Cl^-$ **[10]**

13. 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]**

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

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

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

(iv) $(126 - 90 = 36;\ 36/18 = 2$ hence) $x = 2$ **[1]**
[6]

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

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

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

x = 18 [2]

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

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

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

$A = 84$

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16. MAR 16/P22/Q2

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

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

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

(iv) M_r of $FeCO_3$ = 55.8 + 12.0 + 3(16.0) = **115.8**
(iii) $\times M_r(FeCO_3)$ = **3.79**g **[2]**

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

(b) (i) $2Fe^{3+} + Sn^{2+} \rightarrow 2Fe^{2+} + Sn^{4+}$
species
balancing **[2]**

(ii) $\mathbf{SnCl_2(aq)} + \mathbf{2}HgCl_2(aq) \rightarrow SnCl_4(\mathbf{aq}) + Hg_2Cl_2(\mathbf{s})$
$SnCl_2$ AND 2
state symbols **[2]**

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

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

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

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

18. M/J 15/P22/Q1/a,b,c(ii)

(a)

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

[3]

(b) (i) Mass of an atom(s)
relative to 1/ 12th(the mass) of (an atom of) carbon-12
OR
relative to carbon-12 which is (exactly) 12 **[2]**

(ii) % of third isotope = 10

$$\frac{(24\times79)+(26\times11.0)+10x}{100} = 24.3$$

$10x = 248$
$x = 24.8$ (3s.f.) **[3]**

(c) (i)

Mg	O	H	Cl	
$\frac{31.65}{24.3}$	$\frac{20.84}{16}$	$\frac{1.31}{1}$	$\frac{46.2}{35.5}$	
1.30	1.30	1.31	1.30	= 1:1:1:1

$MgOHCl$ **[2]**

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19. M/J 15/P21/Q1/a,b,c(i)

(a)

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

[3]

(b) (i) RAM = mean/ average mass of the isotopes/an atom(s) 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)

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

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

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

(c) (i)

Te	**C*l***	
47.4 / 128	52.6 / 35.5	
0.370 / 0.370	1.48 / 0.370	
1	4	so EF = $TeCl_4$
		Empirical Formula Mass = 270 so MF = $TeCl_4$ **[3]**

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

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

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

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

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

(ii)

Ba	C*l*	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

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

21. M/J 14/P23/Q2

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

(b) (i) Initial acid = 40 × 0.4/1000 = 0.016 (mol) **[1]**

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

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

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

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

(vi) M_r = 399.7 [1]

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

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

(b) (i) Mass of an atom(s) or isotope
relative to $\frac{1}{12}$ (the mass) of (an atom of) carbon–12
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 $\frac{78.92x+80.92(100-x)}{100} = 79.9$

$x = 51$

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

(c) A Br

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

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

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

3 sig figs **3**
allow alternative correct methods

23. M/J 14/P22/Q2

(a) (i) (The $C_2O_4^{2-}$ ions) lose electrons owtte / ora **1**

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

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

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

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

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

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

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

(ii)

Z	Cl
31.13	68.87
A_r	35.5

$= 1:2$

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

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

Allow alternative correct methods **2**

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

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

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

(ii) MnO_4^- : Fe^{2+} = 1 : 5 **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**
ecf from **(b)(ii)**

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

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

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

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

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

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

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

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

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

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

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

give one mark for the correct expression
give one mark for answer given as 91.2 – i.e to 3 sig. fig.
allow ecf where appropriate **[9]**

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

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

$(NH_4)_2SO_4 + 2NaOH \rightarrow 2NH_3 + Na_2SO_4 + 2H_2O$

allow ionic equations in each case

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

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

(iv) $n(NaOH) = 0.0784 - 0.059 = 0.0194$

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

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

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

give one mark for the correct expression

give one mark for answer given as 43.3 – i.e. to 3 sig. fig.

allow ecf where appropriate [9]

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

(a) $ZnCO_3$ $Zn(OH)_2$ ZnO

not Zn **or** other compounds of Zn [2]

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

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

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

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

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

$ZnSO_4 = 161$ gives 1.30×10^{-2}

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

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

(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 $\frac{9.1 \times 10^{-2}}{1.29 \times 10^{-2}}$

$= 7.054 \equiv 7$ mol H_2O

answer must be expressed as a whole number

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

29. M/J 12/P23/Q2

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

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

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

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

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

M_r of $Na_2CO_3 = 106$

mass of $Na_2CO_3 = 1.90$ g **[6]**

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

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

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

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

this is 10 mol of H_2O

or

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

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

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

30. M/J 12/P21/Q2

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

correct products

correctly balanced equation **[2]**

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

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

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

(iv) n(NaOH) used up $= 0.10 - 0.0312 = 0.0688 = 0.07$

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

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

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

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A Level

Unit 2

ATOMIC STRUCTURE

Chemistry Paper-2
Topical Workbook
Article Number: 232

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Unit 2: Atomic Structure

1. O/N 21/P22/Q2

(a) Table 1 gives physical data for some of the Period 3 elements.

Table 1

atomic number, Z	11	12	13	14	15	16	17
bonding present in element	M						C
first ionisation energy / kJ mol^{-1}	494	736	577	786	1060	1000	1260
maximum oxidation number							+7
anionic radius / nm	–	–	–	0.271	0.212	0.184	0.181

(i) Complete the row in the table labelled 'bonding present in element'.

Use C = covalent, I = ionic, M = metallic, as appropriate. **[1]**

(ii) Explain the difference between the first ionisation energies of the elements with atomic numbers 11 and 17.

.....

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

(iii) Explain the difference between the first ionisation energies of the elements with atomic numbers 15 and 16.

.....

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

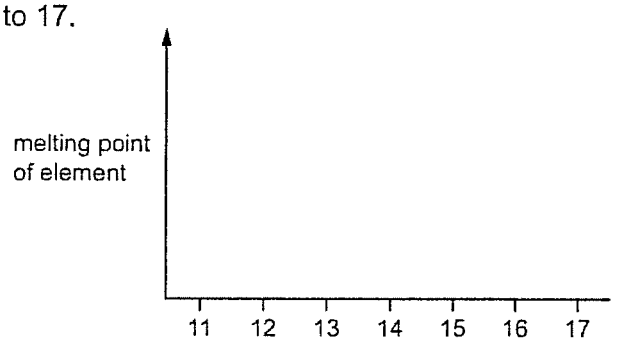
(iv) Complete the row in the table labelled 'maximum oxidation number'. **[1]**

(v) Explain the variation in anionic radius for the elements with atomic numbers 14 to 17.

.....

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

(b) Use the axes to sketch a graph that shows the trend in melting points of the elements with atomic numbers 11 to 17.



[2]

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(c) Dmitri Mendeleev published the first Periodic Table in 1869.

Mendeleev used his knowledge of chemical periodicity to propose the properties of gallium, $_{31}Ga$, a Group 13 element.

Table 2 gives some chemical and physical data of elements in Group 13.

Table 2

element	density /g cm^{-3}	boiling point /K	cationic radius /nm
$_5B$	2.34	3930	0.020
$_{13}Al$		2470	0.050
$_{31}Ga$	5.91	2400	
$_{49}In$	7.30		0.081
$_{81}Tl$	11.8	1460	0.095

Complete the table by predicting values for the missing data. **[3]**

(d) Indium and aluminium are elements in Group 13 of the Periodic Table.

Indium has very similar chemical properties to aluminium.

- Indium reacts vigorously with hydrochloric acid to form a colourless gas and a salt in solution.
- Indium oxide, In_2O_3, is amphoteric.
- Gaseous indium bromide has the formula In_2Br_6. This molecule contains coordinate bonds.

(i) Identify the formula of the salt formed when indium reacts with hydrochloric acid.

..... [1]

(ii) Construct an equation for the reaction of In_2O_3 with excess aqueous NaOH.

..... [1]

(iii) Draw a diagram that clearly shows the types of bond present in $In_2Br_6(g)$.

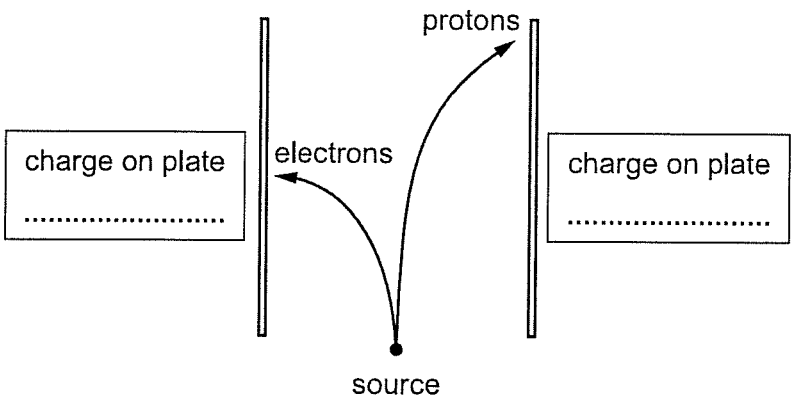
[2]

2. O/N 20/P22/Q1

Atoms contain the subatomic particles electrons, protons and neutrons. Protons and electrons were discovered by observations of their behaviours in electric fields.

(a) The diagram shows the behaviour of separate beams of electrons and protons in an electric field.

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(i) Complete the diagram with the relative charge of each of the electrically charged plates. **[1]**

(ii) On the diagram, draw a line to show how a separate beam of neutrons from the same source behaves in the same electric field. **[1]**

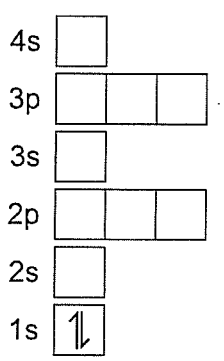
(b) Electrons in atoms up to $_{36}Kr$ are distributed in s, p and d orbitals.

(i) State the number of occupied orbitals in an isolated atom of $_{36}Kr$.

type of orbital	s	p	d
number of orbitals			

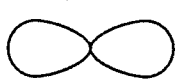
[3]

(ii) Complete the diagram to show the number and relative energies of the electrons in an isolated atom of $_{14}Si$.



[2]

(iii) The diagram shows a type of orbital.



State the total number of electrons that exist in all orbitals of this type in an atom of $_{9}F$.

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

(iv) The first ionisation energies of elements in the first row of the d block ($_{21}Sc$ to $_{29}Cu$) are very similar. For all these elements, it is a 4s electron that is lost during the first ionisation. Suggest why the first ionisation energies of these elements are very similar.

.....

.....

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

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(c) *Hydron* is a general term used to represent the ions $^{1}_{1}H^{+}$, $^{2}_{1}H^{+}$ and $^{3}_{1}H^{+}$.

State, in terms of subatomic particles in the nucleus, what is the same about each of these ions and what is different.

same .....

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

3. O/N 20/P22/Q3

PCl_5, PCl_3 and NCl_3 are halides of Group 15 elements.

(a) PCl_5 can be formed from the reaction of phosphorus with chlorine. PCl_5 has a melting point of 161 °C.

(i) Write an equation for the formation of PCl_5 from the reaction of phosphorus and chlorine.

..... [1]

(ii) State the type of structure and bonding shown by liquid PCl_5.

..... [1]

(b) A small amount of PCl_5 is added to excess water. The PCl_5 reacts vigorously to form a colourless solution.

(i) Give **one** other observation you would make when PCl_5 reacts with excess water.

..... [1]

(ii) Write the equation for the reaction of PCl_5 with excess water.

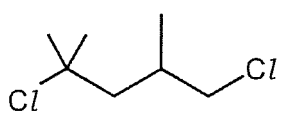
..... [1]

(iii) Estimate the pH of the resulting solution.

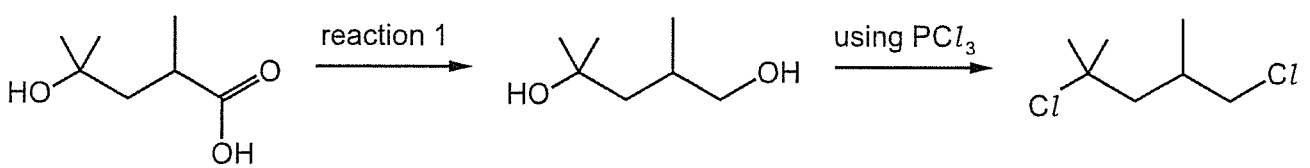
..... [1]

(c) PCl_3 is used to convert alcohols to chloroalkanes, such as compound **T**.

T



A possible synthesis of **T** is shown.



(i) Identify a reagent that could be used in reaction 1.

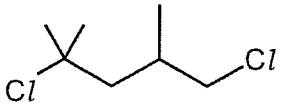
..... [1]

(ii) **T** exhibits optical isomerism.

Explain what is meant by the term *optical isomer* and circle any atom(s) in **T** that give rise to optical isomerism.

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T

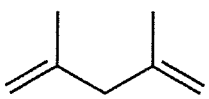


.....

..... [2]

(iii) **T** is a **minor** product in the reaction of compound **S** with excess HCl.

S



Draw the structure of the **major** product of the reaction of **S** with excess HCl.

[1]

(d) NCl_3 is a yellow liquid that can be used to bleach flour.

(i) Predict the shape of the NCl_3 molecule and the Cl–N–Cl bond angle.

shape .....

bond angle ..... [2]

(ii) NCl_3 reacts with water to form HOCl, a weak Brønsted-Lowry acid.

Explain fully what is meant by the term *weak Brønsted-Lowry acid*.

.....

..... [2]

(iii) NCl_3(l) decomposes according to the equation shown.

$$2NCl_3(l) \rightarrow N_2(g) + 3Cl_2(g)$$

A sealed container of volume 250 cm^3 contains an unreactive gas at a pressure of 1.00×10^5 Pa.

0.241 g of NCl_3(l) was injected into the sealed container.

The sealed container was heated to make the NCl_3(l) decompose fully and then cooled to 20 °C.

Calculate the final **total** pressure inside the sealed container at 20 °C after the NCl_3(l) has fully decomposed.

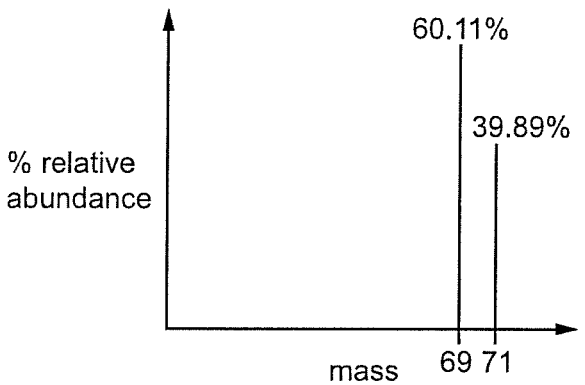
final total pressure = ... Pa [4]

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4. M/J 20/P22/Q1

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]

(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).

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(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).

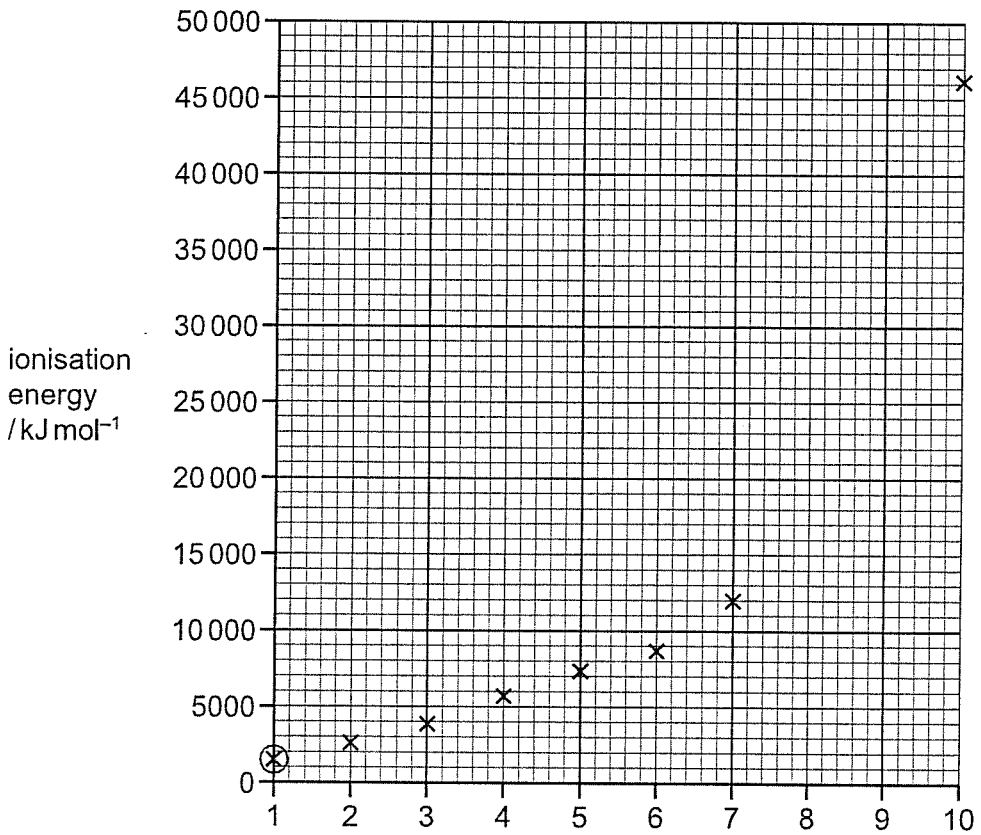
..... [2]

5. M/J 19/P21/Q3

(a) Construct an equation for the **second** ionisation energy of argon.

..... [1]

(b) The graph shows successive ionisation energies for the element argon.
Complete the graph with predictions for the eighth and ninth ionisation energies of argon.
Use a cross (×) for each data point. [2]



(c) The energy value required to remove the first electron from an atom of argon is circled on the graph.
Sketch the shape of the orbital that contains this electron.

[1]

(d) Chlorine exists as a diatomic gas, $Cl_2(g)$. A sample of $Cl_2(g)$ was made during a chemical reaction. When measured at 404 kPa and 25 °C the sample occupied a volume of 20.0 cm^3.

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(i) Calculate the mass, in grams, of $Cl_2(g)$ formed.
For this calculation, assume that chlorine behaves as an ideal gas under these conditions.

mass of $Cl_2(g)$ = ... g **[3]**

(ii) Calculate the number of chlorine atoms in this sample of $Cl_2(g)$. You may find it helpful to use your answer to **(d)(i)**.
If you are unable to calculate an answer to **(d)(i)**, use 0.36 g of Cl_2. This is **not** the correct answer.

number of chlorine atoms = ... **[2]**

(iii) $Cl_2(g)$ does **not** behave as an ideal gas under these conditions.
Explain why $Cl_2(g)$ behaves even **less** ideally at:

- very high pressures

.....

.....

- very low temperatures.

.....

..... [2]

6. M/J 19/P23/Q1

(a) A sample contains three different types of atom: $^{40}_{18}Ar$, $^{40}_{19}K$ and $^{40}_{20}Ca$.

(i) State fully, in terms of the numbers of subatomic particles, what these three atoms have in common.

..... [1]

(ii) State fully, in terms of the numbers of **all** subatomic particles, how these three atoms **differ** from each other.

..... [1]

(b) A sample of sulfur contains only two isotopes, ^{32}S and ^{34}S. The relative atomic mass of this sample is 32.09.

isotope	isotopic mass
^{32}S	32.0
^{34}S	34.0

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Calculate the percentage abundance of the isotopes present in this sample.

% abundance ^{32}S = ...

% abundance ^{34}S = ... **[3]**

(c) The electronic configuration of a sulfur atom is $1s^2 2s^2 2p^6 3s^2 3p^4$.

(i) Identify which orbital in a sulfur atom has the lowest energy.

..... [1]

(ii) Sketch the shape of a p orbital.

[1]

(iii) During the process of ionisation a sulfur atom loses an electron.

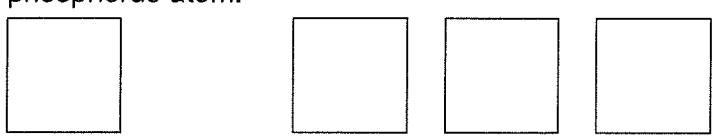
$S(g) \rightarrow S^+(g) + e^-$ $\Delta H = 1000\,kJ\,mol^{-1}$

Identify the orbital from which this electron is removed. Explain your answer.

orbital .....

explanation ..... [2]

(d) (i) Complete the diagram to show the arrangement of electrons within the third shell of a phosphorus atom.



[1]

(ii) Explain why the first ionisation energy of sulfur is less than that of phosphorus.

.....

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

7. O/N 18/P22/Q1/a,b,c

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]

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(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*.

.....

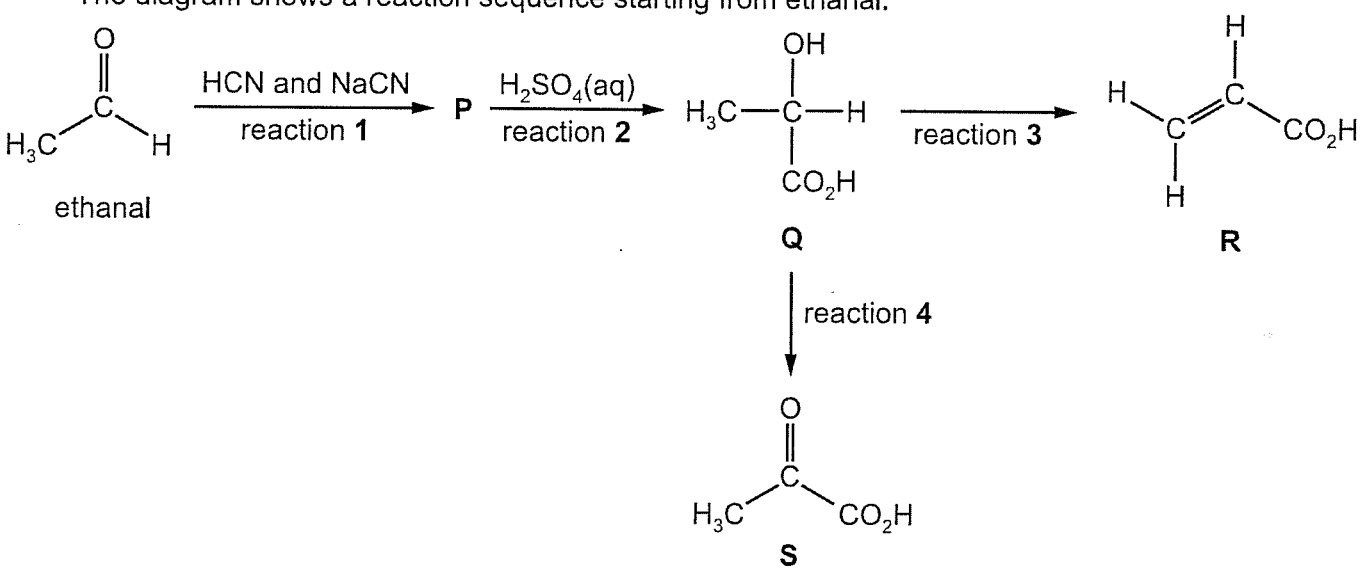
..... **[2]**

(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]**

8. O/N 18/P22/Q4/e(ii),(iii)

The diagram shows a reaction sequence starting from ethanal.



(i) Give the electronic configuration of the Na^+ cation.

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

(ii) Suggest why ionic radius increases down Group 1.

..... [1]

9. M/J 18/P21/Q3/b

(a) The first ionisation energies of the elements across the third period show a general increase. Aluminium and sulfur do **not** follow this general trend.

(i) Explain why aluminium has a lower first ionisation energy than magnesium.

.....

..... [2]

(ii) Explain why sulfur has a lower first ionisation energy than phosphorus.

.....

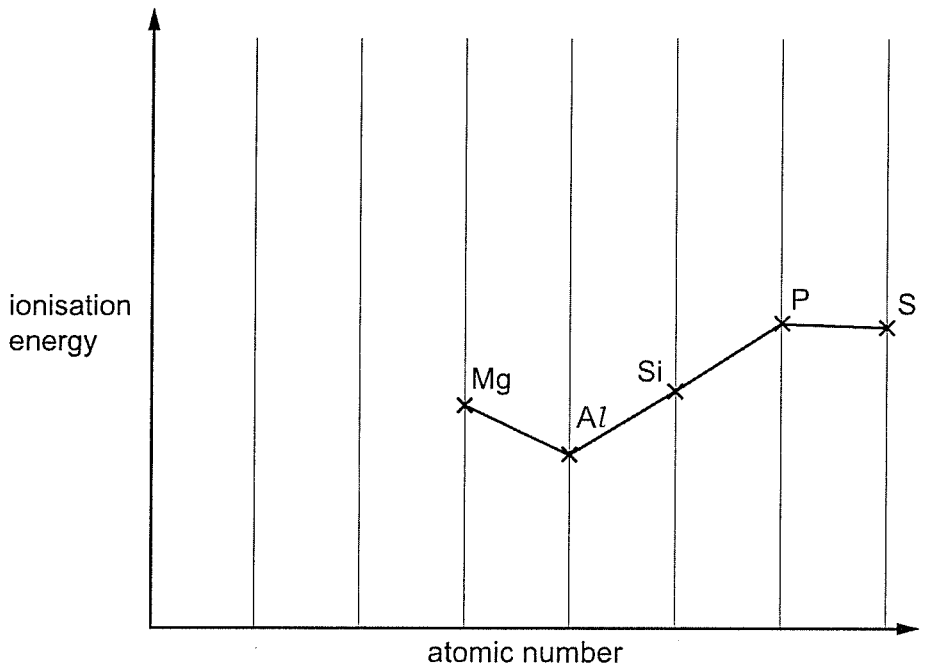
..... [2]

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10. O/N 17/P21/Q2/a, O/N 17/P23/Q2/a

The elements in the third period, and their compounds, show trends in their physical and chemical properties.

(a) A sketch graph of the first ionisation energies of five successive elements in the third period is shown.



(i) Explain why there is a general increase in the first ionisation energy across the third period.

.....

..... [2]

(ii) Sketch, on the graph, the position of the ionisation energies of the two elements that come before Mg in this sequence. [2]

(iii) Explain, with reference to electron arrangements, the decreases in first ionisation energy between Mg and Al and between P and S.

Mg and Al .....

.....

P and S .....

.....

[4]

11. 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	.....

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.....	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]**

12. 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

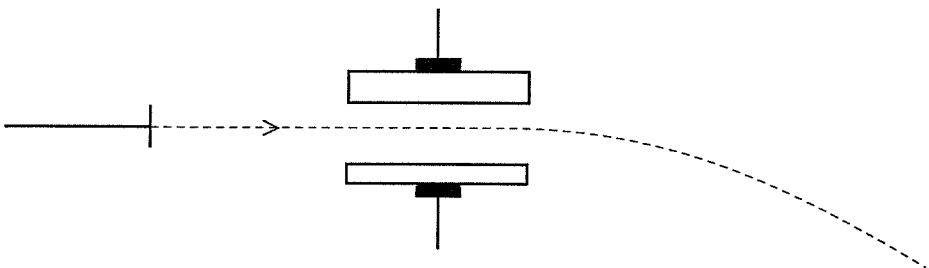
[4]

(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.

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[3]

13. 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

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

.....

.....

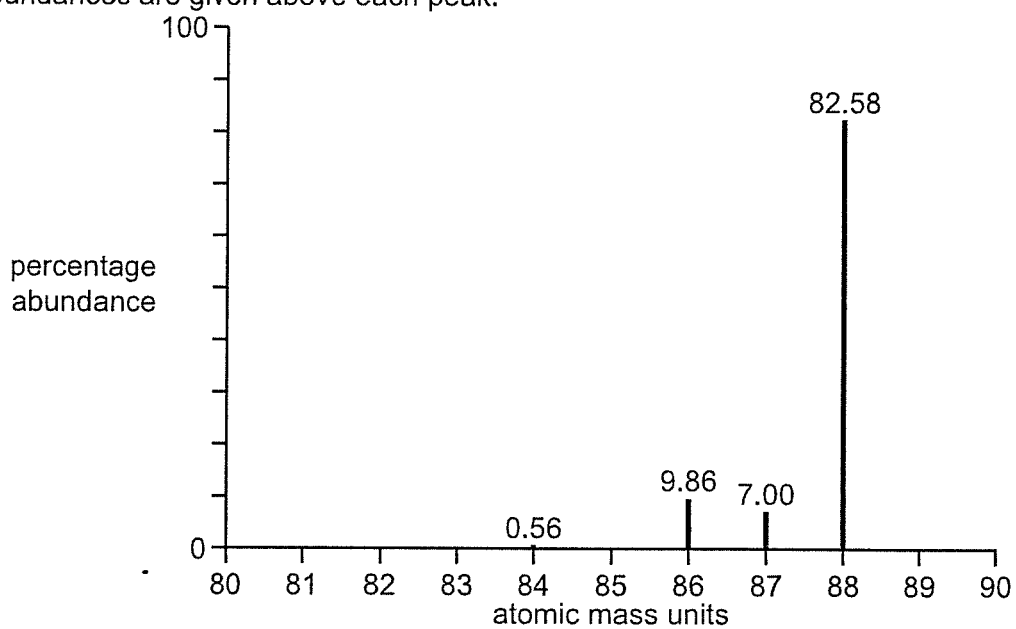
..... [3]

(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.



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(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]

14. 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 21269 25398.

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

.....

..... [2]

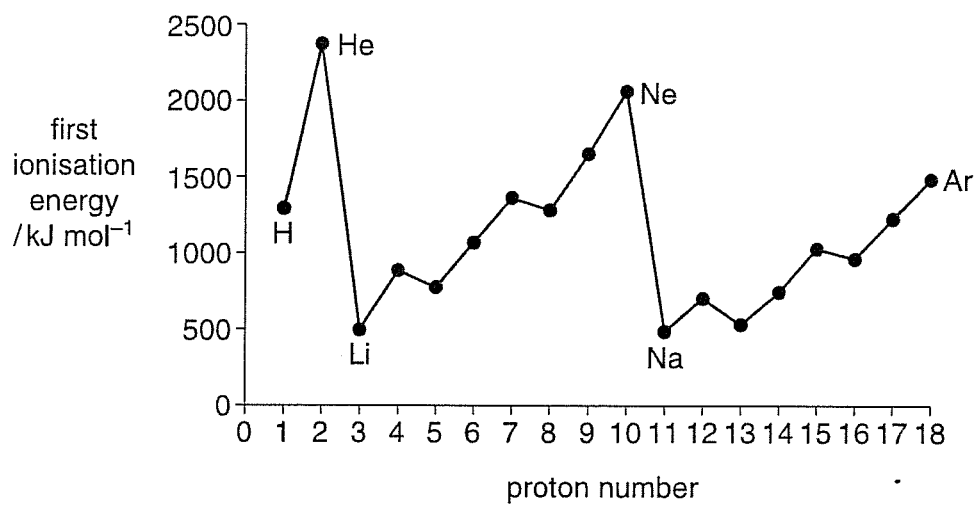
(ii) Complete the electronic configuration of the element in Period 2 that is in the same group as **A**.

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

15. 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]

16. 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* .....

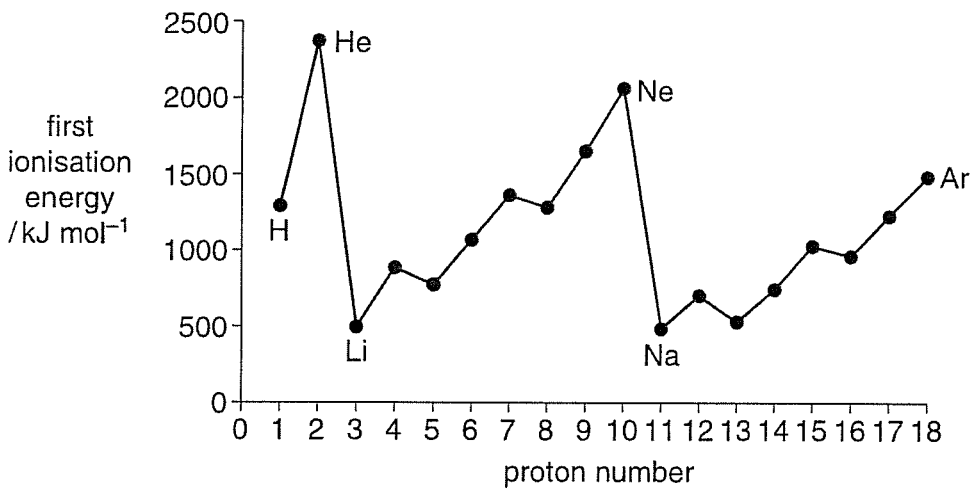
(ii) Hence state the symbol of the element *E*.

..... [3]

17. 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.



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

..... [2]

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(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]

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Answers Section

1. O/N 21/P22/Q2

(a) (i)

M	M	M	C	C	C	C

1

(ii) All 3 points correct scores two marks
Any 2 points scores one mark **2**

- *nuclear charge increases OR increasing proton number*
  e.g. 17 / C*l* has a greater nuclear charge
- *describe the similarity in shielding between the two elements*
  e.g. they have almost the same shielding
- *describe the overall effect in terms of greater nuclear attraction for (outer) electrons*
  e.g. (outer) electrons are attracted more (strongly) to the nucleus

(iii) **M1** describes the difference between 1st IE of elements 15 and 16 (P and S) in terms of either: **2**
spin-pair repulsion (in element 16 / S) **OR** electron pair repulsion (in element 16/ S)

M2 describes the location of the electron pair in the (3)p orbital which repel each other

(iv)

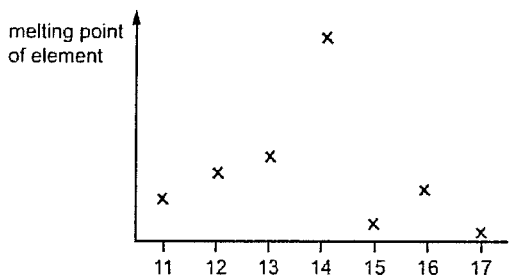
(+)1	(+)2	(+)3	(+)4	(+)5	(+)6

1

(v) **M1** (anions have) same number of electrons (but increasing proton number) **2**

M2 increasing proton number / nuclear charge AND increasing attraction of nucleus for (outer) electrons **OR**
(outer) electrons attracted more (strongly) to the nucleus AND because of increasing proton number/ nuclear charge

(b)



2

(c) **M1** density of $_{13}Al$: value within range 2.5–5.0 (g cm^{-3}) **3**

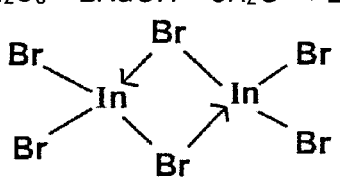
M2 cationic radius of $_{31}$Ga: value within range 0.055–0.075 (nm)

M3 boiling point of $_{49}$In: value within range 1500–2300 (K)

(d) (i) $InCl_3$ **1**

(ii) $In_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaIn(OH)_4$ **1**

(iii)



2

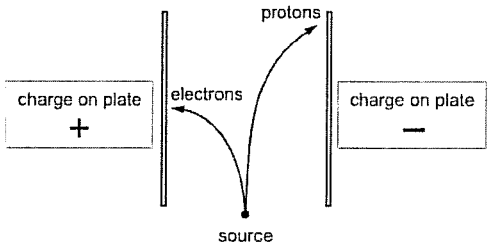
M1 correct connectivity of In_2Br_6

M2 showing the two correct dative covalent bonds

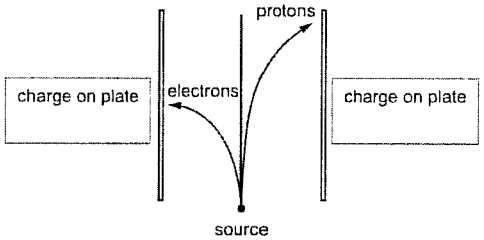
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2. O/N 20/P22/Q1

(a) (i) positive /+ on left **AND** negative /– on right **1**



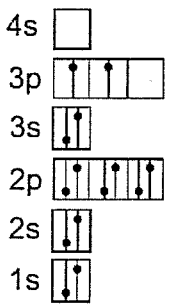
(ii) straight line vertically upwards from the source **1**



(b) (i) **3**

type of orbital	s	p	d
number of orbitals	4	9	5

(ii) **2**



(iii) 5 **1**

(iv) Award one mark for each correct bullet point – max 3 marks **3**

- nuclear charge increases
- extra electron(s) in inner shell / n=3 /d-subshell / d- orbital
- increased shielding (of 4s electrons by electrons in n=3 / 3rd shell / 3d)
- (overall) **similar** nuclear attraction (for outer electron)

(c) *answer in terms of **subatomic particles** in the **nucleus*** **1**
same (number of) protons
AND
different (number of) neutrons

3. O/N 20/P22/Q3

(a) (i) $P_4 + 10Cl_2 \rightarrow 4PCl_5$ **1**

(ii) simple / molecular AND covalent **1**

(b) (i) steamy / misty fumes **1**

(ii) $PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$ **1**

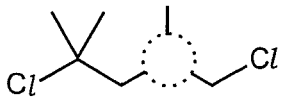
(iii) 0 to 4 **1**

(c) (i) $LiAlH_4$ OR lithium tetrahydridoaluminate((III)) **1**

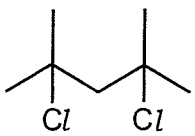
(ii) **M1:** molecule with a non super-(im)posable mirror image **2**

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M2:



(iii)



1

(d) (i) **M1:** (trigonal) pyramidal
M2: 107 **2**

(ii) **M1:** proton / H^+ donor
M2: partially dissociates (in solution) **2**

(iii) **method 1** **4**

M1: *show the number of mol gas produced from 0.241 g NCl_3*
[$M_r(NCl_3)$ = 120.5 1 mol NCl_3 produces 2 mol gas]

$n = 2 \times 0.241 / 120.5$ OR $n = 0.0040$ (mol gas produced.)

M2: *correct conversion of T to Kelvin, V to m^3 and correct value of R*

M3: *use of equation P = nRT/ V with M2 values for n, R, T and V to find pressure of mol gas produced*

increase in $p = nRT/V = \frac{0.0040 \times 8.31 \times 293}{250 \times 10^{-6}}$

$= 3.90 \times 10^4$

M4: = *1.00×10^5 + M3 (Pa)*
total pressure $= 1.00 \times 10^5 + 3.90 \times 10^4$
$= 1.39 \times 10^5$ (Pa)

method 2

M1: *calculate the produced from 0.241 g NCl_3*
0.003 (mol) Cl_2 **AND** 0.001 (mol) N_2

M2: *conversion of T to Kelvin, V to m^3 and correct value of R in all PV/RT equations used*

M3: *use of equation PV/RT= n for both calculations or a combined equation with M2 values for R,T and V to find partial pressure for each of the gases*
$pp Cl_2 = 29217.96$ AND $pp N_2 = 9739.32$

M4: *Use P_{total} = pp unreacted gas + $pp Cl_2$ + $pp N_2$*
$1 \times 10^5 + 2.92 \times 10^4 + 9.74 \times 10^3 = 138\,940$

4. M/J 20/P22/Q1

(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

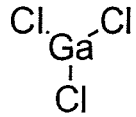
(b) M1 60.11/100 x 69 + 39.89/100x71 **2**
M2 69.80

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(c) **3**

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)

(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

$Ga_2O_3 + 2NaOH \rightarrow 2NaGaO_2 + H_2O$

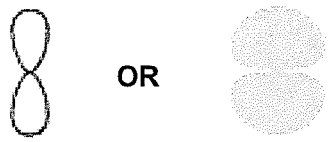
5. M/J 19/P21/Q3

(a) $Ar^+(g) \rightarrow Ar^{2+}(g) + e^{(-)}$ **OR** $Ar^+(g) - e^{(-)} \rightarrow Ar^{2+}(g)$ **1**

(b) at $x = 8$, within range 13000–20000 **1**

at $x = 9$, within range 35000–45000 **1**

(c) **1**



OR

(d) **(i)** **M1** *correct conversions of data to SI/consistent units* **1**

$p = 404\,000$; $V = 20 \times 10^{-6}$; $T = 298$

M2 *calculation of n (= pV/RT) from **M1** values* **1**

$$n = \frac{404000 \times 20 \times 10^{-6}}{8.31 \times 298} = 3.263 \times 10^{-3} \text{ mol of } Cl_2$$

M3 *finding the mass of Cl_2* **1**

$= 3.263 \times 10^{-3} \times 71.0 = 0.23$ (g)

(ii)

Method 1	**Method 2**
M1 $= 3.263 \times 10^{-3} \times 2$	**M1** $= \frac{0.23}{71.0} \times 2$ **OR** 6.53×10^{-3}

1

M2 $= 6.02 \times 10^{23} \times$ **M1** $= 3.93 \times 10^{21}$ atoms of Cl	**M2** $= 6.02 \times 10^{23} \times$ **M1** $= 3.90 \times 10^{21}$ atoms of Cl

1

(iii) **M1** size / volume of **molecule / particle** becomes significant / non-negligible **1**

OR IMFs become significant / non-negligible

M2 IMFs becomes significant / non-negligible / collisions are not elastic **1**

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6. M/J 19/P23/Q1

(a) (i) All have the same nucleon number **1**
OR same sum / **total** number of protons + neutrons

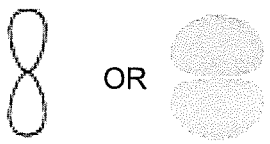
(ii) (different) number of protons, neutrons **and** electrons **1**

(b) M1 $x/100 \cdot 32 + (100-x/100 \cdot 34) = 32.09$ **3**

M2 $(32x + 3400 - 34x) = 3209$ so $x = 95.5$

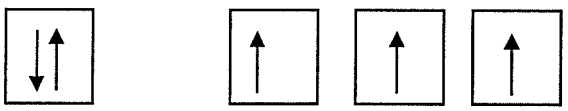
M3 S^{32} 95.5% **AND** S^{34} 4.5%

(c) (i) 1s **1**

(ii)  OR **1**

(iii) M1 3p **2**

M2 It is less attracted to the nucleus (so takes less energy to lose)
OR
It is the highest energy orbital (which is occupied) / it is in the highest energy orbital

(d) (i)  **1**
3s 3p

(ii) M1 (in S, the electron is removed from the) 2 electrons in (3)**p** orbital **2**
OR a pair of electrons in (3)**p** (orbital / sub-shell)

M2 (paired electrons) repel

7. O/N 18/P22/Q1/a,b,c

(a) **4**

particle	relative mass	relative charge	location	total number in an atom of ^{197}Au
electron	0.0005	–1	**shell(s)** [1]	79
neutron	**1.(001)** [1]	**0** [1]	nucleus	**118** [1]

(b) metallic **1**

(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**

8. O/N 18/P22/Q4/e(ii),(iii)

(a) (i) $1s^2\ 2s^2\ 2p^6\ (3s^0)$ **1**

(ii) Ions/elements have more shells / energy levels (as the group is descended) **1**

9. M/J 18/P21/Q3/b

(a) (i) (outer) electron removed from <u>3p</u> subshell /orbital **1**

(3p) higher in energy/ more shielded / further from the nucleus **1**

(ii) (outer) electron for S is paired in a <u>p orbital</u> / S has a full <u>p orbital</u> **1**

causing (spin / electron) pair repulsion (which reduces attraction) **1**

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10. O/N 17/P21/Q2/a, O/N 17/P23/Q2/a

(a) (i) due to increasing nuclear attraction (for electrons) **1**
due to increasing nuclear charge / atomic / proton number AND similar shielding / same (outer/number of) shell / energy level **1**

(ii) Cross shown on first vertical line from the y-axis (Group 0 / Ne) is clearly higher than all shown **1**
Cross shown on second vertical line from the y-axis (Group 1 / Na) lower than all shown **1**

(iii) Al (the outer / valence) electron (which is lost) is in (3)p sub-shell (Mg is in (3)s subshell) **1**
OR
Al (the outer / valence) electron (which is lost) is in higher energy sub-shell ora
(electron to be removed) is more shielded / experiences greater screening effect **1**
ora
S has a pair of electrons in (a) (3)p orbital / (a 3)p orbital is full **ora** **1**
electron pair repulsion **1**

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

(a) [4]

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
nitrogen	15	7	7	8	10	–3
lead	208	82	82	126	80	+2
lithium	6	3	3	3	2	+1

(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]

(ii) increases across period due to increasing attraction (of nucleus for electrons)
due to increasing nuclear charge / atomic / proton number AND constant / similar shielding / same (outer) shell / energy level [2]

(iii) $1s^2 2s^2 2p^6 3s^2 3p^4$ [1]

12. 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
oxygen	17	8	8	9	10	–2
iron	54	26	26	28	24	+2
chlorine	35	17	17	18	17	0

[4]

(b) line straight on labelled 'neutrons'
line (curving) up labelled 'protons'
proton line clearly shows less (overall) deflection than electron curve [3]

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13. 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
increased **shielding**/screening (from inner shells)
reduces **attraction** [3]

(ii) (3rd electron for each in) inner/lower energy level/**shell**/closer to nucleus (than first two)/less shielding
(large) increase in nuclear attraction [2]

(b) (i) $(1s^2\ 2s^2\ 2p^6)\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 5s^2$ [1]

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

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

(a) The amount of energy required/energy change/enthalpy change when one electron is removed
from each atom/(cat)ion in one mol
of gaseous atoms/(cat)ions
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
Big difference between fifth and sixth ionisation energies [2]

(ii) $1s^2\ 2s^2\ 2p^3$
ecf from **(b)(i)** if period 2 [1]

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

(a) $C(g) \rightarrow C^+(g) + e^-$
correct equation
correct state symbols [2]

(b) (i) Na and Mg
Mg has greater nuclear charge/more protons than Na
in both atoms, the 3s electrons are in the same orbital/same energy level/same shell

(ii) Mg and Al
in Al outermost electron is in 3p rather than 3s
3p electron is at higher energy **or**
is further away/is more shielded from nucleus

(iii) He and Ne
both He and Ne have the highest nuclear charges in their Period

(iv) He, Ne, and Ar
going down the group,
valence/outer shell electrons are farther from the nucleus
there is greater shielding
attraction between valence electrons and nucleus is less **or**
effective nuclear charge is less [8]

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

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

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(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]**

(c) (i) nucleon no. is 228
proton no. is 88

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

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

(a) $S(g) \rightarrow S^{+}(g) + e^{-}$
correct equation
correct state symbols **[2]**

(b) from Na to Ar,
electrons are added to the same shell/have same shielding
electrons are subject to increasing nuclear charge/proton number
electrons are closer to the nucleus **or** atom gets smaller **[3]**

(c) (i) Mg and A*l*
in Mg outermost electron is in 3s **and**
in A*l* outermost electron is in 3p
3p electron is at higher energy **or**
is further away from the nucleus **or**
is more shielded from the nucleus

(ii) S and P
for S one 3p orbital has paired electrons **and**
for P 3p sub-shell is singly filled
paired electrons repel **[4]**

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A Level

Unit 3

CHEMICAL BONDING

Chemistry Paper-2
Topical Workbook
Article Number: 232

Editorial Board

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Unit 3: Chemical Bonding

1. M/J 21/P22/Q2

The strength of interaction between particles determines whether the substance is a solid, liquid or is at room temperature.

(a) Lithium sulfide, Li_2S, is a crystalline solid with a melting point of 938 °C. It conducts electricity when it is molten.

(i) Give the formulae of the particles present in solid lithium sulfide.

..... [1]

(ii) Explain, in terms of the structure of the crystalline solid, why lithium sulfide has a high melting point.

.....

..... [2]

(b) Carbon monoxide, CO, is a gas at room temperature and pressure. It contains a coordinate bond.

(i) Explain what is meant by *coordinate bond.*

..... [1]

(ii) Draw a 'dot-and-cross' diagram to show the arrangement of outer electrons in CO.
Show the electrons belonging to the C atom as ×.
Show the electrons belonging to the O atom as •.

[2]

(c) Nitrogen, N_2, is also a gas at room temperature and pressure. Neither CO nor N_2 is an ideal gas.

(i) State two assumptions that are made about the behaviour of particles in an ideal gas.

1 .....

2 .....

..... [2]

(ii) Explain why N_2 does not behave as an ideal gas at very high pressures.

.....

..... [2]

(iii) Complete the table by naming **all** the types of intermolecular forces (van der Waals') in separate samples of $N_2(g)$ and $CO(g)$.

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	$N_2(g)$	CO(g)
number of electrons per molecule	14	14
presence of a dipole moment	✗	✓
boiling point/°C	–195.8	–191.5
intermolecular forces (van der Waals')		

[2]

(iv) Suggest why the bond in a molecule of CO contains a dipole moment.

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

2. O/N 20/P21/Q3, O/N 20/P23/Q3

The reducing agent $LiAlH_4$ can be synthesised by reacting aluminium chloride with lithium hydride, LiH.

(a) (i) At 200 °C, aluminium chloride exists as $Al_2Cl_6(g)$.
Draw the structure of $Al_2Cl_6(g)$, showing fully any coordinate (dative covalent) bonds in the molecule.

[2]

(ii) At 1000 °C, aluminium chloride exists as $AlCl_3(g)$.
State the bond angle in $AlCl_3(g)$.

..... ° [1]

(iii) Lithium hydride contains the ions Li^+ and H^-.
State the electronic configuration of these two ions.

Li^+ ..... H^- .....[1]

(iv) $LiAlH_4$ decomposes slowly to form $LiAl(s)$ and $H_2(g)$.

$$LiAlH_4(s) \rightarrow LiAl(s) + 2H_2(g)$$

$LiAl(s)$ shows metallic bonding.
Describe metallic bonding.

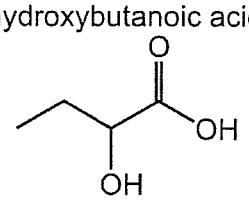
..... [1]

(b) $LiAlH_4$ cannot be used in aqueous solution because it reacts with water to produce LiOH(aq), $H_2(g)$ and a white precipitate which is soluble in excess sodium hydroxide.
Identify the white precipitate.

..... [1]

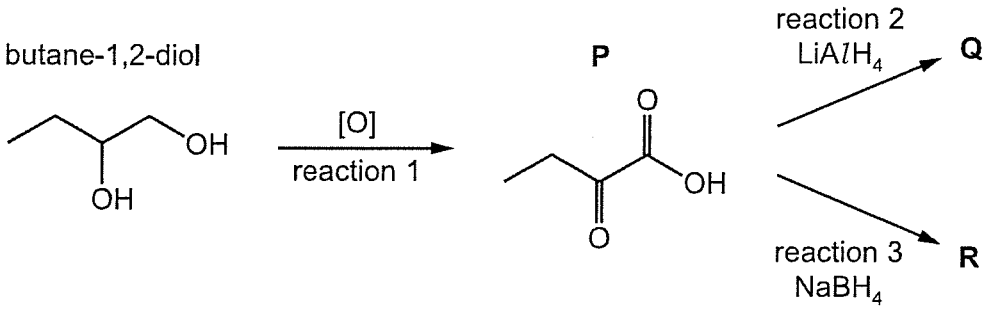
(c) Two students try to prepare 2-hydroxybutanoic acid in the laboratory.

2-hydroxybutanoic acid



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Both students oxidise butane-1,2-diol to form **P** in reaction 1.
One student then reduces **P** using $LiAlH_4$. **Q** is formed.
The other student reduces **P** using $NaBH_4$. **R** is formed.



(i) State the reagents and conditions required for reaction 1.

.....

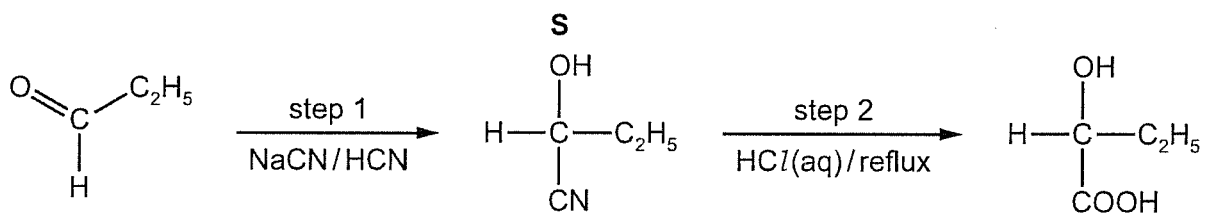
..... [2]

(ii) Only one of the students successfully prepares 2-hydroxybutanoic acid.
Identify which of **Q** or **R** is 2-hydroxybutanoic acid and explain the difference between reactions 2 and 3.

.....

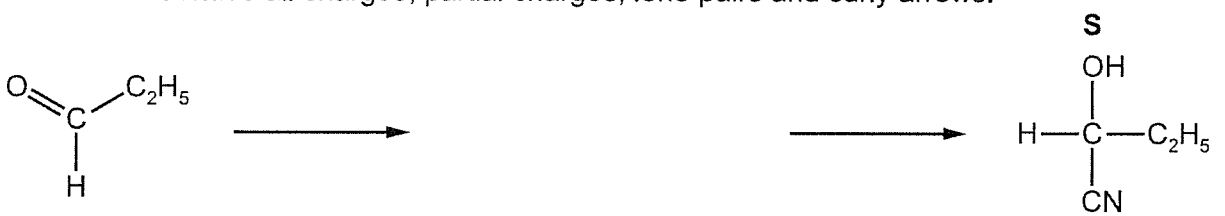
..... [2]

A third student prepares 2-hydroxybutanoic acid using propanal as the starting material. In step 1 the student reacts propanal with a mixture of NaCN and HCN.



(iii) Draw the mechanism for the reaction of propanal with the mixture of NaCN and HCN to form **S**.

- Identify the ion that reacts with propanal.
- Draw the structure of the intermediate of the reaction.
- Include all charges, partial charges, lone pairs and curly arrows.



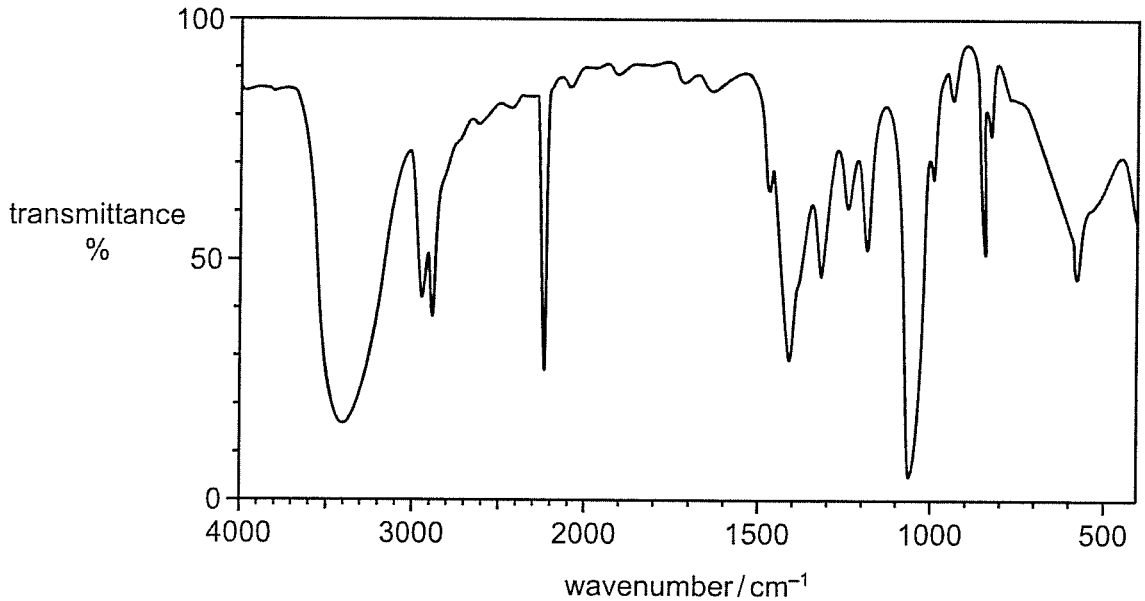
[4]

(iv) Complete the equation for the reaction in step 2, when **S** is heated under reflux with $HCl(aq)$.

$C_2H_5CH(OH)CN$ + ... → $C_2H_5CH(OH)COOH$ + ...[1]

(v) The infrared spectrum of an organic compound is shown. The organic compound is either **S** or 2-hydroxybutanoic acid.

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Deduce the identity of the compound. Give **two** reasons for your answer.
In your answer, identify any relevant absorptions **above 1500 cm^{-1}** in the spectrum and the bonds that correspond to these absorptions.

.....

..... [2]

3. M/J 20/P22/Q2

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]

(b) Draw a 'dot-and-cross' diagram to show the arrangement of outer electrons in a molecule of ammonia.

[1]

(c) (i) In the boxes, give the oxidation numbers of nitrogen in the nitrogen-containing species for the reaction in stage 3.

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

☐ ☐ ☐ [2]

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(ii) Explain why the reaction in stage 3 is described as a disproportionation reaction. Include reference to transfer of electrons in your answer.

.....

.....[2]

(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.

.....

..... [2]

(e) The nitric acid made in stage 3 can then be reacted with ammonia to form ammonium nitrate.

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 pressure, required to make 40 tonnes of ammonium nitrate.
[1 tonne = 1000 kg]
Show your working.

volume of nitrogen dioxide = ... [3]

(f) State **one** use of ammonium nitrate.

..... [1]

4. M/J 20/P21/Q4

Calcium nitrate, $Ca(NO_3)_2$, reacts with ammonia, carbon dioxide and water to form a mixture of ammonium nitrate and calcium carbonate.

$$Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O \rightarrow 2NH_4NO_3 + CaCO_3$$

(a) Explain why ammonia is described as a Brønsted-Lowry base in this reaction.

..... [1]

The product mixture can then be added to soil.

(b) State **two** reasons why this mixture of products is added to some soils.

1 .....

2 .....[2]

(c) Complete the table to name the shape and give the bond angle of each species.

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	name of shape	bond angle / °
CO_2		
NH_3		
H_2O		

[3]

5. M/J 19/P21/Q2

Magnesium silicide, Mg_2Si, is a compound made by heating magnesium with sand.

(a) Draw a 'dot-and-cross' diagram to show the arrangement of outer electrons present in a formula unit of Mg_2Si. Assume magnesium silicide is an ionic compound.

[2]

(b) When solid Mg_2Si is added to water, silane gas, SiH_4, and a solution of magnesium hydroxide are produced.
Construct the equation for this reaction. Include state symbols.

..... [2]

(c) Suggest, with reference to structure and bonding, why SiH_4 is a gas at room temperature.

.....

..... [2]

(d) The table shows the electronegativity values of carbon, hydrogen and silicon.

element	carbon	hydrogen	silicon
electronegativity	2.5	2.1	1.8

(i) C–H and Si–H bonds have weak dipoles.
Use the electronegativity values in the table to show the polarity of the C–H and Si–H bonds.

C—H Si—H [2]

(ii) Explain why methane, CH_4, has no overall dipole moment.

.....

.....[2]

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(e) SiH_4 reacts in air without heating but CH_4 must be ignited before combustion occurs.

$$SiH_4 + 2O_2 \rightarrow SiO_2 + 2H_2O$$
$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Suggest, with reference to bond energies from the *Data Booklet*, why SiH_4 reacts in air without heating but CH_4 must be ignited.

.....

..... [2]

(f) Silicon dioxide reacts with hot, concentrated sodium hydroxide.

(i) Identify the **two** products formed during this reaction.

.....

..... [2]

(ii) Describe the behaviour of the silicon dioxide during this reaction.

..... [1]

6. MAR 19/P22/Q2/a(ii),(iii),(iv), c(i),(ii),(iv)

The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2, HC*l* and CaF_2.

	F_2	HC*l*	CaF_2
boiling point/K	85	188	2773
relative formula mass	38.0	36.5	78.1

(a) (i) F_2 and HC*l* are both covalent molecules.

Suggest why the boiling point of HC*l* is higher than that of F_2.

.....

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

(ii) Explain why CaF_2 has a very high boiling point.

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

(iii) $CaF_2(aq)$ can be made by the reaction of calcium carbonate with hydrofluoric acid, HF(aq).

Write an equation for this reaction. Include state symbols.

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

(b) HOF is the only known molecule that contains only the elements hydrogen, oxygen and fluorine.

(i) Draw a 'dot-and-cross' diagram to represent the bonding in a molecule of HOF.

Show the outer shell electrons only.

[2]

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(ii) HOF can be made by the reaction of F_2 with ice at −40 °C. The reaction is similar to the reaction of Cl_2 with cold water.
Suggest an equation for the reaction of F_2 with ice.

..... [1]

(iii) Pure HF is a colourless liquid at 273 K. The liquid contains HF molecules that have strong hydrogen bonds between them.
Draw a fully labelled diagram to suggest how a hydrogen bond can form between two HF molecules.

[3]

7. O/N 18/P21/Q1/a,b,c(i), O/N 18/P23/Q1/a,b,c(i)
Iron pyrite, FeS_2, has a yellow colour that makes it look like gold metal. The compound contains the ions Fe^{2+} and S_2^{2-}.

(a) (i) Give the full electronic configuration of Fe^{2+}.

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

(ii) Calculate the oxidation number of sulfur in the S_2^{2-} ion.
Assume that each sulfur atom in the ion has the same oxidation number.

oxidation number of sulfur in the S_2^{2-} ion = ... [1]

(b) Describe the metallic bonding in gold.

.....

..... [2]

(c) Iron pyrite is often called *fool's gold* because of its appearance. Impure samples of iron pyrite often contain a small amount of gold.
The gold can be obtained from impure iron pyrite. The impure iron pyrite is roasted in oxygen, to produce iron(III) oxide and sulfur dioxide. Gold does not react with oxygen.

(i) The sulfur dioxide produced during roasting would cause environmental consequences if released into the atmosphere.
State and explain **one** of these environmental consequences.

.....

..... [2]

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8. O/N 18/P21/Q2/a(ii), O/N 18/P23/Q2/a(ii)

(a) Nitrogen, N_2, is an inert gas that makes up 78% of the Earth's atmosphere.

(i) Draw a 'dot-and-cross' diagram of a nitrogen molecule. Show outer electrons only.

[1]

9. M/J 18/P22/Q2/b

(a) 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]

10. M/J 18/P23/Q1/a,b

The elements sodium to chlorine, in the third period, all form oxides.

(a) Draw a diagram to show the shape of the molecule of each of the oxides, SO_3 and Cl_2O.
Name each shape.
In SO_3 each oxygen atom forms a double bond with the sulfur atom.

SO_3	Cl_2O
.....	.....

[4]

(b) (i) Explain why the melting point of MgO is higher than that of Na_2O.

.....

.....[2]

(ii) Explain why the melting point of SiO_2 is much higher than that of SO_3.

.....

..... [2]

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11. 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]**

12. 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]**

(ii) Draw a fully labelled diagram of two water molecules in ice, showing the force in **(i)** and how it forms.

[3]

13. MAR 17/P22/Q2/a(i),(ii)

(a) (i) Explain the meaning of the term *bond polarity*.

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

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(ii) Suggest why the boiling point of HF is **much** higher than the boiling points of the other hydrogen halides.

.....

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

14. 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]**

15. 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.

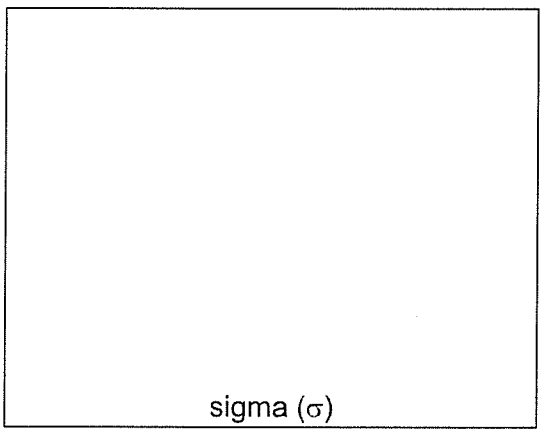
shape of molecule ..... **[3]**

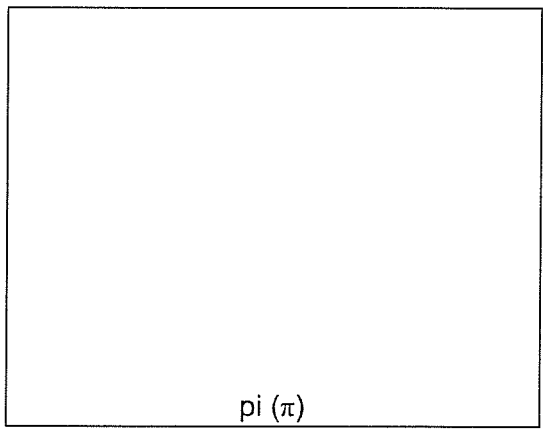
(ii) A molecule of hydrogen cyanide, HCN, is shown.

$$H—C\equiv N$$

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.

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[2]

16. O/N 14/P21/Q2/c, 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]**

17. 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]**

18. 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.

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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]

(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]

19. O/N 13/P21/Q5/e, 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.

.....

.....

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(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]

20. O/N 13/P21/Q1, O/N 13/P22/Q1

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?

..... [3]

21. M/J 13/P23/Q1/a,b

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]**

22. M/J 13/P22/Q3/a(ii),c

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.

.....

(b) 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

(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.

.....

.....

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(iii) Suggest which of these three molecules has the largest permanent dipole.
Explain your answer.

.....

.....

.....[5]

23. 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.

.....

.....

.....

..... [4]

24. O/N 12/P21/Q3/c

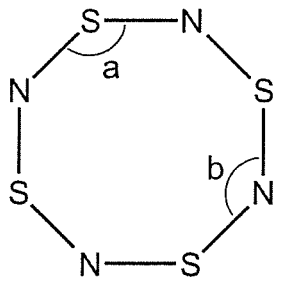
(a) Ammonia is a weak base which forms salts containing the ammonium ion.
Describe, with the aid of an equation, the formation and structure of the ammonium ion.
You should use displayed formulae in your answer.

[3]

25. 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.

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(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]

26. 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.

(ii) Suggest a value for the O–C–S bond angle.

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

27. 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

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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]**

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Answers Section

1. M/J 21/P22/Q2

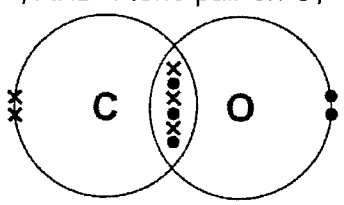
(a) (i) Li^+ AND S^{2-} **1**

(ii) **M1** giant **1**

M2 (many) strong force(s) of attraction between oppositely charged ions **1**
OR
(many) strong ionic bond(s)

(b) (i) (covalent) bond with both electrons are provided from the same / one species **1**
OR
shared pair (of electrons) are provided from the same species / one atom *owtte*

(ii) 3 bonding pairs between C and O, 4•'s AND 2×'s **2**
1 lone pair on C, ××, AND 1 lone pair on O, ••.



(c) (i) *Any two assumptions about the behaviour of particles in an ideal gas from* **2**
- (particles / molecules have mass but) negligible size / volume (compared to total volume of gas / container)
- no / negligible forces / interactions (between particles / molecules)
- collisions are elastic

(ii) **M1** IMF become larger / more significant **1**
M2 volume of molecules / particles becomes significant / no longer negligible **1**

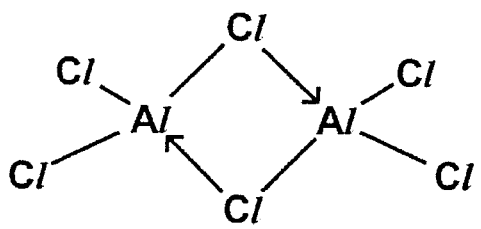
(iii) **2**

$N_2(g)$	$CO(g)$
instantaneous dipole–induced dipole ✓	instantaneous dipole–induced dipole (and) permanent dipole–permanent dipole ✓

(iv) O is more electronegative than C **1**

2. O/N 20/P21/Q3, O/N 20/P23/Q3

(a) (i) **M1:** *correct representation of Al_2Cl_6, dot and cross or line diagram* **2**



M2: TWO correct co-ordinate bonds identified

(ii) 120 **1**

(iii) Li^+ is $1s^2$ H^- is $1s^2$ **1**

(iv) (Lattice of) cations / positive ions surrounded by **delocalised** electrons' **1**

(b) $Al(OH)_3$ / aluminium hydroxide **1**

(c) (i) **M1:** potassium dichromate[(VI)] **2**
M2: acid(ified) AND (heat under) **reflux**

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(ii) **(M1:** *correct identity of **R** and statement re: reaction 3 ONLY ketone reduced*) **2**
R (is 2-hydroxybutanoic acid) **AND** as (only) C=O / ketone reduced
(M2: *correct explanation re: strength of reducing agents*)
$NaBH_4$ cannot reduce the COOH / **carboxylic acid**
OR
$LiAlH_4$ can reduce the COOH / **carboxylic acid**

(iii)  **4**

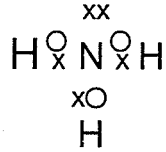
M1: Presence of :CN (if bonding shown, must be unambiguous triple bond)
M2: curly arrow from :CN lone pair to carbonyl carbon
M3: correct dipole **AND** curly arrow from double bond to oxygen
M4: correct intermediate drawn

(iv) $C_2H_5CH(OH)CN + \mathbf{HCl + 2H_2O} \rightarrow C_2H_5CH(OH)COOH + \mathbf{NH_4Cl}$ **1**

(v) Any two of three absorption references: **2**
- absorption 2200–2250 (cm^{-1}) shows presence of C≡N
- lack of absorption at 1680–1730 (cm^{-1}) shows lack of C=O
- lack of absorption at 2500–3000 (cm^{-1}) shows lack of RCO_2–H / O–H in RCO_2H

3. M/J 20/P22/Q2

(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

(ii) *relates the term disproportionation to the reaction described* **2**
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 **OR** 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) fertiliser **1**

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4. M/J 20/P21/Q4

(a) Accepts a proton / H^+ (ion) **1**

(b) *Two reasons why product mixture is added to soil – allow in any order* **2**
M1 Acts as a fertiliser / adds nutrients (for plants)
M2 Neutralise acid soils / increases the pH of acid soil

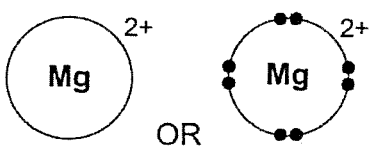
(c) **3**

	name of shape	bond angle / °
CO_2	Linear	180
NH_3	Pyramid(al)	107
H_2O	non-linear / V / bent	104.5

All 6 correct – 3 marks
4 or 5 correct – 2 marks
2 or 3 correct – 1 mark

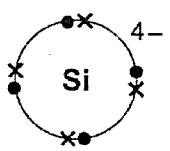
5. M/J 19/P21/Q2

(a) **M1** *magnesium* **1**
+2 charge on **two** Mg
AND both with 0 or 8 electrons



OR

M2 *silicide* **1**
-4 charge on one Si and 8 electrons



(b) $Mg_2Si(s) + 4H_2O(l) \rightarrow 2Mg(OH)_2(aq) + SiH_4(g)$ **1**
M1 correct balancing and formulae
M2 state symbols **1**

(c) **M1** simple (covalent) / molecular / molecules **1**
M2 weak IMF / (temporary) induced dipole (forces) **1**

(d) (i) $C^{\delta-}–H^{\delta+}$ **1**
$Si^{\delta+}$ $H^{\delta-}$ **1**
(ii) **M1** tetrahedral (molecule) **1**
M2 (so individual bond) dipoles / partial charges cancel **1**

(e) **M1** Si—H bond is (much) weaker than C—H bond **1**
M2 low activation energy *ORA* **1**

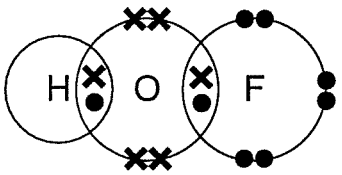
(f) (i) **M1** sodium silicate / Na_2SiO_3 **1**
M2 water / H_2O **1**
(ii) acid(ic) **1**

6. MAR 19/P22/Q2/a(ii),(iii),(iv), c(i),(ii),(iv)

(a) (i) **M1** identification of the IMF between F_2 molecules and between HC*l* molecules **2**
HC*l* has (permanent) dipoles and / or induced dipoles
F_2 has induced dipoles
M2 comparison of strength of IMF's in F_2 and HC*l*
Intermolecular forces in HC*l* are stronger than F_2
(ii) strong (electrostatic) forces of attraction between (oppositely charged) ions **1**
(iii) $CaCO_3(s) + 2HF(aq) \rightarrow CaF_2(aq) + CO_2(g) + H_2O(l)$ **2**
M1 species and balancing
M2 state symbols

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(b) (i)



M1 bonding pairs correct
M2 rest of molecule, incl. lone pairs. **2**

(ii) $F_2 + H_2O \rightarrow HF + HOF$ **1**

(iii) $\delta+ \quad \delta- \qquad \delta+ \quad \delta-$
H—F:::::::::H—F **3**
M1 H-bond labelled / shown as distinct from H—F bond
M2 correct sequence of three correct dipoles
M3 lone pair on F in line with H-bond

7. O/N 18/P21/Q1/a,b,c(i), O/N 18/P23/Q1/a,b,c(i)

(a) (i) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ (4s^0)$ **1**

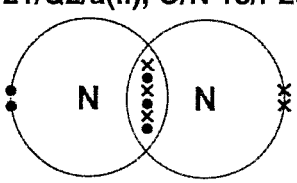
(ii) -1 **1**

(b) **M1** attraction/hold
M2 **positive** ions / cations **AND** delocalised electrons (may be seen in a labelled diagram) **2**

(c) (i) **M1** acid rain **2**
M2
- destroys / damages / weathers / erodes / buildings / statues
- kills/harms fish / coral / plants / crops / trees / deforestation
- leaches salts / ions (aluminium) from soil (into rivers / lakes)
- leaches away soil nutrients
- breathing difficulties
- lowers pH / increases acidity of soil / rivers / oceans / seas

8. O/N 18/P21/Q2/a(ii), O/N 18/P23/Q2/a(ii)

(a) (i)

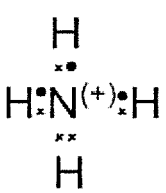


1

6 e^- between atoms **AND** two electrons on each N atom

9. M/J 18/P22/Q2/b

(a) (i)

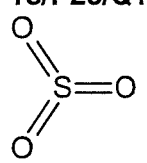


4 shared pairs only (any symbols) (in NH_4) **1**
3 × dot-and-cross bonds AND 1 × 2 crosses (in NH_4) **1**

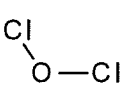
(ii) tetrahedral **1**
109–109.5° (inclusive) **1**

10. M/J 18/P23/Q1/a,b

(a) **4**



trigonal planar



non-linear/bent/V-shaped/angular

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(b) (i) stronger attraction for O^{2-} / stronger ionic bonding / more energy needed to overcome ionic bonding / separate ions **1**
charge density of magnesium (ion) is greater (than sodium ion) ***ora*** **1**

(ii) Either: **2**
M1 SiO_2 has a giant (covalent) structure / giant molecular
M2 Covalent bonds (much) stronger than VdW / id-id / IMFs in SO_3
OR
M1 SO_3 has a (simple) molecular structure / (simple) molecule.
M2 VdW / id-id / IMFs M2 IMF's are (much) weaker than covalent bonds (broken in SiO_2)
OR
M1 Covalent bonds are broken in SiO_2 AND VdW / id-id / IMFs in SO_3
M2 Covalent bonds are stronger (than VdW / id-id / IMFs)

11. 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**

12. M/J 17/P21/Q2/a,b

(a)

substance	type of bonding	type of lattice structure	
copper	metallic	giant/metallic	1
ice	covalent OR hydrogen(-bonding) / H(–bonding)	hydrogen-bonded / simple / molecular	1
silicon(IV) oxide	covalent	giant (molecular) / macromolecular	1
iodine	covalent	simple / molecular	1
sodium chloride	ionic	giant / ionic	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, **1**
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**

13. MAR 17/P22/Q2/a(i),(ii)

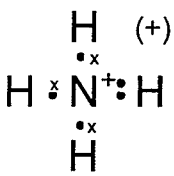
(a) (i) bond in which the centres of positive and negative charges do not coincide **1**
OR electron distribution is asymmetric / unequal
OR two (bonded) atoms are partially charged

(ii) HF has the strongest (permanent) dipole–dipole / van der Waals' **1**
(forces) / HF has hydrogen bonding
requires more energy to overcome (than weaker (permanent) dipole–dipole/ van der Waals' forces between other hydrogen halides) **1**

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14. M/J 16/P23/Q2/d

(a) (i)

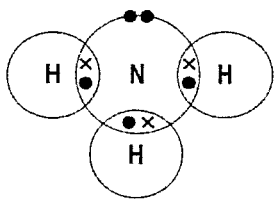


[2]

(ii) shape = tetrahedral
angle = 109°–109.5° [2]

15. MAR 16/P22/Q3/a

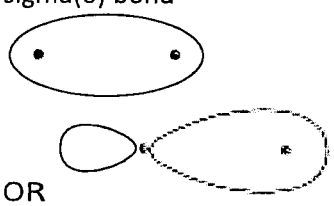
(a) (i)



[3]

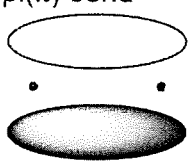
three bonding pairs
lone pair AND octet
shape = (trigonal) pyramidal

(ii) sigma(σ) bond



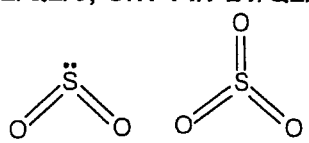
OR [2]

pi(π) bond



16. O/N 14/P22/Q2/c, O/N 14/P21/Q2/c

(a) (i)



M1 SO_2 correct M2 SO_3 correct [2]

(ii) 115–120° bent / non-linear
120° trigonal planar [2]

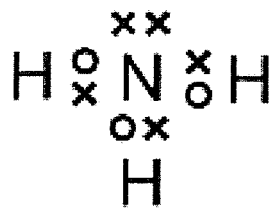
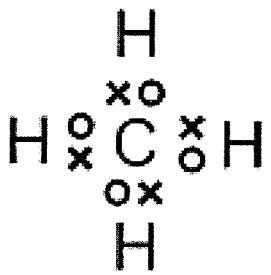
17. M/J 14/P21/Q1/e

(a) shape of SF_6 = Octahedral
bond angle = 90° 2

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18. O/N 13/P23/Q1

(a)

NH_3	CH_4
	
pyramidal	tetrahedral

both 'dot-and-cross' diagrams correct
NH_3 is pyramidal **or** trigonal pyramidal
CH_4 is tetrahedral **[3]**

(b) (i) nitrogen and hydrogen have different electronegativities
N–H bond has a dipole **or**
$N^{\delta-}$—$H^{\delta+}$ **or**
bonding pair is unequally shared

(ii) molecule is not symmetrical **or**
dipoles do not cancel out

(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 **[4]**

(c) three covalent N–H bonds
one co-ordinate (dative covalent) N–H bond
one ionic bond between NH_4^+ and Cl^- **[3]**

19. O/N 13/P21/Q5/e, O/N 13/P22/Q5,e

(a) (i) from methane to butane
there are more electrons in the molecule
therefore greater/stronger van der Waals' forces

(ii) straight chain molecules can pack more closely
therefore stronger van der Waals' forces
or reverse argument **[4]**

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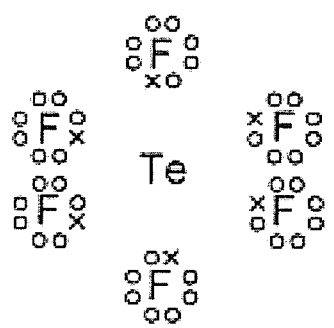
20. O/N 13/P21/Q1, O/N 13/P22/Q1/a,b

(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]**

(b) (i)



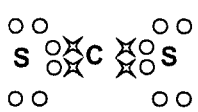
(ii) octahedral **or** square-based bipyramid

(iii) 90°

[3]

21. M/J 13/P23/Q1/a,b

(a) (i)



S atom has 6 **and C** atom has 4 electrons
S=C double bonds (4 electrons) clearly shown

(ii) linear **and** 180°

[3]

(b) (i) $CS_2 + 3O_2 \rightarrow CO_2 + 2SO_2$

(ii) enthalpy change when 1 mol of a substance is burnt in an excess of oxygen/air **or** is completely combusted under standard conditions

[3]

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22. M/J 13/P22/Q3/a(ii),c

(a) penalise (-1) the use of names of elements or formulae of compounds

(i) O **or** N **or** C

(b) (i)

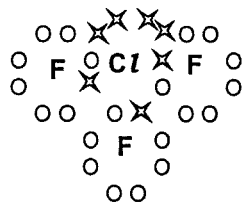


(ii) intermolecular forces/van der Waals' forces
are stronger or greater in I*Cl*
I*Cl* has most electrons **or**
has the largest permanent dipole

(iii) I*Cl*
greatest difference in electronegativity is between I and C*l* **[5]**

23. M/J 13/P21/Q3/c

(a) (i)

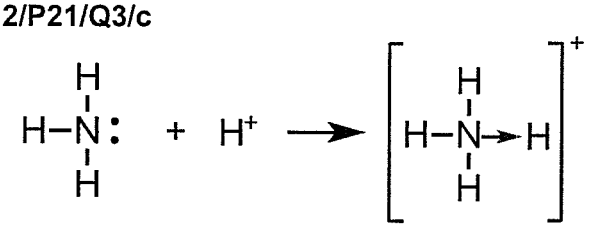


3 bonding pairs **and**
2 lone pairs around C*l* atom
3 lone pairs on **each** of the F atoms

(ii) either
referring to van der Waals' forces in BrF_3
van der Waals' **or**
intermolecular forces are greater/stronger
because there are more electrons in BrF_3 than in ClF_3
OR referring to permanent dipoles
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 between C*l* and F
part **(ii)** has a maximum of 2 marks (max 2) **[4]**

24. O/N 12/P21/Q3/c

(a)



correct displayed eqn.,
with positive charge clearly shown
lone pair on NH_3
co-ordinate / dative bond clearly shown **[3]**

25. M/J 12/P22/Q1/c

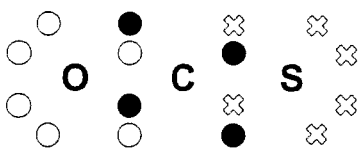
(a) (i) around the N atom there is only one lone pair
around the S atom there are two lone pairs

(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 **[2]**

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26. M/J 12/P21/Q1/f

(a) (i)



(ii) 180° **[2]**

27. M/J 11/P23/Q2/e,f

(a) 18 **[1]**

(b) (i) both have very similar/same van der Waals' forces

(ii) CH_3F has permanent dipole **[2]**

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A Level

Unit 4

STATES OF MATTER

Chemistry Paper-2
Topical Workbook
Article Number: 232

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Unit 4: States Of Matter

1. MAR 19/P22/Q2/d

The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2, HC*l* and CaF_2.

	F_2	HC*l*	CaF_2
boiling point/K	85	188	2773
relative formula mass	38.0	36.5	78.1

(a) Interhalogen compounds, such as BrC*l* or IF_5, contain two or more different halogen atoms that are covalently bonded.

D is an interhalogen compound that contains only chlorine and fluorine.

At 0 °C and 101 325 Pa, 1 dm^3 of **D** has a mass of 4.13 g.

(i) Use the general gas equation to calculate the relative molecular mass, M_r, of **D**.

M_r = ... [3]

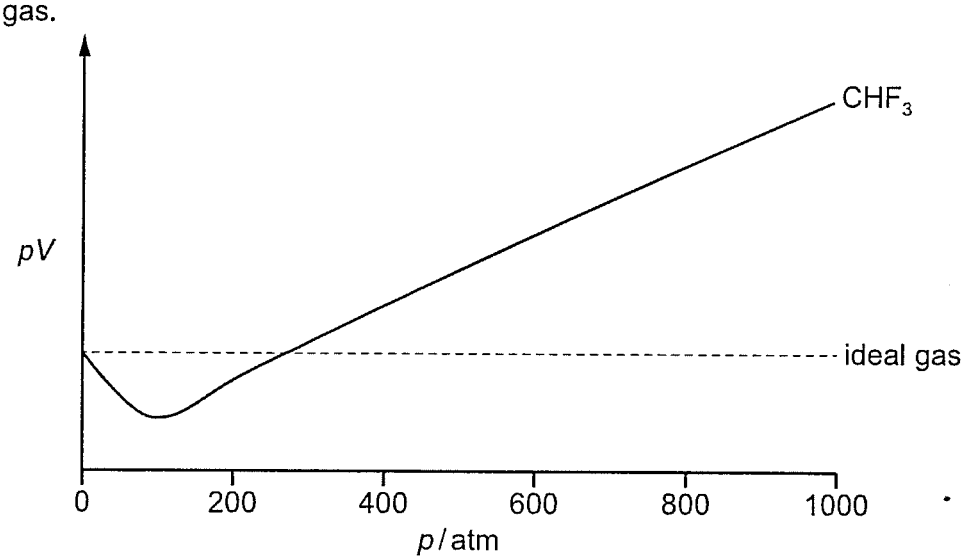
(ii) Use your answer to **(i)** to determine the molecular formula of **D**.

If you were unable to calculate the M_r in **(i)**, assume that the M_r is 130.5. This is **not** the correct value.

molecular formula of **D** = ... [1]

2. O/N 18/P22/Q3/b

(a) 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]

3. O/N 18/P21/Q3/a(i), O/N 18/P23/Q3/a(i)
Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example $CHCl_3$.

(a) $CHCl_3$ is a colourless liquid with a high vapour pressure.

(i) Explain what is meant by *high vapour pressure*.

.....

..... [2]

4. 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.

$$C_xH_yO + zO_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

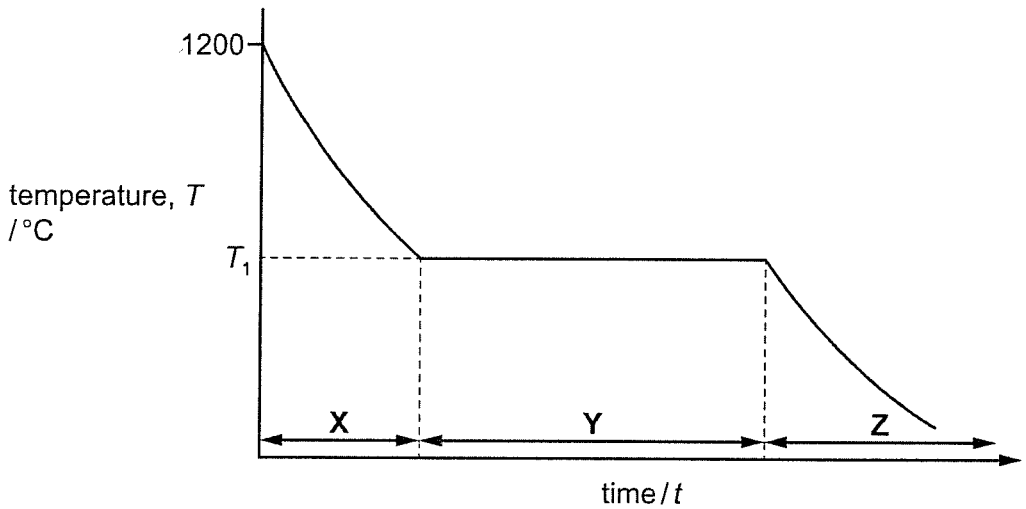
(i) Use the general gas equation to calculate the mass of **T** present in the original 20 cm^3 gaseous sample, which was measured at 120 °C and 100 kPa.
Give your answer to **three** significant figures. Show your working.

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

5. 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.

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(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**.

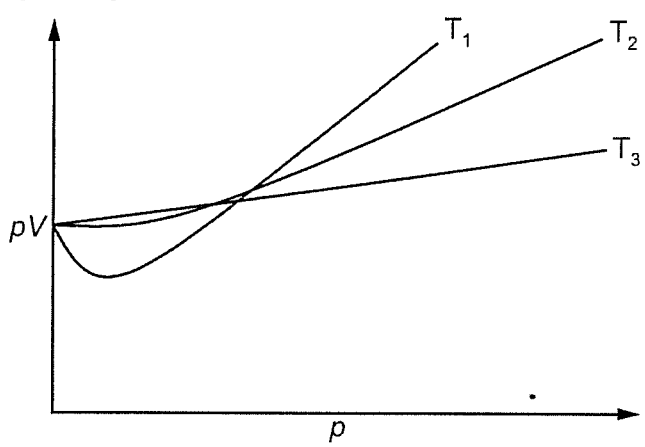
.....

..... [2]

6. 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.



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(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]

(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]

7. 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]

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.

(b) 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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8. **M/J 11/P23/Q2/a,b,c,d** [2]

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]**

9. **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]**

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(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]**

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.

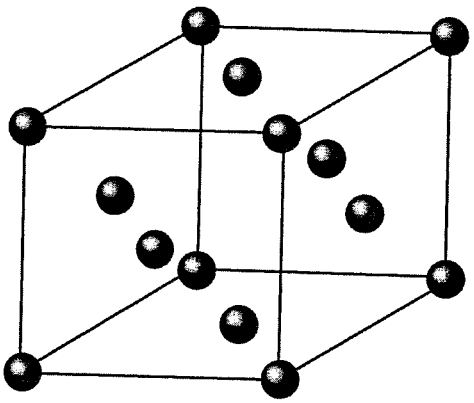
form .....

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

10. 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.

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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 type of particles are present in the iodine crystal? Give their formula.

particle.....

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

(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]

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Answers Section

1. MAR 19/P22/Q2/d

(a) (i) $pV = nRT \therefore n = \frac{pV}{RT} = \frac{101\,325 \times 0.001}{8.31 \times 273} = 0.0447$ mol **3**

$\therefore M_r = \frac{m}{n} = \frac{4.13}{0.0447} = 92.4$ or 92.5

M1 Use of $T = 273$ K, $V = 0.001$ m^3 and $p = 101325$ Pa
M2 correct use of $pV = nRT$ using values from M1
M3 correct calculation of M_r using 4.13 ÷ moles from M2

(ii) ClF_3 **1**

2. O/N 18/P22/Q3/b

(a) (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

3. O/N 18/P21/Q3/a(i), O/N 18/P23/Q3/a(i)

(a) (i) **M1** gas / vapour (particles / molecules) in **equilibrium** (with liquid / solid) **2**
M2 greater proportion of gas (particles) than liquid (particles) (in comparison to a liquid of lower vapour pressure)

4. M/J 17/P21/Q1/b(v)

(a) correct conversions of data to SI/consistent units **1**
$p = 100\,000$; $V = 20 \times 10^{-6}$; $T = 393$
calculation of n ($= pV/RT$) from M1 values **1**
$n = \frac{100 \times 10^3 \times 20 \times 10^{-6}}{8.31 \times 393}$
calculation of mass m ($= n \times Mr$) **AND** answer correct to **3sf** **1**
$m = 6.12 \times 10^{-4} \times 60 = 0.0367$ (g)
Alternative answer for using $C_4H_{10}O$: $m = 6.12 \times 10^{-4} \times 74 = 0.0453$ (g)

5. 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 **1**
compensates for / counteracts heat loss / cooling *owtte* **1**

6. 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]**

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(iv) greatest deviation is at high pressure [1]
increasing pressure decreases volume so volume of particles becomes more significant ora [1]

(b) Mass of air = 100 × 0.00118 = 0.118 g
Mass of flask = 47.930 – 0.118 = **47.812** g
Mass of **Y** = 47.989 – 47.812 = **0.177** g

$$pV = nRT = \frac{m}{M_r}RT$$

$$M_r = \frac{mRT}{pV} = \frac{0.177 \times 8.31 \times 299}{1 \times 10^5 \times 100 \times 10^{-6}}$$

= **44.0** (43.979 to 2 or more sf) **[4]**

7. M/J 11/P21/Q1/d,e

(a) $n = \frac{PV}{RT} = \frac{6 \times 10^5 \times 710 \times 10^{-6}}{8.31 \times 293}$

= 0.175 [2]

(b) $P = \frac{nRT}{V} = \frac{0.175 \times 8.31 \times 278}{710 \times 10^{-6}}$

= 569410.5634 Pa = 5.7×10^5
allow ecf on **(d)** [2]

8. 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
low pressure [2]

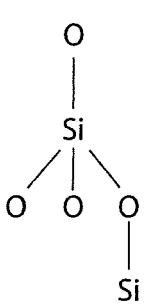
(c) **most ideal** ..... neon..... nitrogen..... ammonia..... **least ideal**
nitrogen has stronger van der Waals' forces than argon
ammonia has hydrogen bonding as well as van der Waals' forces [3]

(d) with increasing temperature,
average kinetic energy of molecules increases
intermolecular forces are more easily broken [2]

9. O/N 09/P22/Q1

(a) CO_2 is simple molecular/simple covalent/has discrete molecules
CO_2 has induced dipole – induced dipole interactions/
van der Waals' forces/weak intermolecular forces
SiO_2 is giant molecular/giant covalent/macromolecular
SiO_2 has strong covalent bonds
[any 3]

(b) minimum is 4-valent Si-O
and at least one Si-O-Si
i.e.



[2]

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(c) (i) for an ideal gas, **any four** from the following
the molecules behave as rigid spheres
there are no/negligible intermolecular forces between the molecules
collisions between the molecules are perfectly elastic
the molecules have no/negligible volume
the molecules move in random motion
the molecules move in straight lines
the kinetic energy of the molecules is directly proportional to the temperature
the pressure exerted by the gas is due to the collisions between the gas molecules and the walls of the container
not an ideal gas obeys $pV = nRT$

(max 4)

(ii) there are intermolecular forces between CO_2 molecules/ CO_2 molecules have volume **[5]**

(d) graphite has delocalised electrons **[1]**

(e) (i) $SiO_2 + 2C \rightarrow SiC + CO_2$ **or** $SiO_2 + 3C \rightarrow SiC + 2CO$

(ii) diamond **because** SiC is hard **[2]**

10. O/N 06/P2/Q2

(a) molecules
I_2 **[2]**

(b) (i) cations held in 'sea' of delocalised electrons by strong metallic bonds

(ii) van der Waals' forces between molecules
van der Waals' forces are weak **[4]**

(c) (i) oxidising agent

(ii) iodine is a weaker oxidising agent than chlorine **[2]**

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A Level

Unit 5
CHEMICAL ENERGETICS

Chemistry Paper-2
Topical Workbook
Article Number: 232

Editorial Board

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Unit 5: Chemical Energetics

1. M/J 21/P22/Q3

A large excess of 2-bromo-2-methylpropane is added to 0.0010 mol of NaOH(aq), which contains a few drops of phenolphthalein indicator. A stopwatch is started as soon as the substances are mixed. The time taken for the pink colour to disappear is recorded.

The experiment is repeated at different temperatures, keeping all concentrations and volumes of reagents constant.

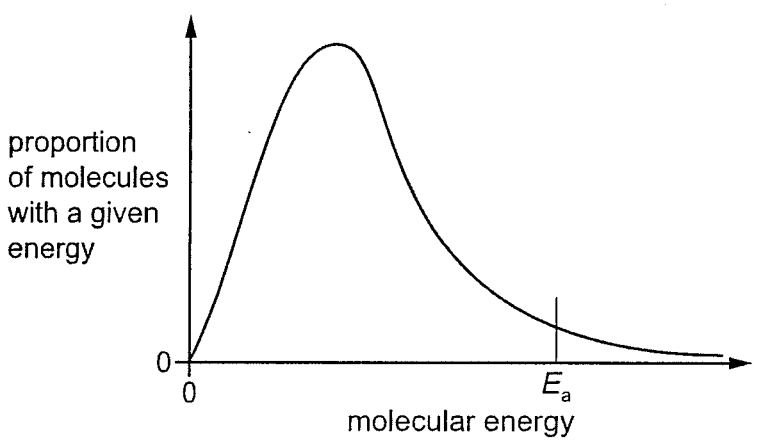
temperature / °C	time taken for pink colour to disappear / s
20	300
25	65
35	20

(a) Explain what is meant by the term *rate of reaction*.

..... [1]

(b) The graph shows the energy distribution of molecules in a sample of 2-bromo-2-methylpropane at 25 °C.

E_a represents the activation energy for the reaction.



(i) Label the graph to show the proportion of 2-bromo-2-methylpropane molecules which have sufficient energy to react. [1]

(ii) Use the same axes to sketch the distribution of energies of molecules in a sample of 2-bromo-2-methylpropane at 50 °C. [2]

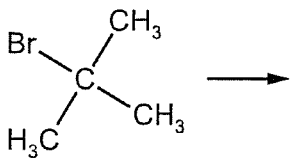
(iii) State the effect of an increase in temperature on E_a for this reaction.

..... [1]

(c) (i) Draw the mechanism to show the reaction of 2-bromo-2-methylpropane with OH^-(aq). Show the intermediate formed in this reaction.

Include all charges, partial charges, lone pairs and curly arrows as appropriate.

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[3]

(ii) Name the mechanism for this reaction.

.....[1]

(d) The original experiment is repeated at 25 °C with 2-chloro-2-methylpropane instead of 2-bromo-2-methylpropane. All other variables remain constant.

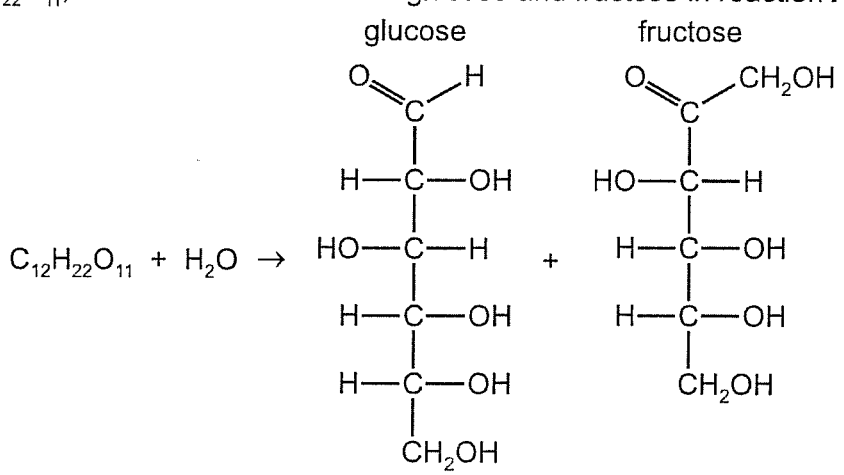
Predict the effect of using 2-chloro-2-methylpropane compared to 2-bromo-2-methylpropane on the time taken for the pink colour to disappear. Explain your answer.

.....

..... [2]

2. M/J 20/P22/Q3

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]

(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**.

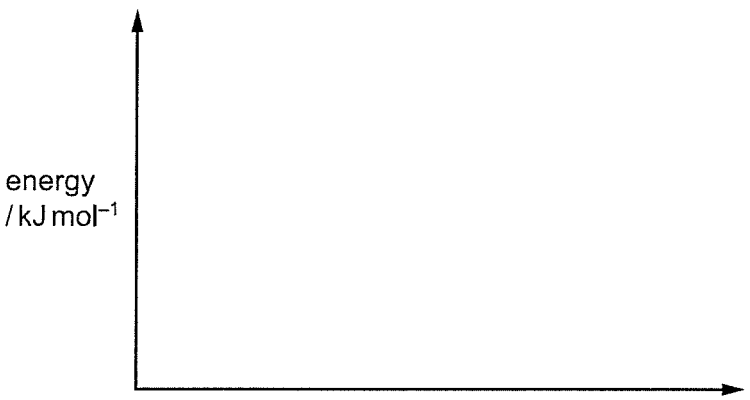
..... [1]

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(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]

(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]

3. M/J 20/P21/Q3

Nitric acid, HNO_3, can be made by reacting nitrogen dioxide with water.
The enthalpy change for the reaction can be measured indirectly using a Hess' cycle.

$$3NO_2(g) + H_2O(l) \xrightarrow{\Delta H_r} 2HNO_3(l) + NO(g)$$

(a) Explain what is meant by the term *enthalpy change of formation*.

.....

..... [2]

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(b) Complete the Hess' cycle using the values given in the table and hence calculate the enthalpy change, ΔH_r, for this reaction.
Show your working.

substance	ΔH_f / kJ mol^{-1}
$NO_2(g)$	34.0
$H_2O(l)$	–286
$HNO_3(l)$	–173
NO(g)	91.1

$$3NO_2(g) + H_2O(l) \xrightarrow[\Delta]{H_r} 2HNO_3(l) + NO(g)$$

ΔH_r = ... kJ mol^{-1} [3]

(c) Nitrogen and oxygen do not react at normal atmospheric temperatures.
Explain why.

.....

..... [2]

Nitrogen oxides can be formed naturally in the Earth's atmosphere from nitrogen and oxygen in the air.

(d) State **one** way that nitrogen oxides are produced naturally.

..... [1]

(e) Nitrogen dioxide, NO_2, acts as a homogeneous catalyst in the oxidation of atmospheric sulfur dioxide.

(i) Explain why NO_2 is described as a homogeneous catalyst.

.....

.....

..... [3]

(ii) Write equations which describe the two reactions occurring when NO_2 acts as a catalyst in the formation of sulfur trioxide from sulfur dioxide.

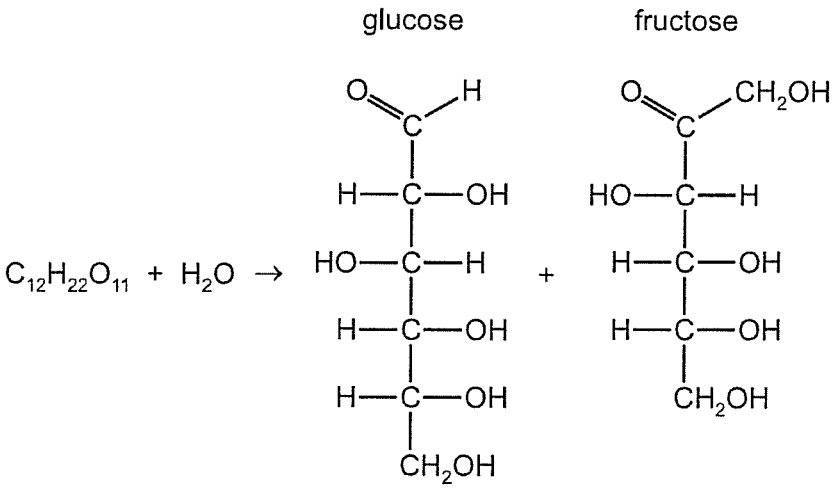
.....

..... [2]

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4. M/J 20/P23/Q3

Sucrose is a white crystalline solid, $C_{12}H_{22}O_{11}$. In reaction **Z**, sucrose reacts with water in the presence of a catalyst, aqueous hydrochloric acid, to form glucose and fructose.

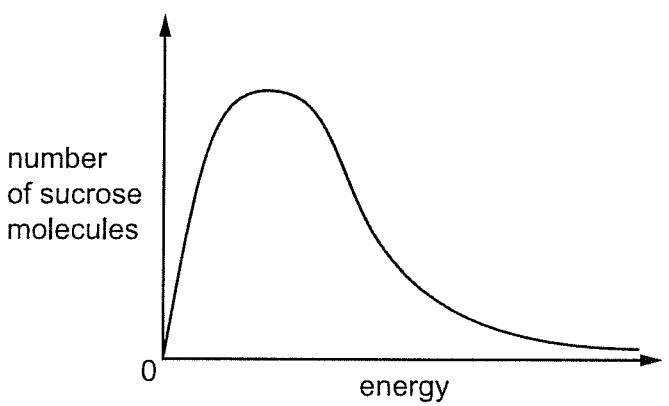


reaction **Z**

(a) (i) Suggest a name for the reaction that occurs when sucrose reacts with water to form glucose and fructose.

..... [1]

(ii) If no catalyst is added in reaction **Z**, the reaction is very slow.
Label the Boltzmann distribution to show the effect of adding a catalyst to the sample of sucrose and water molecules at constant temperature.



Explain your labelled diagram.

.....

.....

.....[3]

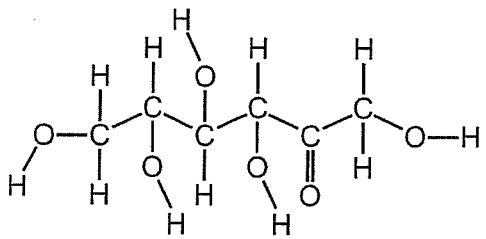
(b) Both fructose and glucose contain chiral centres.

(i) Explain what is meant by the term *chiral centre*.

..... [1]

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(ii) On the diagram of the fructose molecule, label all the chiral centres with an asterisk (*).



[1]

(iii) Determine the empirical formula of fructose.

..... [1]

(c) (i) Explain what is meant by the term *enthalpy change of combustion*.

.....

..... [2]

(ii) Write the equation for the complete combustion of sucrose.

..... [1]

The enthalpy change of reaction **Z**, ΔH_r, can be calculated using the enthalpy change of combustion data given in the table.

substance	enthalpy change of combustion, ΔH_c / kJ mol^{-1}
sucrose	–5643
glucose	–2805
fructose	–2810

(iii) Use the data in the table to calculate the enthalpy change for the reaction occurring when sucrose reacts with water, ΔH_r. You should draw a labelled Hess' cycle to show your working.

ΔH_r = ... kJ mol^{-1} [2]

5. O/N 19/P21/Q2, O/N 19/P23/Q2

(a) Complete the table to give details of the type of bonding and structure shown by some of the oxides of Period 3 elements.

	Na_2O	MgO	Al_2O_3	SiO_2	SO_3
boiling point/ °C	1275	3670	2977	2950	45
nature of oxide	basic	basic	amphoteric	acidic	acidic
bonding					
structure					

[2]

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(b) **(i)** Explain why the boiling point of SiO_2 is much higher than the boiling point of SO_3.

.....

.....

..... [3]

(ii) Al_2O_3 is an amphoteric oxide.

Explain what is meant by the term *amphoteric*. Use chemical equations to illustrate your answer.

.....

.....

..... [3]

(iii) State what you would observe when a small sample of Na_2O is placed in water.

..... [1]

(c) Selenium is a Group 16 element which shows similar chemical reactions to sulfur.

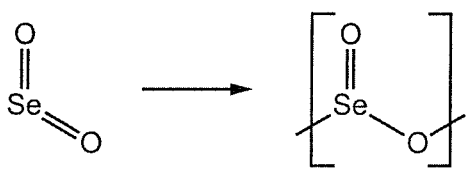
(i) Selenium reacts with fluorine to form SeF_6 molecules.

Predict the shape of a molecule of SeF_6.

..... [1]

(ii) The most stable oxide of selenium is SeO_2.

Gaseous SeO_2 reacts to form a solid polymer, as shown. In the reaction one Se=O is replaced by two Se–O to form a polymer.



$\Delta H = -346\,kJ\,mol^{-1}$

The bond enthalpy of Se=O is $514\,kJ\,mol^{-1}$.

Use these data to calculate the bond enthalpy, in $kJ\,mol^{-1}$, of Se–O.

bond enthalpy of Se–O = ... $kJ\,mol^{-1}$ [2]

(iii) SeO_2 shows similar chemical reactions to SO_2.

Suggest an equation to show the reaction of SeO_2 with aqueous sodium hydroxide, NaOH.

..... [1]

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6. MAR 19/P22/Q2/c(iii)

The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2, HC*l* and CaF_2.

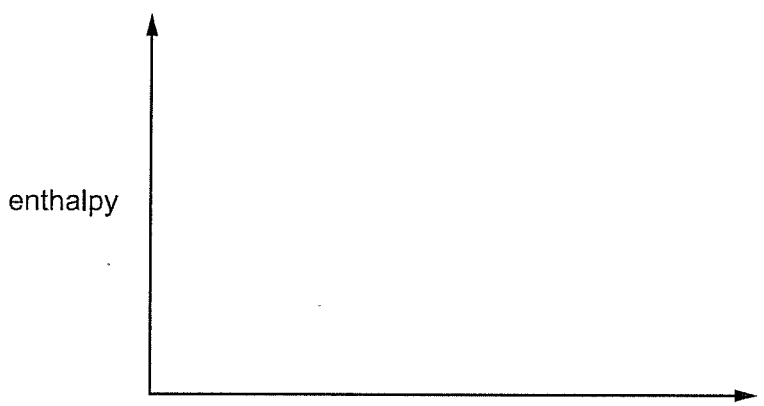
	F_2	HC*l*	CaF_2
boiling point/K	85	188	2773
relative formula mass	38.0	36.5	78.1

(a) HOF is the only known molecule that contains only the elements hydrogen, oxygen and fluorine.

(i) HOF is an unstable compound and decomposes to form HF and O_2.

$$HOF \rightarrow HF + \tfrac{1}{2}O_2 \qquad \Delta H = -139\,kJ\,mol^{-1}$$

Draw a fully labelled reaction pathway diagram on the axes provided to show the decomposition of HOF into HF and O_2.



[2]

7. O/N 18/P22/Q3/a

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]

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8. O/N 18/P21/Q3/a(i),(ii), O/N 18/P23/Q3/a(i),(ii)

Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example $CHCl_3$.

(a) $CHCl_3$ is a colourless liquid with a high vapour pressure.

(i) Explain what is meant by *high vapour pressure*.

.....

..... [2]

(ii) An important reaction of $CHCl_3(g)$ is the manufacture of $CHClF_2(g)$, using the following reversible reaction.

$$CHCl_3(g) + 2HF(g) \quad CHClF_2(g) + 2HCl(g)$$

Use the data to calculate the enthalpy change of reaction, ΔH_r, for the formation of $CHClF_2(g)$ as shown in the equation.

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$CHCl_3(g)$	–103.2
$CHClF_2(g)$	–482.2
HF(g)	–273.3
$HCl(g)$	–92.3

enthalpy change of reaction, ΔH_r = ... kJ mol^{-1} [3]

9. M/J 18/P21/Q1/b

(a) Some bond energies are given.

bond	bond energy / kJ mol^{-1}
S=O (in SO_2)	534
O=O	496

Use the data, and the enthalpy change for the conversion of sulfur dioxide into sulfur trioxide, to calculate a value for the S=O bond energy in SO_3.

S=O bond energy in SO_3 = ... kJ mol^{-1} [2]

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10. O/N 17/P22/Q2/a

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]

11. O/N 17/P21/Q1/a, O/N 17/P23/Q1/a

Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Some bond energies are given.
$N{\equiv}N = 944\,kJ\,mol^{-1}$
$H{-}H = 436\,kJ\,mol^{-1}$

(i) Explain the meaning of the term *bond energy*.

.....

..... [2]

(ii) Use the data to calculate a value for the N–H bond energy.
You must show your working.

N–H bond energy = ... $kJ\,mol^{-1}$ [2]

12. MAR 17/P22/Q2/c(i)

(a) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \quad 2Cl_2(g) + 2H_2O(g)$$

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]**

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13. 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, 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 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]**

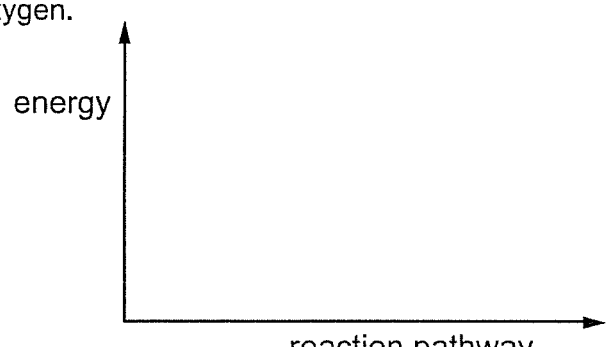
(iii) The standard enthalpy of formation of iodine monochloride, IC*l*, is –24.0 kJ mol^{-1}.
Use this information and the bond energies of iodine and chlorine to calculate the I–C*l* bond energy.

I–C*l* bond energy = ... kJ mol^{-1} **[2]**

14. 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.



[2]

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15. 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.

$$N_2(g) + 3H_2(g) \quad 2NH_3(g)$$

(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]**

16. 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]**

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17. O/N 13/P22/Q5/c,d, 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.

[5]

18. 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]

19. 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]

20. 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]**

21. 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]**

22. 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. Methanol can be obtained from biomass, such as plant waste from agriculture.

(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

Use these values to calculate $\Delta H^\ominus_{reaction}$ for the synthesis of DME, using the following equation. Include a sign in your answer.

$$2CH_3OH(l) \rightarrow CH_3OCH_3(g) + H_2O(l)$$

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$\Delta H^{\ominus}_{reaction}$ = ... kJ mol^{-1} **[3]**

23. 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.

(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]**

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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.

[2]

24. 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

.....

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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.

[6]

25. O/N 10/P21/Q3/d,e,f

(a) Define the term *standard enthalpy change of combustion*.

.....

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

When 0.47 g of **E** was completely burnt in air, the heat produced raised the temperature of 200 g 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]

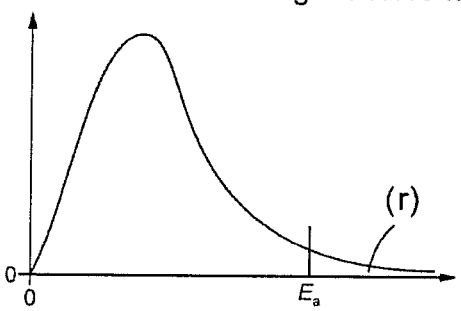
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Answers Section

1. M/J 21/P22/Q3

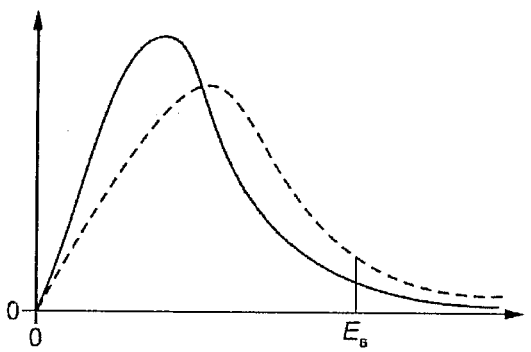
(a) change in amount of substance with time **1**

(b) (i) label **area** under the original curve to the right of E_a. **1**



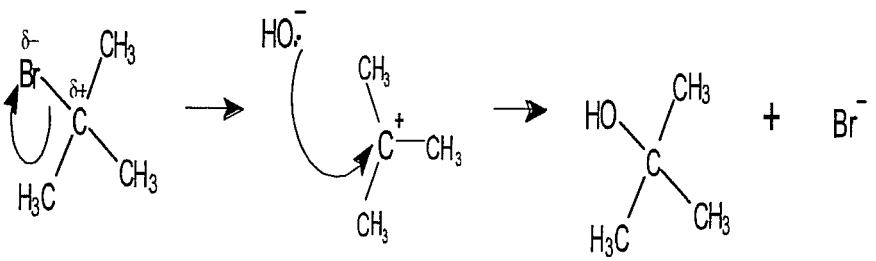
(ii) **M1** *curve starts at the origin but peak lies to the right of original.* **1**

M2 *peak at higher temperature is lower than the original AND graph crosses the original once only – beyond the peak of original* **1**



(iii) no change / none **1**

(c) (i) **1**



M1 correct dipole on haloalkane AND arrow from bond to Br or just beyond

M2 correct intermediate **1**

M3 arrow from lone pair on O of OH^- / ^-OH to central C of their intermediate shown in M2 **1**
OR
arrow from lone pair on O of OH^- / ^-OH to central C of 2-bromo 2-methylpropane if S_N2 mechanism shown

(ii) nucleophilic substitution **1**

(d) **M1** more time (because the rate is lower) **1**

M2 C-Cl (bond) is stronger (than C-Br) **1**

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2. M/J 20/P22/Q3

(a) hydrolysis **1**

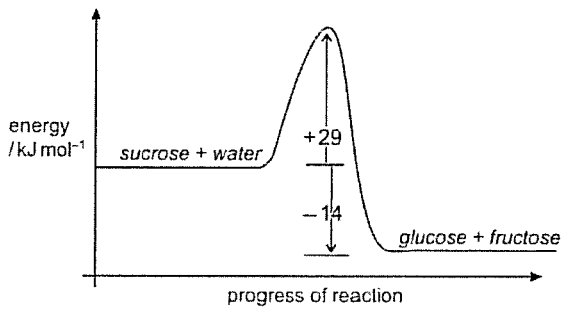
(b) **M1** both have molecular formula - $C_6H_{12}O_6$ **2**

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** (with enzyme)* value / range of values that are more (+) 29 kJ mol^{-1} **1**

(ii) *value for the enthalpy change for reaction **A** (no enzyme) compared to reaction **B** (with enzyme)* -14 kJ mol^{-1} **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)** **2**



(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* ΔH /Q = mcΔ T OR ΔH = – mcΔT = (-)250x4.18x(40.7-25) = (-)16406.5 J per gram OR(-)16.4065 kJ / g **3**
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)

3. M/J 20/P21/Q3

(a) **M1** (enthalpy / energy change) when one mole of a compound/substance is formed **2**
M2 from its elements in their standard states

(b) **M1** *use of correct stoichiometry in calculation* **3**
3xΔH_f NO_2 1x-ΔH_f H_2O 2xΔH_f HNO_3 1xΔH_f NO
M2 *correct signs associated with the appropriate* ΔH_f values/terms *used for the calculation of* $\Delta H_{reaction}$
M3 $\Delta H_{reaction}$ = –(102 – 286) + (–346 + 91.1) = –70.9 kJ mol^{-1}

(c) **M1** nitrogen has a triple bond **2**

M2 EITHER

high energy is needed to break the bond

OR

at normal temperatures there is not enough energy to break the bond / to overcome the activation energy

(d) lightning **1**

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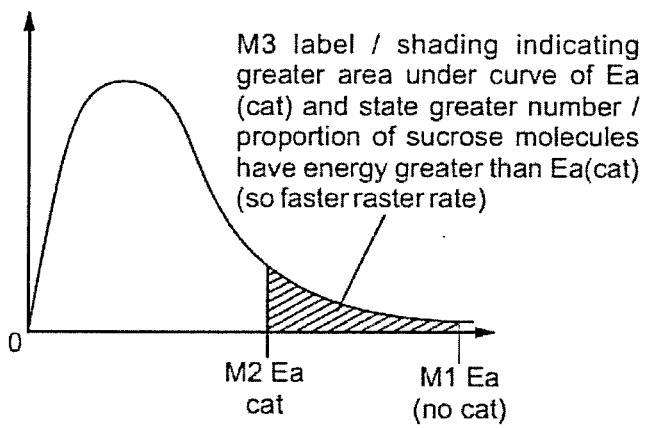
(e) (i) **M1** *define homogeneous* **3**
(homogeneous catalyst is) in the same phase / state as the reactants
M2 and M3 *Define catalyst*
All 3 points scores 2 marks. Any 2 points scores 1 mark
increase the rate
AND
lowers the activation energy
AND
without being chemically altered at the end of the reaction / are regenerated at the end of the reaction

(ii) **M1** $NO_2 + SO_2 \rightarrow NO + SO_3$ **2**
M2 $NO + \frac{1}{2} O_2 \rightarrow NO_2$

4. M/J 20/P23/Q3

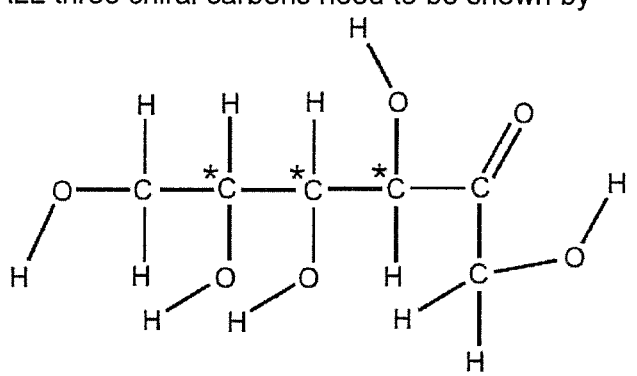
(a) (i) hydrolysis **1**

(ii) **3**



(b) (i) an atom which is bonded to four different substituents /groups / atoms **1**

(ii) ALL three chiral carbons need to be shown by * **1**



(iii) *empirical formula of fructose* CH_2O **1**

(c) (i) **M1** (enthalpy change) when 1 mole of a substance **2**
M2 burns/combusts/reacts in excess air/oxygen
OR
completely burns/combusts/reacts in air/oxygen

(ii) $C_{12}H_{22}O_{11} + 12\ O_2 \rightarrow 12CO_2 + 11H_2O$ **1**

(iii) **M1** $\Delta H = -5643 - (-2805 + -2810)$ **2**
M2 $= -28\ kJ\ mol^{-1}$

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5. O/N 19/P21/Q2, O/N 19/P23/Q2

(a) 2

Na_2O	MgO	Al_2O_3	SiO_2	SO_3
ionic	ionic	ionic	covalent	covalent
giant	giant	giant	giant / macro-molecular	simple / molecular

Award one mark for each correct row.

(b) (i) 3
M1 SiO_2 has a **network** of strong bonds / SiO_2 has **many** strong bonds
M2 SO_3 has weak intermolecular forces
OR
weak VdW forces (between molecules)
M3 high(er) / more energy required to break **bonds** than overcome **forces** (between molecules)

(ii) 3
M1: reacts with both acid and base / alkali
M2: use any equation with Al_2O_3 and an acid, e.g. $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$
M3: use any equation with Al_2O_3 and a base / alkali, e.g. $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$

(iii) 1
solid dissolves / disappears
OR
gets warm / hot

(c) (i) 1
octahedral

(ii) 2
M1: use of the correct expression in terms of specific bond energies.
$(514 - xE_{Se-O} = -346)$
M2: use of correct stoichiometry AND correct processing of expression given in M1. Provided the values 514 and 346 are used.
$(514 - 2E_{Se-O} = -346)$
$= (+)430\ (kJ\ mol^{-1})$

(iii) 1
$SeO_2 + 2NaOH \rightarrow Na_2SeO_3 + H_2O$

6. MAR 19/P22/Q2/c(iii)

(a) (i) 2
M1 labelled reactants **AND** products lower on right
M2 labelled enthalpy change with correct arrow

7. O/N 18 /P22/Q3/a

(a) 3
$\Delta H_r = (-692.9)+3(-61.8)- (-182.1) -3(-204.6)$
$= -82.4\ (kJ\ mol^{-1})$
M1 $\Delta H_r = x(-692.9) + y(-61.8) - v(-182.1) - w(-204.6)$ where x y v and w are integers $\geqslant 1$ [1]
M2 use of correct stoichiometry where $x = 1$ $y = 3$ $v = 1$ and $w = 3$ [1]
M3 –82.4 [1]

8. O/N 18 /P21/Q3/a(i),(ii), O/N 18 /P23/Q3/a(i),(ii)

(a) (i) 2
M1 gas / vapour (particles / molecules) in **equilibrium** (with liquid / solid)
M2 greater proportion of gas (particles) than liquid (particles) (in comparison to a liquid of lower vapour pressure)

(ii) 3
$-17.(0)\ (kJ\ mol^{-1})$ ✓✓✓
M1 $\Delta H_r = x(-482.2) + y(-92.3) - v(-103.2) - w(-273.3)$ where x y v and w are integers $\geqslant 1$ (ignore stoichiometry)
M2 use of correct stoichiometry where $x = 1$ $y = 2$ $v = 1$ and $w = 2$

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9. M/J 18/P21/Q1/b

(a) −196 + 6S=O = (4 × 534) + 496 **1**

S=O = 2828 / 6 = 471(.3) **1**

10. O/N 17/P22/Q2/a

(a) −444 **1**

11. O/N 17/P21/Q1/a, O/N 17/P23/Q1/a

(a) (i) energy needed / required to break a mole of (covalent) bonds **1**

(All) in the gaseous state **1**

(ii) –92 = {944 + 3(436)} – 6E(N–H) **1**

E(N–H) = (+)390.7 / 390.67 / 391 **1**

12. 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**

13. M/J 16/P22/Q2/a

(a) (i) enthalpy / energy / heat change when one mole of gaseous atoms is produced from the element in its standard state under standard conditions **[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]**

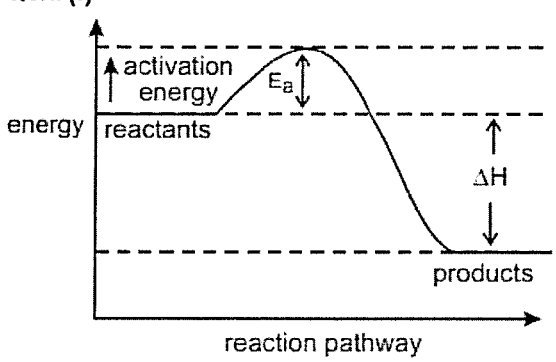
(iii) ($\frac{1}{2}Cl_2 + \frac{1}{2}I_2 \rightarrow ICl$)

$\Delta H_f = (\frac{1}{2}E(Cl_2) + \frac{1}{2}E(I_2)) - E(ICl)$ OR $E(ICl) = (151/2) + (242/2) + 24$

E(IC*l*) = (+) 220.5 / 221 **[2]**

14. 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]**

15. 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) **[2]**

(ii) $S(s) + 1\frac{1}{2}O_2(g) \rightarrow SO_3(l)$ **[1]**

(b) (i) 944 + (3 × 436) = 2252

6 × 390 = 2340

2252 – 2340 = –88 (kJ mol^{-1}) **[3]**

(ii) Fe catalyst

200 atm

400–500 (°)C **[3]**

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(iii) High T increases rate AND Low T improves yield owtte
Chosen temp is a compromise
High P favours/increases (both rate and) yield owtte
pressure chosen limited by cost (of compression and 'thick walls') **[4]**

16. M/J 15/P22/Q3/a(i)

(a) (i) Bond breaking = C*l*-C*l* = 242
C-H = 410 = 652 kJ
Bond forming = C-C*l* = 340
H-C*l* = 431 = 771 kJ
Enthalpy change = 652 – 771 = –119 **[3]**

17. O/N 13/P22/Q5/c,d, 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
or is completely combusted under standard conditions **[2]**

(b) (i) $m = \frac{pVM_r}{RT} = \frac{1.01\times10^5 \times 125\times10^{-6} \times 44}{8.31\times293}$ g
= 0.228147345 g
= 0.23 g

(ii) heat released = m c δ T = 200 × 4.18 × 13.8 J
= 11536.8 J = 11.5 kJ

(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} **[5]**

18. M/J 13/P21/Q2/c

(a) let ΔH_f^e for NO be *y* kJ mol^{-1}

$4NH_3(g) + 5O_2 \rightleftharpoons (g)4NO(g) + 6H_2O(g)$

ΔH_f^e 4 × (–46.0) 4*y* 6 × (–242)

$\Delta H^e_{reaction}$ = 4*y* + [6 × (–242)] – [4 × (–46.0)]
= 4*y* – 1452 + 184

$\Delta H^e_{reaction}$ is –906 kJmol^{-1} so
4*y* = –906 + 1452 – 184 = 362
whence y = ΔH_f^e for NO = +90.5 kJ mol^{-1}
+ sign is required **[4]**

19. 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)

$\Delta H_{reaction}$ = –395 + 2(–298) – x = –1110 kJ mol^{-1}
gives *x* = –395 + (–596) + 1110 = +119 kJ mol^{-1} **[3]**

20. M/J 12/P22/Q2/a,b

(a) $CH_3OH(l) + {}^3/_2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$
the enthalpy change/heat change/heat evolved when
one mole of CH_3OH
is completely burned **or**
is burned in an excess of air/oxygen **[3]**

(b) $\Delta H^e_{reaction}$ = –283 + 2(–286) – (–726)
= –129 kJ mol^{-1}
correct sign **[3]**

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21. M/J 12/P21/Q3/a,b

(a) $C(s) + O_2(g) \rightarrow CO_2(g)$
the enthalpy change/energy change/heat change when one mole of a compound/CO_2 is formed from its elements in their standard states [3]

(b) (i)

	$CO_2(g)$	+ $3H_2(g)$	$\rightleftharpoons$ $CH_3OH(g)$	+ $H_2O(g)$
$\Delta H^{\ominus}_f$/kJ mol^{-1}	–394	0	–201	–242

$\Delta H^{\ominus}_{reaction} = -201 + (-242) - (-394)$
-49 kJ mol^{-1}
correct sign

(ii) removal of CO_2 from the atmosphere
CO_2 is a greenhouse gas/causes global warming [5]

22. M/J 12/P23/Q3/a,b

(a) $CH_3OCH_3(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$
the enthalpy change/heat change/heat evolved when one mole of CH_3OCH_3/a compound is completely burned **or** burned in an excess of air/oxygen [3]

(b)

	$2CH_3OH(l)$	$\rightarrow$ $CH_3OCH_3(g)$	+ $H_2O(l)$
$\Delta H^{\ominus}_f$/kJ mol^{-1}	2(–239)	–184	–286

$\Delta H^{\ominus}_{reaction} = -184 + (-286) - 2(-239)$
$= +8$ kJ mol^{-1}
correct sign [3]

23. 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 [2]

(b) (i) $K_2CO_3 + 2HCl \rightarrow 2KCl + H_2O + CO_2$

(ii) heat produced = $m \times c \times \delta T = 30.0 \times 4.18 \times 5.2$
= 652.08 J per 0.0200 mol of K_2CO_3

(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}

(iv) to prevent the formation of $KHCO_3$ **or** to ensure complete neutralisation [4]

(c) (i) $KHCO_3 + HCl \rightarrow KCl + H_2O + CO_2$

(ii) heat absorbed = $m \times c \times \delta T = 30.0 \times 4.18 \times 3.7$
= 463.98 J per 0.0200 mol of $KHCO_3$

(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} [3]

(d) $\Delta H = 2 \times (+23.20) - (-32.60) = +79.00$ kJ mol^{-1} [2]

24. 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
correct state symbols in this equation

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formation

$2C(s) + H_2(g) \rightarrow C_2H_2(g)$

no mark for state symbols here

(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 $\mathbf{Z} = 2(-394) + (-286) - (-1300)$

$= +226 \text{ kJ mol}^{-1}$

value

sign

allow ecf on wrong equation [6]

25. O/N 10/P21/Q3/d,e,f

(a) 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 [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]

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Unit 6

ELECTROCHEMISTRY

Chemistry Paper-2
Topical Workbook
Article Number: 232

Editorial Board

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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]

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.

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(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]

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.

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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.

$P_4S_{10} + 16H_2O \rightarrow$

(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 2.7g 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?

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(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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Answers Section

1. M/J 15/P23/Q2/b(iv)

(a) N from (+)5 to (+)3
O from –2 to 0
N is reduced **and** O is oxidised [3]

2. M/J 15/P22/Q2/a

(a) (i) $2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$
reagents and formulae
balancing [2]

(ii) S (is oxidised) –2 to (+)4
O (is reduced) 0 to –2 [2]

3. M/J 14/P22/Q2/a(i)

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

5. M/J 13/P23/Q1/d

(a) (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]

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) $P_4S_{10} + 16H_2O \rightarrow 4H_3PO_4 + 10H_2S$

(ii) P_4S_{10} P is +5
H_3PO_4 P is +5
No **because**
there is no change in the oxidation no. of P
ecf on answer to **(c)(i)**
and on calculated oxidation numbers [4]

10. O/N 07/P2/Q3/c,d

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

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

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

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$$1.0 \text{ mol } S_2Cl_2 \rightarrow \frac{0.03 \times 1.0}{0.02} = 1.5 \text{ mol S}$$

(iii) $2S_2Cl_2 + 3H_2O \rightarrow 3S + H_2SO_3 + 4HCl$
correct products
balanced equation [4]

(b) oxidation product is H_2SO_3
reduction product is S [2]

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A Level

Unit 7

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Unit 7: Equilibria

1. O/N 21/22/Q1

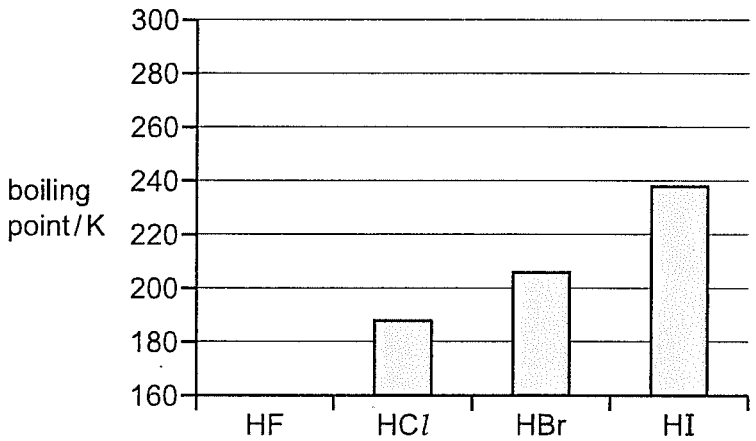
Hydrogen iodide, HI, is a colourless gas at room temperature.

(a) (i) Explain why HI has a higher boiling point than HC*l* and HBr.

.....

..... [2]

(ii) The bar chart shows the boiling points of HC*l*, HBr and HI. The boiling point of HF is not shown.



Hydrogen bonds form between HF molecules.

Draw a bar on the bar chart to predict the boiling point of HF.

Explain your answer.

.....

..... [2]

(b) The standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of HI(g) is +26.5 kJ mol^{-1}.

Define the term *standard enthalpy change of formation.*

.....

..... [2]

(c) HI(g) can be formed by reacting $H_2(g)$ with $I_2(g)$. The reaction is reversible, and an equilibrium forms quickly at high temperatures.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

(i) Construct an expression for the equilibrium constant, K_p, for the reaction of $H_2(g)$ and $I_2(g)$ to form HI(g).

K_p =

[1]

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(ii) The equilibrium partial pressures of the gases at 200 °C are as follows.

$$p_{H_2(g)} = 895\,Pa$$

$$p_{I_2(g)} = 895\,Pa$$

$$p_{HI(g)} = 4800\,Pa$$

Calculate K_p for this reaction.

K_p = ... [1]

(iii) State how the value of K_p would change, if at all, if the reaction were carried out at 100 °C rather than 200 °C.

Explain your answer.

.....

..... [2]

(d) HI reacts with oxygen to form iodine and water.

(i) Construct an equation for the reaction of HI with oxygen.

..... [1]

(ii) Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

.....

..... [2]

(e) HI(g) can also be formed by the reaction of $I_2(g)$ with hydrazine, $N_2H_4(g)$.

$$2I_2(g) + N_2H_4(g) \rightarrow 4HI(g) + N_2(g)$$

State the change in pressure that would occur when 2 mol $I_2(g)$ fully reacts with 1 mol $N_2H_4(g)$ in a sealed container at constant temperature. Explain your answer.

.....

..... [2]

(f) In the laboratory, HI(aq) can be formed in a two-step process.

step 1 $3I_2(s) + 2P(s) \rightarrow 2PI_3(s)$

step 2 $PI_3(s) + 3H_2O(l) \rightarrow H_3PO_3(aq) + 3HI(aq)$

(i) Draw a 'dot-and-cross' diagram of a PI_3 molecule.

[2]

(ii) Name the type of reaction in **step 2**.

..... [1]

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(iii) $H_3PO_3(aq)$ and HI(aq) are both strong Brønsted–Lowry acids.
Give the meaning of the term *strong Brønsted–Lowry acid.*

.....

..... [2]

(iv) Give the formula of the conjugate base of H_3PO_3.

..... [1]

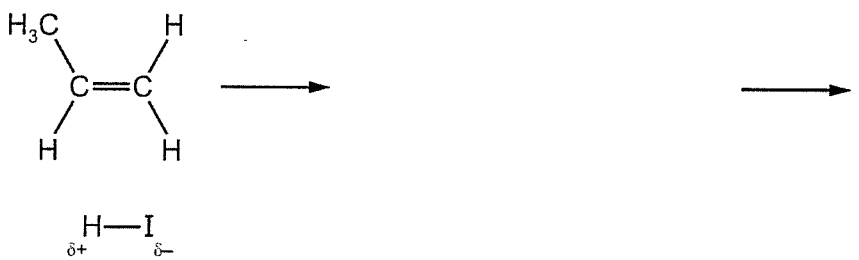
(g) HI(g) reacts with propene, $CH_3CH=CH_2(g)$ to form a mixture of 1-iodopropane and 2-iodopropane.

(i) Identify which of 1-iodopropane and 2-iodopropane is the major product of this reaction.
Explain your answer.

.....

..... [2]

(ii) Complete the diagram to show the mechanism of the reaction between HI and $CH_3CH=CH_2$ that forms the major product identified in **(g)(i)**.
Include curly arrows, lone pairs of electrons and charges as necessary.



[3]

2. M/J 18/P22/Q2/c

Ammonium iron(II) sulfate, $(NH_4)_2Fe(SO_4)_2$, has a relative formula mass, M_r, of 284.

(a) 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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3. M/J 18/P21/Q1/f

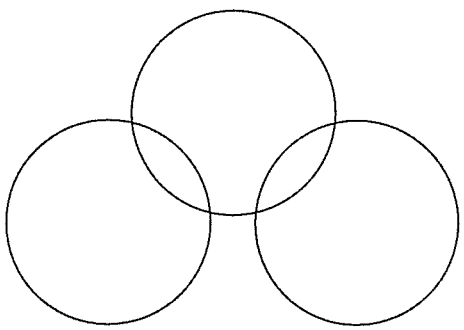
Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5.

$$2\,O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2\,O{=}\overset{\overset{O}{\|}}{S}{=}O(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(a) SO_2 reacts with water to form sulfurous acid.
Sulfurous acid is a weak Brønsted-Lowry acid, while sulfuric acid is a strong Brønsted-Lowry acid.

(i) Complete the 'dot-and-cross' diagram to show the bonding in a molecule of SO_2. Show outer electrons only.



[1]

(ii) State the meaning of the term *strong Brønsted-Lowry acid*.

.....

..... [2]

(iii) Write an equation to show the acid-base behaviour of sulfuric acid with water. Include state symbols.

.....

..... [2]

4. M/J 18/P23/Q1/d

The elements sodium to chlorine, in the third period, all form oxides.

(a) 2.00 moles of $SO_2(g)$ and 2.00 moles of $O_2(g)$ are sealed in a container with a suitable catalyst, at constant temperature and pressure. The resulting equilibrium mixture contains 1.98 moles of $SO_3(g)$.
The total volume of the equilibrium mixture is 40.0 dm^3.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(i) Write the expression for the equilibrium constant, K_c, for the reaction between $SO_2(g)$ and $O_2(g)$ to produce $SO_3(g)$.

$K_c =$

[1]

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(ii) Calculate the amount, in moles, of $SO_2(g)$ and $O_2(g)$ in the equilibrium mixture.

$SO_2(g)$ = ... mol

$O_2(g)$ = ... mol [2]

(iii) Use your answers to **(d)(i)** and **(d)(ii)** to calculate the value of K_c for this equilibrium mixture. Give the units of K_c.

K_c = ...

units = ... [3]

5. O/N 17/P22/Q2/b,c,d

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) (i) State and explain the effect of increasing temperature on the rate of decomposition of $PCl_5(g)$.

.....

..... [2]

(ii) State and explain the effect of increasing temperature on the percentage of $PCl_5(g)$ that decomposes.

.....

..... [2]

(b) Explain the meaning of the term *dynamic equilibrium* and the conditions necessary for it to become established.

.....

..... [2]

(c) 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.

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$p\text{PC}l_5$ = ... Pa **[2]**

(ii) Write the expression for the equilibrium constant, K_p, for the decomposition of $\text{PC}l_5(g)$.

K_p =

[1]

(iii) The partial pressures of $\text{PC}l_3(g)$ and of $\text{C}l_2(g)$ 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]**

6. O/N 17/P21/Q1/c,d, O/N 17/P23/Q1/c,d

Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,\text{kJ mol}^{-1}$$

(a) At a pressure of 2.00×10^7 Pa, 1.00 mol of nitrogen, $N_2(g)$, was mixed with 3.00 mol of hydrogen, $H_2(g)$. The final equilibrium mixture formed contained 0.300 mol of ammonia, $NH_3(g)$.

(i) Calculate the amounts, in mol, of $N_2(g)$ and $H_2(g)$ in the equilibrium mixture.

$N_2(g)$ = ... mol

$H_2(g)$ = ... mol **[2]**

(ii) Calculate the partial pressure of ammonia, pNH_3, in the equilibrium mixture.

Give your answer to **three** significant figures.

pNH_3 = ... Pa **[3]**

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(b) In another equilibrium mixture the partial pressures are as shown.

substance	partial pressure/Pa
$N_2(g)$	2.20×10^6
$H_2(g)$	9.62×10^5
$NH_3(g)$	1.40×10^4

(i) Write the expression for the equilibrium constant, K_p, for the production of ammonia from nitrogen and hydrogen.

K_p =

[1]

(ii) Calculate the value of K_p for this reaction.
State the units.

K_p = ...

units = ... **[2]**

(iii) This reaction is repeated with the same starting amounts of nitrogen and hydrogen. The same temperature is used but the container has a smaller volume.
State the effects, if any, of this change on the yield of ammonia and on the value of K_p.

effect on yield of ammonia .....

effect on value of K_p .....

[2]

7. 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]

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(ii) Calculate the value of K_p for this reaction and state the units.

K_p = ...

units = ... [2]

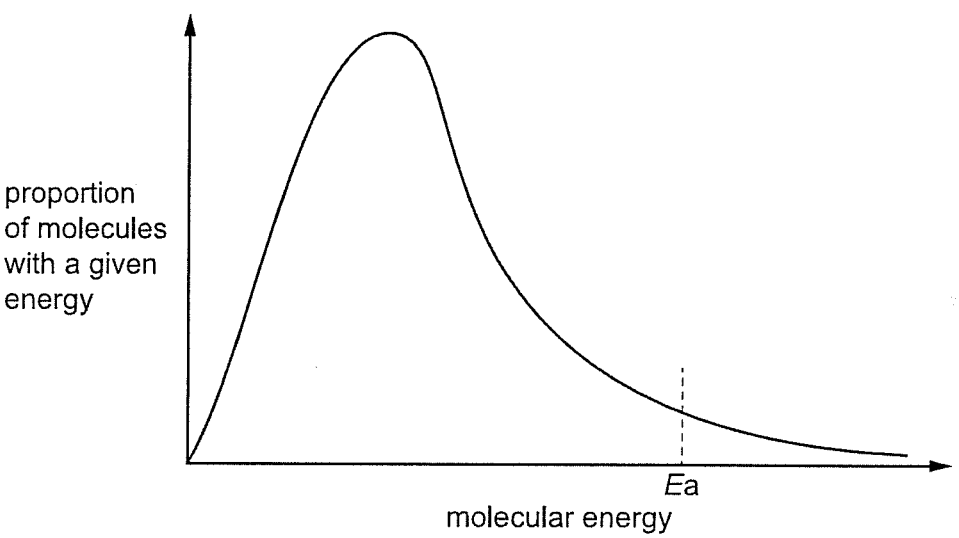
8. M/J 17/P22/Q3/b(iii,iv),c,d

The hydrogen halides, HC*l*, HBr and HI, can undergo thermal decomposition.
In a sealed container an equilibrium is established according to the equation shown.

$$2HX(g) \rightleftharpoons H_2(g) + X_2(g) \qquad \text{(where X = C}l\text{, Br or I)}$$

(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.



(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 700 K 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]

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(b) At temperatures above 1500 K, HCl will decompose.

A sample of 0.300 mol of HCl 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 HCl present in the equilibrium mixture.

H_2 = ... mol

HCl = ... mol **[2]**

(ii) Calculate the mole fraction of each gas in the equilibrium mixture.

mole fraction of HCl = ...

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
HCl	0.88
H_2	0.06
Cl_2	0.06

(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]**

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9. 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]

(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]

10. 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]

11. 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]

12. 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]

(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]

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(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.

K_p = ...

units = ... [5]

13. 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.

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(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.

[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]

14. 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 1150 K.

(a) (i) State Le Chatelier's Principle.

.....

..... [2]

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(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.

$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g)$ $K_c = 1.44$ 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]

15. 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]

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(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]**

16. 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.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H° = -906\ kJ\,mol^{-1}$$

(a) Write the expression for the equilibrium constant, K_p, stating the units.

K_p =

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

(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

.....

.....

.....

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(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.

$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H^{\ominus} = -906\,kJ\,mol^{-1}$

[4]

17. 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.

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H = +206\,kJ\,mol^{-1}$

(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]

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(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.

(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]

18. 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.

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(i) increasing the pressure applied to the equilibrium

.....

.....

(ii) decreasing the temperature of the equilibrium

.....

..... [4]

(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.

	$H_2(g)$	+	$I_2(g)$	$\rightleftharpoons$	$2HI(g)$
initial moles	0.02		0.02		0

[4]

19. 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]

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

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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]

20. M/J 12/P21/Q3/c

(a) The synthesis of methanol is carried out at about 500 K 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]

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21. 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 =

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]

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(c) (i) Use your results from **(b)** to calculate the amount, in moles, of ethanoic acid present at equilibrium. Hence complete the table below.

	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]

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Answers Section

1. O/N 21/P22/Q1

(a) (i) **M1** (HI / I / iodine / hydrogen iodide has a) greater number of electrons **2**
M2 greater induced dipoles (between molecules)

(ii) **M1** bar at HF shows any boiling point above HI on graph **2**
M2 *explanation of difference in boiling point of a sample of HF in terms of strength*
(sum of) hydrogen bonds (and induced dipoles in HF) are **stronger**
than (sum of) induced dipoles (and permanent dipoles in HC*l* / HBr / HI)

(b) (enthalpy / energy change) when one mole of a compound is formed **2**
from its elements in their standard states

(c) (i) $K_p = \dfrac{p\mathrm{HI}^2}{p\mathrm{H_2}\ p\mathrm{I_2}}$ **1**

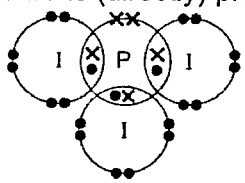
(ii) 28.76 **OR** 28.8 **OR** 29 **1**

(iii) **EITHER** **2**
option 1 which assumes $\Delta H_{reaction}$ *is (still) endothermic (using the value shown in (b)).*
M1 (K_p) decreases **AND** endothermic / $\Delta H_{(f)}$ = + / positive
M2 reaction favours formation of reactants / hydrogen and iodine OR (product) yield / partial pressure of HI decreases / equilibrium shifts to the left
OR
option 2 which realises that $\Delta H_{reaction}$ *is in fact exothermic*
(using bond energy data in Data Booklet)
M1 (K_p) increases **AND** exothermic / $\Delta H_{(f)}$ = + / negative
M2 reaction favours formation of products / hydrogen iodide yield increases / partial pressure of HI increases / equilibrium shifts to the right

(d) (i) $4HI + O_2 \rightarrow 2I_2 + 2H_2O$ **1**

(ii) **M1** I / iodine (increases) oxidation number –1 → 0 so oxidation / is oxidised **2**
OR
HI / is oxidised as I (increases) oxidation number –1 → 0
M2 O (decreases) oxidation number 0 → –2 so reduction / is reduced

(e) **M1** pressure increases **2**
M2 (pressure goes up as) number of moles/molecules increases in ratio 3 (gas) reactants to 5 (gas) products
OR
pressure is (directly) proportional to number of moles/molecules

(f) (i) 

2
M1 correct bonding pairs
M2 correct number of remaining outer electrons on each atom

(ii) hydrolysis **1**

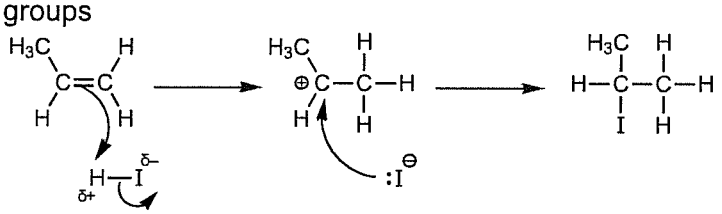
(iii) proton donor / H^+ donor **2**
fully dissociates / fully ionises

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(iv) $H_2PO_3^-$ **1**

(g) (i) **M1** 2-iodopropane – formed from a (more) stable (secondary) (carbo)cation/ intermediate **2**

M2 (because of) greater (positive) inductive effect / (+)I of two alkyl groups
OR
(because of positive) inductive effect / (+)I of more R / more methyl / more alkyl groups

(ii)  **3**

M1 curly arrow from = of C=C to H **AND** curly arrow from bond of H—I to I

M2 curly arrow from lone pair of I^- to $C^{(+)}$ of their intermediate

M3 correct carbocation **AND** product for 2-iodopropane

2. M/J 18/P22/Q2/c

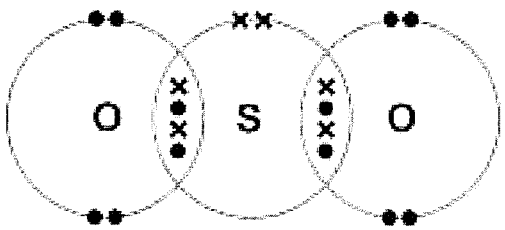
(a) (i) *in any order explain meaning of:* **2**
weak
partially ionises / incompletely dissociates (into ions)
Bronsted-Lowry acid
is a proton donor / H^+ (ion) donor / hydrogen ion donor

(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**

3. M/J 18/P21/Q1/f

(a) (i)  **1**

(ii) fully ionises/dissociates **1**

(Brønsted-Lowry acid is a) proton / H^+ donor **1**

(iii) $H_2SO_4(l)/(aq) + H_2O(l) \rightarrow HSO_4^-(aq) + H_3O^+(aq)$

species and balancing **1**

correct state symbols on left hand side; all products aqueous **1**

4. M/J 18/P23/Q1/d

(a) (i) $K_c = \dfrac{[SO_3]^2}{[SO_2]^2 \times [O_2]}$ **1**

(ii) SO_2 = 0.02 (mol) **1**

O_2 = 1.01 (mol) **1**

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(iii) $K_c = \dfrac{(1.98/40)^2}{(0.02/40)^2(1.01/40)}$ **3**

$= 3.88 / 3.882 \times 10^5$

Units = $dm^3\ mol^{-1} / mol^{-1}\ dm^3$

5. O/N 17/P22/Q2/b,c,d

(a) (i) (higher rate / rate increases) due to higher frequency of successful collisions **1**

more molecules / particles with $E \geqslant E_a$ **1**

(ii) (percentage decomposition of PCl_5) increases **1**

(forward) reaction is endothermic **1**

(b) rates of forward and reverse / backward reactions are equal **1**

closed / sealed system/container **1**

(c) (i) n_{TOTAL} = 1.20 + 0.80 + 0.80 OR 2.80 (mol) **1**

OR mole fraction = 1.20 / 2.80 OR 0.429

$p PCl_5 = 1 \times 10^5 \times (1.20/2.80) = 4.29 \times 10^4$ (Pa) **1**

(ii) $K_p = \dfrac{p PCl_3 \times p Cl_2}{p PCl_5}$ **1**

(iii) 1.91×10^4 **1**

Pa **1**

6. O/N 17/P21/Q1/c,d, O/N 17/P23/Q1/c,d

(a) (i) N_2 = 0.850 (mol) **1**

H_2 = 2.55 (mol) **1**

(ii) n_{TOTAL} = 3.7 mol **1**

mol fraction of NH_3 = 0.3 / 3.7 **1**

$pNH_3 = 2 \times 10^7 \times (0.3/3.7) = 1.62 \times 10^6$ **1**

(b) (i) $K_p = \dfrac{pNH_3^{\,2}}{pN_2 \times pH_2^{\,3}}$ **1**

(ii) $K_p = 1.(00) \times 10^{-16}$ **1**

Pa^{-2} **1**

(iii) (yield of ammonia) increases **1**

(value of K_p) stays the same **1**

7. M/J 17/P23/Q3/d

(a) (i) $(K_p =) \dfrac{pSO_3^{\,2}}{pO_2 \times pSO_2^{\,2}}$ **1**

(ii) 0.1946737305 **1**

Pa^{-1} **1**

8. 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**

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(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 1
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

(c) (i) $(K_p =) \dfrac{pH_2 \times pCl_2}{pHCl^2}$ 1

(ii) equal number of moles (of gas) on either side (of equation) / (total) pressure cancels 1

(iii) 4.649×10^{-3} 1

9. MAR 17/P22/Q2/c(iii,iv,v,vi)

(a) (i) reaction is exothermic 1
(increased temperature) shifts equilibrium to the left **AND** decreases yield of products (Cl_2 and / or H_2O) / less product formed 1

(ii) 3

	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			$\dfrac{0.600}{1.80}$	
M3 partial pressure			$\dfrac{0.600}{1.80} \times p_{tot} =$ 5.00×10^4	

(iii) $K_p = \dfrac{(3.6\times10^4)^2 \times (3.6\times10^4)^2}{(4.8\times10^4)^4 \times 3.0\times10^4} = 1.05 \times 10^{-5}$ 1

units = Pa^{-1} 1

(iv) K_p would not change 1

10. MAR 16/P22/Q3/b

(a) (i) forward and backward reactions occurring <u>at same rate</u>
OR [1]
<u>the rate of</u> forward and backward reactions are equal

(ii) M1 = decreased yield of products / less products formed / ora
M2 = <u>left</u>-hand side has fewer moles of gas
OR [2]

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equilibrium shifts to the left

11. O/N 14/P23/Q2/d

(a) (i) Advantage = higher rate
Greater Kinetic Energy / speed / collision frequency / proportion of successful collisions
Disadvantage – reduced yield / less product / more reactants
(Forward reaction) **exothermic AND** (hence in accordance with Le Chatelier's Principle) equilibrium / reaction **shifts left** (to counteract increasing temp) ora **[4]**

(ii) $K_p = \frac{pNH_3^2}{pN_2 \times pH_2^3}$ **[1]**

(iii)

$N_2(g)$ +	$3H_2(g)$ ⇌	$2NH_3(g)$
2	3	0
(–0.8)	(–1.6×3/2)	
1.2	0.6	1.60

$xNH_3 = 1.6/3.4$ (= 0.471)
$xN_2 = 1.2/3.4$ (= 0.353)
$xH_2 = 0.6/3.4$ (= 0.176)

$K_p = \frac{0.471^2 \times (2 \times 10^7)^2}{0.353 \times 2 \times 10^7 \times 0.176^3 \times (2 \times 10^7)^3} = 2.88 \times 10^{-13}\ Pa^{-2}$ **[5]**

12. O/N 14/P21/Q2/a,b,d

(a) $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$ **[2]**

(b) (i) Very exothermic / gets very hot
OR creates (acid / H_2SO_4) spray / mist / fog / fumes **1**

(ii) $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$
$H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$ **[2]**

(c) (i) Advantage = higher rate
Greater KE / energy / speed / collision frequency / proportion of successful collisions / more particles with E>Ea
Disadvantage – reduced yield / less product
(Forward reaction) **exothermic AND** (hence in accordance with LCP) equilibrium / reaction **shifts left** (to counteract inc T) ora **[4]**

(ii) $K_p = \frac{pSO_3^2}{pSO_2^2 \times pO_2}$ **[1]**

(iii)

$2SO_2(g)$ +	$O_2(g)$ ⇌	$2SO_3(g)$
2	2	0
(–1.8)	(–0.9)	
0.2	1.1	1.80

$xSO_3 = 1.8/3.1 = 0.581$
$xSO_2 = 0.2/3.1 = 0.065$
$xO_2 = 1.1/3.1 = 0.355$

$K_p = \frac{0.581^2 \times (2 \times 10^5)^2}{0.065^2 \times (2 \times 10^5)^2 \times 0.355 \times 2 \times 10^5} = 1.13 \times 10^{-3}\ Pa^{-1}$ **[5]**

13. M/J 14/P23/Q3/a,b

(a) (i) (reaction between atmospheric N_2 and O_2) due to lightning / biological processes or bacteria in soil
AND in car engines / power stations / metal refining / furnaces **[1]**

(ii) $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ **OR**
$2NO_2 + H_2O + 1/2O_2 \rightarrow 2HNO_3$ **OR**
$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$ **[1]**

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(iii) $SO_2 + NO_2 \rightarrow SO_3 + NO$
$NO + 1/2O_2 \rightarrow NO_2$
$SO_3 + H_2O \rightarrow H_2SO_4$ [3]

(b) (i) $K_p = pN_2O_4/(pNO_2)^2$ [1]

(ii) moles of $NO_2 = 0.32$ [1]

(iii) $x(N_2O_4) = 1.84/\ 2.16 = 0.85$
$x(NO_2) = 0.32/2.16 = 0.15$
ecf from **(b)(ii)** [2]

(iv) $pN_2O_4 = 0.85 \times 140 = 119$ (kPa)
$pNO_2 = 0.15 \times 140 = 21$ (kPa)
ecf from **(b)(iii)** [2]

(v) $K_p = 119/21^2 = 0.270\ kPa^{-1}$
ecf from **(b)(i)** and **(b)(iv)** [2]

14. M/J 13/P23/Q2/a ,b

(a) (i) if the conditions of a system in equilibrium are changed
the position of equilibrium moves so as to reduce that change [2]

(ii) lower temperature
because the forward reaction is exothermic
higher pressure
because the forward reaction shows a reduction in volume
or
there are fewer molecules/moles on RHS of equilibrium [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)
equil. concn.	$\frac{(0.70–x)}{1}$		$\frac{(0.70–x)}{1}$		$\frac{(0.30+x)}{1}$		$\frac{(0.30+x)}{1}$

$K_c = \frac{(0.30+x)^2}{(0.70-x)^2} = 1.44$
gives x = 0.25
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 [4]

15. M/J 13/P22/Q1/a ,b

(a) a base is a proton acceptor **or**
a lone pair donor
a weak base is not fully ionised
e.g. $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$ **or**
$B + H^+ \rightleftharpoons BH^+$ **or** equivalent
⇌ is necessary [3]

(b) (i) **stated** pressure greater than 1 atm up to 5 atm
stated temperature 400 to 500 °C
named catalyst V_2O_5/vanadium(V) oxide

(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 [4]

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16. M/J 13/P21/Q2/a,b,c

(a) $K_P = \dfrac{p(NO)^4\, p(H_2O)^6}{p(NH_3)^4\, p(O_2)^5}$

atmospheres **or** Pa **or** kPa

allow ecf on incorrect powers [2]

(b) (i) **increasing temperature**

yield of NO is decreased **or** reaction moves to LHS

forward reaction is exothermic

(ii) **decreasing the pressure**

yield of NO is increased **or** reaction moves to RHS

more moles/molecules of gas on RHS **or**

fewer moles/molecules of gas on LHS [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°	$4 \times (-46.0)$	$4y \quad 6 \times (-242)$

$\Delta H^\circ_{reaction} = 4y + [6 \times (-242)] - [4 \times (-46.0)]$

$= 4y - 1452 + 184$

$\Delta H^\circ_{reaction}$ is -906 kJmol^{-1} so

$4y = -906 + 1452 - 184 = 362$

whence $y = \Delta H_f^\circ$ for NO $= +90.5$ kJ mol^{-1}

+ sign is required [4]

17. O/N 12/P23/Q3

(a) manufacture of ammonia/Haber process **or** hydrogenation of fats/oils **or** making margarine **or** hydrocracking [1]

(b) (i) **increasing the pressure**

equilibrium will move to LHS

fewer moles/molecules on LHS or more moles/molecules on RHS

(ii) **decreasing the temperature**

equilibrium will move to LHS

forward reaction is endothermic [4]

(c) rate will increase

collisions will occur more frequently [2]

(d) (i) $K_c = \dfrac{[CO_2][H_2]}{[CO][H_20]}$

(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}	$\frac{(0.40 - y)}{1}$	$\frac{(0.40 - y)}{1}$		$\frac{(0.20 + y)}{1}$	$\frac{(0.20 + y)}{1}$

$K_c = \dfrac{(0.20 + y)^2}{(0.40 - y)^2} = 6.40 \times 10^{-1}$

$\dfrac{(0.20 + y)}{(0.40 - y)} = \sqrt{6.40 \times 10^{-1}} = 0.8$

$(0.20 + y) = 0.8 \times (0.40 - y)$

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$0.20 + y = 0.32 - 0.8y$

$1.8y = 0.12$

gives $y = 0.067$

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

allow ecf as appropriate **[5]**

18. O/N 12/P21/Q2/b,c,d

(a) $K_c = \dfrac{[HI]^2}{[H_2] \times [I_2]}$

no units – must be clearly stated **[2]**

(b) (i) no change
K_c has no units **or**
same no. of molecules / moles each side of equilibrium

(ii) equilibrium moves to RHS
K_c increases with decreasing temperature **or**
forward reaction is exothermic **or**
reverse reaction is endothermic **[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}	$\frac{(0.02 - y)}{1}$		$\frac{(0.02 - y)}{1}$		$\frac{2y}{1}$

$K_c = \dfrac{HI^2}{[H_2] \times [I_2]} = \dfrac{(2y)^2}{(0.02 - y)^2} = 59$

$\dfrac{2y}{(0.02 - y)} = \sqrt{59} = 7.7$

$2y = (7.7 \times 0.02) - 7.7y$

$9.7y = 0.154$

gives $y = \dfrac{0.154}{9.7} = 0.0159 = 0.016$

at equilibrium

$n(HI) = 2 \times 0.016 = 0.032$ **and**
$n(H_2) = n(I_2) = (0.02 - 0.016) = 0.004$

allow ecf where possible **[4]**

19. M/J 12/P22/Q2/a,c

(a) $CH_3OH(l) + {}^3/_2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

the enthalpy change/heat change/heat evolved when
one mole of CH_3OH
is completely burned **or**
is burned in an excess of air/oxygen **[3]**

(b) pressure
increases rate
by increasing frequency of collisions **or**
by increasing concentration of reactants

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temperature
increases rate
because more molecules have energy $>E_a$
catalyst
increases rate
by providing an alternative route of lower E_a [6]

20. 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
because forward reaction is exothermic/reverse reaction is endothermic
higher pressure
yield is increased **or** equilibrium goes to RHS
fewer moles/molecules on RHS **or** more moles/molecules on LHS
use of catalyst
yield does not change
forward and backward rates speeded up by same amount [6]

21. M/J 11/P22/Q1

(a) $K_c = \dfrac{[CH_3CH_2R][H_20]}{[CH_3CH_2H][ROH]}$
no units [2]

(b) (i) $n(NaOH) = \dfrac{22.5 \times 2.00}{1000} = 0.045$

(ii) $n(NaOH) = n(HCl) = 0.005$

(iii) $CH_3CO_2H + NaOH \rightarrow CH_3CO_2Na + H_2O$

(iv) $n(NaOH) = 0.045 - 0.005 = 0.04$
allow ecf on **(i)** and/or **(ii)** [4]

(c) (i) $n(NaOH)$ **and** $n(CH_3CO_2H) = 0.04$
$n(CH_3CO_2R)$ **and** $n(H_2O) = 0.06$

(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)** [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]

(e) equilibrium moves to RHS/more ester would be formed to maintain value of K_c **or**
to restore system to equilibrium [2]

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A Level

Unit 8

REACTION KINETICS

Chemistry Paper-2
Topical Workbook
Article Number: 232

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Unit 8: Reaction Kinetics

1. O/N 18/P21/Q3/a(iii), O/N 18/P23/Q3/a(iii)

Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example $CHCl_3$.

(a) $CHCl_3$ is a colourless liquid with a high vapour pressure.

(i) The reaction in **(ii)** is carried out using a heterogeneous catalyst.

Explain fully the meaning of the terms *heterogeneous* and *catalyst*.

heterogeneous .....

.....

.....

catalyst .....

.....

.....

..... [3]

2. M/J 18/P21/Q1/a,c

Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5.

$$2\,O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2\,O{=}\overset{\overset{O}{\|}}{S}{=}O(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(a) (i) State the effect of a catalyst on a reaction.

Explain how a catalyst causes this effect.

.....

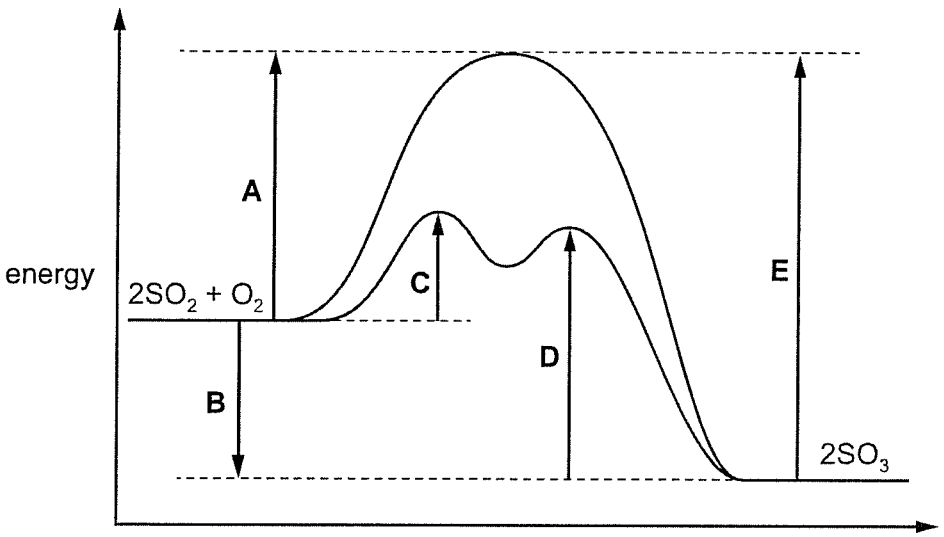
..... **[2]**

(ii) State the meaning of the term *heterogeneous* as applied to catalysts.

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

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(b) A reaction pathway diagram for both the catalysed and uncatalysed reactions between SO_2 and O_2 is shown.



The letters **A–E** represent energy changes.

Complete the table by stating which letter, **A–E**, represents the energy change described.

energy change	letter
the energy change for the production of SO_3	
the activation energy for the production of SO_3 in the absence of a catalyst	
the activation energy for the first step in the **decomposition** of SO_3 in the presence of a catalyst	

[3]

3. O/N 17/P21/Q1/b, O/N 17/P23/Q1/b

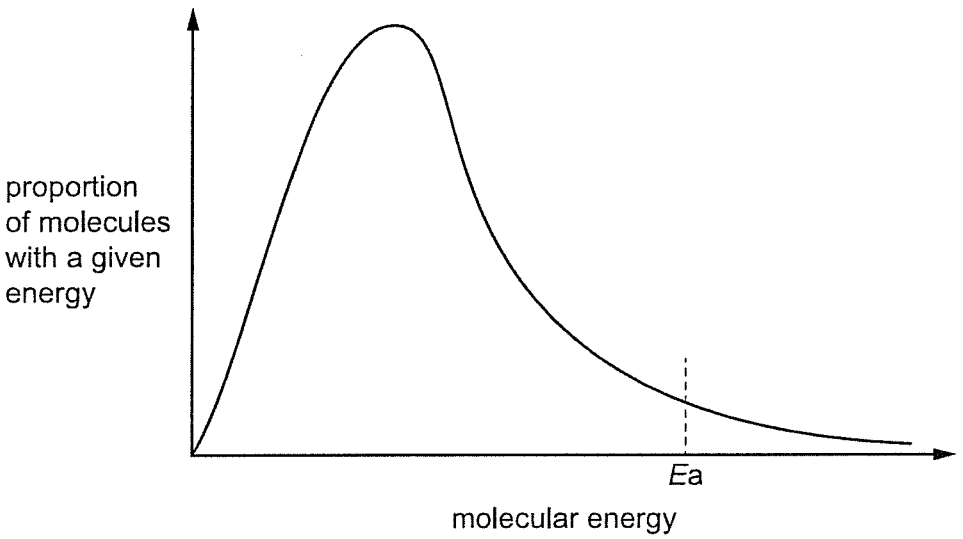
Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) The Haber process is usually carried out at a temperature of approximately 400 °C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400 °C is shown.
*E*a represents the activation energy for the reaction.

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(i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature.

[2]

(ii) **With reference to the Boltzmann distribution**, state and explain the effect of increasing temperature on the rate of production of ammonia.

.....

.....

..... [3]

(iii) State and explain the effect of increasing temperature on the yield of ammonia.
Use Le Chatelier's principle to explain your answer.

.....

.....

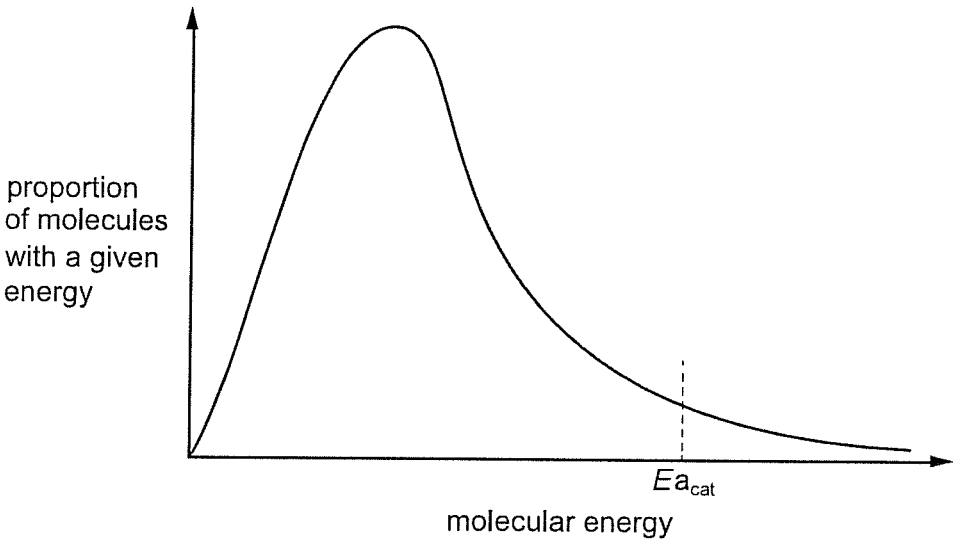
..... [3]

4. 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.

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(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]

(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 .....

.....

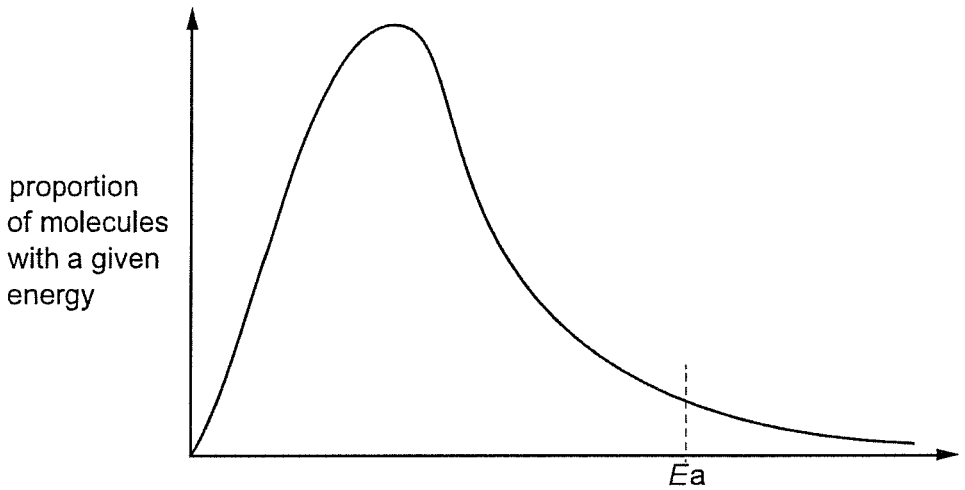
.....[4]

5. 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.

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(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]

6. 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]**

7. MAR 16/P22/Q3/c

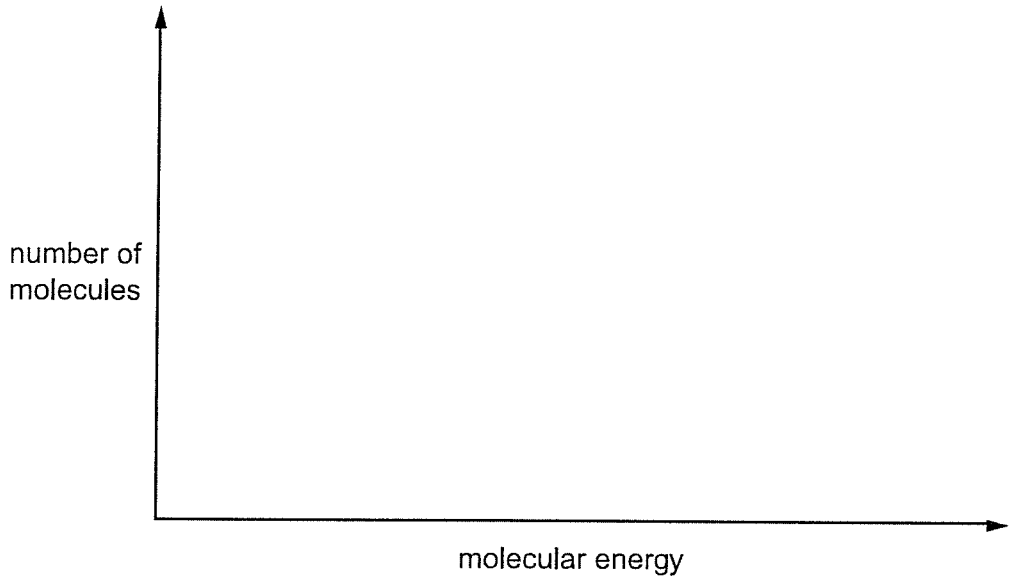
Over one million tonnes of hydrogen cyanide, HCN, are produced each year using the Andrussow process. The overall equation for the reaction is shown.

$$CH_4(g) + NH_3(g) + 1\tfrac{1}{2}O_2(g) \rightleftharpoons HCN(g) + 3H_2O(g)$$

(a) The process uses a platinum catalyst, which increases the rate of reaction.

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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.



.....

.....

..... [3]

8. 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.

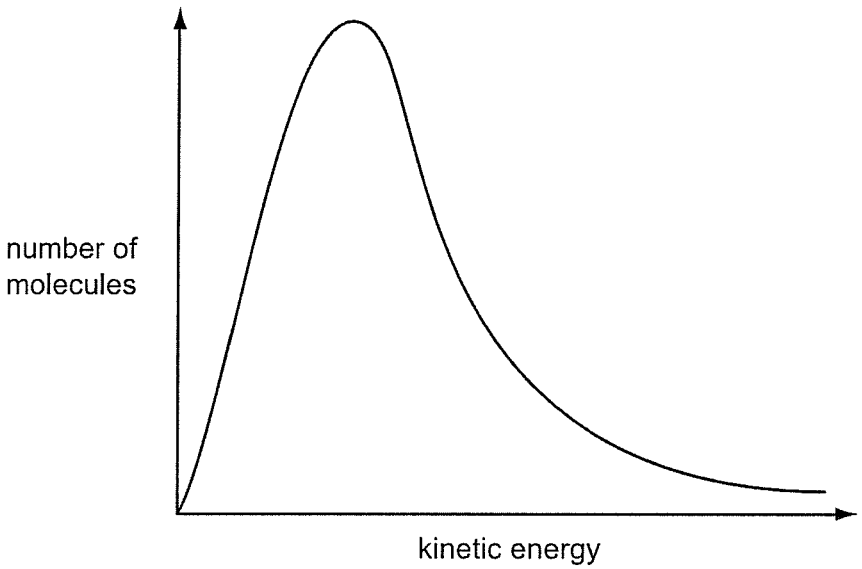
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

(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]

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(b) Use the Boltzmann distribution shown to explain why a catalyst increases the rate of this reaction.



.....

.....

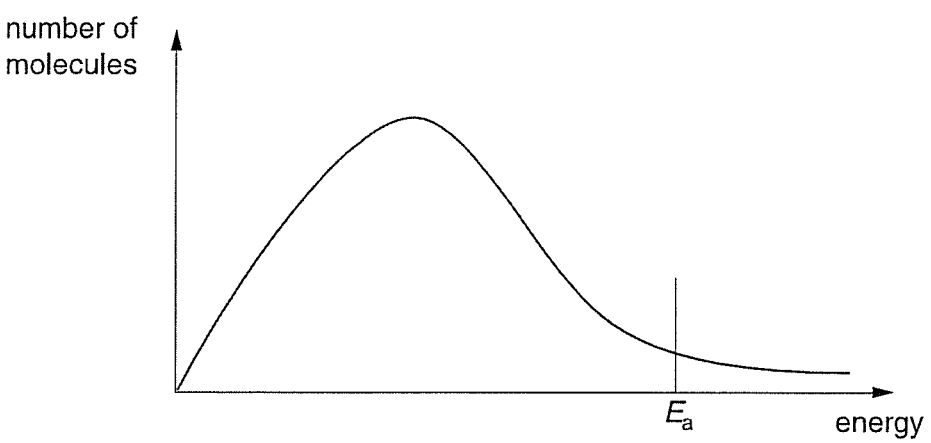
.....

..... [4]

9. 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]**

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(b) Explain the meaning of the term *activation energy*.

.....

..... [2]

10. 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]

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Answers Section

1. O/N 18/P21/Q3/a(iii), O/N 18/P23/Q3/a(iii)

(a) (i) **M1** in a different phase / state from reactants **3**

M2 a substance that speeds up a (chemical) reaction

M3 catalyst is regenerated / not used up / undergoes temporary chemical change / recovered unchanged

2. M/J 18/P21/Q1/a,c

(a) (i) (It is a substance that) speeds up a reaction **1**

(by creating an alternative pathway / mechanism with) lower E_a **1**

(ii) (a heterogeneous catalyst is in a) different state / phase (to the reactants) **1**

(b) **1 = B** **1**

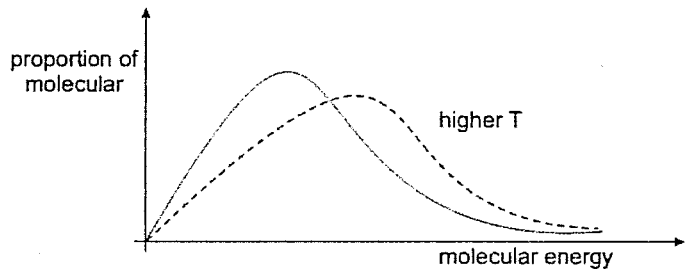
2 = A **1**

3 = D **1**

3. O/N 17/P21/Q1/b, O/N 17/P23/Q1/b

(a) (i) general shape of the curve and peak are displaced to right of original line and starts **1**

at origin the peak is lower and curve crosses once only finishing **above** original line **1**



(ii) rate increases AND explanation in terms of collisions **1**

(at higher T) area above E_a is greater **1**

OR

(at higher T) more molecules with $E \geqslant E_a$

higher frequency of successful collisions **1**

OR

more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time

(iii) reduces yield (of ammonia). **1**

(increasing *T*) shifts equilibrium (reaction) to the left / in the reverse direction / towards N_2 and H_2 / towards reactants endothermic direction **1**

to oppose the change OR oppose the increase in temperature OR to absorb the (additional) heat / energy OR decrease the temperature **1**

4. 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 $E > E_a$

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(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

5. 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 1
origin the peak is lower and curve crosses once only finishing **above** original 1

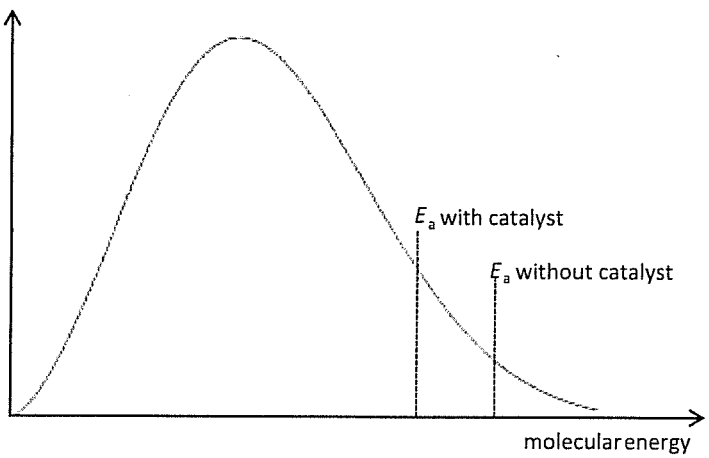
(ii) rate increases AND correct explanation in terms of 'more collisions' 1
at higher T area above *E*a is greater / more molecules with $E \geqslant Ea$ 1
higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time 1

6. MAR 17/P22/Q2/c(ii)

(a) (i) heterogeneous (catalyst) 1
provides an alternative reaction pathway of lower activation energy 1

7. MAR 16/P22/Q3/c

(a) [3]



M1 = correct Boltzmann curve
M2, M3 any 2 from:
- line for **both** E_a values or statement in text that catalyst lowers E_a
- (catalyst) increases proportion/number of molecules/particles with energy ⩾ activation energy
- so more frequent successful collisions

8. O/N 14/P23/Q2/a,b

(a) $CH_4 + H_2O \rightarrow CO + 3H_2$ [1]

(b) Label on graph indicating catalysed and uncatalysed Ea
OR statement Ea catalysed is lower (than Ea uncatalysed) owtte
Reference to catalyst creating alternative mechanism / reaction pathway / route
Idea that more molecules have sufficient energy (to react)
so greater chance / frequency of successful collisions [4]

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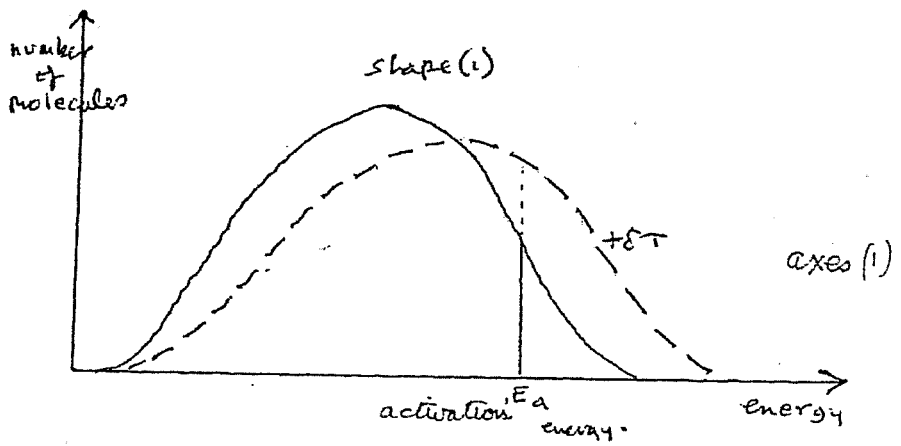
9. M/J 10/P21/Q2/a,b

(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]**

10. O/N 02/P2/Q1

(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~~ dotted 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 the energy greater than E_a. (1)
Rate is proportional to number of molecules with E_a (or more) (1)
Collision rate faster when molecules speed greater (1) [3]

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A Level

Unit 9

THE PERIODIC TABLE: CHEMISTRY PERIODICITY

Chemistry Paper-2
Topical Workbook
Article Number: 232

Editorial Board

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Unit 9: The Periodic Table: Chemistry Periodicity

1. O/N 20/P22/Q2

The Period 3 elements, Na to S, all react with oxygen to form oxides.

(a) State the trend in acid/base behaviour of the oxides of the Period 3 elements, from Na to S.

.....[1]

(b) State and explain the trend, from Na to S, in the maximum oxidation number of the Period 3 elements in their oxides.

.....

.....[2]

(c) Sodium oxide and phosphorus(V) oxide both react with water.
Name the product of each reaction.

reaction	product
sodium oxide with water	
phosphorus(V) oxide with water	

[2]

(d) Explain why phosphorus(V) oxide has a low melting point of approximately 300 °C but magnesium oxide has a high melting point of approximately 2850 °C.

.....

.....

.....[3]

(e) Aluminium oxide, Al_2O_3, reacts separately with both acids and alkalis.

(i) Write an equation for the reaction of aluminium oxide with excess aqueous hydrochloric acid.

.....[1]

(ii) Write an equation for the reaction of aluminium oxide with excess aqueous sodium hydroxide.

.....[1]

(f) Describe the lattice structure of silicon(IV) oxide.
Your answer should include reference to the arrangement of the silicon and oxygen atoms and the bonds between them.

.....

.....[2]

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(g) Sodium oxide and silicon(IV) oxide react to form sodium silicate(IV), Na_2SiO_3.
Sodium oxide is obtained from the thermal decomposition of sodium carbonate.
Write equations for the following reactions:

(i) sodium oxide with silicon(IV) oxide

.....[1]

(ii) the thermal decomposition of sodium carbonate, forming sodium oxide and carbon dioxide.

.....[1]

2. M/J 20/P21/Q1

Gallium is a metal in Group 13 of the Periodic Table.

(a) There are two stable isotopes of gallium, ^{69}Ga and ^{71}Ga.

(i) State, with reference to subatomic particles, how the isotopes ^{69}Ga and ^{71}Ga differ from each other.

.....[1]

(ii) State what further information is needed to calculate the relative atomic mass of gallium.

.....[1]

(b) Gallium and its compounds show similar properties to aluminium and its compounds.
Gallium reacts with excess chlorine to form gallium trichloride.

(i) At 500 °C, gallium trichloride is a gas.
Suggest the type of attraction that exists at 500 °C

- between atoms within a gallium trichloride molecule

.....

- between gallium trichloride molecules.

.....[2]

(ii) When gallium trichloride is cooled a solid, Ga_2Cl_6, forms.
Suggest the name of the attraction formed between two gallium trichloride molecules to form Ga_2Cl_6.

.....[1]

(c) Gallium metal reacts rapidly when exposed to air. A white solid layer is formed on its surface.

(i) Suggest an equation to describe the reaction occurring when gallium metal is exposed to air.

.....[2]

(ii) The table gives the formula of each gallium-containing product formed when gallium oxide reacts separately with hot aqueous hydrochloric acid and hot aqueous sodium hydroxide.

	formula of gallium-containing product
hot aqueous hydrochloric acid	$GaCl_3$
hot aqueous sodium hydroxide	$NaGa(OH)_4$

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Give the name of the type of behaviour shown by gallium oxide in these reactions.

.....[1]

3. M/J 19/P22/Q3

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]

(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]

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(ii) Name the type of reaction occurring.

.....[1]

(iii) Explain why chlorine is used in the purification of water.

.....[1]

(c) A mixture of HC*l* and HC*l*O is added to cold dilute NaOH. One of the products behaves as a bleach.

Suggest the equation for the reaction occurring.

.....[2]

4. O/N 18/P22/Q2

The table gives some data for elements in the third period and some of their compounds.

element	Na	Mg	A*l*	Si	P	S
type of bonding	metallic				covalent	covalent
formula of oxide					P_4O_{10}	SO_2
formula of chloride	NaC*l*	$MgCl_2$				SCl_2

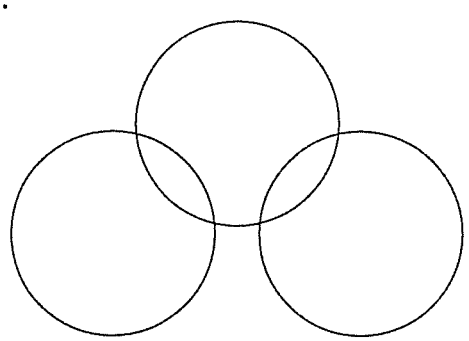
(a) Complete the table to show the bonding in the elements, and the formulae of their oxides and chlorides.

[3]

(b) SCl_2 is formed in the following reaction.

$$S_2Cl_2(l) + Cl_2(g) \rightleftharpoons 2SCl_2(l) \qquad \Delta H = -40.6\,kJ\,mol^{-1}$$

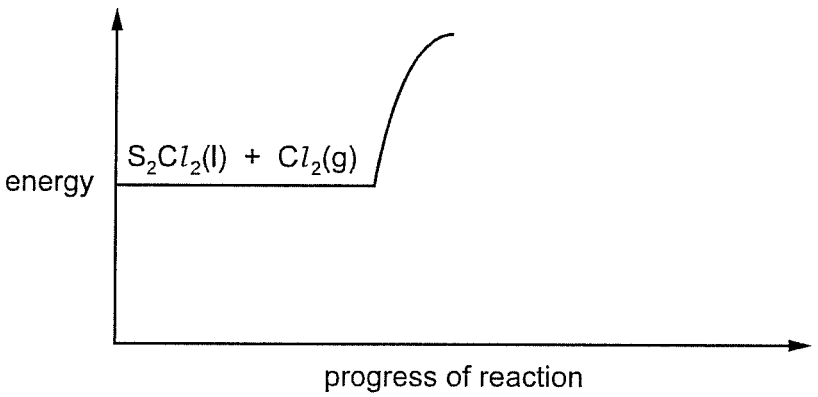
(i) Complete the 'dot-and-cross' diagram to show the bonding in a molecule of SCl_2. Show outer electrons only.



[1]

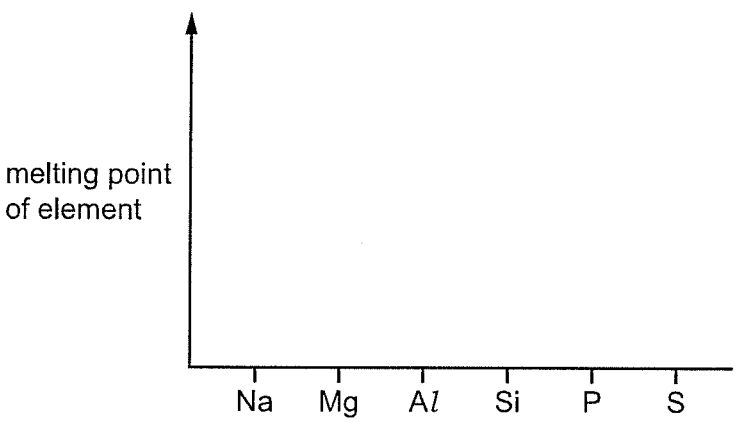
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(ii) Complete and fully label the reaction pathway diagram for the reaction between S_2Cl_2 and Cl_2. Include labels for activation energy, E_a, and enthalpy change of the forward reaction, ΔH.



[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]

(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]

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(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]

5. O/N 18/P21/Q1/c(ii), O/N 18/P23/Q1/c(ii)

(a) Iron pyrite is often called *fool's gold* because of its appearance. Impure samples of iron pyrite often contain a small amount of gold.

The gold can be obtained from impure iron pyrite. The impure iron pyrite is roasted in oxygen, to produce iron(III) oxide and sulfur dioxide. Gold does not react with oxygen.

(i) Complete the equation to show the roasting of iron pyrite in oxygen.

$4FeS_2$ + ... → $2Fe_2O_3$ + ... [2]

6. M/J 18/P22/Q1

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]

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(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.

.....

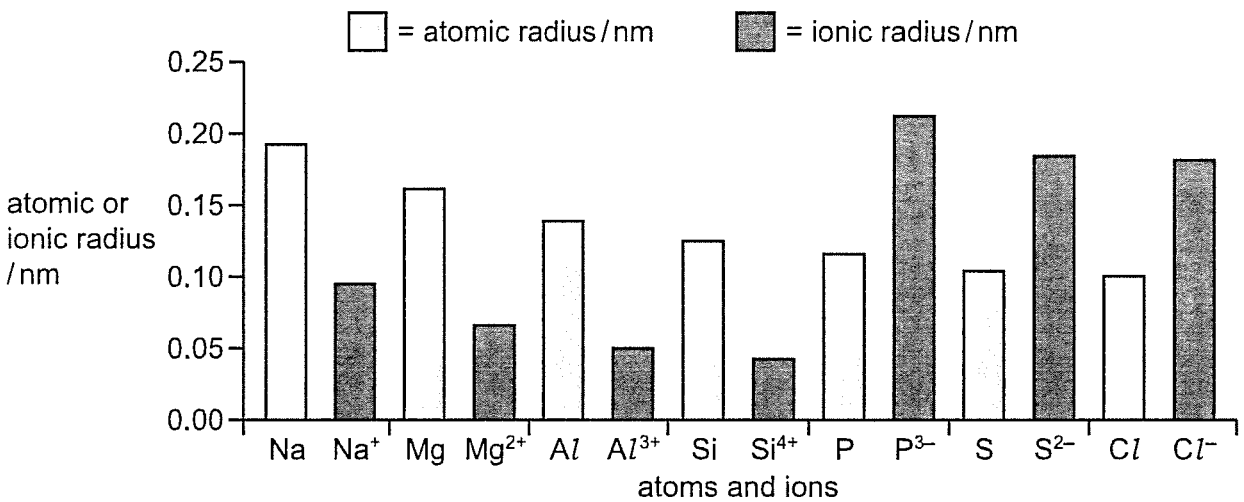
.....

..... [3]

7. M/J 18/P21/Q3/a,c

The elements in the third period exhibit periodicity in both their chemical and physical properties.

(a) A graph of the atomic and ionic radii across the third period is shown.



(i) Explain the decrease in atomic radius across the third period.

.....

..... [2]

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(ii) Explain why, for sodium to silicon, the ionic radii are less than the atomic radii.

..... [1]

(iii) Explain why, for phosphorus to chlorine, the ionic radii are greater than the atomic radii.

.....

..... [2]

(b) The elements in the third period, from sodium to silicon, can react with chlorine to form chlorides.

(i) State and explain the pattern of change of oxidation number which occurs to both chlorine and the different Period 3 elements when they react together.

.....

.....

..... [3]

(ii) Give the equations to show the reactions of sodium chloride and silicon(IV) chloride when separately added to water.

sodium chloride .....

silicon(IV) chloride .....[2]

(iii) Complete the table to describe the structure and bonding in sodium chloride and silicon(IV) chloride.

	structure	bonding
sodium chloride		
silicon(IV) chloride		

[2]

8. O/N 17/P22/Q1

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.

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$AlCl_3$	PCl_3
shape	shape .....
angle	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]**

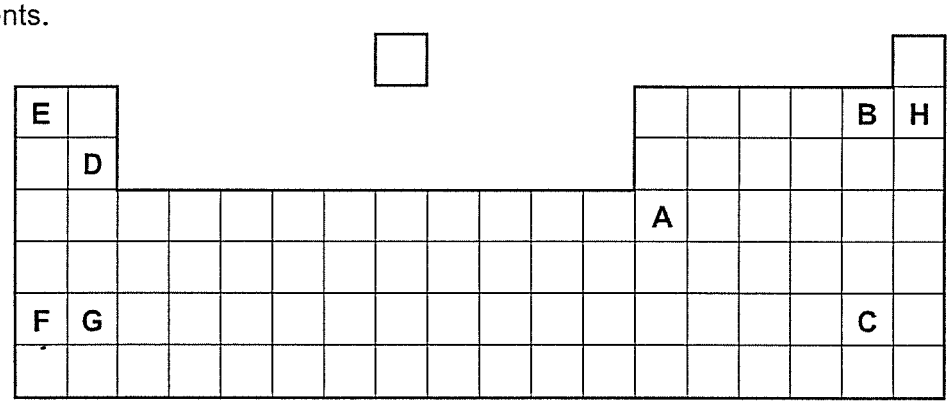
(iii) Draw the 'dot-and-cross' diagram of a molecule of $SiCl_4$.
Show outer electrons only.

[1]

9. 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.



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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]**

10. 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]**

(iii) The radius of the most common ion of Mg is much smaller than the radius of the most common ion of S.

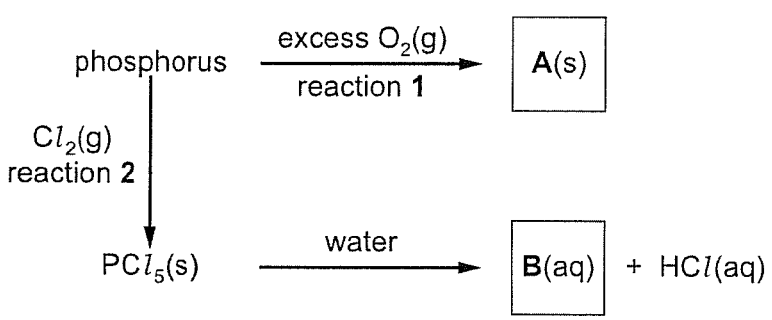
Identify both ions and explain the difference in their radii.

.....

..... **[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.



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(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]

11. 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

(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]

12. 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.

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(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]

13. 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).

.....

..... [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]

14. 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]

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(ii) Write equations for reactions of these three oxides with hydrochloric acid and/or sodium hydroxide as appropriate.

.....

.....

.....

..... [4]

15. 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]

(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 .....

.....

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$SiCl_4$ structure **and** bonding .....

.....

explanation .....

.....

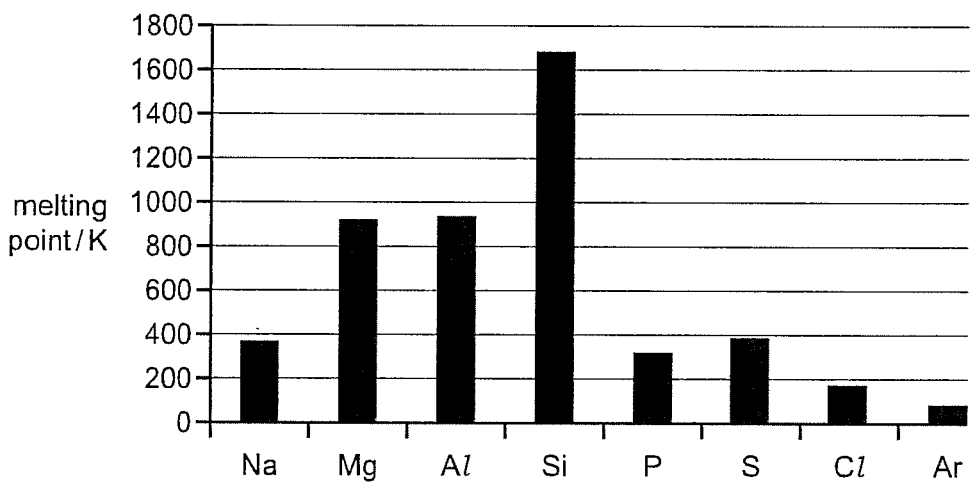
.....

..... [4]

16. 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]

(ii) Explain the variation of melting points from P to Ar.

.....

.....

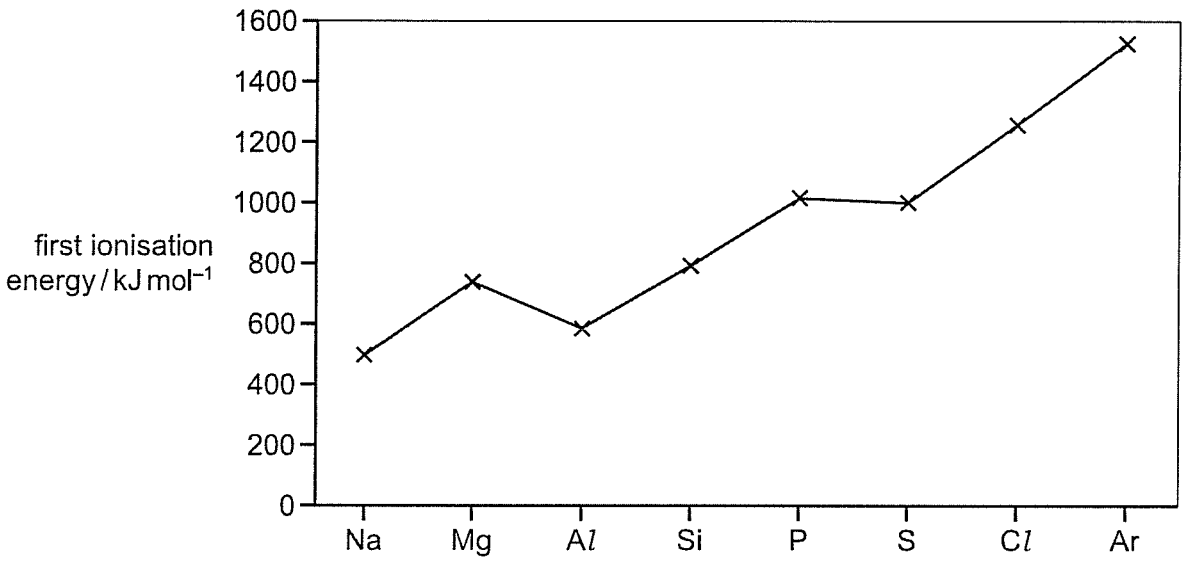
..... [3]

(iii) Explain why Si has a much higher melting point than any of the other elements in the period.

..... [1]

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(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]

(iii) Explain why the first ionisation energy of S is less than that of P.

..... [1]

17. 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]

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18. 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.

.....

(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]

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(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]**

19. 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.

.....

(ii) An element that forms a gaseous toxic oxide.

.....

(iii) The element which has a giant molecular structure **and** forms an oxide which also has a giant molecular structure.

.....

(iv) An element that forms a covalent chloride which dissolves in water to give a conducting solution.

.....

[4]

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20. 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.

.....

(iv) The element in Period 3 (Na to Ar) that has the smallest anion.

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

(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]**

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21. 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 Cl 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 Cl.

element	Na	Mg	Al	Si	P	S	Cl
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.

.....

.....

.....

.....

.....

(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]

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(c) Each of the elements Na to C*l* 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]

22. 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, A*l*, and Si behave when mixed with water. In the first column use only the terms 'dissolve' or 'react'.

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element	Does the chloride dissolve or react?	approximate pH of the resulting solution
Na		
Al		
Si		

(ii) What *type of reaction* takes place between a chloride and water?

..... **[7]**

23. 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.

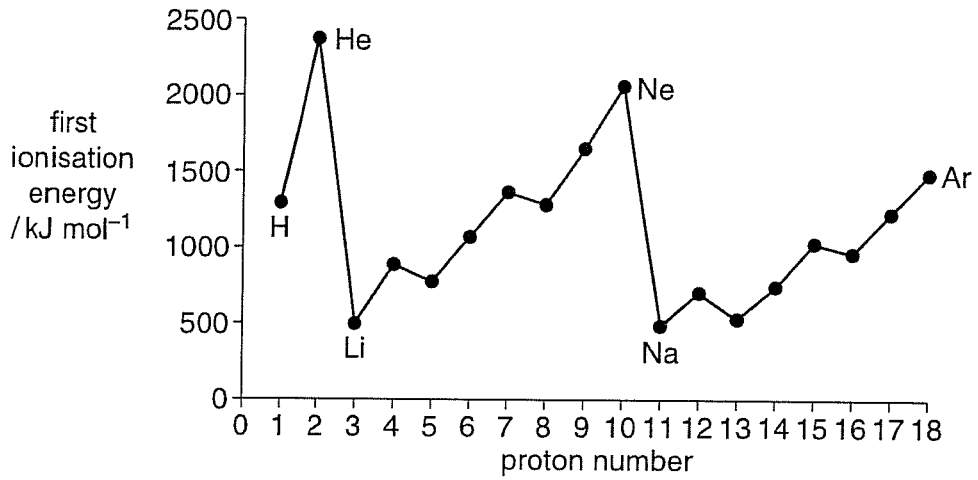
..... **[4]**

24. 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.

.....

.....

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(ii) The cations formed by the elements Na to Al are smaller than the corresponding atoms.

Give a brief explanation of this change.

.....

..... [3]

(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]

25. 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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26. M/J 11/P23/Q3

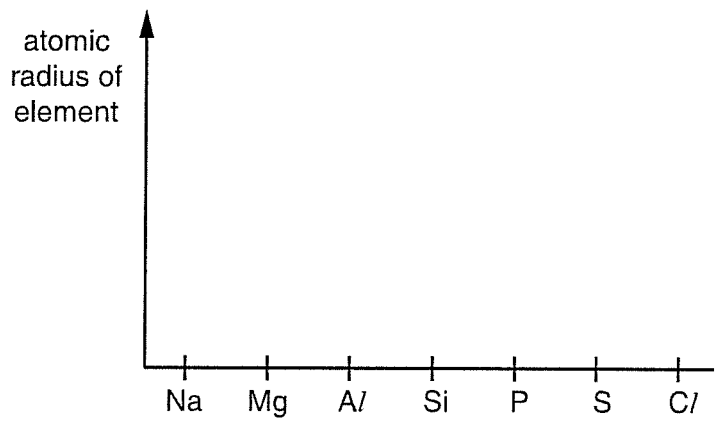
Elements in the same period of the Periodic Table show trends in physical and chemical properties. The grids on this page and on the opposite page refer to the elements of the third period, Na to Cl.

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)



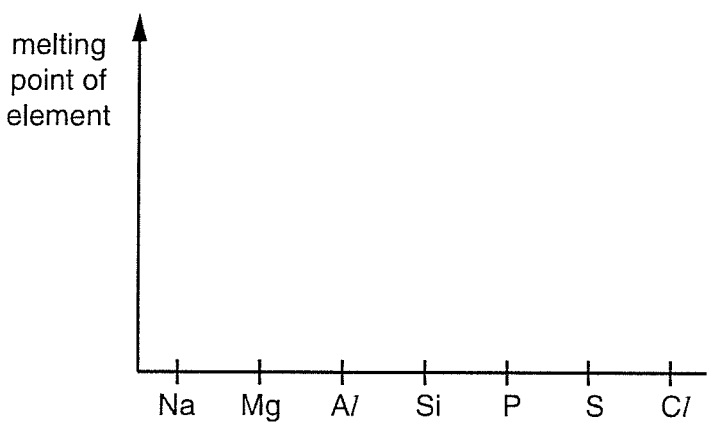
explanation .....

.....

.....

..... [3]

(b)



explanation .....

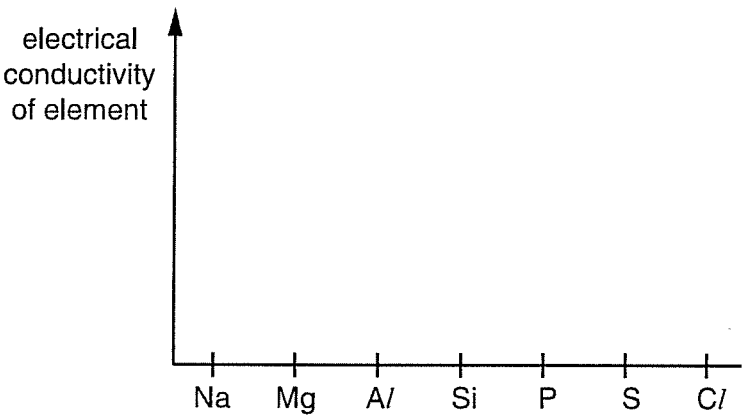
.....

.....

..... [4]

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(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]

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Answers Section

1. O/N 20/P22/Q2

(a) more acidic / less basic (from Na to S across period) **1**

(b) **M1:** increases (from Na to S / across period) **2**
M2: increasing (number of) **valence** electrons **OR** (number of) electrons in **outer** (electron) shell increases

(c)

reaction	**name** of product
sodium oxide with water	sodium hydroxide
phosphorus(V) oxide with water	phosphoric(V) acid

2

(d) **M1:** *identification of forces broken during melting of phosphorus(V) oxide* **3**
intermolecular forces in phosphorus(V) oxide (are broken)
M2: *identification of force broken during melting of magnesium oxide*
electrostatic forces of attraction between (many oppositely charged) **ions** in magnesium oxide
M3: *statement linking difference in strength of appropriate forces described in M1& M2 to explain difference in melting point*
(only) **intermolecular forces** weaker than forces (of attraction) between ions / ionic bonds

(e) (i) $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ **1**

(ii) $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$ **1**

(f) **M1:** giant **2**
M2: covalent **AND** tetrahedral / four Si—O bonds

(g) (i) $Na_2O + SiO_2 \rightarrow Na_2SiO_3$ **1**

(ii) $Na_2CO_3 \rightarrow Na_2O + CO_2$ **1**

2. M/J 20/P21/Q1

(a) (i) (different) number of neutrons. **1**

(ii) the relative abundance / % abundance of (each) the isotopes. **1**

(b) (i) **M1** *attractions between atoms within a gallium trichloride molecule* **2**
covalent (bonds)
M2 *attractions between gallium trichloride molecules*
temporary induced dipoles

(ii) coordinate / dative (covalent) **1**

(c) (i) $4Ga + 3O_2 \rightarrow 2Ga_2O_3$ **2**
M1 correct formula of Ga_2O_3
M2 correctly balanced equation based on $Ga + O_2$ and formula of gallium oxide in M1

(ii) amphoteric **1**

3. M/J 19/P22/Q3

(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**

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$SiCl_4$ – 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)

Chlorine containing species	Cl_2	HCl	HOCl
Oxidation number of chlorine	0	–1	(+)1

2

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. O/N 18/P22/Q2

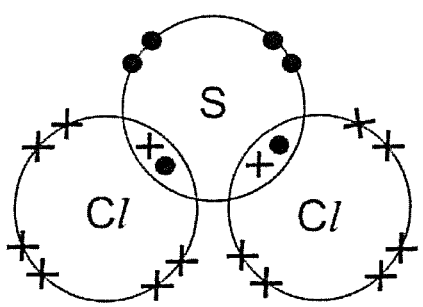
(a)

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

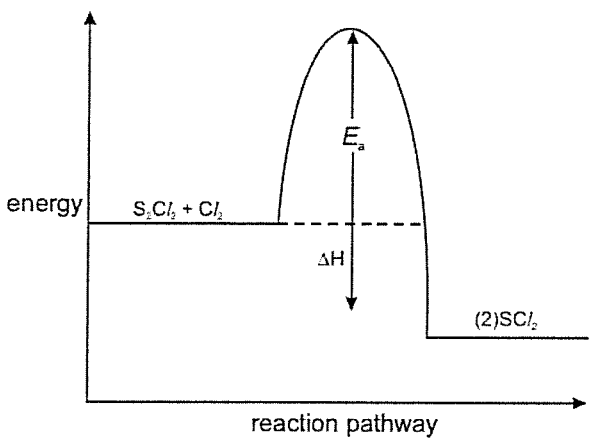
(b) (i)



1

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(ii)



M1 profile for exothermic reaction [1]
M2 identification of ΔH and E_a [1] **2**

(c) (i) graph rises to maximum for Si, then falls **1**

(ii) **Max. 3 from:** **3**

- increasing strength of metallic bond; Na < Mg < A*l*
  OR
  stronger attraction between delocalised electrons and (positive) ion so melting point of Na < Mg < A
- Si is giant covalent **AND** it has the highest melting point due to breaking / presence of strong
  OR
  Si requires the most energy because the covalent bonds in Si are stronger than metallic bonds (in Na/ Mg / A*l*)
- 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 A*l* **AND** S and P (in either order) [1]
M3 For A*l* **3p** (orbital / sub-level / sub-shell) is higher in energy / further from the nucleus / more shielded (than Mg) [1]
M4 For S the pair of electrons in the (3)**p-orbital** repel [1]

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5. O/N 18/P21/Q1/c(ii), O/N 18/P23/Q1/c(ii)

(a) (i) balanced equation with $11O_2$ and $8SO_2$ **2**

M1: O_2 and SO_2
M2: 11 and 8

6. M/J 18/P22/Q1

(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**

7. M/J 18/P21/Q3/a,c

(a) (i) increasing attraction between nucleus and (outer) electrons **1**

increasing nuclear charge with similar shielding / (electrons in) same (outer) shell **1**

(ii) (ions of Na to Si have) lost outer shell / outer electrons **1**

OR

atoms have one more shell than (corresponding) ions

OR

effective nuclear charge is greater for the ion

(iii) (P to Cl form ions by) gaining electrons (to the same outer shell / p sub-shell) **1**

Increased repulsion between electrons in same / outer shell / p sub-shell **1**

(b) (i) oxidation numbers / states of elements (Na-Si) increase from +1 to +4 / by 1 every time **1**

increasing number of valence electrons / NaCl, $MgCl_2$, $AlCl_3$, $SiCl_4$ / number of chlorines matches group number **1**

chlorine oxidation number / state –1 in all / stays the same **1**

(ii) $NaCl \rightarrow Na^+ + Cl^-$ **1**

$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$ **1**

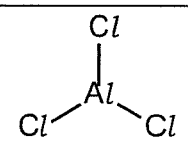
(iii) **2**

	structure	bonding
sodium chloride	giant / ionic	ionic
silicon(IV) chloride	simple / molecular	covalent

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8. O/N 17/P22/Q1

(a)

 trigonal planar 120°	 (trigonal) pyramid(al) 100–107°

4

3 marking points for each box: diagram, name and shape.
for each box:
all three correct = 2 marks
two correct = 1 mark

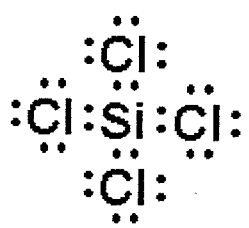
(b) (i) $SiCl_4$ simple / molecular **AND** Van der Waals' / id-id forces / London / dispersion forces / IMFs NaCl ionic **OR** giant **1**

bonding (in NaCl) stronger (than forces in $SiCl_4$) owtte **1**

(ii) $SiCl_4$ has more electrons ORA **1**

stronger Van der Waals' / id-id forces / London / dispersion forces / IMFs **1**

(iii) **1**



9. M/J 17/P21/Q3/a

(a) (i) **A** **1**

(ii) **H** **1**

(iii) **G** **1**

(iv) **B** **1**

(v) **F** **1**

10. MAR 17/P22/Q1/a,b

(a) (i)

max O.N.	+1	(+)2	(+)3	(+)5	(+)6	+7

1

(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**

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11. 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]

(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]

12. M/J 16/P21/Q2

(a) **D** = Ga **G** = Se **[1]**

(b) (i) $\mathbf{D}_2O_3 + 6HCl \rightarrow 2\mathbf{D}Cl_3 + 3H_2O$ **[2]**

M1 = species;
M2 = balancing

(ii) $\mathbf{D}_2O_3 + 2NaOH + 7H_2O \rightarrow 2Na\mathbf{D}(OH)_4(H_2O)_2$ OR
$\mathbf{D}_2O_3 + 2NaOH + 3H_2O \rightarrow 2Na\mathbf{D}(OH)_4$ OR
$\mathbf{D}_2O_3 + 2NaOH \rightarrow 2Na\mathbf{D}O_2 + H_2O$ OR
$\mathbf{D}_2O_3 + 2OH^- + 7H_2O \rightarrow 2[\mathbf{D}(OH)_4(H_2O)_2]^-$ OR
$\mathbf{D}_2O_3 + 2OH^- + 3H_2O \rightarrow 2[\mathbf{D}(OH)_4]^-$ OR
$\mathbf{D}_2O_3 + 2OH^- \rightarrow 2\mathbf{D}O_2^- + H2O$ **[2]**

M1 = species;
M2 = balancing

(c) giant ionic / ionic lattice [1]

(d) $\mathbf{G}O_2 + H_2O \rightarrow H_2\mathbf{G}O_3$ [1]

13. MAR 16/P22/Q1/a

(a) (i) greater attractive force
OR
greater force between nucleus and (outer) electrons
proton number / atomic number /
nuclear charge increases across period AND electrons occupy same shell / shielding roughly constant [2]

(ii) sulfur's electron removed from full (3p) orbital
OR
sulfur has two electrons in the same orbital
electron–electron repulsion (reduces energy required) [2]

(iii) sodium has mobile / free electrons / electrons free (to move throughout the structure)
phosphorus is simple / covalent / molecular [2]

(iv) magnesium has two free / delocalised / outer / valence electrons per atom
OR
more free / delocalised / outer electrons than sodium [1]

14. M/J 15/P22/Q1/d

(a) (i) Na_2O basic / alkaline; Al_2O_3 amphoteric / acidic and basic; SO_3 acidic
Na_2O (giant) ionic **AND** SO (simple / molecular) covalent **[2]**

(ii) $Na_2O + 2HCl \rightarrow 2NaCl + H_2O$

$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$

$Al_2O_3 + 2NaOH + 7H_2O \rightarrow 2NaAl(OH)_4(H_2O)_2$ **OR**
$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$ **OR**
$Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$ **OR**

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$Al_2O_3 + 2OH^- + 7H_2O \rightarrow 2[Al(OH)_4(H_2O)_2]^-$ **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**
$SO_3 + 2NaOH \rightarrow Na_2SO_4 + H_2O$ [4]

15. M/J 15/P21/Q1/c,d

(a) (i)

	Te	**Cl**
	47.4 / 128	52.6 / 35.5
	0.370 / 0.370	1.48 / 0.370
	1	4

so EF = $TeCl_4$

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

(ii) Covalent **AND** simple / molecular
low melting point / reaction with water [2]

(iii) $TeCl_4 + 3H_2O \rightarrow H_2TeO_3 + 4HCl$
OR $TeCl_4 + 2H_2O \rightarrow TeO_2 + 4HCl$ [1]

(b) (i) Yellow / orange flame [1]
White fumes / solid [1]
Yellow / green gas disappears [1]

(ii) $NaCl$ giant / lattice **AND** ionic
$SiCl_4$ simple / molecular **AND** covalent
For $NaCl$ large difference in electronegativity
(of sodium / Na and chlorine / Cl / Cl_2) (indicates electron transfer/ions)
For $SiCl_4$ smaller difference (indicates sharing/covalency) with (weak)
van der Waals' / IM forces (between molecules) ora [4]

16. M/J 14/P22/Q3

(a) (i) metallic bonding
strength of attraction / metallic bonding increases (Na–Al) / more energy is needed to break 'bonds'
due to increasing cation charge / charge density / increasing number of delocalised electrons / decreasing ionic radius 3

(ii) van der Waals' (forces)
are greatest / more in sulfur / relative magnitude of forces S > P > Cl > Ar
because sulfur has the greatest number of electrons / as no. of electrons (in the molecules) decreases 3

(iii) Covalent bond(s) broken **OR**
(Si has a) giant covalent (structure) 1

(b) (i) Nuclear charge (in Ar) greater (than Cl) **AND** same shielding owtte 1

(ii) p subshell / orbital in Al at higher energy (than s subshell in Mg) **ora** 1
OR
p subshell / orbital more shielded **ora**

(iii) repulsion due to electron pair (in same / p orbital) 1

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

(a) (i) $NaCl$ (+ aq) → $Na^+ + Cl^-$
$NaCl + H_2O \rightarrow Na^+ + Cl^- + H_2O$
$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$
$SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$
$SiCl_4 + 4H_2O \rightarrow SiO_2.2H_2O + 4HCl$
Allow correct equation with other molar amounts of water 2

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(ii) NaCl is ionic **AND** giant/lattice
NaCl dissolves/does not react
$SiCl_4$ is covalent **AND** molecular/simple
$SiCl_4$ is hydrolysed/reacts 4

18. M/J 13/P23/Q3

(a) (i) He **or** Ne **or** Ar **or** Kr

(ii) P **or** As

(iii) Br

(iv) Na allow Ar

(v) Si

(vi) P allow Si

(vii) Cl **or** F **or** Br [7]

(b) (i) any **two** from P_4O_6, SO_2 and Cl_2O_7

(ii) Al_2O_3 **or** SiO_2

(iii) $MgSO_3$ [4]

(c) (i) Si is giant molecular/giant covalent **or**
P, S, and Cl are simple molecular

(ii) the molecules are S_8, P_4, Cl_2
larger molecules have more electrons
and hence greater van der Waals' forces [4]

19. 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

(ii) C **or** N **or** S **or** F **or** Cl **or** Br

(iii) Si **or** Ge **or** B

(iv) Al **or** Si **or** P **or** S **or** H [4]

20. M/J 13/P21/Q3/a,i,iii,iv,v,b

(a) penalise (–1) for names of elements

(i) Na **or** K **or** Li

(ii) K

(iii) C

(iv) Cl [4]

(b) (i) Al_2O_3 **or** SiO_2

(ii) Na_2O

(iii) P_2O_3 **or** P_4O_6 **and** P_2O_5 **or** P_4O_{10} **or** SO_2 **and** SO_3

(iv) Al_2O_3 [5]

21. M/J 12/P23/Q1

(a) (i) **from Na to Cl**
nuclear charge increases
electrons are in the same shell/have the same shielding
nuclear attraction increases

(ii) argon does not form any bonds/compounds **or**
argon exists as single atoms/is monatomic [4]

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(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

(ii) cations contain fewer electrons than the corresponding atoms **or**
cations contain fewer electrons than they do protons
nucleus has a greater attraction

(iii) anions contain more electrons than the corresponding atoms **or**
anions contain more electrons than they do protons
nucleus has a smaller attraction **[5]**

(c) (i) $Na_2O + H_2O \rightarrow 2NaOH$
$SO_2 + H_2O \rightarrow H_2SO_3$

(ii) for Na_2O 10 to 14
for SO_2 1 to 4

(iii) $NaOH + H_2SO_3 \rightarrow NaHSO_3 + H_2O$ **or**
$2NaOH + H_2SO_3 \rightarrow Na_2SO_3 + 2H_2O$ **[5]**

22. M/J 12/P22/Q1/a,b

(a) (i) silicon/Si **or** phosphorus/P

(ii) sodium **or** sulfur **name required**

(iii) white solid formed/white fumes seen
chlorine gas decolourised
aluminium glows **or** burns

(iv) $2Al(s) + 3Cl_2(g) \rightarrow Al_2Cl_6(s)$ **or**
$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$
equation
state symbols

(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 **[7]**

(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

(ii) hydrolysis **[7]**

23. 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

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MgO is basic – allow alkaline

Al_2O_3 is amphoteric

SiO_2, P_4O_{10}, and SO_2 are **all** acidic [4]

(b) any **two** from:
sodium, phosphorus, sulfur and chlorine
two names required [1]

(c) **(i)** any **three** from:
floats
vigorous/violent reaction occurs
melts/forms a sphere
moves
disappears – allow dissolves
effervescence/gas produced

(ii) $Na + H_2O \rightarrow NaOH + \frac{1}{2}H_2$
or
$2Na + 2H_2O \rightarrow 2NaOH + H_2$ [4]

24. O/N 11/P23/Q3

(a) $C(g) \rightarrow C^+(g) + e^-$
correct equation
correct state symbols [2]

(b) **(i)** **Na and Mg**
Mg has greater nuclear charge/more protons than Na

in both atoms, the 3s electrons are in the same orbital/
same energy level/same shell

(ii) **Mg and Al**
in Al outermost electron is in 3p rather than 3s

3p electron is at higher energy **or**
is further away/is more shielded from nucleus

(iii) **He and Ne**
both He and Ne have the highest nuclear charges in their Period

(iv) **He, Ne, and Ar**
going down the group,

valence/outer shell electrons are farther from the nucleus

there is greater shielding

attraction between valence electrons and nucleus is less **or**
effective nuclear charge is less [8]

(c) **(i)** **from Na to Cl**
increased nuclear charge/nuclear attraction

(ii) cation has fewer electrons than atom **or**
cation has lost outer electrons **or**
cation has fewer shells

but cation has same nuclear charge as atom **or**
proton number is the same [3]

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(d) ignore any state symbols

MgO(s)	+	NaOH(aq)			→	NO REACTION
MgO(s)	+	**2**HC*l*(aq)			→	$MgCl_2 + H_2O$
Al_2O_3(s)	+	**2**NaOH(aq)	+	**3**H_2O(l)	→	**2**$NaAl(OH)_4$ **or**
Al_2O_3(s)	+	**2**NaOH(aq)	+	H_2O(l)	→	**2**$NaAlO_2 + 2H_2O$ **or**
Al_2O_3(s)	+	**6**NaOH(aq)	+	**3**H_2O(l)	→	**2**$Na_3Al(OH)_6$
Al_2O_3(s)	+	**6**HC*l*(aq)			→	**2**$AlCl_3$ + **3**H_2O **or**
Al_2O_3(s)	+	**6**HC*l*(aq)			→	Al_2Cl_6 + **3**H_2O
SO_2(g)	+	NaOH(aq)			→	$NaHSO_3$ **or**
SO_2(g)	+	**2**NaOH(aq)			→	$Na_2SO_3 + H_2O$
SO_2(g)	+	HC*l*(aq)			→	NO REACTION

[6]

25. O/N 11/P22/Q2/d,e, O/N 11/P21/Q2,d,e

(a) (i) and (ii)

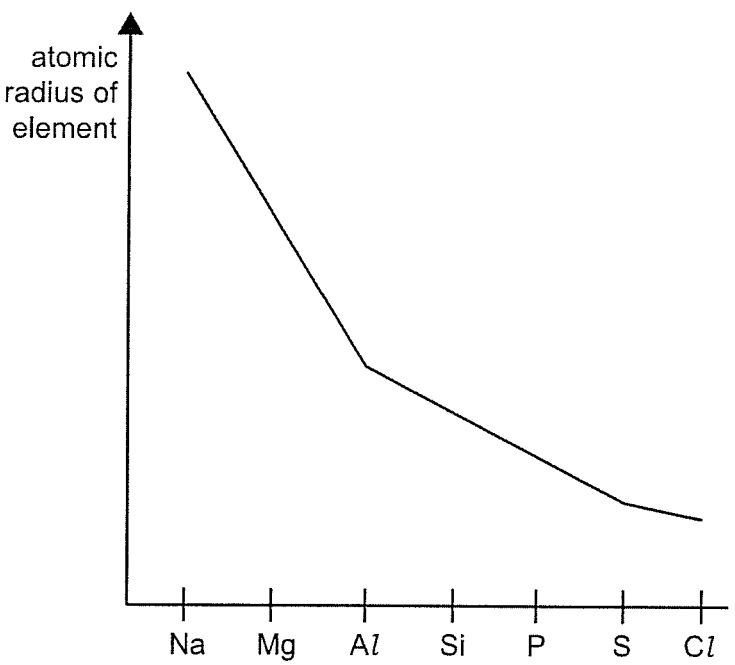
element	Na	Mg	A*l*	Si	P	S
conductivity	high	high	—	moderate	low	low
melting point	low	high	—	high	low	low

one mark for each correct column **[5]**

(b) germanium/Ge **[1]**

26. M/J 11/P23/Q3

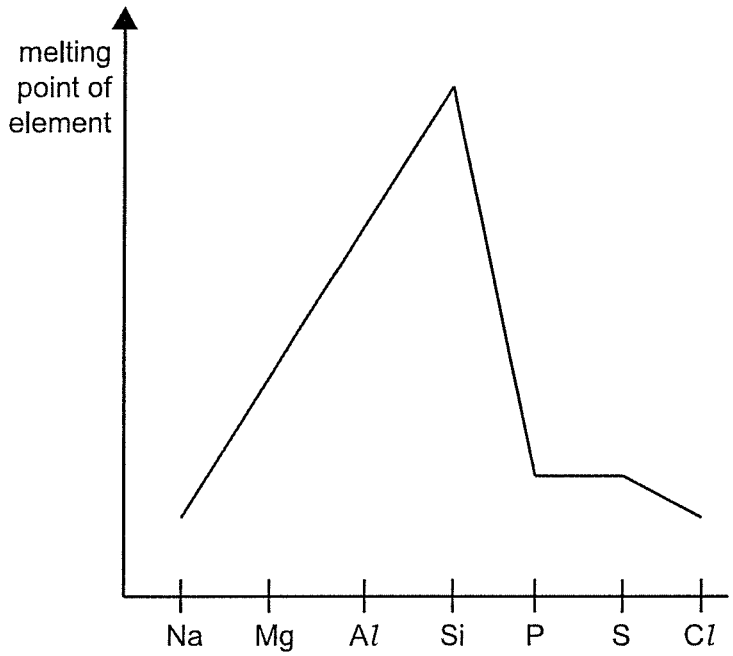
(a)



general shape of curve for Na → Ar
nuclear charge increases
electrons are added to same shell **[3]**

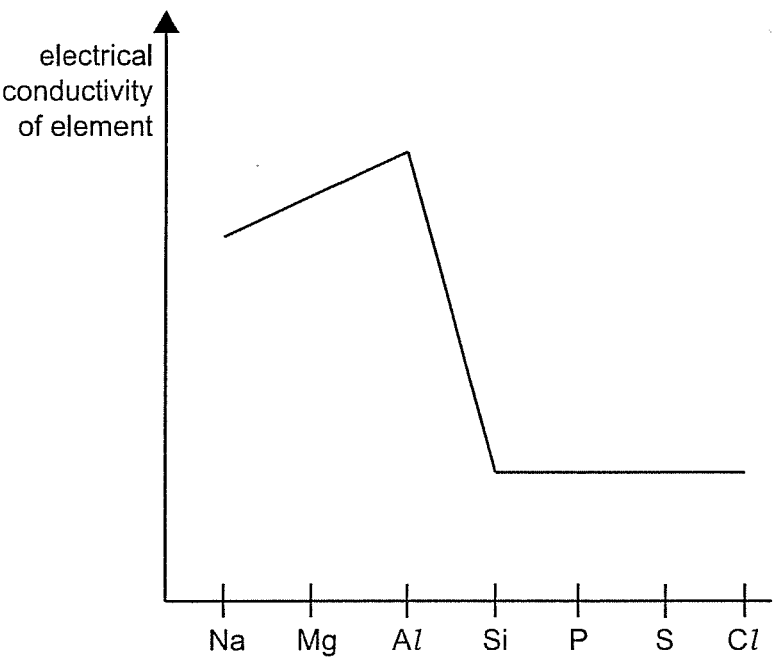
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(b)



general shape of curve
Na, Mg and Al have metallic bonding
Si is giant molecular
P, S, and Cl are simple molecular [4]

(c)



general shape of curve
Na, Mg and Al have increasing no. of outer shell electrons
Si is a semi-conductor
P, S and Cl are covalent/simple molecular [4]

(d) **(i)**

Na_2O	ionic
SiO_2	covalent
P_4O_6	van der Waals' forces/induced dipoles

(ii) Al_2O_3 **or** SiO_2 [4]

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Unit 10

GROUP II

Chemistry Paper-2
Topical Workbook
Article Number: 232

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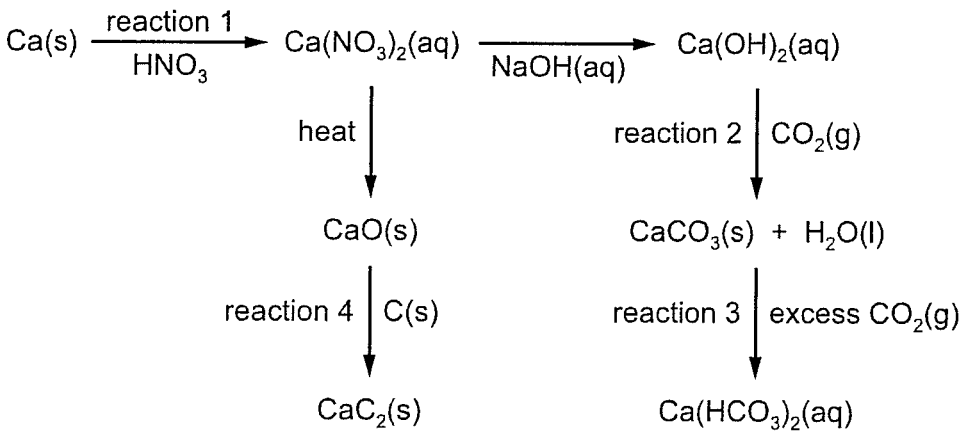
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Unit 10: Group II

1. O/N 21/P21/Q2, O/N 21/P23/Q2

The reaction scheme shows some reactions of calcium.



(a) (i) Reaction 1 produces $Ca(NO_3)_2$ and one other product.

Identify the other product.

.....[1]

(ii) Construct an equation for the thermal decomposition of $Ca(NO_3)_2(s)$.

.....[1]

(iii) State the trend in the thermal stability of the Group 2 nitrates down the group.

.....[1]

(iv) In reaction 3, excess CO_2 is bubbled through water containing $CaCO_3$. A solution of $Ca(HCO_3)_2(aq)$ forms.

Construct an equation for reaction 3.

.....[1]

(b) Describe how $Ca(OH)_2$ is used in agriculture.

.....[1]

(c) In reaction 4, calcium carbide, CaC_2, is formed from CaO.

CaC_2 contains the C_2^{2-} anion. Each carbon in C_2^{2-} is sp hybridised.

(i) Describe how sp hybridised orbitals are formed.

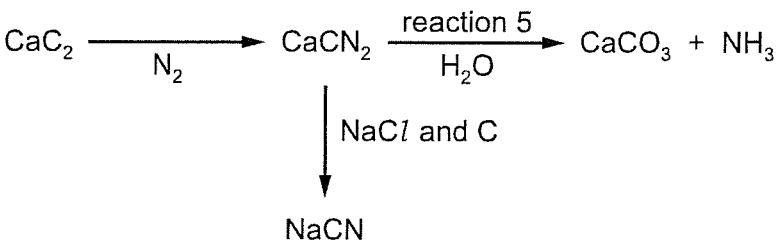
.....[1]

(ii) Sketch a diagram to show how two sp hybrid orbitals can form a sigma (σ) bond.

[2]

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(d) The flowchart shows some reactions of CaC_2.



(i) Reaction 5 can be used to prepare NH_3.

$$CaCN_2 + 3H_2O \rightarrow CaCO_3 + 2NH_3$$

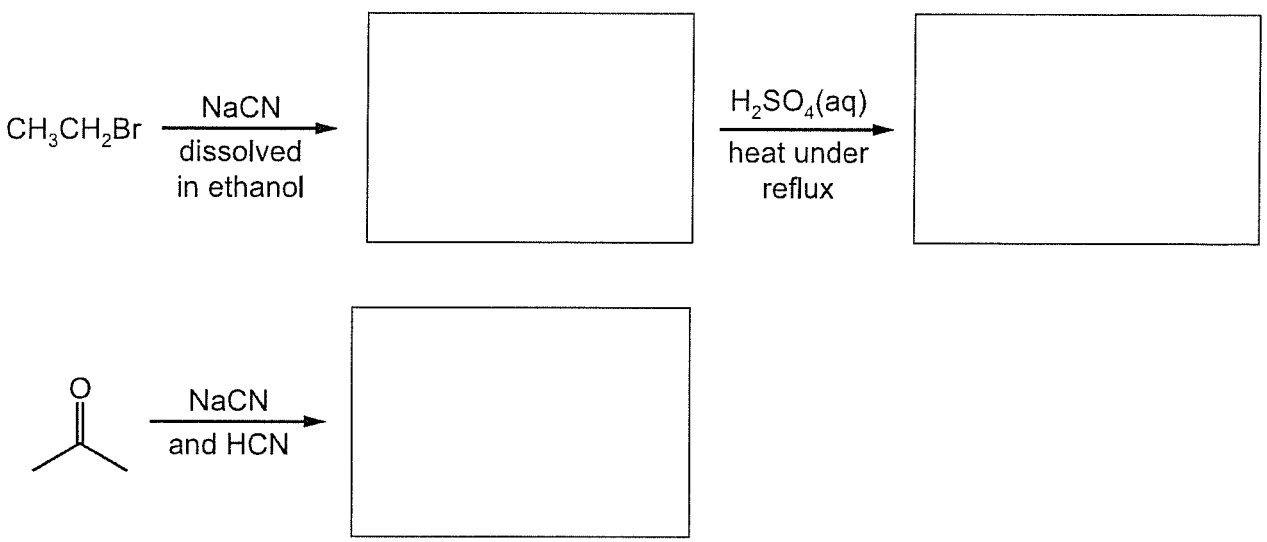
Calculate the minimum mass, in tonnes, of calcium cyanamide, $CaCN_2$, that is required to produce 1.50×10^6 tonnes of NH_3.

Show your working.

1 tonne = 1.00×10^6 g

minimum mass of $CaCN_2$ = ... tonnes [2]

(ii) Draw the structure of the organic products formed in the following reactions.



[3]

2. M/J 21/P22/Q1

A Group 2 metal combines with bromine to form a crystalline solid, MBr_2.

Excess aqueous $AgNO_3$ is added to a solution of MBr_2 and a precipitate forms. The mixture is filtered. The precipitate is dried and the mass of the precipitate is recorded.

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(a) State the formula and colour of the precipitate.

.....[2]

(b) Complete the equation to represent the reaction between **M**Br_2 and $AgNO_3$.

.....**M**Br_2 + ...$AgNO_3$ → ..... [1]

(c) A 0.250 g sample of pure **M**Br_2 contains 8.415×10^{-4} mol **M**Br_2.
Calculate the relative formula mass, M_r, of **M**Br_2. Use this to identify **M**.
Show your working.

M_r = ...

M = ...
[3]

(d) A sample of **M**Br_2 is dissolved in water. Chlorine gas is then bubbled into the solution.

(i) Describe the observations for this reaction.

..... [1]

(ii) Name the type of reaction that occurs when **M**Br_2 reacts with chlorine gas.

..... [1]

(e) Compound **Y** is a pure **insoluble** solid which contains halide ions.
A single reagent is added directly to compound **Y** to determine the halide ion present.
Identify the reagent added. State the observation which would confirm that **Y** contains bromide ions.

reagent .....

observation .....[2]

(f) Separate 1.0 g samples of three different magnesium salts are tested in order to identify the anion present in each sample.

(i) Explain how the action of heat is used to identify which sample is:

- $MgCO_3$
- $Mg(NO_3)_2$
- MgO.

.....

.....

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..... [3]

(ii) Complete the electron configuration of the magnesium cation present in these salts.

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

(g) A sample of $MgCO_3(s)$ is distinguished from a sample of $Mg(OH)_2(s)$ by adding a small amount of each solid to $HCl(aq)$.

State **one** similarity and **one** difference in these two reactions.

similarity .....

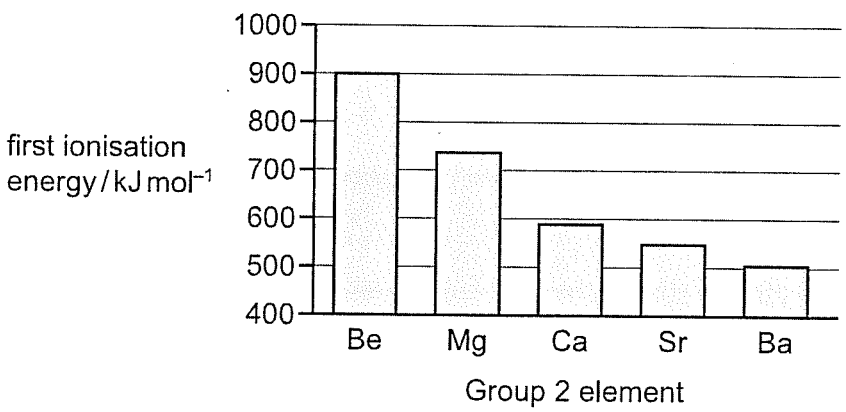
.....

difference .....

.....[2]

3. O/N 20/P21/Q1, O/N 20/P23/Q1

The graph shows the first ionisation energies of some of the elements in Group 2.



(a) Write an equation for the first ionisation energy of Mg.
Include state symbols.

..... [1]

(b) Explain the observed trend in first ionisation energies down Group 2.

.....

.....

..... [3]

(c) The second ionisation energy of Be is 1757 kJ mol^{-1}.

Explain why the second ionisation energy of Be is higher than the first ionisation energy of Be.

.....

..... [2]

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4. M/J 20/P23/Q1

(a) A sample of barium is heated in oxygen.

(i) Describe **two** observations for this reaction.

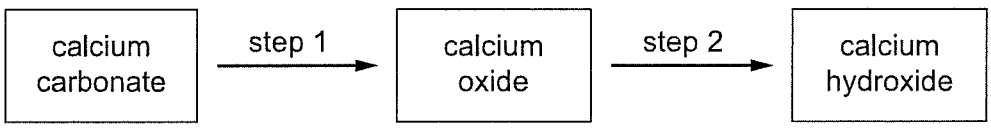
.....

..... [2]

(ii) Write an equation for this reaction. Include state symbols.

..... [1]

(b) Calcium carbonate can be converted into calcium hydroxide in a two-step process.



(i) Describe how the two-step process is carried out to convert calcium carbonate into calcium hydroxide. Include relevant equations.

.....

.....

..... [3]

(ii) Name the type of reaction occurring when calcium carbonate is converted into calcium oxide.

..... [1]

(iii) State **one** common use for both calcium carbonate and calcium hydroxide.

..... [1]

(c) Gallium is a silver-grey solid. Aluminium and gallium share many similar chemical properties.

(i) Construct an equation for the reaction of gallium when heated in oxygen to form gallium oxide, Ga_2O_3.

..... [1]

(ii) Deduce the oxidation number of gallium in Ga_2O_3.

..... [1]

(iii) Complete the table by predicting the formula of each gallium-containing product formed when gallium oxide reacts separately with hot aqueous hydrochloric acid and with hot concentrated sodium hydroxide.

reagents and conditions	formula of gallium-containing product
gallium oxide + hot HC*l*(aq)	
gallium oxide + hot concentrated NaOH(aq)	

[2]

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5. O/N 19/P22/Q2/a,b

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.

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.

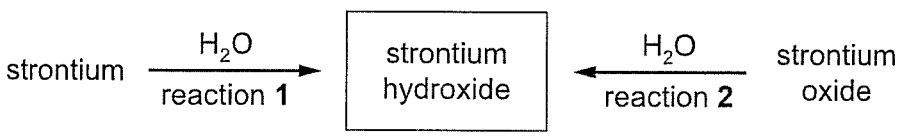
State the meaning of the term *amphoteric*.

..... **[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.



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]

6. M/J 19/P21/Q1

(a) Group 2 elements share common chemical properties.

(i) Calcium reacts in cold water more quickly than magnesium because more energy is required to remove the outer electrons in magnesium. This occurs even though calcium atoms have a greater nuclear charge.

Explain why more energy is required to remove the outer electrons in magnesium than in calcium.

.....

..... [2]

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(ii) 0.001 mol of strontium reacts with an excess of cold water. When the reaction is complete a colourless solution is seen.
Construct the equation for the reaction of strontium with cold water. Include state symbols.

.....[2]

(iii) 0.005 mol of calcium and 0.005 mol of strontium are added separately to two beakers. Each beaker contains 100 cm^3 of cold water.
At the end of each reaction a white solid and a colourless solution are seen in both beakers.
Predict which element, calcium or strontium, produces the more alkaline solution. Explain your answer.

.....

.....[2]

(iv) Describe one observation when magnesium carbonate is added to excess dilute sulfuric acid.

.....[1]

(b) Element **X** is a metal. **X** reacts with oxygen to form a black solid oxide. The oxidation state of **X** in this oxide is +2. The carbonate of **X**, XCO_3, is a green solid. It decomposes on heating to form the oxide and a colourless gas.

(i) From the information given, state two similarities and one difference that metal **X** and its compounds have with Group 2 metals and their compounds.

similarity 1 .....

similarity 2 .....

difference 1 .....[3]

(ii) Write the formula of the oxide of **X**.

.....[1]

(iii) Write an equation for the reaction of XCO_3 when it is heated.

.....[1]

7. M/J 19/P23/Q3

(a) Magnesium reacts with oxygen to form magnesium oxide.
State **two** observations that would be made when magnesium is heated strongly and placed in a gas jar of pure oxygen.

.....[1]

(b) Acid indigestion is caused by an excess of hydrochloric acid in the stomach.
Magnesium oxide is commonly found in indigestion tablets.

(i) Give the equation to show how magnesium oxide relieves acid indigestion.

.....[1]

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(ii) Name the type of reaction that occurs in **(b)(i)**.

.....[1]

(c) Magnesium oxide is described as a ceramic material. It has a high melting point.
State and explain why ceramic materials such as magnesium oxide have high melting points.

.....

.....[2]

(d) Magnesium oxide can be made from magnesium carbonate in a one-step reaction using heat.

(i) Write an equation for this reaction. Include state symbols.

.....[1]

(ii) Name the type of reaction occurring during this process.

.....[1]

8. O/N 17/P22/Q3

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.

.....

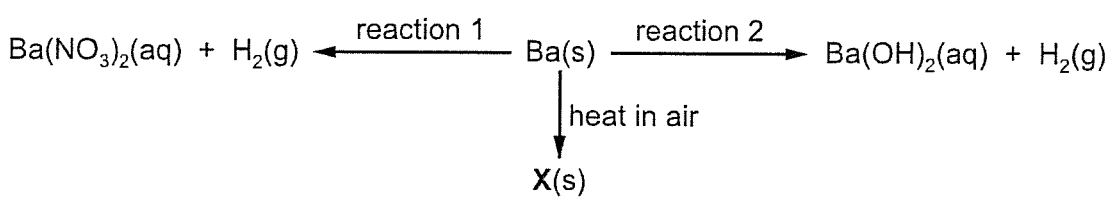
.....[2]

(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]

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(ii) Name **X** and write an equation for its formation.

name .....

equation .....[2]

(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]

9. 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]

10. MAR 17/P22/Q1/c(i,ii)

(a) Cerium is a lanthanoid metal that shows similar chemical reactions to some elements in the 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.

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Suggest **two** physical properties of cerium(IV) oxide.

1. .....

2. ..... [2]

11. 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]

(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]

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(ii) Give the equation for the thermal decomposition of magnesium carbonate.

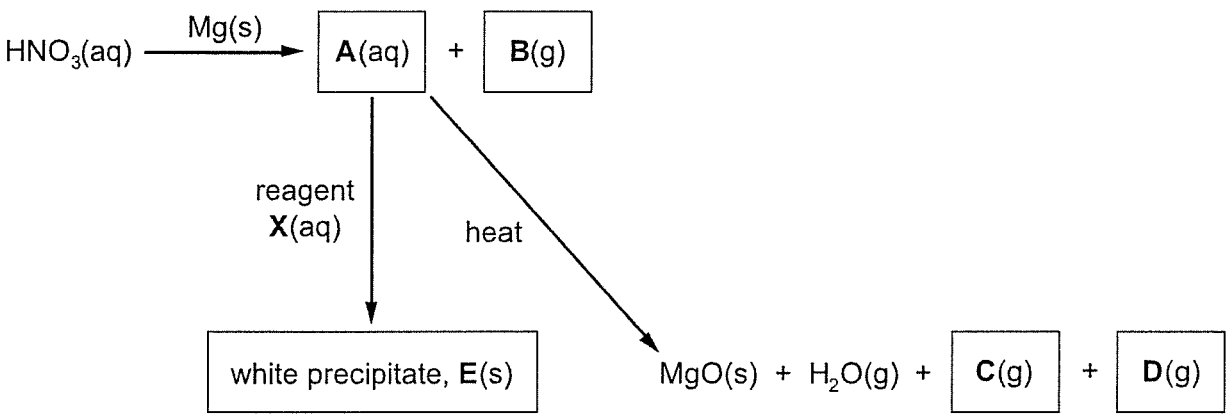
..... [1]

(iii) Give the equation for the thermal decomposition of calcium nitrate.

..... [1]

12. MAR 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]

13. 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]

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(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]

(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]

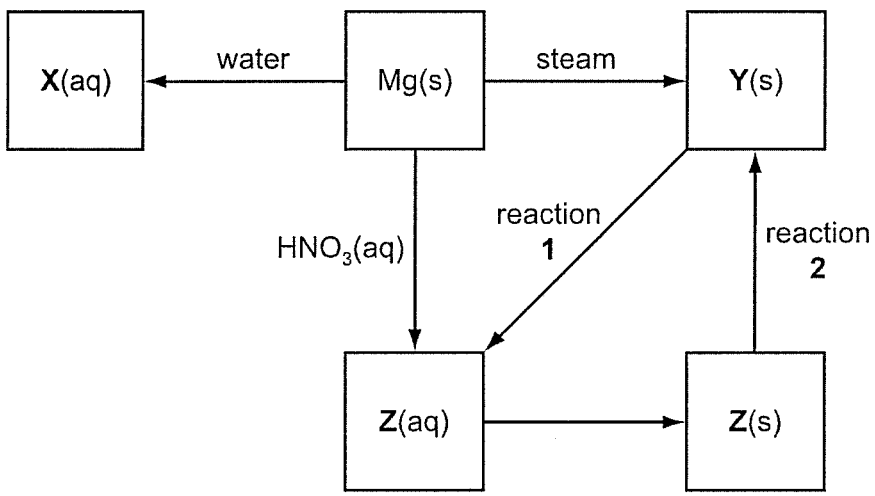
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(iii) Use your equation to calculate the mass of powdered calcium carbonate that would need to be added to the pond to neutralise the acidity.

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

14. 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]

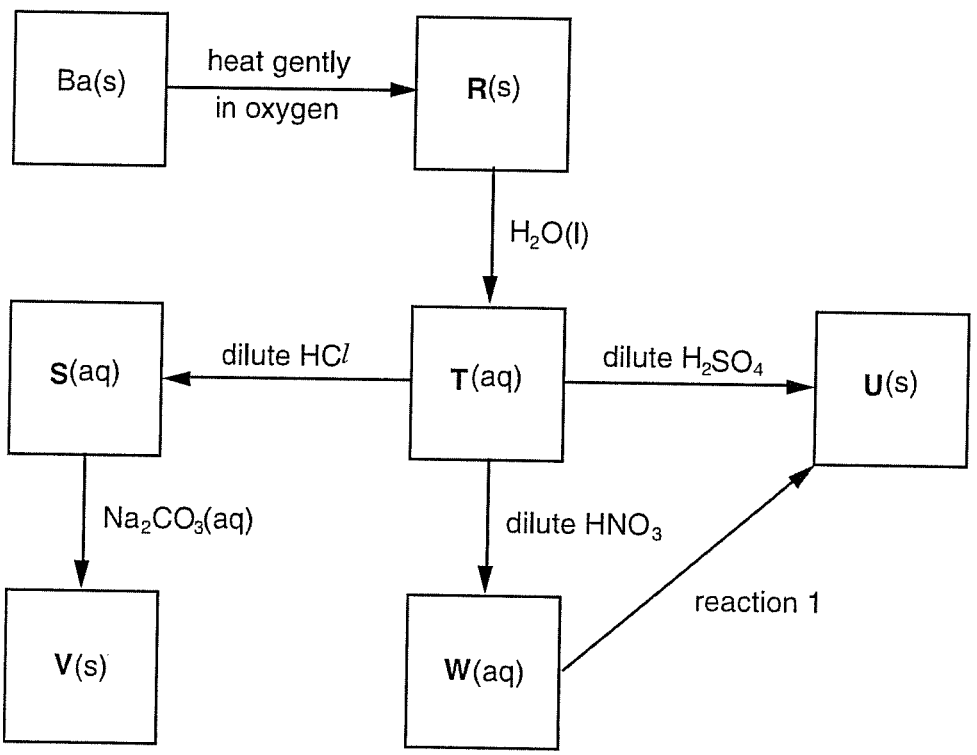
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15. M/J 11/P22/Q3

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.

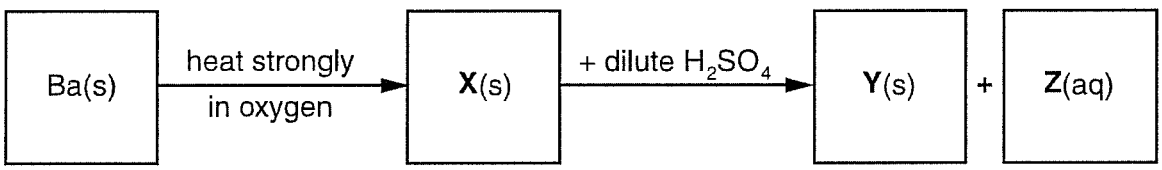
..... [1]

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**.

.....

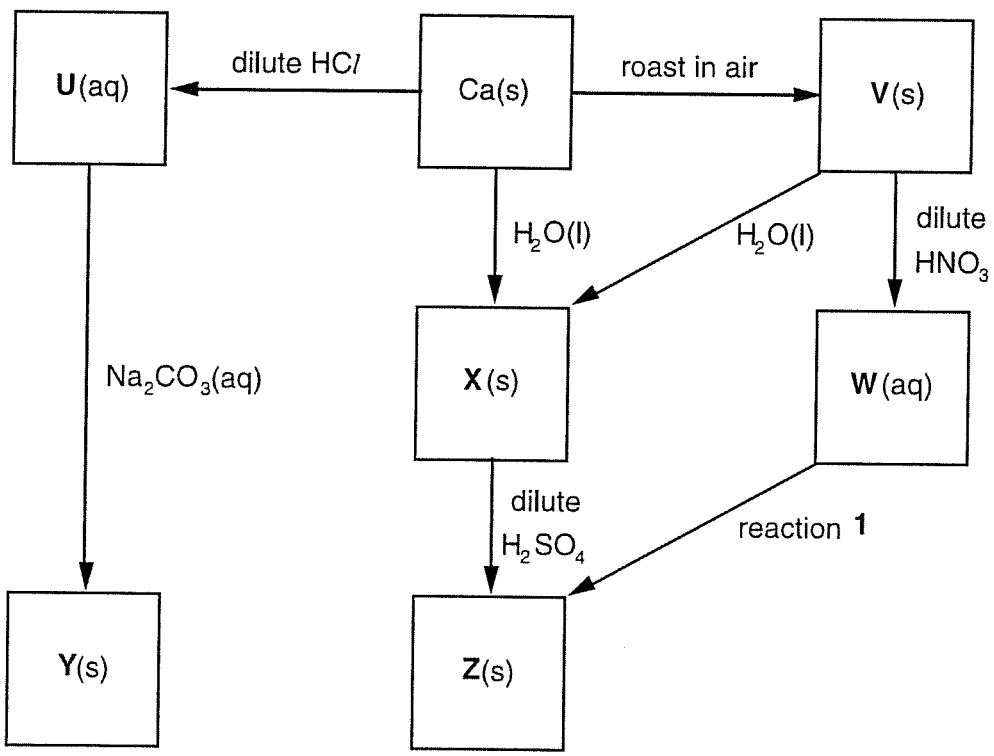
(iii) Use your answers to **(i)** and **(ii)** to construct an equation for the reaction of **X** with H_2SO_4.

..... [4]

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16. M/J 11/P21/Q3

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]

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Answers Section

1. O/N 21/P21/Q2, O/N 21/P23/Q2

(a) (i) hydrogen / H_2 **1**

(ii) $Ca(NO_3)_2 \rightarrow CaO + 2NO_2 + \frac{1}{2}O_2$ **1**

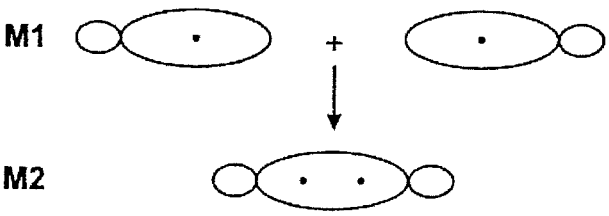
(iii) (thermal stability) increases **1**

(iv) $CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$ **1**

(b) reduces acidity of soil **1**

(c) (i) Mixing / overlap / combination of one / an s and one / a p orbital **1**

(ii) *Sketch a diagram to show HOW two sp hybrid orbitals can form a SIGMA bond* **2**



(d) (i) **M1** moles of $NH_3 = 1.50 \times 10^6 \times 10^6 \div 17 = 8.82 \times 10^{10}$ **2**

M2 mass of $CaCN_2 = \frac{\frac{1}{2} \times M1 \times 80.1}{10^6} = 3.53 \times 10^6$

(ii)

CH_3CH_2CN	$CH_3CH_2CO_2H$
$CH_3C(OH)(CN)CH_3$	

3

2. M/J 21/P22/Q1

(a) **M1** cream **1**

M2 AgBr **1**

(b) (1)$MBr_2 + 2AgNO_3 \rightarrow 2AgBr + M(NO_3)_2$ **1**

(c) **M1** *calculate Mr of* MBr_2 *using* 8.415×10^{-4} *mol* MBr_2 *in 0.250 g* **1**
M_r = ... = 297(.1).....

M2 *calculate the atomic mass of* **M** *using* M_r *calculated in M1* **1**
$297.1 - (2 \times 79.9) = 137(.4)$

M3 *identify group 2 element from* A_r *in M2* **1**
Ba / barium

(d) (i) (solution / mixture / liquid) turns (colourless to) orange or brown **1**

(ii) displacement **1**

(e) **M1** *reagent:* concentrated sulfuric acid **1**

M2 *observation:* brown vapour / gas (forms) **1**

(f) (i) *explain* ***how the action of heat*** *is used to identify the 3 samples* **1**

M1 nitrate AND carbonate lose mass / less than 1 g

M2 nitrate produces brown (NO_2) fumes **1**

M3 MgO no reaction / MgO no change **1**

(ii) *electronic configuration of* Mg^{2+} $(1s^2)\ 2s^2 2p^6$ **1**

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(g) One similarity **1**
M1 solid(s) disappear(s)

One difference **1**
M2 $MgCO_3$ fizzes (due to CO_2) OR no fizzing with $Mg(OH)_2$

3. O/N 20/P21/Q1, O/N 20/P23/Q1

(a) $Mg(g) \rightarrow Mg^{+}(g) + e^{(-)}$ **1**

(b) **M1:** distance between nucleus and **outer e⁻** increases **OR outer electron** removed from higher energy shell **3**
M2: increased **shielding**
M3: decreased **nuclear** attraction

(c) **M1**: **greater nuclear attraction** **2**
M2: (2nd / 2s) electron being removed from **smaller** (ion)

4. M/J 20/P23/Q1

(a) (i) **M1** green flame / white flame (with green tinge) **2**
M2 white solid formed

(ii) $2Ba(s) + O_2(g) \rightarrow 2BaO(s)$ **1**

(b) (i) **M1** heat (followed by) add water **3**
M2 $CaCO_3 \rightarrow CaO + CO_2$
M3 $CaO + H_2O \rightarrow Ca(OH)_2$

(ii) thermal decomposition. **1**

(iii) neutralise acid soil / reduce the acidity in soil / increase the pH in soil **1**

(c) (i) $4Ga + 3O_2 \rightarrow 2Ga_2O_3$ **1**

(ii) (+)3 **1**

(ii) **2**

reagent and conditions	Formula of gallium containing product
M1 gallium oxide+ hot HCl(aq)	**M1** $GaCl_3$
M2 gallium oxide+hot concentrated NaOH(aq)	**M2** $NaGa(OH)_4$ OR $NaGaO_2$

5. O/N 19/P22/Q2/a,b

(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

(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**

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6. M/J 19/P21/Q1

(a) (i) **M1** (one) fewer (inner) shell of electrons / less shielding (effect) *ORA* **1**

M2 smaller distance of the **outer** electrons (from the nucleus) / stronger nuclear attraction to the (outer) electrons *ORA* **1**

(ii) $Sr(s) + 2H_2O(l) \rightarrow Sr(OH)_2(aq) + H_2(g)$ **1**

M1 species AND balancing

M2 state symbols **1**

(iii) **M1** strontium AND forms a more soluble hydroxide **1**

M2 strontium hydroxide is a stronger base / produces more OH^- / it dissociates more **1**

(iv) (white) **solid** dissolves / effervescence **1**

(b) (i) Similarities (any two from the following list) **2**

(both have) +2 ion / (+2) same oxidation state / same stoichiometry of oxide / carbonates decompose (on heating)

Difference **1**

(X) forms coloured compounds/oxides/ carbonates **OR** Group 2 elements form white compounds/oxides/carbonates

(ii) XO **1**

(iii) $XCO_3 \rightarrow XO + CO_2$ **1**

7. M/J 19/P23/Q3

(a) white light / flame **1**
AND
(produces a) white / grey solid / ash / powder / smoke

(b) (i) $MgO + 2HCl \rightarrow MgCl_2 + H_2O$ **1**

(ii) neutralisation **1**

(c) **M1** giant (structure / lattice) **2**

M2 (so) lots of energy needed to break the bonds OR strong bonds

(d) (i) $MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$ **1**

(ii) (thermal) decomposition **1**

8. O/N 17/P22/Q3

(a) (IE) decreases / lower 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**

(b) (i) (Melting point) increases / higher because (molecules have an)

increasing (number of) electrons **1**

increasing strength / number / amount of IMFs / Van der Waals' / id–id / London / dispersion (forces) **1**

(ii) increased metallic / (cat)ionic radius / size **1**
OR decreasing (cat)ion charge-density

decreased attraction (of ions) for delocalised / outer electrons **1**

(c) (i) reaction 1: HNO_3 or nitric((V)) acid **1**

reaction 2: water / H_2O **1**

(ii) barium oxide **1**

$2Ba + O_2 \rightarrow 2BaO$ **1**

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(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**

(iv) white 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**

9. 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**

10. MAR 17/P22/Q1/c(i,ii)

(a) (i) **2**

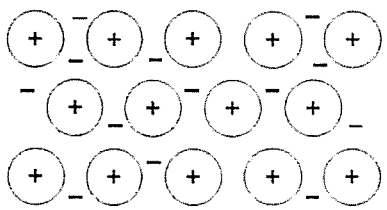


diagram showing regular arrangement of (positive) ions **1**

surrounded by / sea of (delocalised) electrons **1**

(ii) any 2 from: **2**

- high melting / boiling / sublimation point
- electrical / thermal insulator
- hard / rigid
- retains strength at high temperature / pressure

11. M/J 16/P21/Q3/a,b(ii,iii,iv),c

(a) (i) bubbles / effervescence / fizzing [1]

calcium gets smaller / disappears [1]

water turns cloudy / milky [1]

calcium sinks [1]

(ii) $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$ [1]

(iii) faster bubbling / disappearance of Ba
OR
no / less precipitate forms (owtte) [1]

(b) (i) activation energy is high
so few/no particles with $E \geqslant E_a$ [2]

(ii) high melting / boiling point [1]

strong forces (of attraction / between oppositely charged ions) / strong (ionic) bonding [1]

(iii) MgO is basic / reacts with acid [1]

(c) (i) increases (down the group) [1]

(ii) $MgCO_3 \rightarrow MgO + CO_2$ [1]

(iii) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$ [1]

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12. MAR 16/P22/Q1/b(i)

(a) (i) **A** = $Mg(NO_3)_2$
B = H_2
C = NO_2 OR O_2
D = O_2 OR NO_2 [4]

13. M/J 15/P23/Q2

(a) (i) Reactivity increases down the group
OR reference to observations that indicate trend
Outer electrons lost more easily down group
Due to increased distance/shielding of outer electrons from nucleus [3]

(ii) $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$ [1]

(iii) Magnesium hydroxide sparingly soluble/insoluble [1]

(iv) $Mg + H_2O \rightarrow MgO + H_2$ [1]

(b) (i) $MgO + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$ [1]

(ii) (thermal stability) increases down the group [1]

(iii) $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$ [1]

(iv) N from (+)5 to (+)3
O from –2 to 0
N is reduced **and** O is oxidised [3]

(c) (Very) strong electrostatic attraction/ionic bond
High charge (density) of cation and anion/Mg^{2+} and O^{2-} [2]

(d) (i) $CaCO_3 \rightarrow CaO + CO_2$
$CaO + H_2O \rightarrow Ca(OH)_2$ [2]

(ii) $2H^+ + CO_3^{2-} \rightarrow CO_2 + H_2O$ [1]

(iii) $1 \times 10^{-4} \times 8000 = 0.8$ mol H^+

$\frac{0.8}{2} \times 100.1 =$ mass $CaCO_3 = 40$ g [2]

14. O/N 14/P22/Q1/d

(a) (i) **X** = $Mg(OH)_2$
Y = MgO
Z = $Mg(NO_3)_2$ [3]

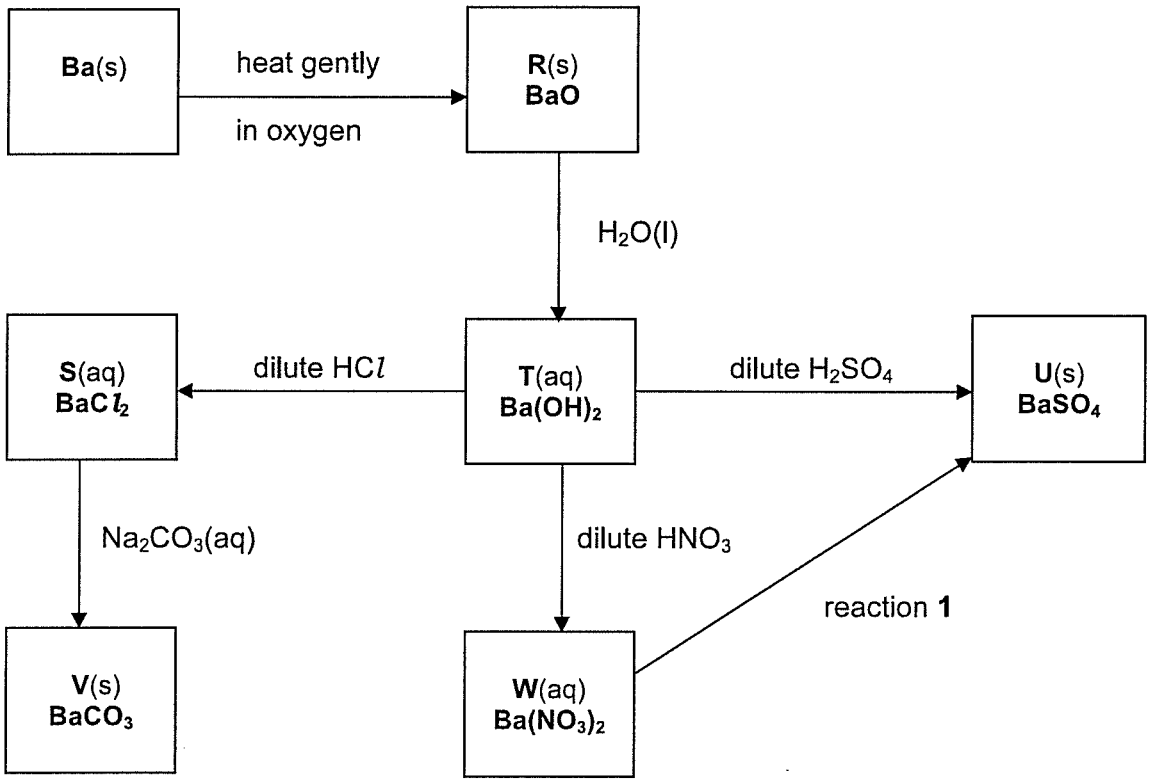
(ii) reagent = nitric acid
$MgO + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$ [2]

(iii) Heat/thermal decomposition [1]

(iv) $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$
$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$ [2]

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15. M/J 11/P22/Q3



(a) **R** BaO
S $BaCl_2$
T $Ba(OH)_2$
U $BaSO_4$
V $BaCO_3$
W $Ba(NO_3)_2$ [6]

(b) **(i)** **T** to **W**

$$Ba(OH)_2 + 2HNO_3 \rightarrow Ba(NO_3)_2 + 2H_2O$$

heat on **V**

$$BaCO_3 \rightarrow BaO + CO_2$$

(ii) **T** to **V**
CO_2

$$Ba(OH)_2 + CO_2 \rightarrow BaCO_3 + H_2O$$ **[4]**

(c) $Na_2SO_4(aq)/K_2SO_4(aq)$ or any soluble sulfate [1]

(d) **(i)** Ba:O = $\frac{81.1}{137} : \frac{18.9}{16}$

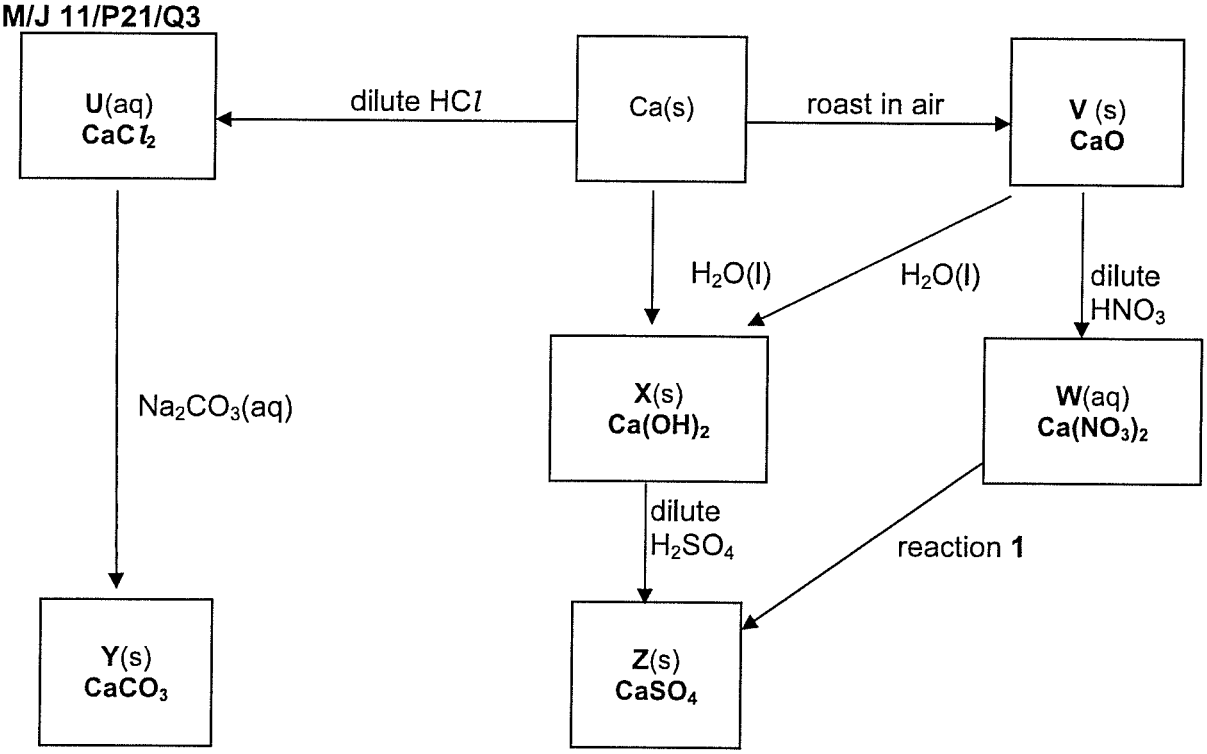
= 0.59 : 1.18
= 1 : 2
gives BaO_2

(ii) $BaSO_4$

(iii) $BaO_2 + H_2SO_4 \rightarrow BaSO_4 + H_2O_2$ **[4]**

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16. M/J 11/P21/Q3



(a)

U	$CaCl_2$
V	CaO
W	$Ca(NO_3)_2$
X	$Ca(OH)_2$
Y	$CaCO_3$

[5]

(b) heat strongly in a test-tube or a boiling tube
do not allow 'heat gently' or 'reflux' **[1]**

(c) **(i)** Ca to **U**

$Ca + 2HCl \rightarrow CaCl_2 + H_2$

V to **W**

$CaO + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$

U to **Y**

$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$

(ii) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$ **[4]**

(d) $Na_2SO_4(aq)/K_2SO_4(aq)$ **or** formula of any **soluble** sulfate [1]

(e) **(i)** Ca to X
colourless gas formed/fizzing/effervescence/bubbles or
Ca dissolves or
white precipitate/suspension formed

(ii) strongly exothermic/vigorous reaction or
steam formed/steamy fumes or
surface crumbles
do not allow white ppt. **[2]**

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Unit 11

GROUP 17

Chemistry Paper-2
Topical Workbook
Article Number: 232

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Unit 11: Group 17

1. M/J 21/P21/Q3

Sodium halide salts react with concentrated sulfuric acid at room temperature.

(a) (i) Write an equation to represent the reaction of NaCl(s) with concentrated sulfuric acid.

..... [1]

(ii) Name this type of reaction.

..... [1]

(b) NaI(s) reacts with concentrated sulfuric acid, at room temperature, to form steamy fumes.

(i) Identify the chemical responsible for the steamy fumes.

..... [1]

(ii) The reaction of NaI(s) with concentrated sulfuric acid continues, forming several other products, including a dark grey solid.

Identify the chemical responsible for the dark grey solid and **one** other product of this further reaction.

dark grey solid .....

other product .....[2]

(c) Explain the differences in observations, at room temperature, when NaI(s) reacts with concentrated sulfuric acid compared to those for NaCl(s).

.....

..... [2]

(d) Complete the equation for the reaction of Br^- with excess concentrated H_2SO_4 at room temperature.

.....Br^- + ...H^+ + ...H_2SO_4 → ..... [1]

2. M/J 21/P21/Q4

Aqueous bromine reacts with methanoic acid to form hydrogen bromide and carbon dioxide gas.

$$Br_2(aq) + HCO_2H(aq) \rightarrow 2HBr(aq) + CO_2(g)$$

The table shows the oxidation numbers of bromine and carbon in the species involved in this reaction.

	Br in Br_2	C in HCO_2H	Br in HBr	C in CO_2
oxidation number	0	+2	–1	+4

(a) Identify the oxidising agent in this reaction. Explain your reasoning with reference to oxidation numbers.

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

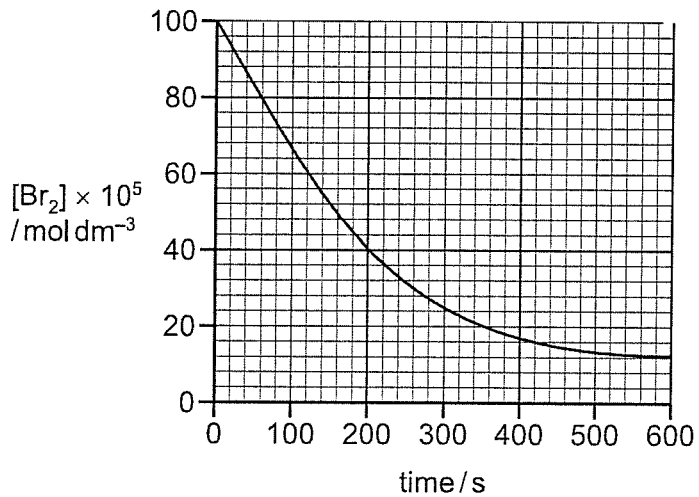
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(b) Suggest one change you would observe, ignoring temperature changes, when bromine reacts with methanoic acid.

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

(c) This reaction can be followed by measuring the concentration of bromine present in the mixture at regular time intervals.

The graph shows the change in concentration of bromine against time in a reaction carried out at 20 °C.



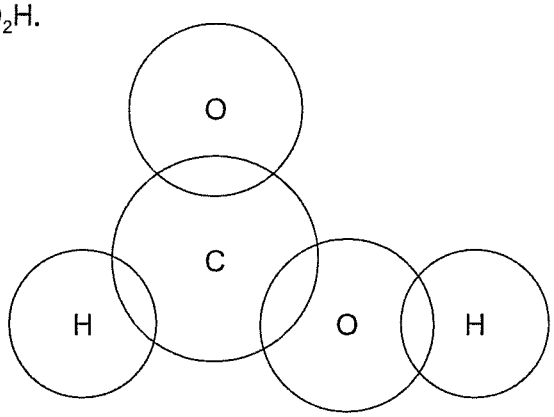
(i) Use the graph to calculate the average rate of reaction at 20 °C during the first 600 s. State the units of this rate of reaction.

average rate of reaction ..... units .....[2]

The experiment is repeated

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(d) Complete the 'dot-and-cross' diagram, showing outer electrons only, to show the bonding in methanoic acid, HCO_2H.



[2]

3. M/J 21/P23/Q1

The elements in Group 17 are known as the halogens.

(a) Between the molecules of Group 17 elements van der Waals' forces exist.

(i) State the trend in the relative strength of van der Waals' forces down Group 17.

..... [1]

(ii) State the physical state of each of the halogens under room conditions.

chlorine .....

bromine .....

iodine .....[1]

(b) A solution of aqueous bromide ions, $Br^-(aq)$, is added to separate samples of $Cl_2(aq)$ and $I_2(aq)$.

Describe what is observed in each reaction. Explain your answer in terms of the relative reactivity of these elements as oxidising agents.

observation on addition to $Cl_2(aq)$ .....

.....

observation on addition to $I_2(aq)$ .....

.....

explanation .....

.....

.....[3]

(c) Bleach is made by reacting Cl_2 with cold NaOH(aq).

Write an equation for the reaction of Cl_2 with cold NaOH.

..... [1]

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(d) When ClO^-(aq) is added to water, it behaves as a Brønsted-Lowry base.

(i) Define the term *Brønsted-Lowry base*.

.....[1]

(ii) Write an ionic equation for the reaction between ClO^- and H_2O.

.....[1]

(e) The concentration of NaClO in bleach **S** is x g dm^{-3}.

NaClO reacts with H_2O_2(aq) as shown.

$$H_2O_2(aq) + NaClO(aq) \rightarrow H_2O(l) + NaCl(aq) + O_2(g)$$

A 5.00 cm^3 sample of **S** completely reacts with H_2O_2(aq). The volume of O_2(g) produced is 24.0 cm^3 under room conditions.

Assume that only the NaClO in **S** reacts with H_2O_2(aq).

Calculate x. Show your working.

x = ... g dm^{-3} [3]

(f) Sodium chlorate(I), NaClO, oxidises dilute hydrochloric acid to form three products. The products which contain chlorine have chlorine species with oxidation number –1 or 0.

No other species changes its oxidation number during the reaction.

Use this information to complete the ionic equation.

.....ClO^- + ...HCl $\rightarrow$ ..... + ... + ... [2]

4. O/N 20/P21/Q4, O/N 20/P23/Q4

Iodine is used in many inorganic and organic reactions.

(a) (i) State and explain the trend in volatility of the halogens, from chlorine to iodine.

.....

.....[2]

(ii) Explain why HI is the **least** thermally stable of HCl, HBr and HI.

.....[1]

(iii) The table shows the electronegativity values for hydrogen, fluorine and iodine.

element	electronegativity value
H	2.1
F	4.0
I	2.5

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Explain, in terms of intermolecular forces, why HI has a lower boiling point than HF.

.....

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

(iv) Iodine reacts with hot concentrated aqueous sodium hydroxide in the same way as chlorine.

Write an equation for the reaction of iodine and hot aqueous sodium hydroxide.

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

(b) Iodoalkanes contain carbon-iodine bonds.

The simplest iodoalkane is CH_3I.

(i) CH_3I can be made from methanol, CH_3OH.

Identify a reagent that can convert CH_3OH to CH_3I.

..... [1]

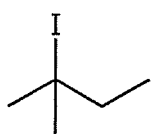
(ii) 1,2-diiodoethane, CH_2ICH_2I, can be made by bubbling ethene into liquid iodine.

Fully name the type of mechanism shown in this reaction.

..... [1]

(c) **J** reacts with NaOH, forming different products dependent on the conditions used.

J

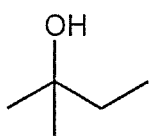


(i) Name **J**.

..... [1]

(ii) **J** reacts with NaOH(aq) to form **K**.

K

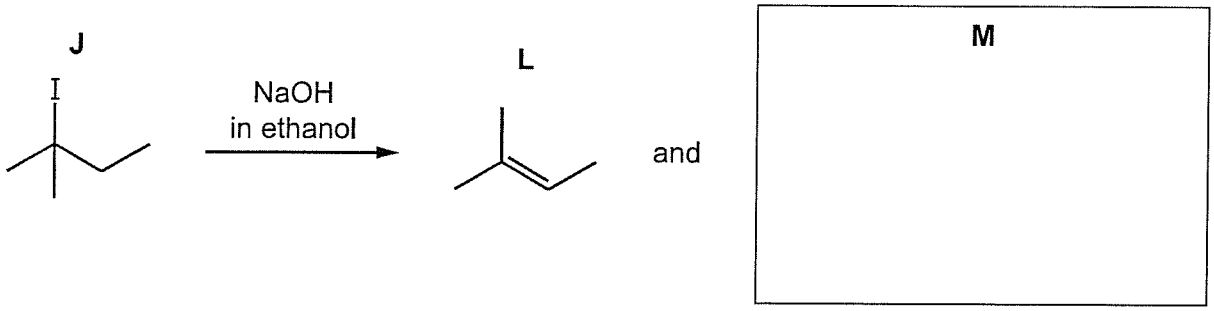


Fully name the mechanism of the reaction of **J** with NaOH(aq) to form **K**.

..... [1]

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(iii) **J** reacts with NaOH dissolved in ethanol to form a mixture of two alkenes, **L** and **M**. Alkene **L** is shown.



In the box provided, draw the structure of **M**. [1]

(iv) Explain why **L** does **not** show geometrical (cis-trans) isomerism.

..... [1]

(v) **L** reacts with hot concentrated acidified $KMnO_4(aq)$ to form propanone and one other organic product.
Identify the other organic product.

..... [1]

(vi) Propanone reacts with excess alkaline aqueous iodine.
Complete and balance the equation for this reaction.

$$CH_3COCH_3 + ...I_2 + ...OH^- \longrightarrow .....CH_3COO^- + ...H_2O + ...I^- + ...$$

[2]

(vii) State **one** observation that can be made in the reaction in **(c)(vi)**.

..... [1]

5. O/N 19/P21/Q1, O/N 19/P23/Q1

(a) Chlorine can be prepared using the following reaction.

$$MnO_2(s) + 4HCl(aq) \rightarrow MnCl_2(aq) + 2H_2O(l) + Cl_2(g)$$

(i) Explain why $MnO_2(s)$ is described as an oxidising agent in this reaction.
Refer to oxidation numbers in your answer.

..... [1]

(ii) State what you would observe during this reaction.

..... [1]

(b) The halogens chlorine, bromine and iodine are all volatile elements.
State and explain the trend in volatility down Group 17.

.....

.....

.....[3]

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(c) Chlorine undergoes disproportionation during many chemical reactions.

(i) Write an equation for the reaction of chlorine with cold aqueous sodium hydroxide, NaOH.
Explain why it is a disproportionation reaction.

equation .....

explanation .....

.....[2]

(ii) One of the products of the reaction of chlorine with **hot** aqueous sodium hydroxide differs from those in **(c)(i)**.
Identify the compound that is formed in this reaction that is different from that formed in the reaction in **(c)(i)**.

..... [1]

(d) State and explain the use of chlorine in water purification.

.....

..... [2]

(e) Under certain conditions, chlorine undergoes a free-radical substitution reaction with ethane.

(i) State the conditions required to initiate this reaction.

..... [1]

(ii) Write the overall equation for this free-radical substitution reaction.

..... [1]

6. M/J 19/P22/Q2

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]

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(c) Hydrogen chloride reacts with water.

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

(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]

7. M/J 19/P23/Q2

Iodine is an element in Group 17 of the Periodic Table.

(a) (i) At room temperature, iodine solid has a lattice structure.
Describe the arrangement of the iodine molecules within the solid.

..... [1]

(ii) List **all** of the forces of attraction present in solid iodine and identify which of these are overcome when solid iodine is heated to produce iodine vapour.

force(s) of attraction present

.....

.....

force(s) of attraction overcome

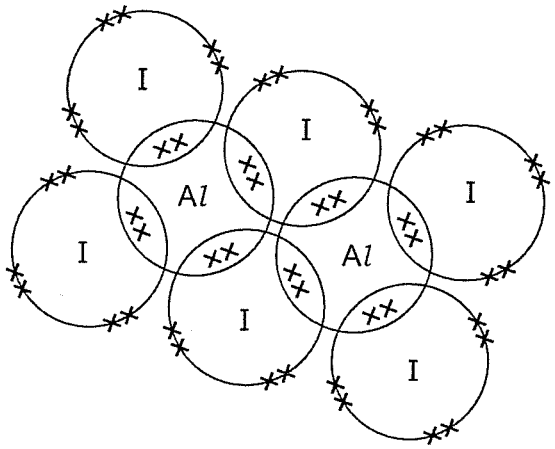
.....

.....[2]

Iodine reacts with aluminium to form a white solid, Al_2I_6.

(b) The diagram shows the arrangement of the outer electrons within a molecule of Al_2I_6.

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(i) How many co-ordinate (dative covalent) bonds are made when a molecule of Al_2I_6 is formed from its atoms?

..... [1]

(ii) Describe how co-ordinate (dative covalent) bonds form within this molecule.

..... [1]

(c) In a reaction between hydrogen iodide and concentrated sulfuric acid, the products are hydrogen sulfide, sulfur, iodine and water.

(i) Write an equation for this reaction.

You may wish to use oxidation numbers to help you.

..... [2]

(ii) Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

.....

..... [2]

8. MAR 19/P22/Q2/b

The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2, HCl and CaF_2.

	F_2	HCl	CaF_2
boiling point/K	85	188	2773
relative formula mass	38.0	36.5	78.1

(a) (i) Complete the electronic configuration of a chloride ion.

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

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(ii) When Cl_2 is passed over hot iron, $FeCl_3$ is formed.

However, when $I_2(g)$ is passed over hot iron, the following reaction occurs.

$$Fe(s) + I_2(g) \rightarrow FeI_2(s)$$

State what you would observe during the reaction between Fe and I_2. Explain why $FeI_2(s)$ is formed rather than $FeI_3(s)$.

observation .....

.....

explanation .....

.....[2]

(iii) FeI_2 is soluble in water.

A student carries out a chemical test to confirm that a solution of FeI_2 contains aqueous iodide ions, $I^-(aq)$. The student adds a single reagent and a precipitate forms.

Identify the reagent the student uses. State the colour of the precipitate that forms.

reagent .....

colour of precipitate .....[2]

(iv) Compounds containing I^- are often contaminated by bromide ions, Br^-.

Identify a further reagent that the student could use to show that the precipitate formed in **(iii)** contained iodide ions.

..... [1]

9. M/J 18/P23/Q3

The elements in Group 17, the halogens, show trends in both their chemical and physical properties. The elements and their compounds have a wide variety of uses.

(a) At room temperature fluorine and chlorine are gases, bromine is a liquid and iodine is a solid.

(i) State the trend in the volatility of the Group 17 elements down the group.

..... [1]

(ii) Explain this trend.

.....

..... [2]

(b) Iodine, I_2, can be displaced from NaI(aq), by chlorine, Cl_2.

Write an equation for this reaction.

.....[1]

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(c) Silver nitrate solution, $AgNO_3(aq)$, is added to separate solutions of NaI and NaC*l*.
Precipitates form. An excess of aqueous ammonia is then added to both precipitates.

(i) Complete the table to give the colour and name of the precipitate formed in each reaction and the effect of the addition of an excess of aqueous ammonia to each of the precipitates formed.

	NaI(aq) + $AgNO_3(aq)$	NaC*l*(aq) + $AgNO_3(aq)$
colour of precipitate		
name of precipitate		
effect of addition of an excess of aqueous ammonia to the precipitate		

[3]

(ii) Write an ionic equation, including state symbols, to show the reaction occurring when $AgNO_3(aq)$ is added to NaI(aq).

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

(d) Solid NaI reacts with concentrated sulfuric acid to form purple fumes of $I_2(g)$ and hydrogen sulfide gas, $H_2S(g)$.
However, when solid NaC*l* reacts with concentrated sulfuric acid the only gas produced is HC*l*(g).
Explain the difference in the reactions of concentrated sulfuric acid with NaI and with NaC*l*.
Your answer should refer to the role of the sulfuric acid in each reaction.

.....

.....

.....[3]

(e) Chlorine is commonly used in water purification. When chlorine is added to water it reacts to produce a mixture of acids, one of which is chloric(I) acid, HC*l*O, a powerful oxidising agent.

(i) Explain the meaning of the term *oxidising agent*, in terms of electron transfer.

..... [1]

(ii) Suggest an equation for this reaction of chlorine with water.

..... [1]

(iii) Write an equation for the reaction of chlorine with **hot** aqueous sodium hydroxide.
Use oxidation numbers to explain why this is a redox reaction.

equation .....

..... [2]

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10. O/N 17/P21/Q2/b, O/N 17/P23/Q2/b

(a) The chlorides of the elements in the third period behave in different ways when added to water, depending on their structure and bonding.

L and **M** are each a chloride of an element in Period 3. A student investigated **L** and **M** and their results are given.

L is a white crystalline solid with a melting point of 987 K. **L** dissolves in water to form an approximately neutral solution. Addition of NaOH(aq) to an aqueous solution of **L** produces a white precipitate.

M is a liquid with a boiling point of 331 K. **M** is hydrolysed rapidly by cold water to form a strongly acidic solution, a white solid and white fumes.

Identify **L** and **M**.

Explain any properties and observations described.

Give equations where appropriate.

(i) **L** is .....

.....

..... [3]

(ii) **M** is .....

.....

..... [3]

11. 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.

.....

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.....

..... [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]

(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]

12. M/J 17/P22/Q3/a

The hydrogen halides, HC*l*, HBr and HI, can undergo thermal decomposition.
In a sealed container an equilibrium is established according to the equation shown.

$$2HX(g) \rightleftharpoons H_2(g) + X_2(g) \qquad \text{(where X = C}l\text{, Br or I)}$$

(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]**

13. 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]

(ii) Explain why the reaction of concentrated sulfuric acid and sodium iodide is **not** suitable for the preparation of hydrogen iodide.

.....

..... [2]

14. 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.

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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

(a) **(i)** Explain the trend in the boiling points of the hydrogen halides, HCl, HBr and HI.

.....

..... [2]

(ii) Suggest why the hydrogen halide HF does not follow the trend in boiling points shown by HCl, 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]

(ii) H**P** readily decomposes into its elements when heated but H**Q** is stable to heat.
Explain this with reference to bond energies.

.....

..... [2]

(iii) Write an equation for the thermal decomposition of H**P**.

..... [1]

(iv) Write ionic equations, including state symbols, for

1. the formation of the white precipitate on addition of aqueous silver ions to aqueous H**Q**,

.....

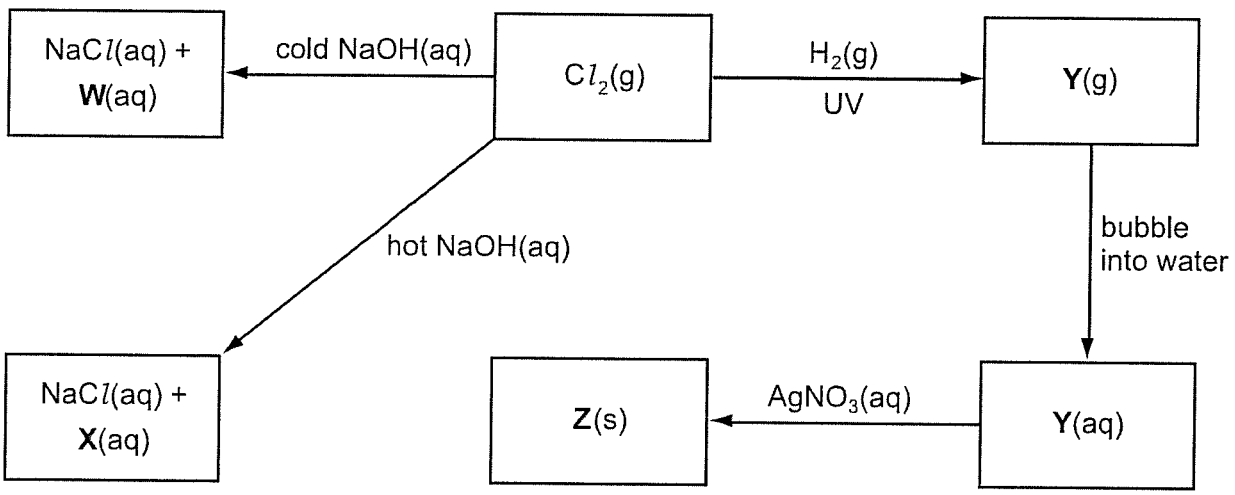
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2. the subsequent dissolving of this precipitate in dilute aqueous ammonia.

.....[2]

15. 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]

(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]

16. 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]

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(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]

17. 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]

18. 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.

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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]

19. 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]

20. 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.

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chlorine	$1s^2 2s^2 2p^6$
bromine	$1s^2 2s^2 2p^6$

(ii) Draw a 'dot-and-cross' diagram of the BrC*l* molecule.
Show outermost electrons only.

[2]

(c) Interhalogen compounds like BrC*l* have similar properties to the halogens.

(i) By considering your answers to **(a)** and **(b)**, predict the physical state of BrC*l* at room temperature. Explain your answer.

physical state .....

explanation .....

.....

.....

(ii) Suggest the colour of BrC*l*.

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

(d) Cl_2 and BrC*l* 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 BrC*l* and aqueous KI.

.....

(iv) How do Cl_2 and BrC*l* behave in these reactions?

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

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21. 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.

.....

.....

.....

.....

(ii) Write balanced equations, with state symbols, for **all** reactions that occur in this process.

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(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]**

22. 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]**

23. 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]

(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]

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Answers Section

1. M/J 21/P21/Q3

(a) (i) $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ OR $2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$ **1**

(ii) displacement / acid-base (reaction) **1**

(b) (i) hydrogen iodide / HI **1**

(ii) dark grey solid I_2 / iodine other product S / sulfur OR H_2S / hydrogen sulfide **1**
OR H_2O / water / steam **1**

(c) **M1** iodide ions are strong(er) reducing agents (than chloride ions) ORA **1**

M2 HI / iodide is oxidised OR HCl / chloride is not oxidised **1**

(d) $2Br^- + 2H^+ + H_2SO_4 \rightarrow Br_2 + 2H_2O + SO_2$ **1**

2. M/J 21/P21/Q4

(a) Br / bromine as the oxidation number of Br decreases / goes from $0 \rightarrow -1$ OR bromine as it causes oxidation number of C (in methanoic acid) to increase / go from $(+)2 \rightarrow (+)4$ **1**

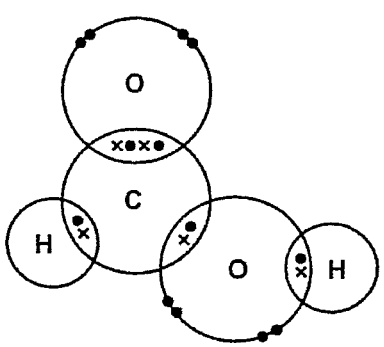
(b) (solution) turns (from brown / orange / red to) colourless / decolorises **1**
OR brown / orange / red fades

(c) (i) rate = total change in concentration of Br_2 divided by time taken **1**
calculation dependent on graph
$(100 \times 10^{-5} - 12 \times 10^{-5}) / 600$
M1 average rate of reaction 1.47×10^{-6}
M2 units mol dm^{-3} s^{-1} **1**

(ii) graph shown on same axes has steeper initial gradient **1**
AND reaches the same final $[Br_2]$

(iii) **M1** (at increased temp the average kinetic) energy of particles / species / molecules increases. **1**
M2 (many) more/greater proportion of particles with energy $\geqslant E_a$ **1**

(d)



M1 correct bonding electrons
M2 correct number of non-bonding electrons around each oxygen **1**

3. M/J 21/P23/Q1

(a) (i) increases **1**

(ii) chlorine gas **1**
bromine liquid
iodine solid

(b) **M1** observation with $Cl_2(aq)$ (colourless / pale green to) orange / brown **1**
M2 observation with $I_2(aq)$ no visible change **1**

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M3 explanation chlorine is a stronger oxidising agent (than bromine) AND iodine is a weaker oxidising agent **1**

(c) $Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$ **1**

(d) (i) proton / H^+ acceptor **1**

(ii) $ClO^- + H_2O \rightarrow HClO + OH^-$ **1**

(e) **M1** *Use volume O_2 to express / find no mol O_2 produced* 24 / 24 000 mol O_2 produced = 1×10^{-3} (mol) **1**

M2 *Use 1:1 ratio to deduce no mol NaClO in 1000 cm^3 sample* M1 × 1000 / 5 = 0.2 (mol dm^{-3}) **1**

M3 *Use amount of NaClO and its molecular mass (74.5) to find the mass of NaClO added* -24 / 24000 ×1000/5×74.5=14.9 (g dm^{-3}) **1**

(f) **M1** products contain Cl^- AND Cl_2 **1**

M2 correct balanced equation $ClO^- + 2HCl^- \rightarrow Cl^- + H_2O + Cl_2$ **1**

4. O/N 20/P21/Q4, O/N 20/P23/Q4

(a) (i) **M1:** (Volatility) decreases (down the group) **2**

M2: more electrons so greater intermolecular forces / intermolecular attractions **OR** more electrons so greater VdW **between molecules**

(ii) (HI has the) lowest bond enthalpy **1**

(iii) **M1:** HF has permanent dipole(-dipole forces) **AND** HI has ((only)) instantaneous dipole / induced dipole(forces) / permanent dipole(-dipole forces) **2**

M2: IMF's in HI are **weaker** (than IMF's in HF)

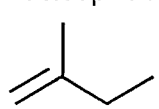
(iv) $3I_2 + 6NaOH \rightarrow 5NaI + NaIO_3 + 3H_2O$ **1**

(b) (i) HI(g) / PI_3 / P and I_2 **1**

(ii) Electrophilic addition **1**

(c) (i) 2(-)iodo(-)2(-)methylbutane **1**

(ii) Nucleophilic substitution / S_N **1**

(iii)  **1**

(iv) (**L** has) two identical / two methyl groups attached to one end / one carbon of the C=C / double bond **1**

(v) ethanoic acid / CH_3COOH **1**

(vi) $CH_3COCH_3 + 3I_2 + 4OH^- \rightarrow (1)CH_3COO^- + 3H_2O + 3I^- + \mathbf{CHI_3}$ **2**

M1: correctly balanced

M2: CHI_3 product

(vii) yellow ppt / yellow solid **1**

5. O/N 19/P21/Q1, O/N 19/P23/Q1

(a) (i) It oxidises chlorine from –1 to 0 **1**

(ii) effervescence / fizzing / bubbling **OR** green gas formed **OR** solid dissolves / disappears / soluble **1**

(b) **M1:** decreases (down the group) **3**

M2: increasing induced dipoles

M3: greater number of electrons

(c) (i) **M1:** $Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$ **2**

M2: chlorine is oxidised and reduced

(ii) $NaClO_3$ / sodium chlorate(V) **1**

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(d) **M1:** chloric(I) acid / hypochlorous acid / HC*l*O **2**
M2: kills bacteria / micro-organisms / microbes

(e) (i) ultra-violet (light) / sunlight **1**

(ii) $C_2H_6 + Cl_2 \rightarrow C_2H_5Cl + HCl$ **1**

6. M/J 19/P22/Q2

(a) *trend in volatility down the group*
decrease (in volatility) **1**

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

(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 HC*l* AND conjugate base Cl^- **1**

(iii) co-ordinate / dative (covalent) **1**

(iv) (triangular / trigonal) pyramid(al) **1**

$107^{(0)}$ **1**

7. M/J 19/P23/Q2

(a) (i) held in regular / uniform arrangement **1**

(ii) **M1** covalent (bonds) AND (temporary) induced dipoles **2**
M2 (temporary) induced dipoles

(b) (i) 2 **1**

(ii) iodine (atom / s) donates a pair of electrons (to the A*l*-I covalent bond / s). **1**

(c) (i) $2H_2SO_4 + 14HI \rightarrow 7I_2 + 8H_2O + H_2S + S$ **2**
M1 correct species
M2 correctly balanced equation

(ii) *explain with ref to ox no's why the reaction in **(c)(i)** is a redox reaction* **2**
M1 I (oxidation number increases) from –1 to 0 = oxidation / reducing agent
M2 S (oxidation number decreases) from (+) 6 to 0 **OR** –2 = reduction / oxidising agent

8. MAR 19/P22/Q2/b

(a) (i) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ **1**

(ii) **M1** purple gas / vapour disappears **2**
M2 iodine is not a strong enough oxidising agent ORA

(iii) **M1** silver nitrate / $AgNO_3$ **2**
M2 yellow

(iv) (aqueous) ammonia / $NH_3(aq)$ / ammonium hydroxide / $NH_4OH(aq)$ **1**

9. M/J 18/P23/Q3

(a) (i) (volatility) decreases **1**

(ii) increasing numbers / more of electrons (in molecules) **1**
increased strength of id-id / VdW / IMFs **1**

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(b) $Cl_2 + 2NaI \rightarrow 2NaCl + I_2$ **1**

(c) (i) **3**

	NaI(aq) + $AgNO_3$(aq)	NaCl(aq) + $AgNO_3$(aq)
colour of ppt	yellow	white
name of ppt	silver iodide	silver chloride
effect of addition of aqueous ammonia to the precipitate	No (visible) change	dissolves / soluble

(ii) $Ag^+(aq) + I^-(aq) \rightarrow AgI(s)$ **1**

(d) M1 sulfuric acid acts as an acid with NaCl (and NaBr) OR **1**
$NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ OR
$2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$
sulfuric acid acts as an oxidising agent with NaI / I OR **1**
NaI is a reducing agent
I^- more powerful reducing agent than Cl^- OR **1**
sulfuric acid can oxidise I^- but not Cl^- OR
sulfuric acid is a stronger oxidising agent than iodide ions OR
sulfuric acid is not as strong an oxidising agent than chloride ions

(e) (i) (Species that) gains <u>electrons</u> / <u>electron</u> acceptor **1**

(ii) $Cl_2 + H_2O \rightarrow HCl + HClO$ **1**

(iii) $3Cl_2 + 6NaOH \rightarrow 5NaCl + NaClO_3 + 3H_2O$ **1**
0 to –1 (+)5 AND chlorine has been oxidised and reduced. **1**

10. O/N 17/P21/Q2/b, O/N 17/P23/Q2/b

(a) (i) (**L**=) $MgCl_2$ / magnesium chloride **1**
Any two from **2**
(giant) ionic (with strong attractions)
$Mg^{2+}(aq)$ / $Mg(H_2O)_6^{2+}(aq)$ is neutral / undergoes (partial) hydrolysis
$Mg(OH)_2$ is the white precipitate / solid / insoluble / partially soluble
$MgCl_2 + 2NaOH \rightarrow Mg(OH)_2 + 2NaCl$

(ii) (**M**=) $SiCl_4$ / silicon chloride **1**
Any two from **2**
(simple) molecular / simple covalent
hydrolysis possible due to available d orbitals
forms HCl (aq) / hydrochloric acid / solution and / or HCl gas / fumes
white solid is (hydrated) SiO_2
$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$

11. M/J 17/P23/Q2

(a) (i) **2**

halogen	colour	state
chlorine	yellow / green	gas
bromine	red / brown / orange	liquid
iodine	grey / black	solid

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(ii) increasing number of electrons **1**

(gives) increasing strength of van der Waals' / id-id forces / London / dispersion 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 OR **1**

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) OR **1**
chloride not powerful enough reducing agent (to reduce sulfuric acid)

iodide reduces sulfuric acid OR iodide / I^- is oxidised OR **1**
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**

12. M/J 17/P22/Q3/a

(a) (+) 103 **1**

13. 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** base is Cl^- **AND** conjugate acid is HCl **OR** **1**
base is HSO_4^- **AND** conjugate acid is H_2SO_4

M2 Cl^- / HSO_4^- / base is a proton acceptor **OR** **1**
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**

14. M/J 16/P22/Q2/b,c

(a) (i) stronger / more / greater id–id / London / dispersion forces
due to increasing numbers of electrons [2]

(ii) (intermolecular forces in HF are) hydrogen bonds
(which are) stronger (than vdW) / more energy needed to separate molecules
OR HF much more polar / F much more electronegative
Intermolecular forces in HF stronger (than in HCl, HBr, HI) [2]

(b) (i) **P** = iodine / I_2 / I; **Q** = chlorine / Cl_2 / Cl [1]

(ii) weaker H–**P** than H–**Q** bond ORA / easier / less energy to break H–**P** than H–**Q** ORA
due to greater distance / shielding of nucleus from bond pair ORA [2]

(iii) $2HP$ (or 2HI) $\rightarrow$ (or $\rightleftharpoons$) $H_2 + P_2$ (or I_2) [1]

(iv) $Ag^+(aq) + Q^-(aq)$ (or Cl^-) $\rightarrow AgQ(s)$ (or AgCl(s))
$AgQ(s)$ / $AgCl(s) + 2NH_3(aq) \rightarrow Ag(NH_3)_2^+(aq) + Q^-(aq)$ / $Cl^-(aq)$ [2]

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15. O/N 14/P23/Q1/d

(a) (i) **W** = NaC*l*O; **Y** = HC*l*;
X = NaC*l*O_3; **Z** = AgC*l* [4]

(ii) $3Cl_2 + 6NaOH \rightarrow 5NaCl + NaClO_3 + 3H_2O$
M1: correct species
M2: balanced equation [2]

(iii) 0 to –1
(0 to) +5 [2]

(iv) $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$ [1]

16. M/J 14/P23/Q4/a,b

(a) (i) decreases down the group **ora** [1]

(ii) X–X bond strength decreases from C*l*–C*l* to I – I
But decreasing strength of H–X down group more significant [2]

(b) (i) $CaCl_2 + H_2SO_4 \rightarrow CaSO_4 + 2HCl$ **OR**
$CaCl_2 + 2H_2SO_4 \rightarrow Ca(HSO_4)_2 + 2HCl$ [1]

(ii) HI / I^- reduces / is oxidised by conc H_2SO_4 / because iodine is produced instead [1]

(iii) brown gas / fumes produced
$2H_2SO_4 + 2KBr \rightarrow SO_2 + Br_2 + 2H_2O + K_2SO_4$ (or ionic) [3]

17. M/J 14/P21/Q3/a

(a) (i) **K** = Cl^- / chloride / F^- / fluoride
$H_2SO_4 + 2NaCl \rightarrow Na_2SO_4 + 2HCl$ (or equation with F or **K** for C*l*) **OR**
$H_2SO_4 + NaCl \rightarrow NaHSO_4 + HCl$ (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 3

(ii) **L** = I^- / iodide
colour = yellow
ecf from identity of **L** i.e. Cl^-(white) or Br^-(cream)
$Ag^+ + I^- \rightarrow AgI$ (or equation with **L**) 3
$AgNO_3 + NaI \rightarrow AgI + NaNO_3$ (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
intermolecular / van der Waals' forces (in Br_2 / M_2) **weaker** than in iodine / **stronger** than in chlorine 2

18. O/N 13/P22/Q3/d

(a) $MgCl_2$ 6.5 to 6.9
$SiCl_4$ 0 to 3
$MgCl_2$ dissolves without reaction **or** slight **or** partial hydrolysis occurs
$SiCl_4$ reacts with water **or** hydrolysis occurs
$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$ **or**
$SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$ **or**
$SiCl_4 + 4H_2O \rightarrow SiO_2.2H_2O + 4HCl$ [5]

19. O/N 13/P21/Q3/c

(a) cold dilute aqueous NaOH
NaOC*l*
+1
hot concentrated aqueous NaOH
NaC*l*O_3
+5 [4]

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20. 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
iodine correct **for solid**

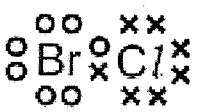
(ii) down the Group
there are more electrons in the molecule
hence stronger van der Waals' forces [4]

(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)



[2]

(c) (i) gas **or** low boiling liquid
BrCl has fewer electrons than Br_2
hence weaker van der Waals' forces

(ii) accept colours in the range yellow, orange, red, brown [4]

(d) (i) **initially** solution begins to turn yellow/brown
after several minutes black/dark grey solid formed

(ii) $Cl_2 + 2KI \rightarrow 2KCl + I_2$

(iii) $BrCl + 2KI \rightarrow KCl + KBr + I_2$

(iv) as oxidising agents [5]

21. O/N 12/P23/Q2

(a) (i) white fumes/steamy fumes

(ii) $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ **or**
$2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$

(iii) an acid that is completely ionised in solution **or**
an acid that is completely dissociated into H^+ ions in solution [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)

(ii) conc. H_2SO_4 is an oxidising agent **or** HI is a reducing agent
which oxidises HI **or** which reduces H_2SO_4 [3]

(c) (i) white ppt formed – **not** creamy white or off white
which dissolves in $NH_3(aq)$

(ii) $NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$ **or**
$Cl^-(aq) + Ag^+(aq) \rightarrow AgCl(s)$

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equation
all state symbols correct
$AgCl(s) + 2NH_3(aq) \rightarrow [Ag(NH_3)_2]^+ Cl^-(aq)$ **or**
$AgCl(s) + 2NH_3(aq) \rightarrow [Ag(NH_3)_2] Cl(aq)$
equation
all state symbols correct

(iii) precipitate is yellow
precipitate does not dissolve [8]

22. O/N 12/P22/Q2/a

(a) (i) thermal stability decreases down Group VII

(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
hence H—X bond strength decreases down Group VII [3]

23. 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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Unit 12
NITROGEN AND SULFUR

Chemistry Paper-2
Topical Workbook
Article Number: 232

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Unit 12: Nitrogen And Sulfur

1. O/N 21/P21/Q1, O/N 21/P23/Q1

Sulfides are compounds that contain sulfur but not oxygen.

(a) Carbon disulfide, CS_2, is a volatile liquid at room temperature and pressure.

(i) State the meaning of *volatile*.

..... [1]

(ii) Draw a 'dot-and-cross' diagram of the CS_2 molecule.

[2]

(iii) Suggest the bond angle in a molecule of CS_2.

..... [1]

(iv) CS_2 is a liquid under room conditions, while CO_2 is a gas.
Explain what causes the difference in the physical properties between CS_2 and CO_2.

.....

..... [2]

(b) The enthalpy change of combustion of $CS_2(l)$ is represented by the following equation.

$$CS_2(l) + 3O_2(g) \xrightarrow{\Delta H_c} CO_2(g) + 2SO_2(g)$$

(i) Define *enthalpy change of combustion*.

.....

..... [2]

(ii) The table shows the enthalpy changes of formation of $CS_2(l)$, $CO_2(g)$ and $SO_2(g)$.

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$CS_2(l)$	+89.7
$CO_2(g)$	–394
$SO_2(g)$	–297

Use the data in the table to calculate the enthalpy change of combustion, ΔH_c, of $CS_2(l)$, in kJ mol^{-1}.

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Show your working.

ΔH_c of $CS_2(l)$ ..... kJ mol^{-1} **[2]**

(c) Hydrogen sulfide gas, $H_2S(g)$, is slightly soluble in water. It acts as a weak acid in aqueous solution.

(i) State the meaning of *weak acid*.

..... [1]

(ii) Give the formula of the conjugate base of H_2S.

..... [1]

(iii) $H_2S(aq)$ reacts slowly with oxygen dissolved in water. The reaction is represented by the following equation.

$$H_2S(aq) + \tfrac{1}{2}O_2(aq) \rightarrow H_2O(l) + S(s)$$

Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

.....

..... [2]

(d) The compound As_2S_3 is a common mineral.

When As_2S_3 is heated strongly in air, it forms a mixture of products, as shown.

$$2As_2S_3(s) + 9O_2(g) \rightarrow As_4O_6(s) + 6SO_2(g)$$

(i) A sample containing 0.198 g As_2S_3 is placed in 0.100 dm^3 of pure oxygen, an excess, in a reaction chamber connected to a gas syringe at room temperature.

The reactants are heated until no further change is observed. The products are then allowed to cool to room temperature.

Calculate the volume, in dm^3, of gas present at the end of the experiment.

The molar volume of gas is 24.0 dm^3 mol^{-1} under these conditions. Assume that the pressure is constant throughout the experiment.

Show your working.

volume of gas remaining = ... dm^3 [4]

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(ii) State the environmental consequences of releasing $SO_2(g)$ into the atmosphere.

..... [1]

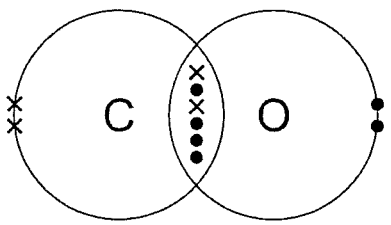
(iii) $SO_2(g)$ can be removed from the air by reacting it with NaOH(aq).
Construct an equation for the reaction of $SO_2(g)$ with NaOH(aq). Include state symbols.

..... [2]

2. M/J 21/P21/Q2

Carbon monoxide gas, CO(g), and nitrogen gas, $N_2(g)$, are both diatomic molecules.

(a) The diagram shows the arrangement of outer electrons in a molecule of CO(g).



(i) State **one** similarity and **one** difference in the way the atoms in a carbon monoxide molecule are bonded together compared to the atoms in a nitrogen molecule.

.....

..... [2]

(ii) The table states the electronegativity values of carbon, nitrogen and oxygen atoms.

	C	N	O
electronegativity	2.5	3.0	3.5

Use the electronegativity values and relevant details from the *Data Booklet* to complete the table below.

	N_2	CO
number of electrons per molecule		
type(s) of intermolecular (van der Waals') force		

[2]

(b) $N_2(g)$ is less reactive than CO(g) even though $N_2(g)$ has a lower bond energy than CO(g).
Suggest why CO(g) is more reactive than $N_2(g)$.

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

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(c) Both carbon monoxide and nitrogen are gases at room temperature and pressure.
They both behave like ideal gases under certain conditions.

(i) State the **two** conditions necessary for these two gases to approach ideal gas behaviour.

..... [1]

(ii) Explain why $N_2(g)$ behaves more like an ideal gas than CO(g) does at 20.0 °C and 101 kPa.

.....

..... [2]

(d) Calculate the amount, in mol, of pure nitrogen gas which occupies 100cm^3 at 101 kPa and 20.0 °C.
Use relevant information from the *Data Booklet*. Show your working.
Assume nitrogen behaves as an ideal gas.

..... mol [3]

3. O/N 20/P21/Q2, O/N 20/P23/Q2

Phosphorus, sulfur and chlorine can all react with oxygen to form oxides.

(a) Phosphorus reacts with an excess of oxygen to form phosphorus(V) oxide.

(i) Write an equation to show the reaction of phosphorus with excess oxygen.

..... [1]

(ii) Describe the reaction of phosphorus(V) oxide with water.

.....

..... [2]

(iii) State the structure and bonding of solid phosphorus(V) oxide.

..... [1]

(b) The two most common oxides of sulfur are SO_2 and SO_3.
When SO_2 dissolves in water, a small proportion of it reacts with water to form a weak Brønsted-Lowry acid.

(i) Explain the meaning of the term *weak Brønsted-Lowry acid*.

.....

..... [2]

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(ii) Write the equation for the reaction of SO_2 with water.

..... [1]

(iii) SO_2 reacts with NO_2 in the atmosphere to form SO_3 and NO.

NO is then oxidised in air to form NO_2.

$$SO_2 + NO_2 \rightarrow SO_3 + NO$$

$$2NO + O_2 \rightarrow 2NO_2$$

State the role of NO_2 in this two-stage process.

..... [1]

(c) Emissions of SO_2 from coal-fired power stations can be reduced by mixing the coal with powdered limestone.
Limestone is heated to form CaO in reaction 1. This then reacts with SO_2 and O_2 to form $CaSO_4$ in reaction 2.

reaction 1: $CaCO_3(s) \rightarrow CaO(s) + CO_2(s)$

reaction 2: $CaO(s) + SO_2(g) + \frac{1}{2}O_2(g) \rightarrow CaSO_4(s)$

(i) State the type of reaction occurring in reaction 1.

..... [1]

(ii) Use the data to calculate the enthalpy change of reaction 2.

compound	ΔH_f / kJ mol^{-1}
CaO(s)	–635
$SO_2(g)$	–297
$CaSO_4(s)$	–1434

enthalpy change of reaction 2 ..... kJ mol^{-1} **[2]**

(d) Chlorine forms several oxides, including Cl_2O, ClO_2 and Cl_2O_6.

(i) Draw a 'dot-and-cross' diagram of Cl_2O. Show outer-shell electrons only.

[1]

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(ii) ClO_2 can be prepared by reacting $NaClO_2$ with Cl_2.

Write the oxidation state of chlorine in each species in the boxes provided.

$$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + 2NaCl$$

oxidation state of chlorine: | +3 | | | |

[1]

(iii) $Cl_2O_6(g)$ is produced by the reaction of $ClO_2(g)$ with $O_3(g)$.

$$2ClO_2(g) + 2O_3(g) \rightleftharpoons Cl_2O_6(g) + 2O_2(g) \qquad \Delta H \ -216\,kJ\,mol^{-1}$$

The reaction takes place at 500 K and 100 kPa.

State and explain the effect on the yield of $Cl_2O_6(g)$ when the experiment is carried out:

- at 1000 K and 100 kPa

.....

.....

.....

.....

- at 500 K and 500 kPa.

.....

.....

.....

.....[4]

(e) Element **E** is a Period 5 element.

E reacts with oxygen to form an insoluble white oxide that has a melting point of 1910°C. The oxide of **E** conducts electricity only when liquid.

E also reacts readily with $Cl_2(g)$ to form a white solid that reacts exothermically with water. The resulting solution reacts with aqueous silver nitrate to form a white precipitate that dissolves in dilute ammonia.

(i) Suggest the type of bonding shown by the **oxide** of **E**. Explain your answer.

.....

..... [2]

(ii) Suggest the type of bonding shown by the **chloride** of **E**. Explain your answer.

.....

..... [2]

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4. M/J 19/P23/Q4

Release of sulfur dioxide, SO_2, into the atmosphere causes acid rain.

(a) Explain why high levels of SO_2 may be found in the atmosphere near power stations that burn fossil fuels.

.....

.....[2]

(b) The SO_2 released can be converted in the atmosphere into sulfuric acid, H_2SO_4, by reaction with nitrogen dioxide gas, NO_2, and water, H_2O.

$$SO_2 + NO_2 \rightarrow NO + SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

During one year, 1590 tonnes of SO_2 was released into the atmosphere by a fossil-fuel burning power station.

(i) Use the equations to calculate how many tonnes of H_2SO_4 were formed in the atmosphere. Assume that all of the SO_2 released was converted into H_2SO_4.

mass of H_2SO_4 = ... tonnes **[2]**

(ii) Describe how NO_2 is also produced by these power stations.

.....

..... [2]

(iii) State one natural cause of NO_2 being formed in the atmosphere.

..... [1]

(iv) Explain why NO_2 can be described as a catalyst in the oxidation of atmospheric SO_2.

.....

..... [2]

5. 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.

.....

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.....

..... [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]

6. 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]

(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]

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(c) Explain why sulfur dioxide is used as an additive in some foods and wines.

.....

..... [2]

7. 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]**

(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]**

8. 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]

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9. 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.

.....

.....

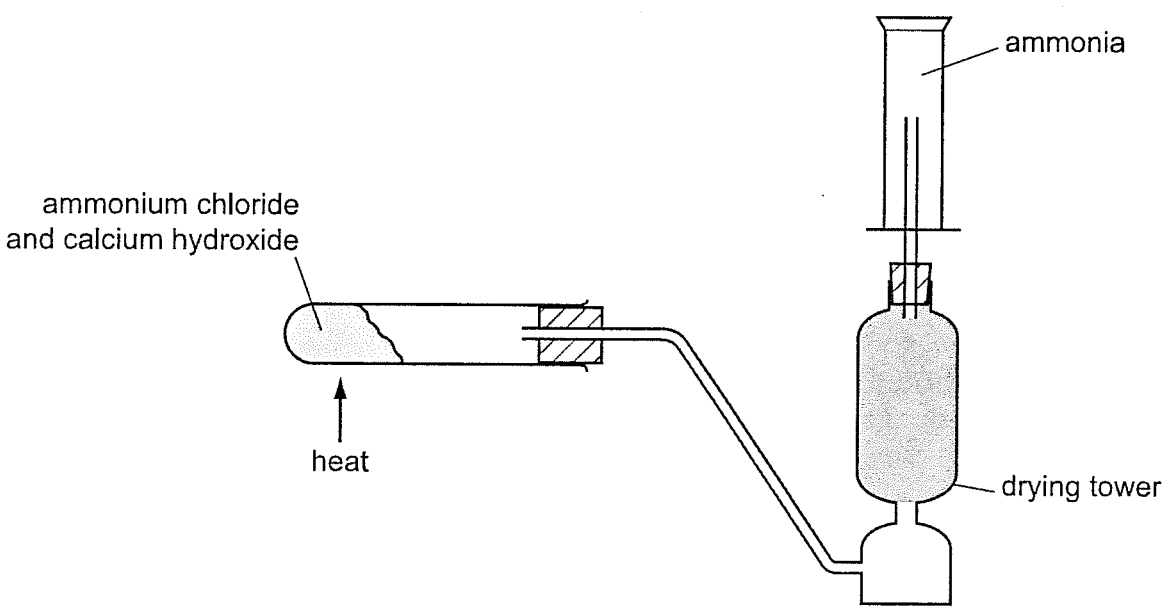
.....

(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.

.....

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(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]

10. 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.

.....

(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]**

11. 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]**

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(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.

$$.....H_2S + ...O_2 \rightarrow .....SO_2 + ...H_2O$$

(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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12. 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 .....

.....

NO .....

.....

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(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]

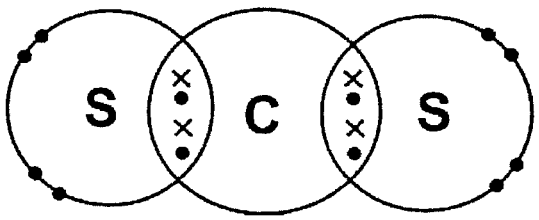
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Answers Section

1. O/N 21/P21/Q1, O/N 21/P23/Q1

(a) (i) easily vaporised / easily evaporates / turns to gas easily **1**

(ii) **2**



M1 bonding pairs
M2 Correct number of remaining outer electrons

(iii) 180° **1**

(iv) **M1** CS_2 has more electrons **2**
M2 So stronger induced dipole (forces) (between molecules)

(b) (i) **M1** (enthalpy/energy change when) 1 mole of a compound **2**
M2 *burns/combusts/reacts in* ***excess*** *oxygen/O_2*
OR
completely *burns/* ***completely*** *combusts/****completely*** *reacts in oxygen/O_2*

(ii) **M1** (–394 +**2** (–297) – (+89.7) **2**
M2 = –1080 (kJ mol^{-1})

(c) (i) *weak [acid]* **1**
partially dissociates/partially ionises (into H^+ ions/protons)

(ii) HS^- **1**

(iii) **M1** S (increases) oxidation number –2 → 0 so oxidation / or is oxidised **2**
M2 O (decreases) O.N. 0 → –2 so reduction / is reduced

(d) (i) **M1** moles of As_2S_3 = 0.198 / 246.1 / 8.05×10^{-4} **4**

M2 moles SO_2 (using moles of As_2S_3 as limiting factor) = $2.41(36) \times 10^{-3}$ moles ($6 / 2 \times 8.05 \times 10^{-4}$)

Volume SO_2 = $2.41(36) \times 10^{-3} \times 24$ = 0.0579 dm^3

M3 Moles O_2 used in reaction = $8.05 \times 10^{-4} \times 9 / 2 = 3.62 \times 10^{-3}$
Volume O_2 used in reaction = $3.62 \times 10^{-3} \times 24$ = 0.0869 dm^3

M4 Final total volume gas = (0.1 – 0.0869) + 0.0579 =
[0.0131 + 0.0579] = <u>0.071</u>(0) dm^3

M4 ONLY award 4th mark if the final answer rounds to <u>0.071</u>
Answer to minimum of 2 sig figs

MAX 3 for using ecf from M1 to M2 to M3 and M4

Award all 4 marks if final answer rounds to 0.071

(ii) acid rain

(iii) **M1** $SO_2(g) + 2NaOH(aq) \rightarrow Na_2SO_3(aq) + H_2O(l)$ **AND** **2**
correct species and balancing

M2 State symbols

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2. M/J 21/P21/Q2

(a) (i) **M1** both make triple (covalent) bond / 3 shared pairs of electrons **1**

M2 one bond in CO is coordinate / dative covalent / formed by donating a pair of electrons from O (to C) **1**

(ii) **2**

	N_2	CO
number of electrons per molecule	14	14
type of van der Waals'	temporary / instantaneous dipole–induced dipole	permanent dipoles–(permanent) dipoles (and temporary / induced / instantaneous dipoles)

(b) CO / it is a polar molecule / it has a (permanent) dipole (but N_2 is non-polar) **1**

(c) (i) high temperature AND low pressure **1**

(ii) **M1** CO is polar / has a permanent dipole OR N_2 is non-polar **1**

M2 IMF in CO are (more) significant / larger OR IMF in N_2 are smaller / less significant **1**

Alternative answer

M1 (Size of) N_2 smaller than CO
OR volume of N_2 molecules / particles smaller

Alternative answer

M2 volume of N_2 molecules / particles is more negligible
ORA

(d) **M1** correct conversion to consistent units **1**

P = 101 000 V = 100 / 1 000 000 = (1×10^{-4}) T = 293

M2 use of all values from M1 in correct relationship, n = PV / RT **1**

M3 calculation = 4.15×10^{-3} mol **1**

3. O/N 20/P21/Q2, O/N 20/P23/Q2

(a) (i) $P_4 + 5O_2 \rightarrow P_4O_{10}$ **1**

(ii) any **two** from: **2**

- reacts vigorously
- solid disappears / colourless solution forms
- hydrolysis
- exothermic
- acid(ic) (solution)
- steamy / misty fumes

(iii) Simple and covalent OR molecular and covalent **1**

(b) (i) **M1:** proton / H^+ donor **2**

M2: partially dissociates (in solution)

(ii) $SO_2 + H_2O \rightarrow H_2SO_3$ **1**

(iii) (homogeneous) catalyst **1**

1

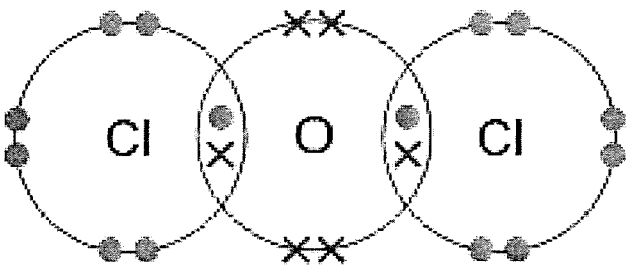
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(c) (i) **thermal** decomposition

(ii) **M1:** $\Delta H_r = -1434 - (-635 + -297)$ **2**

M2: $= -502$ (kJ mol^{-1})

(d) (i) **1**



(ii)

0	(+)4	–1

1

(iii) ***(at 1000 K and 100 kPa)*** **4**

M1: (yield) **decreases**

M2: reaction is exothermic **AND** equilibrium moves **left**

(at 500 K and 500 kPa)

M3: (yield) **increases**

M4: fewer moles (<u>of gas</u>) on right-hand side **AND** equilibrium moves right

(e) (i) **M1:** ionic **2**

M2: ions only able / free to move / free to conduct (when liquid / molten)

(ii) **M1:** covalent **2**

M2: hydrolysed (by water)

4. M/J 19/P23/Q4

(a) **M1** sulfur impurities OR sulfur in fossil fuels **2**

M2 converted into SO_2 by combustion / burning sulfur

OR

heat sulfur with oxygen (from the air)

(b) (i) **M1** 1 mol SO_2 → 1 mol H_2SO_4 **2**

64.1 g / tonne → 98.1 g / tonne

M2 SO_2 → 98.1 / 64.1 . 1590 = 2433.369735 tonnes

(ii) high (enough) temperature / (a lot of) heat (energy) is produced **2**

AND

to break (strong) triple bond in N_2 / break N≡N

AND

nitrogen (and oxygen) from the air / atmosphere react

Award two marks for three correct points

Award one mark for two correct points

(iii) lightning **1**

(iv) **M1** nitrogen dioxide increases the rate **2**

OR

lowers the activation energy

M2 (NO_2) is regenerated by reaction of NO with O_2 (in the air)

OR

NO (formed) reacts with O_2 (in air) to (re)form NO_2

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5. O/N 15/P21/Q2/d, O/N 15/P23/Q2/d

(a) (i) nitrates / fertilisers wash into rivers
eutrophication / algal bloom / promote algal growth
bacteria use up oxygen in decay process **[3]**

(ii) (oxides of nitrogen/ NO_x / NOs) cause acid rain
$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$
OR
$4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$
OR
$SO_2 + NO_2 \rightarrow SO_3 + NO$ AND $SO_3 + H_2O \rightarrow H_2SO_4$ **[2]**

6. M/J 15/P22/Q2/b,c,d

(a) (i) T = 400 – 600 °C (chosen as a compromise because)
High T increases rate ora
High T decreases yield / moves eqm left / makes less SO_3 as forward reaction exothermic ora **[3]**

(ii) High pressure increases rate as collision frequency increases ora
High pressure moves eqm right / favours forward reaction as more moles on left ora
Uneconomic to use high pressures / high yield at low pressure **[3]**

(b) (i) Reaction (too) exothermic / acid spray produced **[1]**

(ii) $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$
$H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$ **[2]**

(c) Preservative owtte
antimicrobial/antioxidant/reducing agent **[2]**

7. M/J 15/P21/Q2/c

(a) (i) strong <u>triple</u> bond **[1]**

(ii) high temperature (needed for reaction between N_2 and O_2) **[1]**

(iii) $2NO + 2CO \rightarrow N_2 + 2CO_2$
OR $2NO + C \rightarrow N_2 + CO_2$ **[1]**

(iv) $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$ **[1]**

(v) $NO + \frac{1}{2}O_2 \rightarrow NO_2$
$NO_2 + SO_2 \rightarrow NO + SO_3$
OR $NO_2 + SO_2 + H_2O \rightarrow NO + H_2SO_4$ **[2]**

8. M/J 13/P21/Q1/b,c

(a) fertiliser in the river causes
excessive growth of aquatic plants/algae **or** algal bloom
when plants and algae die O_2 is used up **or** fish or aquatic life die **[2]**

(b) manufacture of HNO_3 **or** explosives **or** nylon **or**
as a cleaning agent **or** as a refrigerant
not detergent **[2]**

9. 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**
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
state symbols required

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(ii) **pressure** between 60 and 250 atm **or**
between 60×10^5 Pa and 250×10^5 Pa

temperature between 300 and 550 °C

catalyst iron / iron oxide

(iii) manufacture of HNO_3 / as a cleanin g agent / refrigerant / fertiliser / manufacture of fertilisers / explosives / to remove SO_2 from combustion products of hydrocarbon fuels **[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
it is not an acid / it is basic / it does not react with NH_3 **or**
both P O / P O **and** H SO are acidic / react with NH **[3]**

10. 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

(ii) H_2SO_4
or
SO_3 allow H_2SO_3 **formula required**

(iii) acid rain
or
its consequences e.g. damage to buildings,
damage to crops, plants, marine life
deforestation
or
SO_3 is toxic **[2]**

(b) it is a reducing agent/antioxidant
or
it kills bacteria **[1]**

11. O/N 10/P23/Q2

(a) 1 $S + O_2 \rightarrow SO_2$ (1)

2 $2SO_2 + O_2 \rightleftharpoons 2SO_3$ equation
equilibrium sign

3 $SO_3 + H_2O \rightarrow H_2SO_4$ **or**
$SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ **[4]**

(b) condition 1 400 – 600 °C (650 – 900K)
condition 2 1–10 atm/just above atmospheric pressure
allow equivalent pressure units
condition 3 vanadium pentoxide/vanadium(V) oxide/V_2O_5 **[3]**

(c) fertilisers/phosphates/ammonium sulfate **or**
lead/acid batteries **or** paints/pigments **or** dyestuffs **or**

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steel pickling **or** metal treatment **or** detergents **or** explosives **[1]**

(d) **(i)** $2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$

(ii) H_2S –2 SO_2 +4 S 0 **all three**
SO_2 **because** the oxidation number of S is reduced **[3]**

(e) **(i)** $2NO + O_2 \rightarrow 2NO_2$ (1)
$SO_2 + NO_2 \rightarrow SO_3 + NO$
$SO_3 + H_2O \rightarrow H_2SO_4$
final product must be H_2SO_4

(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 **[4]**

(f) it is a reducing agent/inhibits oxidation **[1]**

12. O/N 10/P21/Q2, O/N 10/P22/Q2

(a) $N_2 + 3H_2 \rightleftharpoons 2NH_3$ **[1]**

(b) temperature between 300 and 550°C
correct explanation of effect of temperature on
rate of formation of NH_3 **or** on position of equilibrium

(c) manufacture of HNO_3
or explosives
or nylon
or as a cleaning agent
or as a refrigerant [1]

(d) fertiliser in rivers causes excessive growth of aquatic plants/algae
when plants and algae die O_2 is used up/fish or aquatic life die **[2]**

(e) **(i)** CO by incomplete combustion of the hydrocarbon fuel
NO by reaction between N_2 and O_2 in the engine

(ii) CO toxic/effect on haemoglobin
NO toxic/formation of acid rain **[4]**

(f) **(i)** platinum/Pt – allow palladium/Pd **or** rhodium/Rh

(ii) $2CO + 2NO \rightarrow 2CO_2 + N_2$ **[2]**

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Unit 13

AN INTRODUCTION TO ORGANIC CHEMISTRY

Chemistry Paper-2
Topical Workbook
Article Number: 232

Editorial Board

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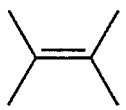
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Unit 13: An Introduction To Organic Chemistry

1. O/N 21/P22/Q3

Compound **T** is an isomer of C_6H_{12}.

T



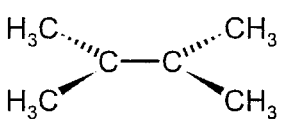
(a) Name **T**.

.....[1]

(b) Draw the skeletal formula of a structural isomer of **T** that shows *cis-trans* (geometrical) isomerism.

[1]

(c) Each carbon atom in **T** forms a sigma (σ) bond to at least one other carbon atom, as shown.

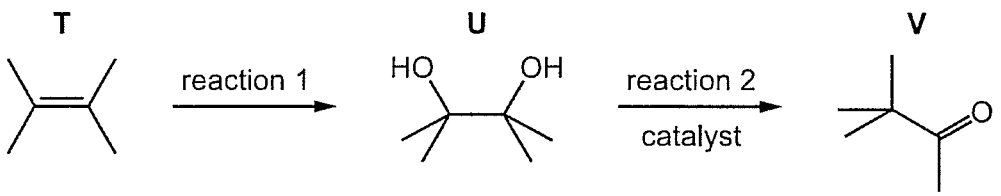


(i) On the diagram, draw the orbitals that represent the pi (π) bond that is also present in **T**.
[1]

(ii) State the hybridisation of the two carbon atoms between which the pi (π) bond forms.

.....[1]

(d) A reaction scheme starting with **T** is shown. Reaction 2 occurs in the presence of a catalyst; knowledge of the mechanism for this reaction is not required.



(i) Give the reagent(s) and conditions for reaction 1.

.....[1]

(ii) State and explain how 2,4-dinitrophenylhydrazine (2,4-DNPH) can be used to detect the presence of **V** as a product of reaction 2.

.....

.....[2]

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(iii) The progress of reaction 2 can be monitored by infrared spectroscopy.

The absorption caused by O–H bonds is always present because water is used as a solvent.

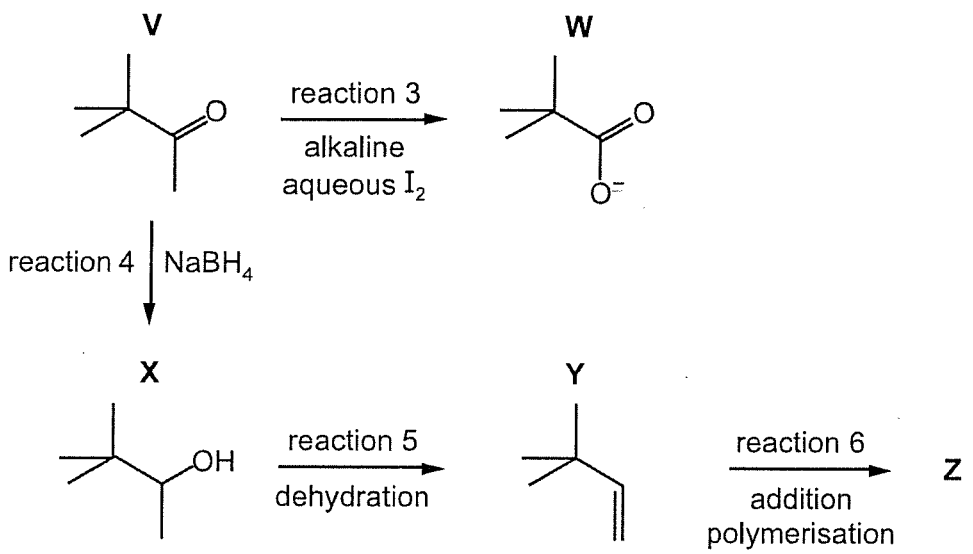
Identify two absorptions, and the bonds responsible for these absorptions, whose appearance will change significantly during the reaction.

1 .....

2 ..... [2]

(e) **V** is used in a wide range of organic reactions.

Some reactions of **V** are shown.



(i) **V** and **W** are colourless and soluble in water.

State what you would observe in reaction 3.

.....[1]

(ii) Reaction 3 is a redox reaction.

Identify which of the **reactants** is reduced in this reaction.

..... [1]

(iii) Construct an equation for reaction 4.

Use [H] in the equation to represent an atom of hydrogen from $NaBH_4$.

$C_6H_{12}O$ + ... [1]

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(iv) **X** is a mixture of two optical isomers.
Draw the two optical isomers in the boxes provided.

[2]

(v) Both optical isomers of **X** can be dehydrated to form a single product, **Y**.
Give the reagent(s) and conditions required for reaction 5.

.....[1]

(vi) **Y** can form an addition polymer **Z**.
Draw one repeat unit of **Z**.

[1]

(vii) Reaction 6 does not proceed quickly at room temperature.
Suggest why this is the case.

.....[1]

2. O/N 21/P21/Q3, O/N 21/P23/Q3

Phosphorus is a reactive Period 3 element.

(a) Phosphorus has several allotropes. Details of two allotropes are given.

allotrope of phosphorus	formula	melting point/°C
white	P_4	44
red	P	590

(i) White phosphorus and red phosphorus both have covalent bonding.
Suggest the types of structure shown by white phosphorus (P_4) and red phosphorus (P).
Explain why red phosphorus (P) has a higher melting point than white phosphorus (P_4).

structure of P_4 .....

structure of P .....

explanation .....[3]

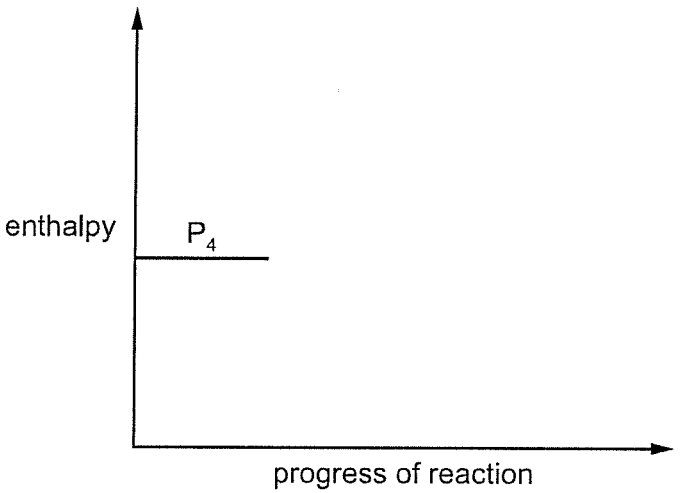
(ii) Red phosphorus (P) forms when white phosphorus (P_4) is exposed to sunlight.

$$\tfrac{1}{4}P_4(s) \rightarrow P(s) \qquad \Delta H = -17.6\,kJ\,mol^{-1}$$

white red

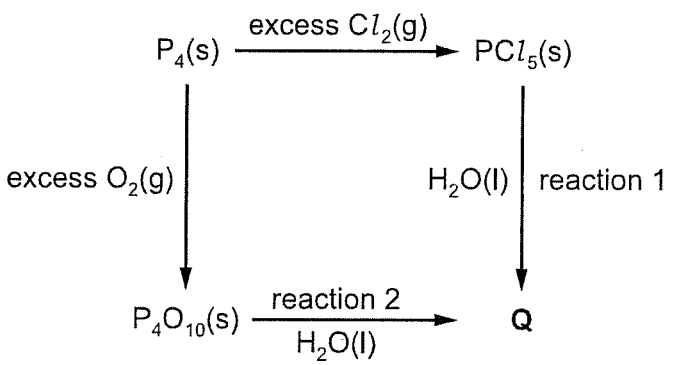
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Use this information to draw a reaction pathway diagram to show the formation of red phosphorus (P) from white phosphorus (P_4).



[1]

(b) Some reactions of $P_4(s)$ are shown in the reaction scheme.



(i) State the oxidation number of phosphorus in P_4O_{10}.

.....[1]

(ii) Deduce the identity of **Q** and hence construct chemical equations for reactions 1 and 2.

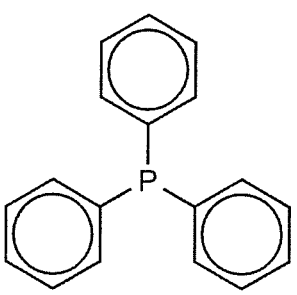
reaction 1 PCl_5 + ...H_2O → .....

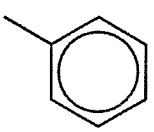
reaction 2 P_4O_{10} + ...H_2O → .....

[2]

(c) Triphenylphosphine is used in a type of reaction known as a *Wittig reaction*.

triphenylphosphine



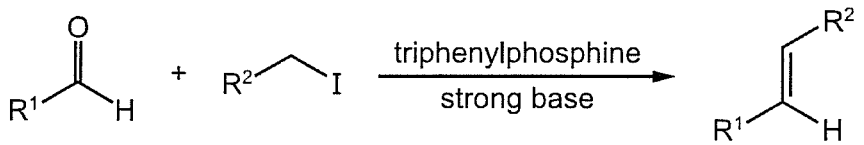
where  = $-C_6H_5$

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(i) Give the empirical formula of triphenylphosphine.

.....[1]

In a Wittig reaction, an aldehyde reacts with a halogenoalkane to form an alkene. The conversion is shown in the following unbalanced equation.



Compound **H** can be made from propanal, C_2H_5CHO. Stage 3 in the reaction scheme is a Wittig reaction.

stage 1 $C_2H_5CHO \xrightarrow{NaBH_4} \mathbf{G}$

stage 2 $\mathbf{G} \xrightarrow{\text{red phosphorus and } I_2} C_2H_5CH_2I$

stage 3 (Wittig reaction) $C_2H_5CH_2I + C_2H_5CHO \xrightarrow[\text{strong base}]{\text{triphenylphosphine}} \mathbf{H}$

(ii) State the types of reaction that occur in stages 1 and 2.

stage 1 .....

stage 2 .....[2]

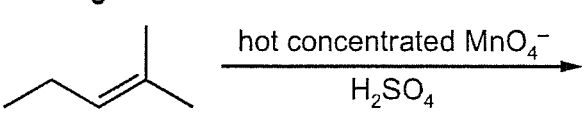
(iii) Draw the structures of **G** and **H** in the boxes provided.

G	**H**

[2]

(d) Identify the organic products formed when compound **J**, shown below, is heated with hot concentrated acidified manganate(VII) ions.

J



[2]

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3. M/J 20/P21/Q5

(a) Below is a list of species which can react with organic compounds.

CN^- HCl Cl H_2O CO_3^{2-}

(i) From the list, identify a species which can react with ethane.

.....[1]

(ii) From the list, identify **two** species which can attack the π bond in ethene.

.....[1]

(iii) From the list, identify a species which can be used to distinguish between solutions of propanoic acid and propan-1-ol. Describe any relevant observations.

.....

.....[2]

(b) Cl(g) can be made from Cl_2(g).

(i) Describe the conditions required for this process.

.....[1]

(ii) Name this process.

.....[1]

(c) (i) Name an organic functional group which reacts with a nucleophile in an addition reaction.

.....[1]

(ii) Name an organic functional group which tends to react with a nucleophile in an S_N1 substitution mechanism.

.....[1]

(d) But-1-ene reacts with steam in the presence of concentrated phosphoric acid to form two isomers of molecular formula $C_4H_{10}O$.

Each reaction occurs via a different intermediate ion.

(i) Draw the structure of both intermediate ions.

[2]

(ii) Circle the more stable intermediate ion drawn in **(d)(i)**. Explain your answer.

.....

.....[2]

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4. M/J 20/P23/Q4

Hexane, C_6H_{14}, is a colourless liquid.

Two test-tubes contain equal amounts of hexane. 1 cm^3 of bromine, $Br_2(aq)$, is added to both test-tubes. One test-tube is kept in the dark and the other is exposed to sunlight.

The table describes the appearance of each test-tube after one hour.

test-tube conditions	observations
in the dark	no change, mixture remains orange
in sunlight	colour of mixture fades to pale yellow

(a) The test-tube in the dark is kept cool and is not exposed to ultraviolet light.

Explain the observations for the test-tube kept in the dark.

.....

..... [2]

(b) In sunlight, bromine reacts with hexane by a mechanism which occurs via a series of steps.

(i) State the name of the mechanism of the reaction that occurs.

..... [1]

(ii) Give an equation which shows a propagation step in this reaction in which hexane produces $\bullet C_6H_{13}$.

..... [1]

(iii) Give an equation which shows a propagation step in this reaction that produces 1-bromohexane.

..... [1]

(iv) Give an equation which shows a termination step in this reaction that produces 1-bromohexane.

..... [1]

(c) **A** and **B** are different straight chain alkenes with molecular formula, C_6H_{12}.

A does not show stereoisomerism.

A reacts with potassium manganate(VII) to form hexane-1,2-diol.

(i) Draw the structural formula of **A**.

[1]

(ii) State the conditions needed for this reaction of **A**.

..... [2]

(d) **B** reacts with hydrogen gas in the presence of a platinum catalyst to produce hexane.

(i) Name the type of reaction occurring.

..... [1]

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(ii) In terms of σ and π bonds, describe any similarities and differences in the type of carbon-carbon bonds in **B** and the type of carbon-carbon bonds in hexane.

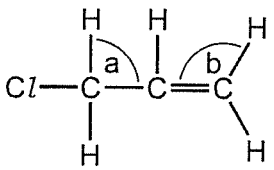
.....

..... [2]

5. M/J 19/P21/Q4

The structure of compound **Y** is shown.

Y



(a) Give the systematic name for **Y**.

..... [1]

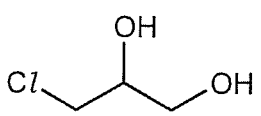
(b) Predict the values for the bond angles a and b shown in the diagram.

a .....

b ..... [2]

(c) When **Y** reacts with cold, dilute, acidified manganate(VII) ions, compound **Z** is produced.

Z



(i) State the molecular formula of **Z**.

..... [1]

(ii) Name the type of reaction occurring when **Y** is converted into **Z**.

..... [1]

(iii) Alcohols can be classified as primary, secondary or tertiary.

Identify with a tick (✓) the alcohol group(s) present in **Z**.

	alcohol group present in **Z**
primary	
secondary	
tertiary	

[1]

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(d) Samples of organic compounds, **A**, **B**, **C** and **D**, are placed in unlabelled bottles.

A	**B**	**C**	**D**
$CH_3CH_2COCH_3$	$CH_3(CH_2)_2CHO$	CH_3CH_2OH	CH_3CO_2H

(i) Identify all of the compound(s), **A–D**, that contain a carbonyl group.

..... [1]

(ii) **A–D** are reacted separately with the reagents given in the table.

Complete the table to:

- identify which of the compounds, **A–D**, reacts with the reagents
- give an appropriate observation when a reaction occurs.

reagent	compounds identified	observation when a reaction occurs
Tollens' reagent		
alkaline solution of iodine		
sodium metal		

[8]

6. M/J 19/P21/Q5

Ethanal reacts with a mixture of HCN and NaCN to make 2-hydroxypropanenitrile, $CH_3CH(OH)CN$.

The reaction mechanism is nucleophilic addition.

(a) Explain the meaning of the term *nucleophile* and identify the species which acts as the nucleophile during this reaction.

.....

species acting as nucleophile ..... [2]

(b) $CH_3CH(OH)CN$ exists as a pair of stereoisomers.

(i) Name the type of stereoisomerism shown by $CH_3CH(OH)CN$.

..... [1]

(ii) Draw three-dimensional diagrams of this pair of stereoisomers.

Indicate with an asterisk (*) the chiral centre on one of the structures drawn.

[3]

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(c) Give the structure of the organic product of the reaction of $CH_3CH(OH)CN$ with dilute sulfuric acid.

.....[1]

7. MAR 19/P22/Q1/a,b,c,d

Nitrogen, N_2, is the most abundant gas in the Earth's atmosphere and is very unreactive.

(a) State why N_2 is very unreactive.

.....[1]

(b) Magnesium and lithium both form nitrides with N_2. These compounds both contain the N^{3-} ion.

(i) Write an equation for the reaction of magnesium with N_2 to form magnesium nitride.

.....[1]

(ii) Solid lithium nitride, Li_3N, reacts with water according to the following equation.

$$Li_3N(s) + 3H_2O(l) \rightarrow 3LiOH(aq) + NH_3(aq)$$

State **one** observation you would make during this reaction.

.....[1]

(c) (i) State the industrial importance of ammonia.

.....[1]

(ii) One method of producing NH_3 is by heating ammonium chloride, NH_4Cl, with CaO.

$$2NH_4Cl + CaO \rightarrow 2NH_3 + CaCl_2 + H_2O$$

Explain why the reaction of NH_4Cl with CaO produces ammonia.

.....

.....[2]

(d) Three oxides of nitrogen, NO, NO_2 and N_2O, can be formed under different conditions.

(i) Complete the table to give the oxidation numbers of nitrogen in NO and NO_2.

compound	NO	NO_2
oxidation number of N		

[1]

(ii) NO_2 can be formed by different chemical reactions.
Write equations for the formation of NO_2 by:

- the reaction of N_2 with O_2

.....

- the thermal decomposition of magnesium nitrate.

.....[2]

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(iii) Molecules of N_2O can be formed by the reaction between N_2 and O_2. The bond between the N and O atoms (N→O) is a co-ordinate (dative covalent) bond.

$$2N_2(g) + O_2(g) \rightarrow 2N{\equiv}N{\rightarrow}O(g)$$

The enthalpy change of reaction for this reaction is +82 kJ mol^{-1}.
Calculate the bond enthalpy, in kJ mol^{-1}, of the N→O bond.
Use relevant data from the *Data Booklet* to answer this question.

bond enthalpy of the N→O bond = ... kJ mol^{-1} **[2]**

8. O/N 18/P21/Q1/c(i), O/N 18/P23/Q1/c(i)

(a) Iron pyrite is often called *fool's gold* because of its appearance. Impure samples of iron pyrite often contain a small amount of gold.
The gold can be obtained from impure iron pyrite. The impure iron pyrite is roasted in oxygen, to produce iron(III) oxide and sulfur dioxide. Gold does not react with oxygen.

(i) The sulfur dioxide produced during roasting would cause environmental consequences if released into the atmosphere.
State and explain **one** of these environmental consequences.

.....

..... [2]

9. O/N 18/P21/Q2/a(i),b,c,d, O/N 18/P23/Q2/a(i),b,c,d

(a) Nitrogen, N_2, is an inert gas that makes up 78% of the Earth's atmosphere.

(i) Explain why nitrogen is inert.

.....

..... [2]

(b) Nitrogen, N_2, and oxygen, O_2, react together in the air during lightning strikes to form nitrogen monoxide, NO.

(i) Explain why the reaction of N_2 and O_2 occurs during lightning strikes.

..... [1]

(ii) Write two equations to suggest how the NO formed reacts further to create nitric acid, HNO_3.

1 .....

2 ..... [2]

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(c) Nitrate fertilisers are used to provide nitrogen for plant growth. Uncontrolled use of these can cause a reduction in animal and plant life in natural water supplies.
Explain how uncontrolled use of nitrate fertilisers can cause this problem.

.....

.....

..... [3]

(d) Some soils have compounds such as ammonium nitrate, calcium carbonate and calcium hydroxide added to them.

(i) Suggest why calcium hydroxide is added to some soils.

..... [1]

(ii) When calcium hydroxide reacts with compounds containing the ammonium ion, NH_4^+, a gas is produced.
State the identity of this gas and explain why the reaction occurs.

gas .....

explanation ..... [2]

(iii) Another fertiliser, calcium ammonium nitrate, is formed when solid calcium carbonate is added to a mixture of aqueous ammonium nitrate and dilute nitric acid.
Suggest what would be **observed** in this reaction.

.....

..... [2]

(iv) Calcium nitrate decomposes at a higher temperature than calcium ammonium nitrate.
Write an equation for the thermal decomposition of calcium nitrate.

..... [1]

10. M/J 18/P22/Q3/c,d
Most vehicle fuels contain hydrocarbons obtained from crude oil.

(a) 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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(b) 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]

11. M/J 18/P21/Q1/d,e

Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5.

$$2\,O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2\,O{=}\overset{\overset{O}{\|}}{S}{=}O(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

The equation for this stage of the Contact Process is shown.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(a) (i) State and explain the effect of increasing temperature on the rate of production of SO_3.

.....

.....

..... [3]

(ii) State and explain the effect of increasing temperature on the yield of SO_3.

.....

.....

..... [3]

(b) The SO_3 produced is converted to sulfuric acid in two stages. In the first stage the SO_3 is reacted with concentrated sulfuric acid to produce oleum, $H_2S_2O_7$.
The oleum is then reacted with water to form sulfuric acid.

Suggest an equation for the reaction of oleum, $H_2S_2O_7$, with water to form sulfuric acid.

[1]

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12. M/J 18/P23/Q1/c

The elements sodium to chlorine, in the third period, all form oxides.

(a) SO_3 is produced by the reaction between SO_2 and O_2 in the Contact process. A dynamic equilibrium is established.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(i) Explain why increasing the total pressure, at constant temperature, increases the rate of production of SO_3 and increases the yield of SO_3.

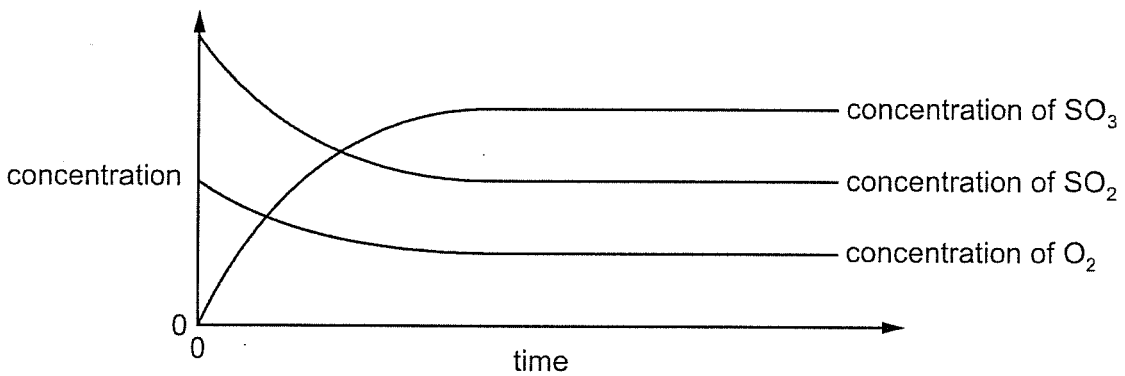
rate .....

.....

yield .....

..... [4]

The graph shows how the concentrations of all three species in the system change with time for a typical reaction mixture. The gradients of all three lines decrease with time and then level off in this dynamic equilibrium.



(ii) Explain why the gradients of the SO_2 and O_2 lines decrease with time.

.....

..... [2]

(iii) Explain why all three lines become horizontal.

..... [1]

(iv) Suggest a reason why the initial gradient of the SO_2 line is steeper than that of the O_2 line.

..... [1]

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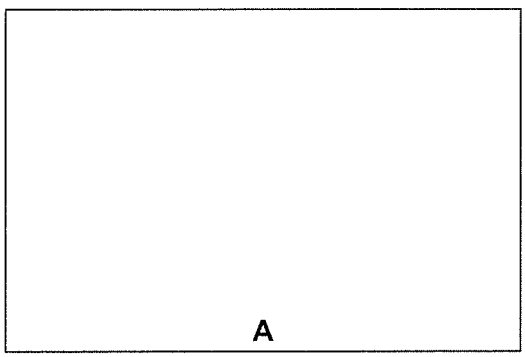
13. M/J 17/P22/Q4/a (a,b,c)

(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]**

(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]**

14. 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.

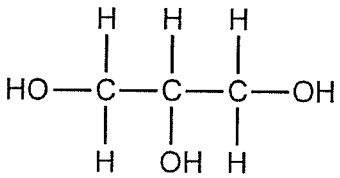
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(a) **(i)** Explain the meaning of the term *structural isomers*.

.....

.....[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

(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]

(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.

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[3]

15. 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]

(c) Only **A** shows geometrical isomerism.

(i) Explain the meaning of the term *geometrical isomerism*.

.....

..... [2]

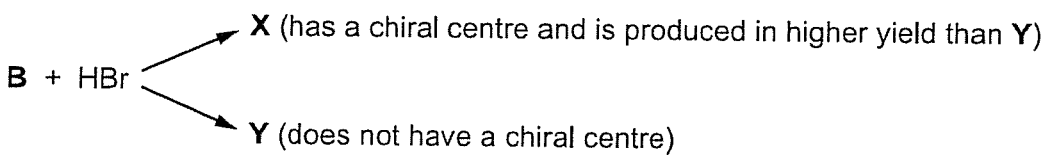
(ii) Draw the displayed formula of **A** and use it to show the mechanism of the reaction of **A** with HBr. Include all necessary charges, dipoles, lone pairs and curly arrows.

[4]

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(d) **B** does **not** show geometrical isomerism.

B reacts with HBr to form a mixture of two structural isomers, **X** and **Y**.



(i) State the meaning of the term *chiral centre*

.....[1]

(ii) Name **B**.

.....[1]

(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]

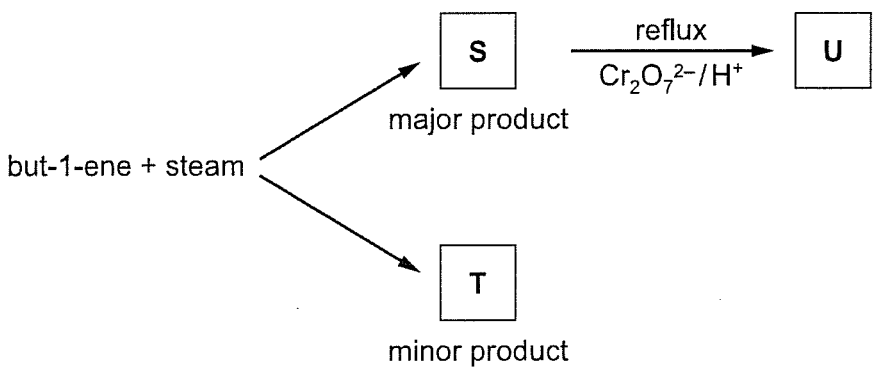
(ii) Draw the **displayed** formula of each of the structural isomers produced by the reaction of **C** with HBr.

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[2]

16. 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]

17. 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.

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organic reaction	type of reaction	reagent(s)
$CH_3CH_2CH_2CH_2Br \rightarrow$ $CH_3CH_2CH_2CH_2NH_2$		
$CH_3CH_2CH_2CH_2OH \rightarrow$ $BrCH_2CH_2CH_2CH_2OH$		
$CH_3COCH_3 \rightarrow$ $CH_3C(OH)(CN)CH_3$		
$CH_3CH(OH)CH_2CH_3 \rightarrow$ $CH_3CH=CHCH_3$		

[11]

18. 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.

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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.

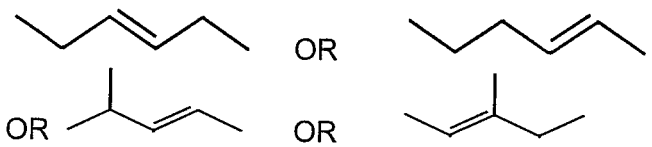
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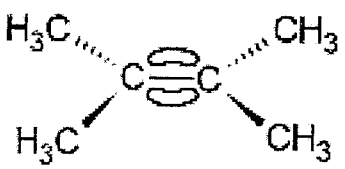
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Answers Section

1. O/N 21/P22/Q3

(a) (2,3-)dimethylbut-2-ene **1**

(b)  **1**

(c) (i)  **1**

(ii) sp^2 **1**

(d) (i) cold dilute acidified potassium manganate(VII) **1**

(ii) **M1** (2,4-DNPH will produce a) red / orange / yellow precipitate

M2 V has a carbonyl group **2**

(iii) **M1** C—O in range 1040–1300 (cm^{-1})

M2 C=O in range 1670–1740 (cm^{-1}) **2**

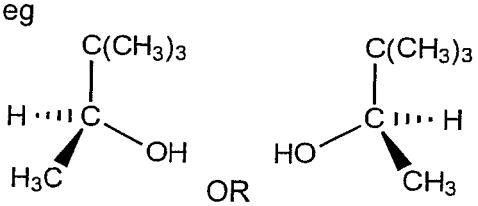
(e) (i) yellow precipitate **1**

(ii) Iodine / I_2 **1**

(iii) $C_6H_{12}O + 2[H] \rightarrow C_6H_{14}O$ **1**

(iv) Draw two optical isomers of X. **1**

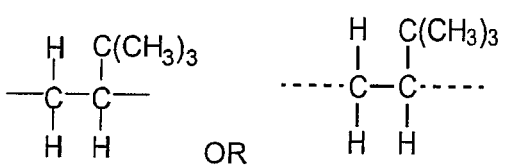
eg

 **1**

M1 *One correct 3-dimensional representation of X*

M2 *3-d structure which represents the enantiomer of their X*

(v) heat **AND** concentrated H_2SO_4 / concentrated H_3PO_4 / concentrated sulfuric [(VI)] acid / concentrated phosphoric[(V)] acid **1**

(vi)  **1**

(vii) high activation energy **1**

2. O/N 21 /P21/Q3, O/N 21 /P23/Q3

(a) (i) **M1** simple molecular

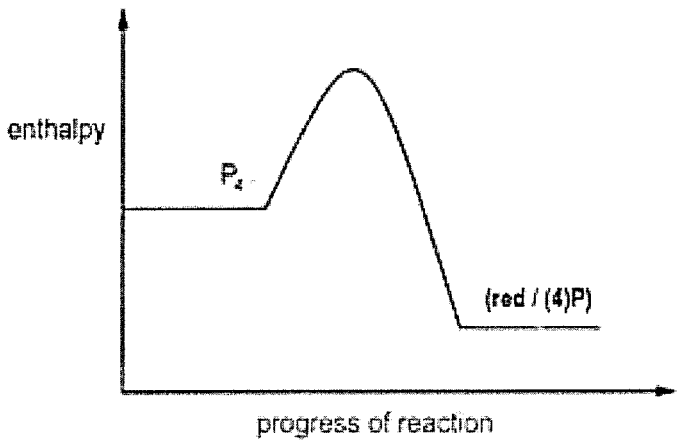
M2 giant molecular **3**

M3 weak IMFs (overcome) in P_4 **AND** strong (covalent) bonds (broken) in P

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1

(ii)



(b) (i) (+)5/V 1

(ii) $PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$ 2
$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$

(c) (i) $C_{18}H_{15}P$ 1

(ii) stage 1 = reduction 2
stage 2 = substitution

(iii)

G = $C_2H_5CH_2OH$	**H** = $C_2H_5CH{=}CHC_2H_5$

2

(d)

$CH_3CH_2CO_2H$	CH_3COCH_3

2

3. M/J 20 /P21/Q5

(a) (i) Cl 1

(ii) HCl **AND** H_2O 1

(iii) **M1** CO_3^{2-} 2
M2 propanoic acid – effervesce. (Propan-1-ol – no reaction)

(b) (i) ultraviolet light /uv 1

(ii) homolytic fission (of chlorine (gas) / Cl_2) 1

(c) (i) carbonyl / aldehyde / ketone 1

(ii) tertiary halogenoalkane 1

(d) (i) *Two structures representing the intermediate* 2
M1 $C_2H_5C^+HCH_3$
M2 $CH_3CH_2CH_2C^+H_2$

(ii) *Identify the most stable intermediate* 2
M1 $C_2H_5C^+HCH_3$
explanation
M2 (more / 2 alkyl groups attached so) it has the greater inductive / electron donating effect

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4. M/J 20 /P23/Q4

(a) **M1** (no reaction) not enough energy **2**

M2 bromine (free) radicals are not produced OR homolytic fission of bromine does not occur.

(b) (i) free-radical substitution **1**

(ii) $C_6H_{14} + (\cdot)Br \rightarrow (\cdot)C_6H_{13} + HBr$ **1**

(iii) $(\cdot)C_6H_{13} + Br_2 \rightarrow C_6H_{13}Br + (\cdot)Br$ **1**

(iv) $(\cdot)C_6H_{13} + (\cdot)Br \rightarrow C_6H_{13}Br$ **1**

(c) (i) $CH_3(CH_2)_3CH=CH_2$ **1**

(ii) cold **AND** acidified **AND** dilute **2**

2 marks for 3 correct conditions
1 mark for 2 correct conditions

(d) (i) addition **OR** reduction **1**

(ii) **M1** only sigma / σ (bonds) in hexane / alkanes **2**
M2 B has sigma σ (bonds) and a / one pi / π (bond)

5. M/J 19 /P21/Q4

(a) 3-chloroprop-1-ene **1**

(b) *a* = 109(.5)° **1**

b = 120° **1**

(c) (i) $C_3H_7ClO_2$ **1**

(ii) oxidation **1**

(iii) **1**

	alcohol group present in Z
primary	✓
secondary	✓
tertiary	

(d) (i) A and B **1**

(ii)

	Compound(s)	Observation
Reaction with Tollens' reagent	B ✓	silver mirror OR grey / black / brown / silver precipitate ✓

2

	Compound(s)	Observation
Reaction with alkaline aq. iodine	A ✓ and C ✓	(Pale) yellow precipitate /solid ✓

3

	Compound(s)	Observation
Reaction with sodium metal	C ✓ and D✓	Effervescence / sodium/solid disappears ✓

3

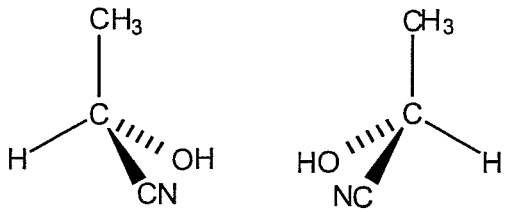
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6. M/J 19 /P21/Q5

(a) **M1** a lone pair / electron pair donor **1**

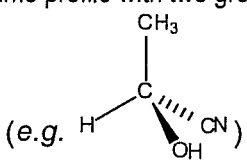
M2 (:)CN–/–(:)CN / cyanide ion **1**

(b) (i) optical **1**

(ii)  **1**

M1 one 3-D structure of **correct** molecule shown.

M2 a mirror image of the molecule drawn in **M1 OR** same profile with two groups swapped **1**

(*e.g.* )

M3 central chiral C shown as * **1**

(c) $CH_3CH(OH)CO_2H$ **OR** $HO_2CCH(OH)CH_3$ **1**

7. MAR 19 /P22/Q1/a,b,c,d

(a) strong triple bond/ strong N≡N **1**
OR high activation energy / E_a
OR non-polar

(b) (i) $3Mg + N_2 \rightarrow Mg_3N_2$ **1**

(ii) solid disappears **1**

(c) (i) (it is used to make) fertilisers **1**

(ii) **M1** CaO displaces NH_3 (from its salt / NH_4^+) **2**

M2 CaO is a stronger base / more basic (than NH_3)

(d) (i) **1**

NO	NO_2
(+)2 / (+)II	(+)4 / (+)IV

(ii) **M1** $\frac{1}{2}N_2 + O_2 \rightarrow NO_2$ **2**

M2 $Mg(NO_3)_2 \rightarrow MgO + 2NO_2 + \frac{1}{2}O_2$

(iii) **M1** $+82 (= E_{o=o} - 2E_{N\rightarrow O}) = (+)496 - 2 \times E_{N\rightarrow O}$ **2**

M2 $E_{N\rightarrow O} = \frac{1}{2} \times (496–82) = \frac{1}{2} \times 414 = 207$ (kJ mol^{-1})

8. O/N 18 /P21/Q1/c(i), O/N 18 /P23/Q1/c(i)

(a) (i) **M1** <u>acid rain</u> **2**

M2

- destroys / damages / weathers / erodes / buildings / statues
- kills/harms fish / coral / plants / crops / trees / deforestation
- leaches salts / ions (aluminium) from soil (into rivers / lakes)
- leaches away soil nutrients
- breathing difficulties

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- lowers pH / increases acidity of soil / rivers / oceans / seas

9. O/N 18 /P21/Q2/a(i),b,c,d, O/N 18 /P23/Q2/a(i),b,c,d

(a) (i) 1 mark for each bullet, max 2 **2**
- triple bond
- non-polar / no dipole
- needs a lot of energy to break / strong

(b) (i) (lightning) provides the (high) activation energy **1**

(ii) **M1** $NO + \frac{1}{2}O_2 \rightarrow NO_2$ **2**

M2 $2NO_2 + H_2O + \frac{1}{2}O_2 \rightarrow 2HNO_3$

(c) **M1** **3**
fertiliser / nitrates dissolve in (river / ground water)
OR
fertiliser / nitrates are washed / leached out / flows into (river/groundwater)

M2 algal bloom / promote algal growth / explosion of plant growth
AND
sunlight is blocked out (preventing photosynthesis) / plants can no longer carry out photosynthesis (and die)
AND
bacteria break down or decay **dead** organisms /plants / algae
M3 drop in oxygen (concentration)

(d) (i) to increase / raise pH **1**

(ii) **M1** ammonia / NH_3 **2**
M2 displaces NH_3

(iii) **M1** effervescence / fizzing / bubbling **2**
M2 solid disappears

(iv) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$ **1**

10. M/J 18 /P22/Q3/c,d

(a) (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

(b) (i) *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

(ii) $NO_2 + SO_2 \rightarrow NO + SO_3$ **1**

$SO_3 + H_2O \rightarrow H_2SO_4$ **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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11. M/J 18 /P21/Q1/d,e

(a) (i) Increases rate **AND** explanation re collisions **1**

By increasing number / proportion of / more molecules / particles / species with $E \geqslant E_a$ **1**

(So) increases frequency of successful collisions / more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time **1**

(ii) (Increasing T) decreases yield (of SO_3) **1**

(Forward) reaction is exothermic (or reverse argument) **1**

So increasing T shifts (equilibrium) reaction to left / towards reactants / in endothermic direction (to oppose the change in T) **1**

(b) $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$ **1**

12. M/J 18 /P23/Q1/c

(a) (i) molecules / particles / reacting species are closer together **1**

so frequency of collisions increases **1**

few(er) moles on right **1**

so (equilibrium) reaction shifts right / towards products / (as pressure increases to oppose the change) **1**

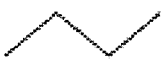
(ii) Decreasing reactant concentrations (at different time intervals / as reaction progresses) **1**

So rate decreases OR change in concentration ÷ time taken decreases **1**

(iii) (line becomes horizontal when) forward and reverse rates equal / equilibrium established **1**

(iv) 2:1 ratio in equation / SO_2 used up more quickly (than O_2) / 2 × SO_2 react for every 1× O_2 **1**

13. M/J 17/P22/Q4/a

(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**

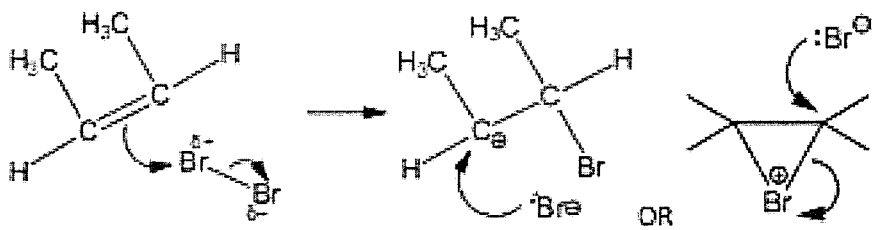
OR

(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

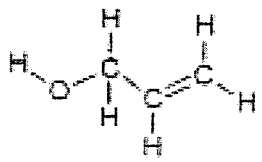
using both arrows shown (in alternative diagram)

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(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

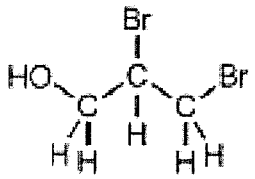
14. M/J 17/P21/Q4/a(i),b,d

(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

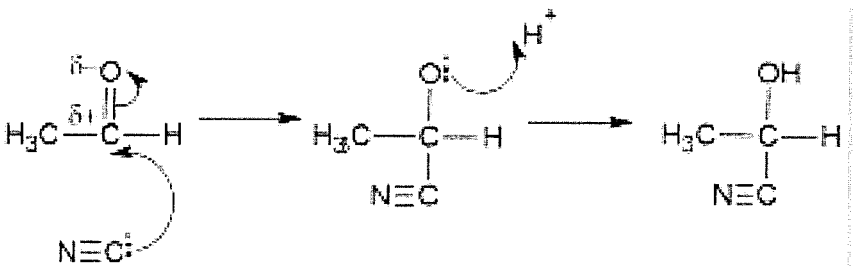
(ii) (electrophilic) addition 1
bromine decolourises / turns colourless / fades (from orange / brown) 1

(iii) 1

$HOCH_2CHBrCH_2Br$ OR 

(iv) CO_2 / carbon dioxide 1

(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

15. M/J 17/P23/Q4

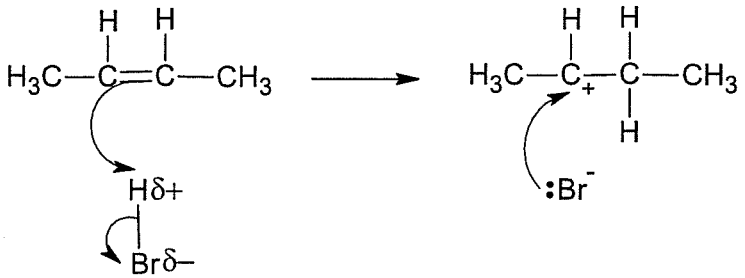
(a) cracking 1

(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
$(CH_3)_2C=CH_2$ / $(CH_3)_2CCH_2$

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(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**

(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**

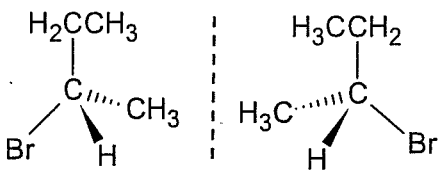
Br^- with lone pair, negative charge AND arrow from lone pair to the positively charged carbon atom of intermediate **1**

(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

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**

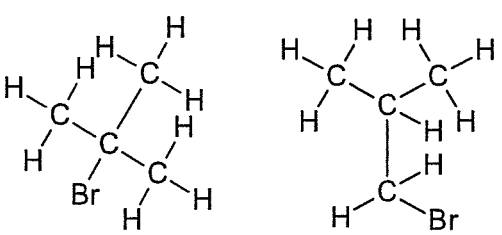
(iv) intermediate / (secondary carbo) cation from **X** is more stable ora **1**

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**

16. 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**

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17. 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)

[11]

18. O/N 11/P23/Q2/b

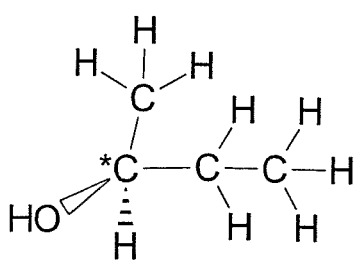
(a) (i) C : H : O = $\frac{64.86}{12} : \frac{13.50}{1} : \frac{21.64}{16}$ (1)

= 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)

$CH_3CH_2CH_2CH_2OH$	$CH_3C(H)(CH_3)CH_2OH$	$CH_3C(OH)(CH_3)CH_3$
(1)	(1)	(1)

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Unit 14

HYDROCARBONS

Chemistry Paper-2
Topical Workbook
Article Number: 232

Editorial Board

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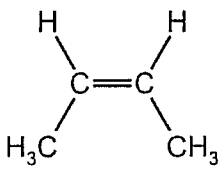
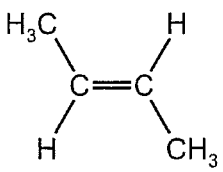
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Unit 14: Hydrocarbons

1. M/J 21/P22/Q4

(a) The table shows the structural formulae of four compounds, **A**, **B**, **C** and **D**, with molecular formula C_4H_8.

(i) Complete the table by giving the systematic name of **A**, **B**, **C** and **D**.

	structural formula	name
A	$CH_3CH_2CH{=}CH_2$	
B		
C		
D	$CH_2{=}C(CH_3)_2$	

[4]

(ii) Explain what is meant by *stereoisomerism*.

.....

.....[1]

(b) **W** is an alkene with formula C_4H_8. It reacts with HBr to form two possible carbocations, $CH_3C^+(H)(CH_2CH_3)$ and $H_2C^+CH_2CH_2CH_3$.

(i) Identify **W** as compound **A**, **B**, **C** or **D**.

.....[1]

(ii) Draw the skeletal formula of the major organic product formed when HBr reacts with **W**. Explain why this is the major organic product.

.....

.....

.....[3]

(c) A sample of propan-1-ol reacts with concentrated sulfuric acid to form propene.
Identify the role of concentrated sulfuric acid in this reaction.

.....[1]

(d) Alcohol **Y** reacts completely when warmed with acidified $Cr_2O_7^{2-}$ to form **Z**.
Z is distilled from the reaction mixture as soon as it is made.
Tollens' reagent is added to a sample of **Z** and warmed. A silver mirror forms.

(i) Name the type of reaction that occurs when **Y** reacts to form **Z**.

.....[1]

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(ii) Identify with a tick (✓) the functional group(s) present in **Z**.

functional group	present in **Z**
aldehyde	
ketone	
carboxylic acid	

[1]

2. M/J 21/P21/Q5

(a) Naphtha is a mixture which contains only hydrocarbon molecules.

(i) What is meant by the term *hydrocarbon*?

.....

..... [1]

(ii) Name the raw material that is used to produce a sample of naphtha.

..... [1]

(b) Compound **V** is found in naphtha. It has a molecular formula $C_{10}H_{22}$.
When **V** is heated at high pressure in the absence of air, an equal number of moles of ethene, propene and **W** are made. **W** is a compound made of straight chain, saturated molecules.

(i) Name the process that describes this reaction.

..... [1]

(ii) Deduce the structure of **W**. Draw its structure below.

[1]

(c) Propene is separated from the mixture and heated in air in the presence of a catalyst. Propene is oxidised to **X**, which contains two functional groups.

(i) Effervescence is seen when $Na_2CO_3(aq)$ is added to **X**.
Identify the functional group present in **X** which is responsible for this observation.

..... [1]

(ii) Identify a reagent which could be used to show that **X** contains a C=C. Include relevant observations.

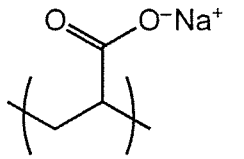
.....

..... [2]

(d) **X** reacts with another reagent to form **Y**.
Molecules of **Y** react together to form addition polymer **Z**. The diagram shows the repeat unit of polymer **Z**.

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repeat unit of polymer **Z**



Draw the structural formula of monomer **Y**.

[1]

(e) Polymer **Z** is useful because it absorbs large amounts of water. However, there are problems associated with the disposal of products containing polymer **Z**.
Combustion is not an appropriate method to dispose of pure **Z** because the process releases harmful gases. Some of these gases contribute to the enhanced greenhouse effect.

(i) Identify a gas released during the combustion of **Z** which contributes to the enhanced greenhouse effect.

..... [1]

(ii) Identify another gas which could be produced during the combustion of pure **Z**. Describe a consequence, other than the enhanced greenhouse effect, of its release into the atmosphere.

gas .....

consequence .....[1]

3. M/J 21/P21/Q6

Propene, C_3H_6, reacts with H_2O in the presence of an acid catalyst to form an alcohol with molecular formula C_3H_8O.

(a) Name this type of reaction.

..... [1]

(b) Name the catalyst used and state the conditions needed for this reaction to occur.

catalyst .....

conditions ..... [2]

(c) Complete the table to show the numbers of sigma (σ) bonds and pi (π) bonds present in propene, C_3H_6, and C_3H_8O.

	σ	π
C_3H_6		
C_3H_8O		

[2]

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(d) The reaction of propene, C_3H_6, with H_2O occurs in a two-step mechanism. In step 1 C_3H_6 reacts with the catalyst, H^+, to form a carbocation.

(i) Draw structures to identify the more stable and less stable carbocations which can form in step 1. Explain your answer.

more stable carbocation	**less** stable carbocation

explanation .....

.....

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

(ii) Name the major organic product formed from the reaction of propene, C_3H_6, with H_2O.

..... [1]

(e) 2-bromopropane reacts to form propene, hydrogen bromide and water under certain conditions.

(i) Name this type of reaction.

..... [1]

(ii) Describe the reagents and conditions needed to favour this reaction.

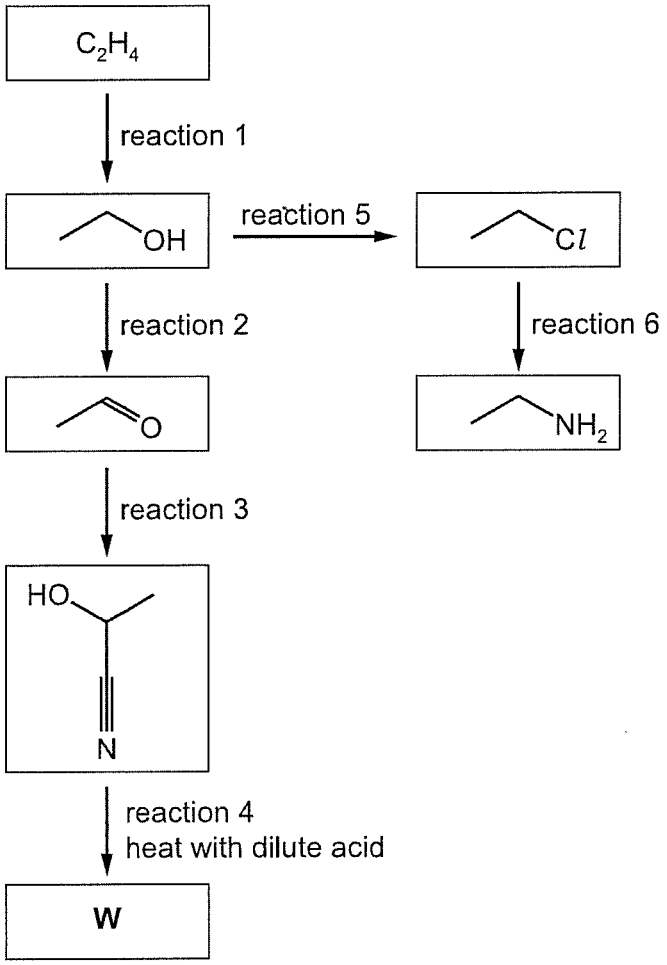
reagents .....

conditions ..... [2]

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4. M/J 20/P22/Q5

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.

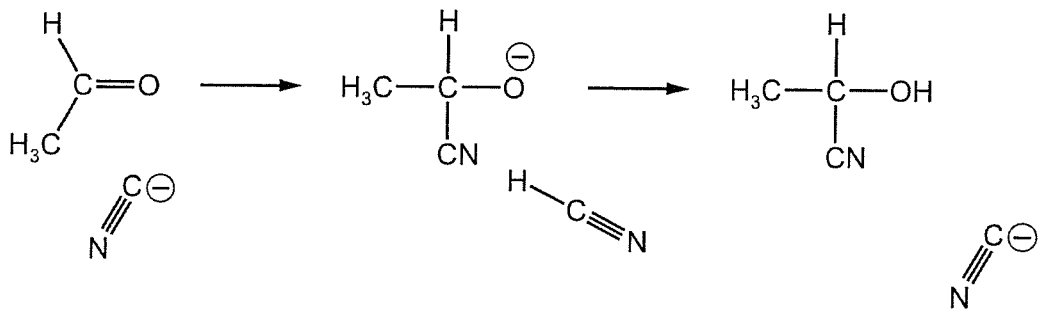
reaction	name of mechanism	**name** of reagents and conditions
1		
2		
6		

[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.

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[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]

5. O/N 19/P21/Q3, O/N 19/P23/Q3

Crude oil is a natural source of hydrocarbons that are used as fuels.

(a) Hydrocarbons with low relative molecular mass, M_r, are used as fuels in industry, in the home and for transport.

There is a high demand for the hydrocarbons with low M_r.

(i) Name the process by which long-chain hydrocarbons are broken down into shorter-chain hydrocarbons.

..... [1]

(ii) Give one reason why hydrocarbons with low M_r are suitable for use as fuels.

..... [1]

(iii) Incomplete combustion of hydrocarbons can release carbon monoxide, CO, into the atmosphere.

Write an equation for the formation of CO from the incomplete combustion of butene, C_4H_8.

..... [1]

(iv) Identify an analytical technique that can be used to monitor the levels of CO in the atmosphere.

Outline how this analytical technique may be used to monitor the levels of CO.

.....

..... [2]

(b) Thiophene, $C_4H_4S(l)$, is an organic compound that is found as a contaminant in crude oil.

(i) Construct the equation for the complete combustion of thiophene, $C_4H_4S(l)$.

Include state symbols in your answer.

.....[2]

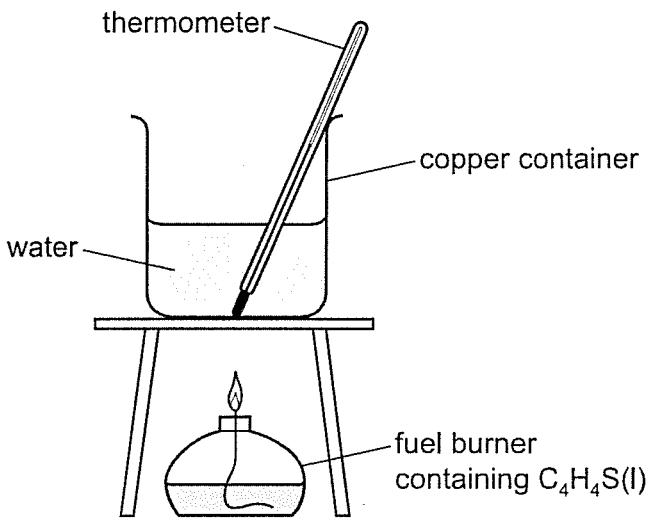
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(ii) A student carries out an experiment to determine the enthalpy change of combustion of $C_4H_4S(l)$.
Explain the meaning of the term *enthalpy change of combustion*.

.....

..... [2]

(iii) The student uses the following apparatus in the experiment.



mass of water in copper container/g	200
initial temperature of water/°C	18.5
highest temperature of water/°C	37.5

Calculate the heat energy released, in J, by the reaction.
Assume that 4.18 J of heat energy changes the temperature of 1.0 cm^3 of water by 1.0 °C.
Assume no heat is lost to the surroundings.

heat energy released = ... J
[2]

(iv) The student used 0.63 g of $C_4H_4S(l)$ in the experiment.
Calculate the enthalpy change of combustion of thiophene, $\Delta H_c(C_4H_4S(l))$. Include a sign in your answer.

$\Delta H_c(C_4H_4S(l))$ = ... $kJ\,mol^{-1}$
[2]

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6. M/J 19/P22/Q1

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.

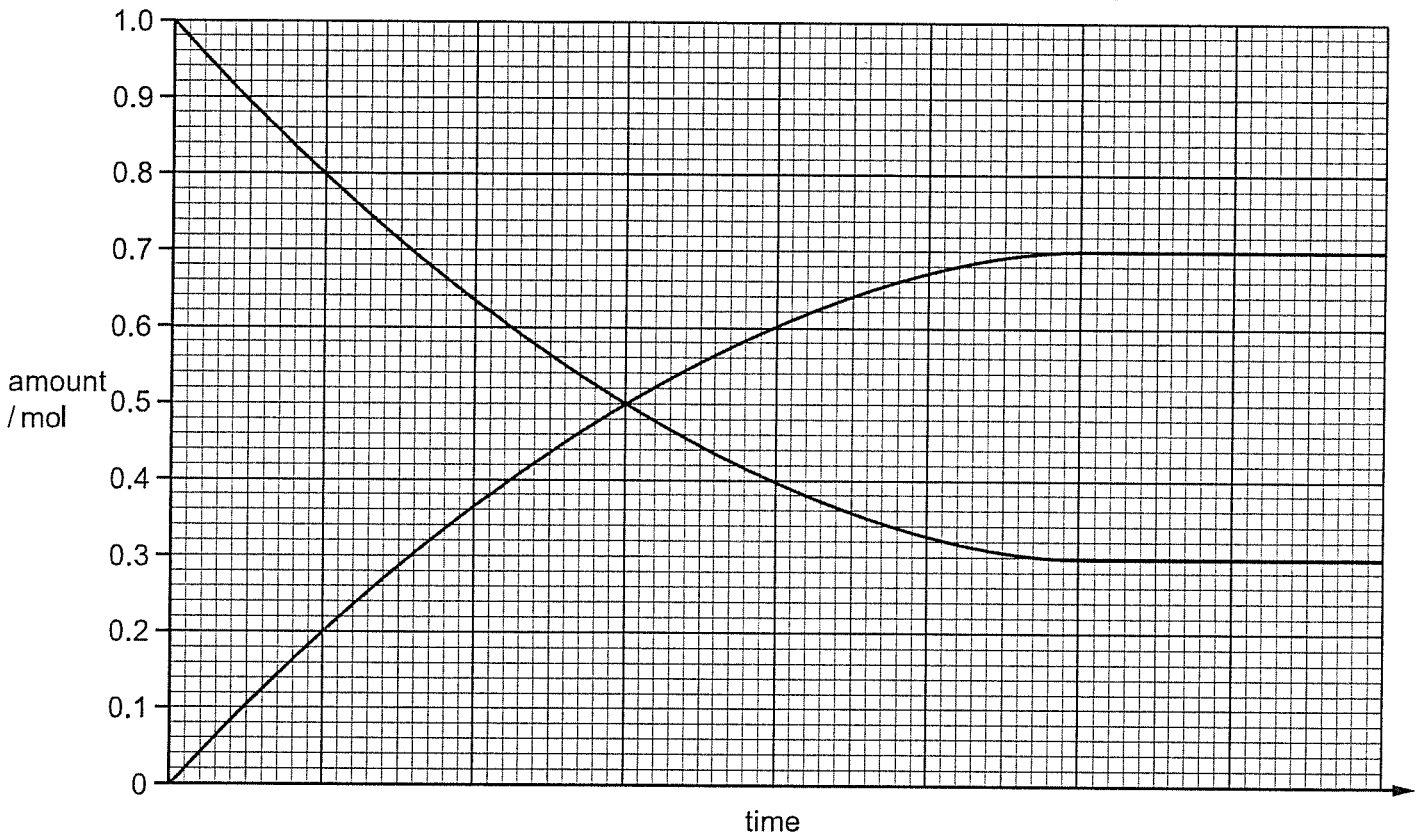
$$CH_3(CH_2)_2CH_3(g) \rightleftharpoons (CH_3)_2CHCH_3(g) \qquad \Delta H = -8.0\,kJ\,mol^{-1}$$

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.



(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 = ... $mol\,dm^{-3}$

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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]

7. M/J 19/P22/Q4

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]

(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 1.00g of ethene at room temperature and pressure.

volume of CO_2 = ... dm^3 [3]

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(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.

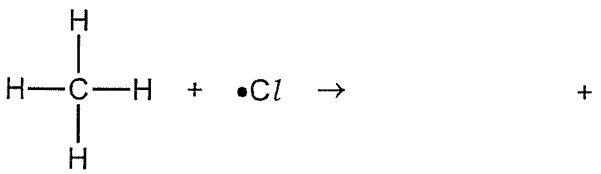
.....

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

(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]

8. M/J 19/P23/Q6

(a) Three alkenes, **X**, **Y** and **Z**, have the same molecular formula.

(i) Describe what is seen when aqueous bromine is added to **X**.

..... [1]

X, **Y** and **Z** are reacted separately with hot, concentrated, acidified manganate(VII) ions until no further reaction occurs. The carbon-containing products are shown in the table.

alkene	carbon-containing products
X	CO_2 + $(CH_3)_2CO$
Y	CO_2 + $CH_3CH_2CO_2H$
Z	CH_3CO_2H

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(ii) Draw the structures of **X**, **Y** and **Z**.

X	Y	Z

[3]

(iii) Deduce the molecular formula of **X**, **Y** and **Z**.

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

(b) The structures of **V** and **W** are shown.

$CH_3(CH_2)_2CH_2OH$ $(CH_3)_3COH$

V **W**

(i) Name the class of compound that **V** and **W** each belong to.

V .....

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

(ii) **V** and **W** both react with sodium metal.
Write an equation for the reaction of **V** with sodium metal.

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

(iii) Name a reagent used to distinguish **V** from **W**. Describe any observations.

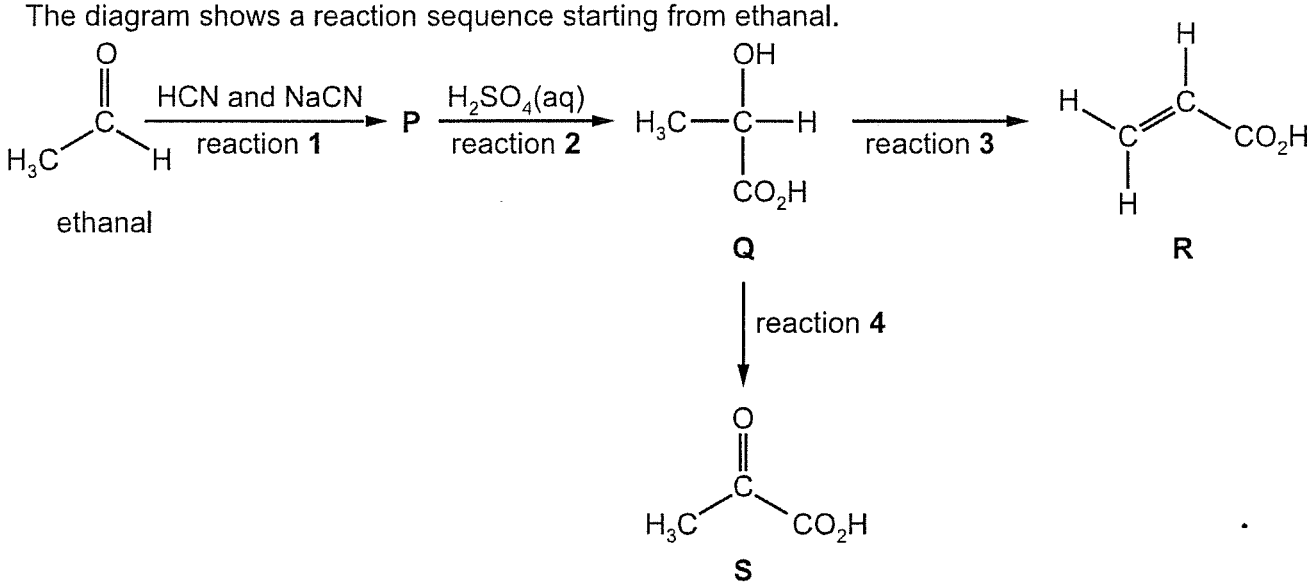
reagent .....

observations with **V** .....

observations with **W** .....[3]

9. O/N 18/P22/Q4/b,c

The diagram shows a reaction sequence starting from ethanal.



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(a) Compound **Q** is formed as a mixture of two optical isomers.

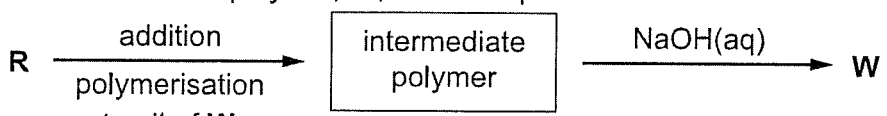
(i) Explain what is meant by the term *optical isomers*.

..... [1]

(ii) Draw the **two** optical isomers of **Q**, showing clearly their three-dimensional structures.

[2]

(b) **R** can be used to make a polymer, **W**, in two steps.



Draw one repeat unit of **W**.

[3]

10. M/J 18/P23/Q2

One reason for the wide variety of organic compounds is isomerism, either structural isomerism or stereoisomerism.

(a) (i) Explain the meaning of the term *structural isomerism*.

.....

..... [2]

(ii) Explain the meaning of the term *stereoisomerism*.

.....

..... [2]

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(b) Pent-1-ene, $CH_2=CH(CH_2)_2CH_3$, does not show stereoisomerism.

(i) Give **two** reasons why pent-1-ene does **not** show stereoisomerism.

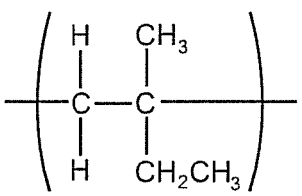
reason 1 .....

.....

reason 2 .....

..... [2]

(ii) A structural isomer of pent-1-ene is used as the monomer to form a polymer. The repeat unit of this polymer is shown.



Draw the **displayed** formula of the monomer used to make this polymer.
Give the name of the monomer.

.....

[2]

(iii) A different structural isomer of pent-1-ene shows geometrical isomerism.
Draw the structure of **one** of the two geometrical isomers with the formula C_5H_{10}.
Give the full name of this isomer.

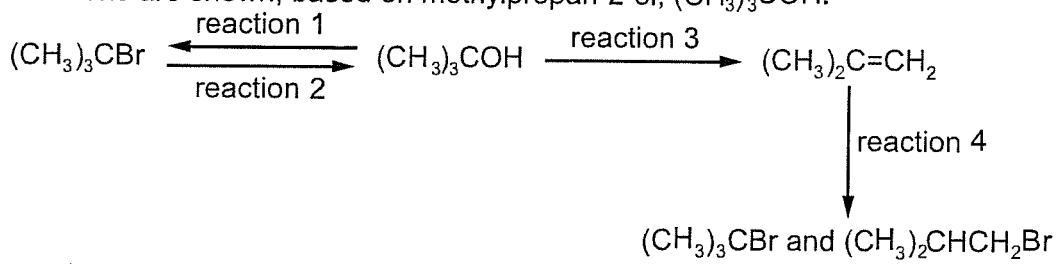
.....

[2]

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11. O/N 17/P22/Q4/a,b,c(i),d(i),e

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]

(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 .....

.....

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types of structural isomerism

1 .....

2 .....

3 ..... [4]

(d) The product of reaction 3, methylpropene, does **not** show stereoisomerism.

(i) Give **two** reasons why methylpropene does **not** show stereoisomerism.

.....

..... [2]

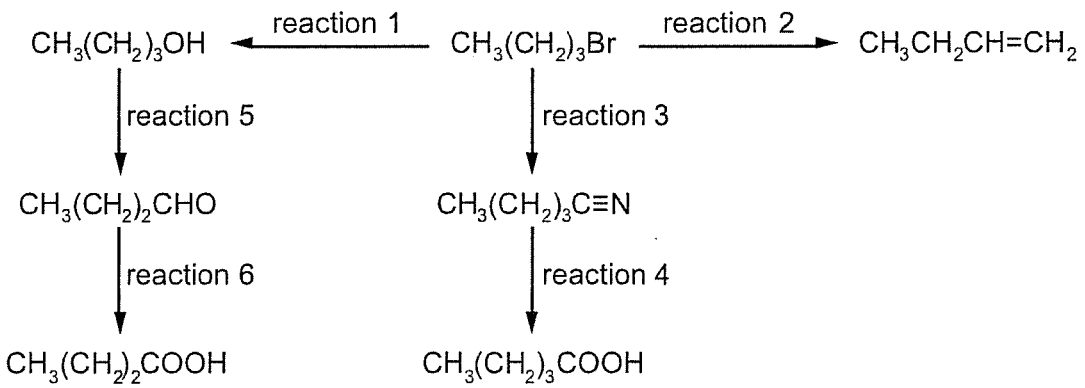
(e) Name the two products of reaction 4.

name of $(CH_3)_3CBr$ .....

name of $(CH_3)_2CHCH_2Br$ ..... [2]

12. O/N 17/P21/Q3/a,c(i),d, O/N 17/P23/Q3/a,c(i),d

Some reactions based on 1-bromobutane, $CH_3(CH_2)_3Br$, are shown.



(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 more than one type.

elimination	hydrolysis	substitution
oxidation	addition	condensation

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reaction	reagent(s) and conditions	type(s) of reaction
1		
2		
3		
4		
5		
6		

[6]

(b) 2-bromo-2-methylpropane is a tertiary halogenoalkane that is a structural isomer of 1-bromobutane.

(i) Define the term *structural isomer* and name the three different types of structural isomerism.

definition .....

.....

types of structural isomerism

1 .....

2 .....

3 ..... [4]

(c) The product of reaction 2, but-1-ene, does **not** show stereoisomerism. However, but-1-ene reacts with HC*l* to form a mixture of structural isomers **X** and **Y**.

but-1-ene + HC*l* → **X** (exists as a pair of stereoisomers and is produced in higher yield than **Y**)

but-1-ene + HC*l* → **Y** (does not show stereoisomerism)

(i) Explain the meaning of the term *stereoisomers*.

.....

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..... [2]

(ii) Give **two** reasons why but-1-ene does **not** show stereoisomerism.

.....

..... [2]

(iii) Name **X** and **Y**.

X .....

Y ..... [2]

(iv) Name the type of stereoisomerism shown by **X**.

..... [1]

(v) Use the conventional representation to draw the two stereoisomers of **X**.

[2]

13. 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.

$$C_xH_y + (x + \frac{y}{4})O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

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(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]

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.

$x = 6$ $\quad$ $(x + \frac{y}{4}) = 9$

(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]

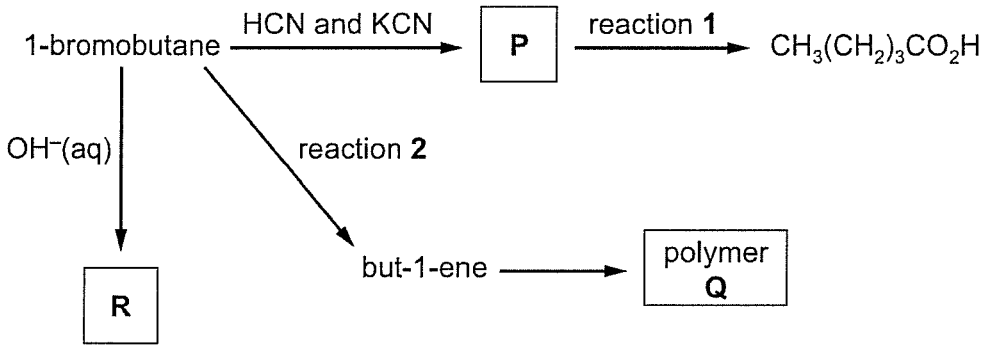
(v) Use the general gas equation to calculate the mass of **P** present in the original 25 cm^3 gaseous sample, which was measured at 37 °C and 100 kPa.
Give your answer to **three** significant figures.

mass = ... g [3]

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14. 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]

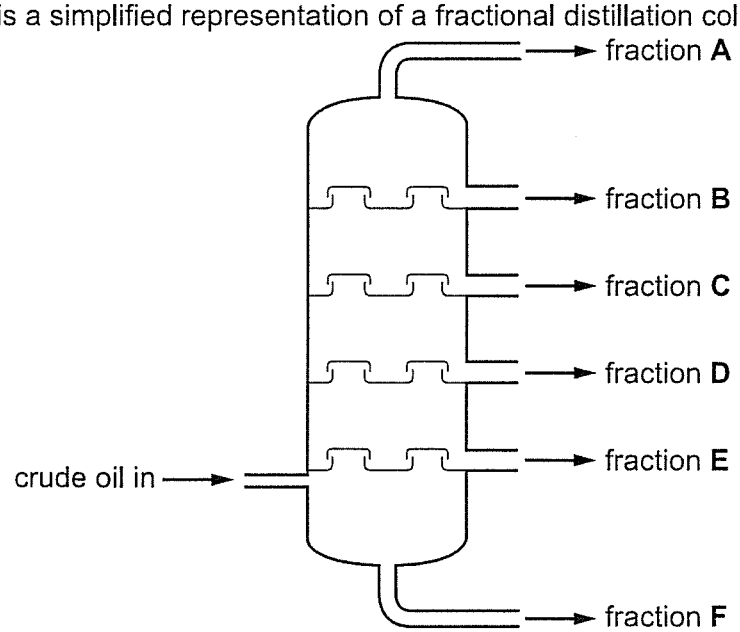
(iii) Draw the structure of the repeat unit of polymer **Q**.

[2]

15. 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.



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(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]

(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.

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.....

.....

..... [3]

(iv) Describe two of the problems associated with acid rain.

.....

..... [2]

16. 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]

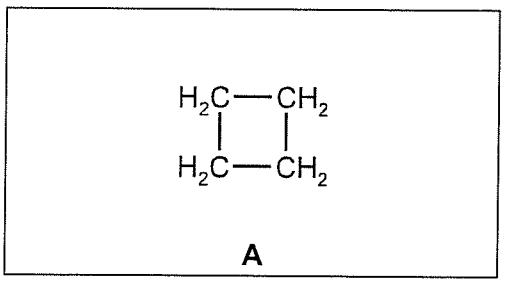
(c) Give the structures and full names of a pair of **stereoisomers** with the formula C_4H_8.

....

[2]

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(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

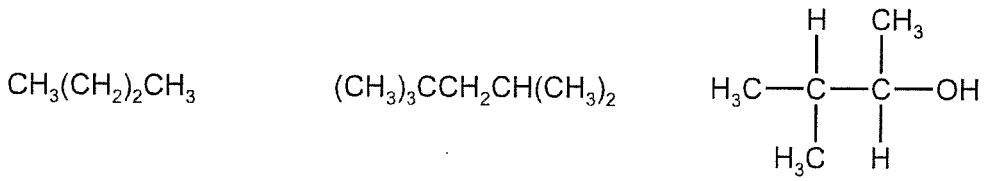
.....

.....

..... [3]

17. 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]**

18. 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]

(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]

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(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]

(ii) Describe this mechanism, using suitable equations and including the names of each stage in the process.

.....

.....

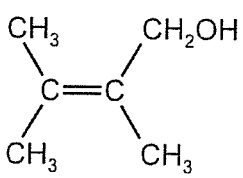
.....

.....

..... [5]

19. 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).

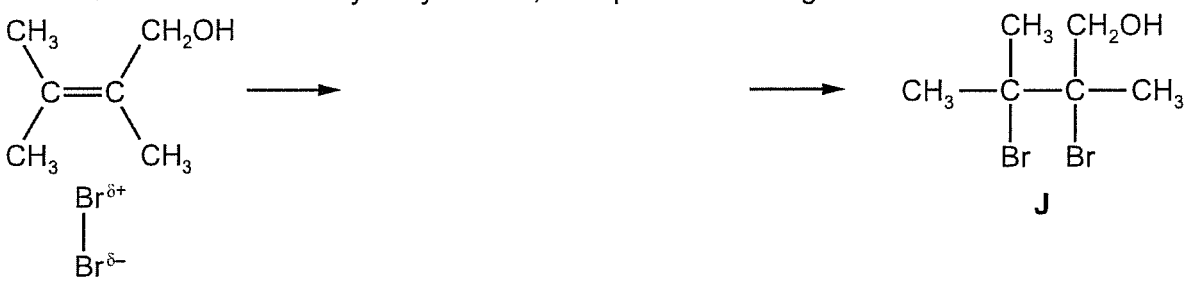
[1]

(ii) Give the structures of the organic products of the reaction of **H** with hot, concentrated, acidified potassium manganate(VII).

[2]

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(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

[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]

20. 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]

(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]

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21. 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.

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]

22. 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]

23. 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]

(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]

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(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.

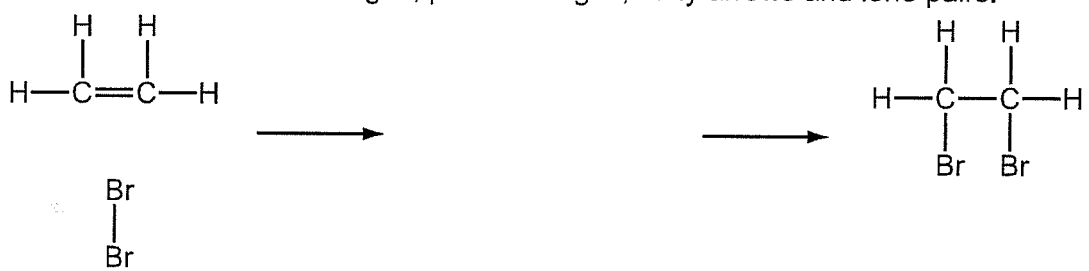
..... [1]

(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.

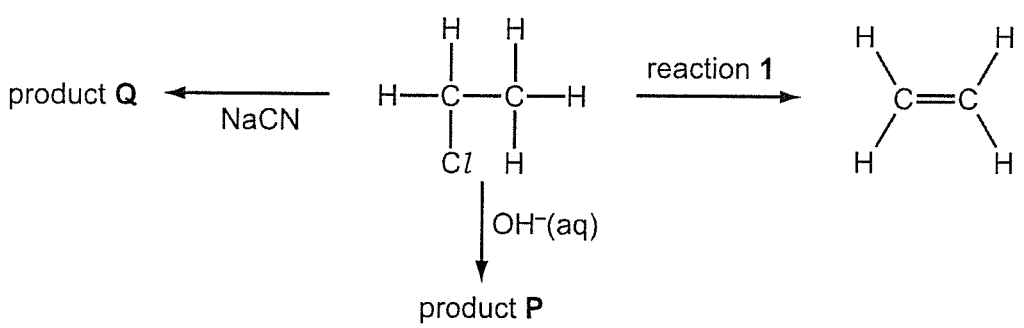


[4]

(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.

[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]

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(iii) Give the **displayed** formula and the name of product **Q**.

.....

..... [2]

24. 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]

(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]

25. 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?

.....

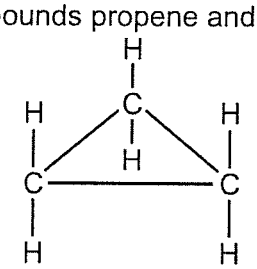
(ii) Write a balanced equation for its formation from butane.

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

26. O/N 13/P22/Q2

The molecular formula C_3H_6 represents the compounds propene and cyclopropane.

$CH_3CH{=}CH_2$



propene cyclopropane

(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]**

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(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]

27. 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.

(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]

[5]

(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]

28. 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.

.....

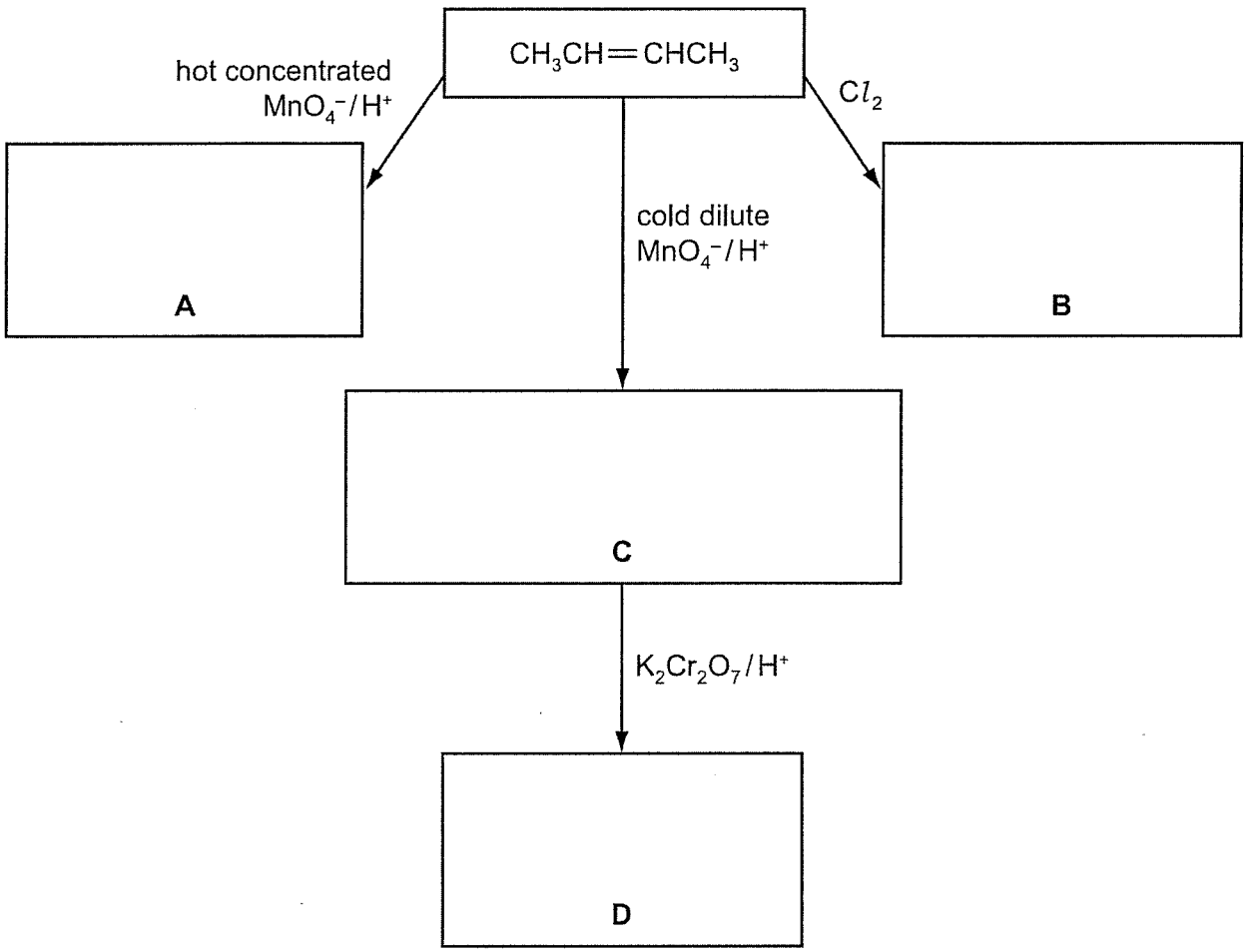
..... [2]

(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**.

(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**.

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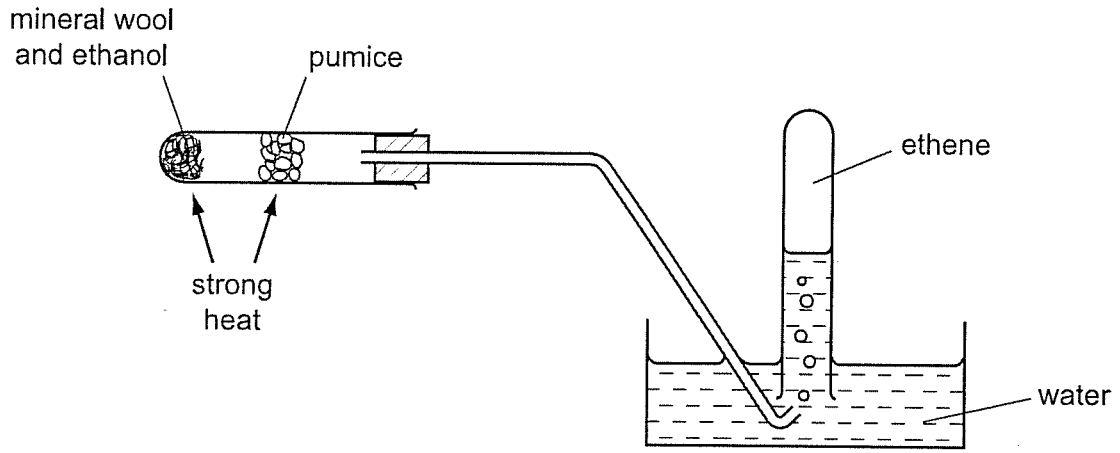
(ii) Suggest the **structural** formula of the product of the reaction between **E** and an excess of bromine.

(iii) What *type of reaction* occurs between **E** and an excess of bromine?

[3]

29. 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.



(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]**

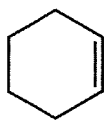
(b) Ethene is bubbled into two separate test-tubes, one containing aqueous hydrogen bromide and the other containing cold, dilute acidified potassium manganate(VII).
In **each** case, describe any colour changes you would see and give the structural formula of the organic product.

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	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?

.....

(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).

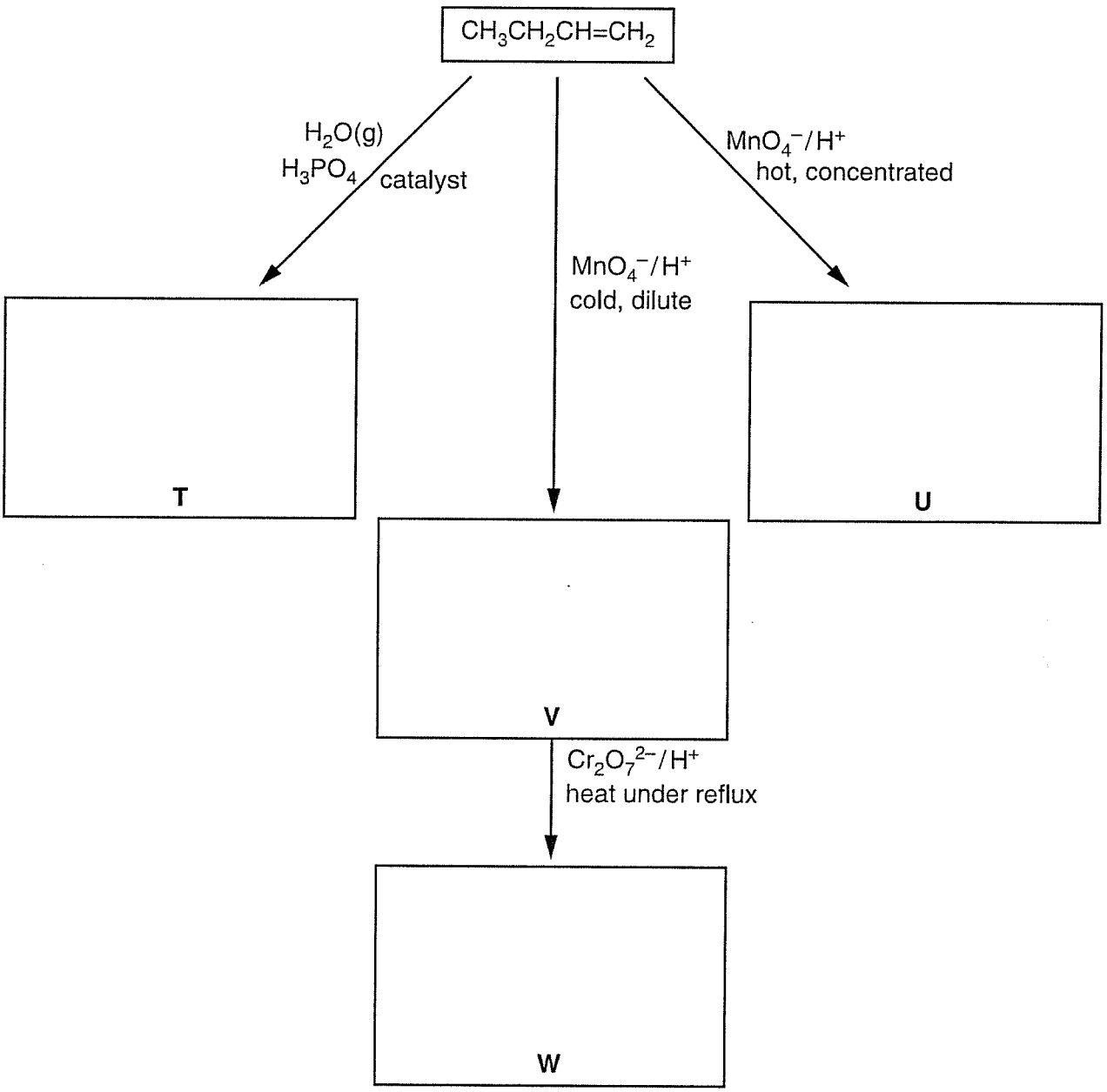
[5]

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30. 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]

(b) Compound **T** reacts with compound **U**.
Draw the **displayed** formula of the organic product of this reaction.

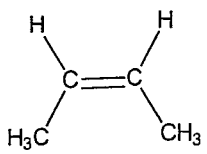
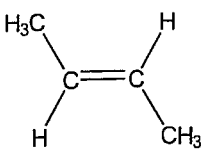
[2]

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Answers Section

1. M/J 21/P22/Q4

(a) (i)

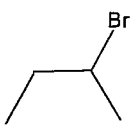
	structural formula	name
A	$CH_3CH_2CH=CH_2$	but-1-ene OR 1-butene
B		cis / Z but-2-ene OR cis / Z 2-butene
C		trans / E but-2-ene OR trans / E 2-butene
D	$CH_2=C(CH_3)_2$	(2) methyl prop(-1-)ene

4

M1 correct identification of but-1-ene (for **A**)
M2 correct identification of but-2-ene for **B** and **C**
M3 identification of cis / trans (Z / E) for **B** and **C** (in correct order)
M4 correct name of **D**

(ii) (molecules with the) same structural formula (and same molecular formula) with different arrangement of atoms / groups in space **1**

(b) (i) **A** **1**

(ii)  **1**

M1 skeletal formula only

M2 *explanation in terms of increased / greater stability of intermediate / carbocation* intermediate / (secondary) carbocation / $CH_3C^+(H)(CH_2CH_3)$ is (more) stable **1**

M3 *reason for increased stability of intermediate in terms of greater number* of alkyl groups showing largest inductive *(electron releasing) effect*
greater (positive) inductive effect due to two alkyl groups
OR
greater electron donation of two alkyl groups **1**

(c) dehydrating agent / cause dehydration **1**

(d) (i) oxidation **1**

(ii)

functional group	present in **Z**
aldehyde	✓
ketone	
carboxylic acid	

1

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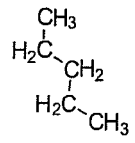
2. M/J 21/P21/Q5

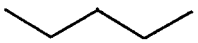
(a) (i) (compounds / molecules) containing only / entirely carbon and hydrogen (atoms) **1**

(ii) crudeoil **1**

(b) (i) (thermal) cracking **1**

(ii) *structure of* ***W*** **1**

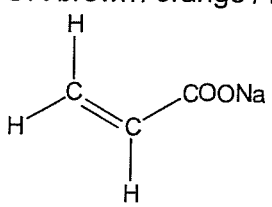


OR $CH_3(CH_2)_3CH_3$ OR 

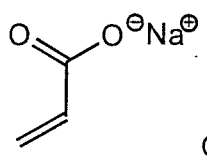
(c) (i) CO_2H / carboxylic acid **1**

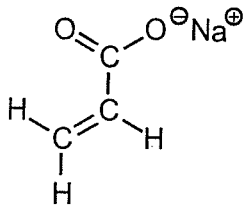
(ii) **M1** (add) $Br_2(aq)$ / bromine water **1**

M2 (solution) turns (from brown / orange / red to) colourless / decolorises **1**
OR brown / orange / red fades

(d)  **1**

OR $CH_2CH(CO_2^{(-)}Na^{(+)})$
OR $CH_2{=}CH(COO^{(-)}Na^{(+)})$



OR 

OR , etc.

(e) (i) carbon dioxide / CO_2 **1**

(ii) CO / hydrocarbons **AND** toxic / poisonous / harmful to health / (catalyses formation of) photochemical smog **1**

3. M/J 21/P21/Q6

(a) addition **1**

(b) **M1** *catalyst* = sulfuric acid / phosphoric(V) acid **1**

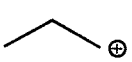
M2 *conditions of reaction* = steam / heat (and pressure) **1**

(c)

	σ	π
C_3H_6	8	1
C_3H_8O	11	0

2

(d) (i) **M1** more stable = $CH_3C^+(H)(CH_3)$  **1**

M2 less stable = $CH_3CH_2C^+(H_2)$ / 

M3 greater (positive) inductive effect of two alkyl groups **1**
OR greater electron donation of two alkyl groups owtte

(ii) propan-2-ol **1**

(e) (i) elimination **1**

(ii) **M1** NaOH / KOH **1**

M2 ethanolic solution / ethanol / alcohol + heat **1**

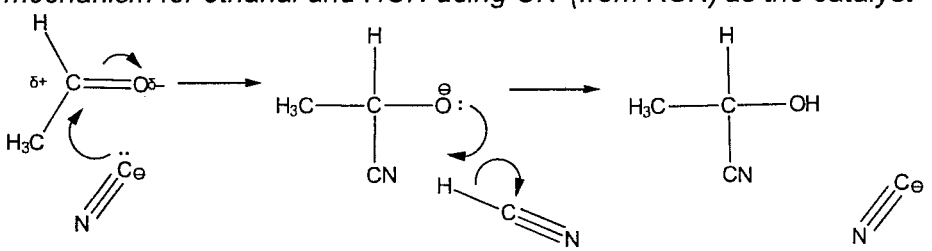
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4. M/J 20/P22/Q5

(a) **6**

Rxn.	name of mechanism	**Name** of reagents and conditions
1	**M1** electrophilic addition	**M2** steam **AND** concentrated phosphoric acid (catalyst)
2		***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

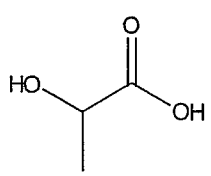
(b) (i) *mechanism for ethanal and HCN using CN^- (from KCN) as the catalyst* **3**



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≡

(ii) ALLOW in any order **2**
M1 nitrile
M2 (secondary) alcohol

(c) **1**



ALLOW any unambiguous structure

5. O/N 19/P21/Q3, O/N 19/P23/Q3

(a) (i) cracking **1**

(ii) enthalpy change of combustion / ΔH_c is high / large energy release (per mole / per unit mass) **OR** combust / burn easily **1**

(iii) $C_4H_8 + 4O_2 \rightarrow 4CO + 4H_2O$ **1**

(iv) **M1**: infrared spectroscopy **2**
M2: Compare / measure (characteristic) wavelengths

(b) (i) $C_4H_4S(l) + 6O_2(g) \rightarrow 4CO_2(g) + 2H_2O(l) + SO_2(g)$ **2**
- correct species
- balancing

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- state symbols

Award one mark for two correct bullet points, award two marks for all three correct.

(ii) **M1** (enthalpy change when) 1 mol of a substance **2**

M2 EITHER burns / combusts / reacts in excess air / oxygen
OR completely burns / combusts / reacts in air / oxygen

(iii) **M1** m = 200 and ΔT = 37.5–18.5 **2**

M2 $Q = mc\Delta T = 200 \times 4.18 \times (37.5 - 18.5) = 15\,884$ (J)

(iv) **M1** mol of thiophene used **2**

= 0.63 / 84.1 OR $7.49(1\,082\,045) \times 10^{-3}$

M2 calculation ÷ 1000 AND negative sign

$$\Delta H_c = \frac{-\textbf{(iii)}}{\textbf{1000}} \div n = \frac{-\textbf{(iii)}}{\textbf{21000}} \div (0.63 / 84.1)$$

$= -2120$ (–2120.39) (kJ mol^{-1})

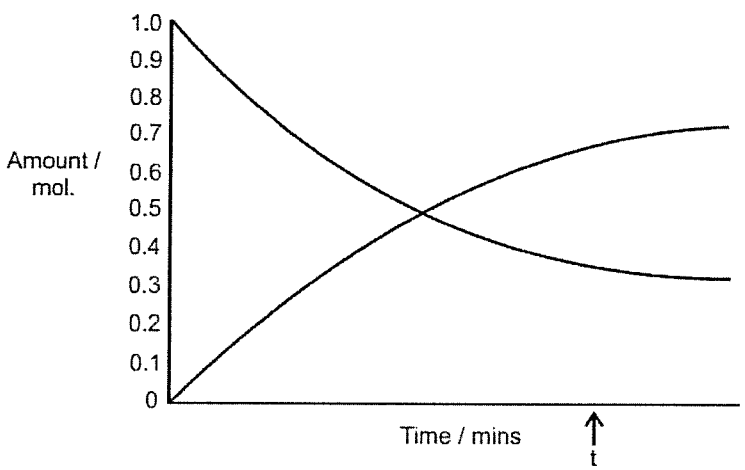
6. M/J 19/P22/Q1

(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**

$$K_c = \frac{\text{value of methylpropane in (ii)}}{\text{value of butane in (ii)}} = 0.7 / 0.3 = 2.3\ (3)$$

M2 *units consistent with expression used in* M1 **1**
no units / dimensionless / none

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7. M/J 19/P22/Q4

(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**

(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

8. M/J 19/P23/Q6

(a) (i) Orange / brown **to** colourless / decolourises **1**

(ii) any non-ambiguous structures of:
X $(CH_3)_2C = CH_2$ / $(CH_3)_2CCH_2$ **1**
Y $CH_3CH_2CH = CH_2$ / $C_2H_5CHCH_2$ **1**
Z $CH_3CH = CHCH_3$ / $CH_3CHCHCH_3$ **1**

(iii) C_4H_8 **1**

(b) (i) V = primary / 1° alcohol **1**
W = tertiary / 3° alcohol **1**

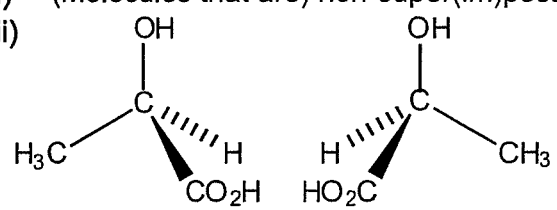
(ii) $CH_3(CH_2)_2CH_2OH + Na \rightarrow CH_3(CH_2)_2CH_2ONa + ½\ H_2$ **1**

(iii) **M1** Reagent $H^+ / Cr_2O_7^{2-}$ **3**
M2 Observations for V orange to green
M3 Observations for W no change / remains orange

9. O/N 18/P22/Q4/b,c

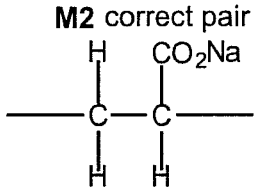
(a) (i) (Molecules that are) non-super(im)posable mirror images **1**

(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]

(b) **3**



OR $-CH_2CH(CO_2Na)-$

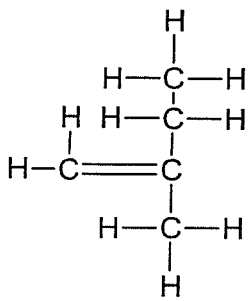
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10. M/J 18/P23/Q2

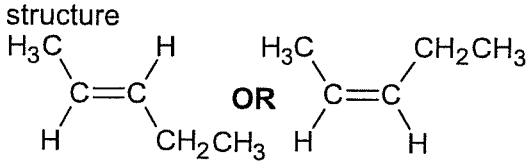
(a) (i) (molecules / isomers with) the same molecular formula / same number of atoms of each element — 1
different structural formulae / different structures — 1

(ii) (Molecules / isomers) with the same (molecular and) structural formula — 1
different arrangement of atoms in space / different spatial arrangement of atoms. — 1

(b) (i) two Hs on one of the C=C carbons / terminal C / C–1 — 1
no chiral C / no C with 4 different groups / atoms / chains attached has a super(im)posable mirror image — 1

(ii) 
2-methylbut-1-ene — 1

(iii) structure — 1



trans–pent–2–ene or or *E*– cis–pent–2–ene or *Z*– — 1

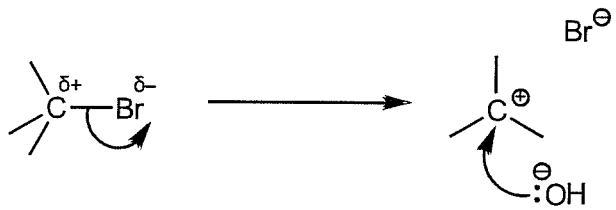
11. O/N 17/P22/Q4/a,b,c(i),d(i),e

(a) — 5

1	concentrated 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	concentrated 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*

(b) — 3



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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 $:\overset{\ominus}{O}H$ to C^+ of carbocation

(c) (different molecules) same molecular formula / 1
same numbers of atoms of each (type of) element different structural formulae 1
/ displayed formulae 2
chain/ skeletal
functional group
position(al) / regioisomerism
two types correct = 1 mark, all three correct = 2 marks

(d) mirror images are super(im)posable 1
OR not chiral / no chirality / no chiral/asymmetric carbon/centre / achiral
one or both C/end of **double bond** has identical groups / 2 methyl groups / 2 H (atoms) 1

(e) 2-bromo-2-methylpropane 1
1-bromo-2-methylpropane

12. O/N 17/P21/Q3/a,c(i),d, O/N 17/P23/Q3/a,c(i),d 1

(a) 6

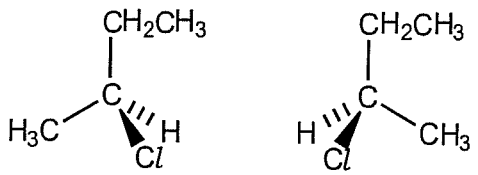
reaction	reagent(s) and conditions	reaction type(s)
1	aqueous / aq / dilute NaOH / KOH OR water	substitution OR hydrolysis
2	alcoholic / ethanolic NaOH / KOH	elimination
3	NaCN / KCN in ethanol / alcohol	substitution
4	aqueous /dilute H_2SO_4 / H^+(aq)	hydrolysis OR substitution OR addition-elimination
5	acidified / H^+ (with) $K_2Cr_2O_7$ / $Cr_2O_7^{2-}$ (and distil) NOT reflux	oxidation OR elimination
6	acidified / H^+ $K_2Cr_2O_7$ / $Cr_2O_7^{2-}$ Fehling's / Tollens' / Benedict's (reagent)	oxidation

(b) (i) (different molecules) with same molecular formula / 1
same numbers of atoms of (each type) of element
different structural formulae / displayed formulae 1
chain / skeletal 2
functional group
position(al) / regioisomerism
two types correct = 1 mark, all three correct = 2 marks

(c) (i) (different molecules) with the same (molecular and) structural formula / 1
with different arrangements of atoms in space / spatial arrangement of atoms
(ii) mirror images are super(im)posable / no chiral carbon / no chiral centre / it is achiral 1
(one) C of double bond has identical groups / H (atoms) (attached) 1
OR
(one) end of double bond has identical groups / 2 H (atoms) (attached)

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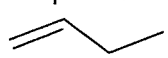
(iii) **X** = 2-chlorobutane **1**
Y = 1-chlorobutane **1**
(iv) optical (isomerism) **1**
(v) one acceptable 3D structure of 2-chlorobutane **1**
the 2nd optical isomer EITHER drawn as a mirror image of the first **1**
OR
the same bond pattern is shown but two of the groups swap positions.

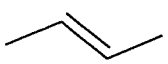


13. M/J 17/P23/Q1

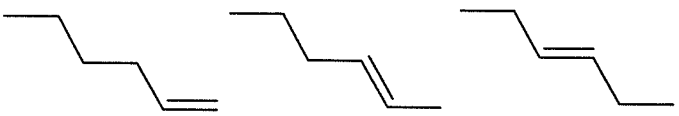
(a) (molecules / isomers with) the same molecular formula / **1**
same number of atoms of each element
different structural / displayed formulae / different arrangement of bonds **1**

(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

(iv)  **1**

 **1**

alternative using supplied data: any two



(v) correct conversions of data to SI / consistent units **1**
P = 100 000; V = 25×10^{-6}; T = 310
calculation of n (= pV/RT) **1**

$$n = \frac{100 \times 10^3 \times 25 \times 10^{-6}}{8.31 \times 310}$$

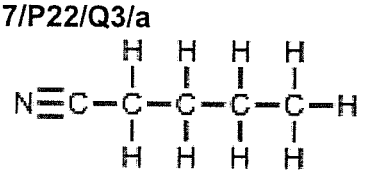
calculation of mass m (= $n \times M_r$) AND answer correct to **3sf** **1**

$m = 9.705 \times 10^{-4} \times 56 = 0.0543$ (g)

Alternative answer for using C_6H_{12}:

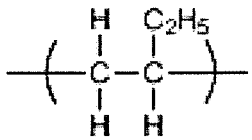
$m = 9.705 \times 10^{-4} \times 84 = 0.0815$ (g)

14. MAR 17/P22/Q3/a

(a) (i)  **1**

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(ii) reaction **1** = HC*l*(aq) **1**
reaction **2** = (conc.) NaOH / KOH **AND** ethanol **1**

(iii)  **2**
C–C backbone with dangling bonds
rest of structure

15. M/J 16/P23/Q3

(a) **(i)** vaporise / boil / turn to gas [1]
(ii) increasing molecular size / no of carbon atoms per molecule / length of carbon chain [1]
(iii) increasing b.pt / decreasing volatility [2]
increasing viscosity
increasing density
increasing depth of colour
decreasing flammability / decreasing 'cleanliness' of flame owtte

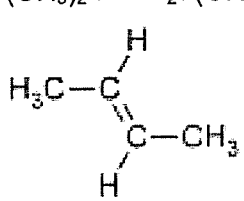
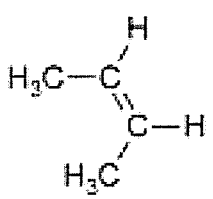
(b) **(i)** $C_{12}H_{26} \rightarrow 2C_2H_4 + C_8H_{18}$ [1]
(ii) ethene use = making polythene / plastic / polymers [1]
feature of ethene = double bond / unsaturated [1]
octane / alkane use = fuel / petrol [1]
feature of octane / alkane = flammability / releases energy when burned / combusted [1]

(c) **(i)** (produced by) reaction of (atmospheric) oxygen and nitrogen [1]
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]
(iii) $NO + \frac{1}{2}O_2 \rightarrow NO_2$ [1]
$NO_2 + SO_2 \rightarrow SO_3 + NO$ [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]
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]

16. M/J 16/P21/Q4

(a) $CH_2=CHCH_2CH_3$ / $CH_2CHCH_2CH_3$
AND [1]
$CH_3CH=CHCH_3$ / $CH_3CHCHCH_3$

(b) $CH_2=CHCH_2CH_3$ / $CH_2CHCH_2CH_3$
AND [1]
$(CH_3)_2C=CH_2$ / $(CH3)_2CCH_2$

(c)  
trans-but-2-ene (or *E*) *cis*-but-2-ene (or *Z*) [2]

(d) **B** is $CH_2=CHCH_2CH_3$ OR $CH_3CH=CHCH_3$ OR $(CH_3)_2C=CH_2$
distinguished by addition of bromine
brown/red/orange/yellow to colourless/decolourises with **B** (but not **A**) [3]

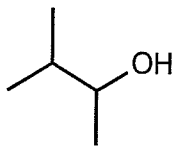
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17. MAR 16/P22/Q4

(a) (i) $\underline{C_4H_{10}}$ [1]

(ii) $\underline{C_4H_9}$ [1]

(iii)



[1]

(b) $C_8H_{18} + 12½O_2 \rightarrow 8CO_2 + 9H_2O$ [1]

(c) sulfur dioxide would be produced on combustion
(which contributes to) acid rain [2]

(d) M1 = **H** has more / greater / stronger van der Waals' / intermolecular forces than **G** / ora
M2 = (because) **H** has more electrons (than **G**)
M3 = **J** has hydrogen bonding (between molecules)
M4 = strong(er) / great(er) forces require AND high / more energy to overcome [4]

(e) NaOH(aq) [1]

18. O/N 15/P21/Q3

(a) (i) structural isomers: (different molecules with) same molecular formula
but different structural formulae
chiral: has a carbon / C attached to 4 different groups / atoms / chains OR has no plane / line of symmetry / has non-superimposable mirror images [2]

(ii) $CH_3CH_2CH(CH_3)CH_2CH_2CH_3$
3-methylhexane
$CH_3CH(CH_3)CH(CH_3)CH_2CH_3$ / $(CH_3)_2CHCH(CH_3)CH_2CH_3$
2,3-dimethylpentane [4]

(b) (i) $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ [1]

(ii) $C_7H_{16} + 4O_2 \rightarrow 7C + 8H_2O$ [1]

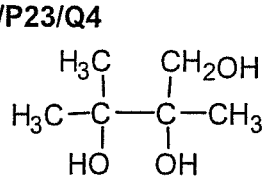
(iii) global dimming / PAN / smog / global warming [1]

(c) (i) (Free) Radical Substitution [1]

(ii) $Cl_2 \rightarrow 2Cl\bullet$
OR
$Cl_2 \rightarrow Cl\bullet + Cl\bullet$
$C_7H_{16} + Cl\bullet \rightarrow \bullet C_7H_{15} + HCl$
$\bullet C_7H_{15} + Cl_2 \rightarrow C_7H_{15}Cl + Cl\bullet$
$\bullet C_7H_{15} + Cl\bullet \rightarrow C_7H_{15}Cl$ OR $\bullet C_7H_{15} + \bullet C_7H_{15} \rightarrow C_{14}H_{30}$
Initiation; Propagation; Termination (used correctly) [5]

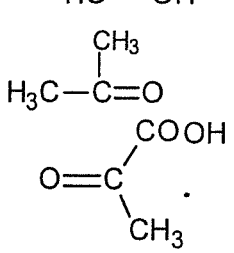
19. M/J 15/P23/Q4

(a) (i)



[1]

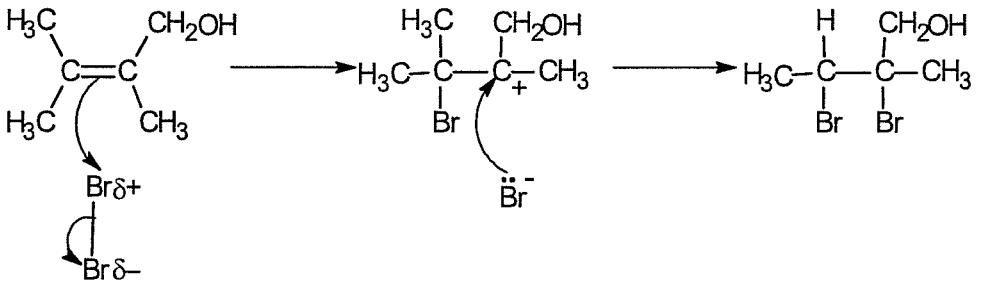
(ii)



[2]

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(b) (i)

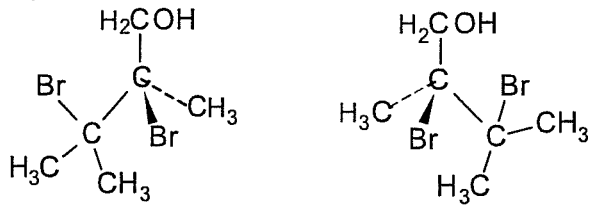


M1 = 2 curly arrows
M2 = intermediate ion
M3 = Br with –ve charge, lone pair and curly arrow to C+ [3]

(ii) dipole is induced by proximity to C=C [1]

(iii) Optical [1]

(iv)



[2]

20. M/J 15/P22/Q3/a

(a) (i) Bond breaking = C*l*-C*l* = 242
C-H = 410 = 652kJ
Bond forming = C-C*l* = 340
H-C*l* = 431 = 771kJ
Enthalpy change = 652 – 771 = –119 [3]

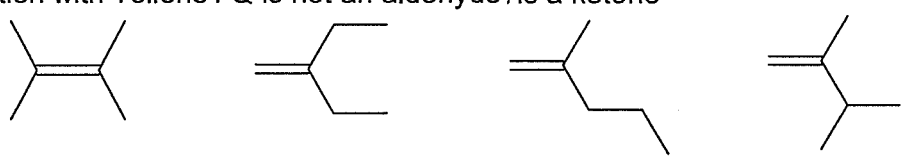
(ii) UV / High T / sunlight [1]

(iii) Initiation
$Cl_2 \rightarrow 2Cl\bullet$
Propagation
$C_2H_6 + Cl\bullet \rightarrow \bullet C_2H_5 + HCl$
$\bullet C_2H_5 + Cl_2 \rightarrow C_2H_5Cl + Cl\bullet$
Termination
$\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_4H_{10}$
All three names correctly assigned [5]

21. M/J 14/P22/Q5

(a) (i) decolourisation of bromine: P is an alkene / contains C=C / is unsaturated
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
2,4–DNPH confirms >C=O / carbonyl / ketone in Q
no reaction with Tollens': Q is not an aldehyde / is a ketone **4**

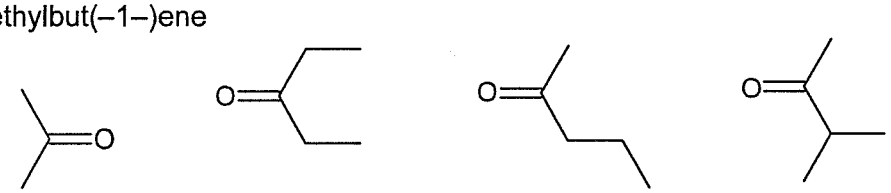
(ii)



2

(2,3–)dimethylbut–2–ene, 2–ethylbut(–1–)ene, 2–methylpent–1–ene, (2,3–)dimethylbut(–1–)ene

(iii)



propan(–2–)one / acetone, pentan–3–one, pentan–2–one, 3–methylbutan(–2–)one
ecf possible on **(a)(ii)** **2**

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(b) any 3 of
$CH_3CH=C(CH_3)C_2H_5$
$CH_3CH=CHCH_2CH_2CH_3$
$CH_3CH=CHCH(CH_3)_2$
$C_2H_5CH=CHC_2H_5$ **3**

22. M/J 14/P22/Q4

(a) physical: fractional distillation / fractionation
chemical: crack(ing) (allow: reforming, isomerisation, thermal decomposition, desulfurisation) **2**

(b) (i) Strong (C–C and C–H) bonds / high bond energies
Non-polar / C and H have similar electronegativities **2**

(ii) 109.5° **AND** 120° (117° – 122°) **1**

(iii) ethane = tetrahedral
ethene = trigonal planar **1**

(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**

(c) (i) $Cl_2 \rightarrow 2Cl\bullet$
$C_2H_6 + Cl\bullet \rightarrow \bullet C_2H_5 + HCl$
$\bullet C_2H_5 + Cl_2 \rightarrow C_2H_5Cl + Cl\bullet$
$\bullet C_2H_5 + Cl\bullet \rightarrow C_2H_5Cl$
correct alternative terminations allowed
initiation, propagation, termination (correctly assigned) **5**

(ii) $\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_4H_{10}$ **1**

23. 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
double / π / pi bond / C=C present in alkenes **2**

(b) (i) UV light / sunlight / high temperature **1**

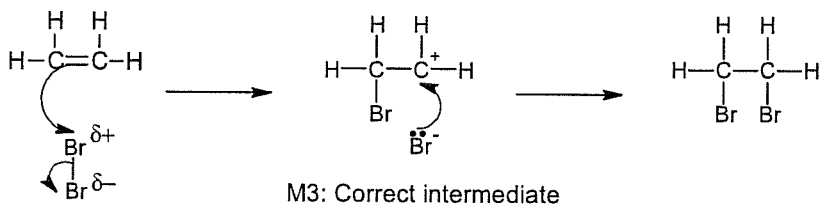
(ii) (Free) radical Substitution **2**

(iii) $\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_4H_{10}$ **1**

(iv) $C_2H_5Br + Br\bullet \rightarrow \bullet C_2H_4Br + HBr$ **OR** **1**
$\bullet C_2H_4Br + Br_2 \rightarrow C_2H_4Br_2 + Br\bullet$

(c) (i) Electrophilic Addition **2**

(ii)



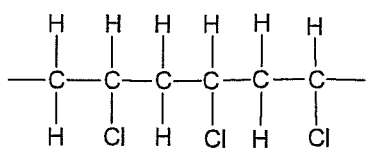
M1: 2 correct curly arrows

M2: dipole

M3: Correct intermediate

M4: Curly arrow from lone pair on Br⁻ to C+ **4**

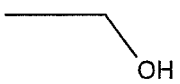
(d)

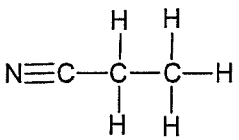


minimum of three repeat units **2**

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(e) (i) NaOH/KOH
ethanolic/alcoholic AND heat/reflux **2**

(ii)  **1**

(iii) 
Propanenitrile/propanonitrile/propionitrile/ethyl cyanide / cyanoethane **2**

24. O/N 13/P23/Q2

(a) (i) alkanes **or** paraffins **not** hydrocarbons
(ii) $\mathbf{1}C_9H_{20} + \mathbf{14}O_2 \rightarrow \mathbf{9}CO_2 + \mathbf{10}H_2O$ **[2]**

(b) (i) carbon
carbon monoxide
(names required)
(ii) CO is toxic **or** affects or combines with haemoglobin
or carbon causes respiratory problems
(iii) $\mathbf{2}C_{14}H_{30} + \mathbf{15}O_2 \rightarrow \mathbf{28}C + \mathbf{30}H_2O$ **or**
$\mathbf{2}C_{14}H_{30} + \mathbf{29}O_2 \rightarrow \mathbf{28}CO + \mathbf{30}H_2O$
or other balanced equations such as
$C_{14}H_{30} + \mathbf{11}O_2 \rightarrow \mathbf{7}C + 7CO + \mathbf{15}H_20$
$C_{14}H_{30} + \mathbf{18}O_2 \rightarrow \mathbf{7}CO + 7CO_2 + \mathbf{15}H_20$ **[4]**

(c) enthalpy change when 1 mol of a substance
is burnt in an excess of oxygen/air under standard conditions
or is completely combusted under standard conditions **[2]**

(d) working **must** be shown
(i) heat released = m c δT = 250 × 4.18 × 34.6
= 36157 J = 36.2 kJ
(ii) M_r of $C_{14}H_{30}$ = 198
mass of $C_{14}H_{30}$ = 1.00 × 0.763 = 0.763 g
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} **[5]**

25. O/N 13/P22/Q5/a,b

(a) (i) alkanes **or** paraffins **not** hydrocarbons
(ii) $\mathbf{2}C_4H_{10} + \mathbf{13}O_2 \rightarrow \mathbf{8}CO_2 + \mathbf{10}H_2O$ **[2]**

(b) (i) **carbon** allow graphite
(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 **[2]**

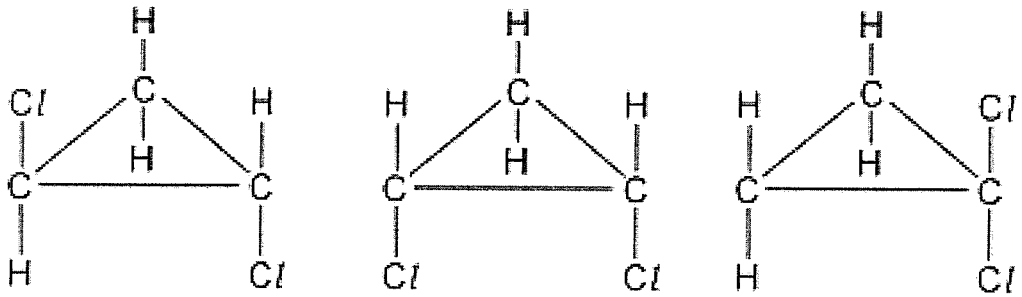
26. O/N 13/P22/Q2

(a) 117° to 120° **[1]**

(b) (i) electrophilic addition

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(ii)



1 mark for each correct structure
allow correctly drawn optical isomers of the first structure [4]

27. O/N 12/P23/Q1

In this question, numerical answers should be given to three significant figures.

(a) (i) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

(ii) $M_r\ C_6H_{12}O_6 = 180$

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

(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

2.728×10^{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 [5]

allow ecf on answer from **(ii)**

(b) (i) $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$ **or**
$C_8H_{18} + 12\frac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$

(ii) $M_r\ C_8H_{18} = (8 \times 12) + (18 \times 1) = 114$

mass of 4.00 dm^3 of octane $= 4000 \times 0.70 = 2800$ g

$n(C_8H_{18}) = \frac{2800}{114} = 24.56140351$ mol in 4.00 dm^3

$= 24.6$ mol to 3 sf

(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 [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

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 [2]

(d) possible pollutants and the damage they cause

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CO	NO_X		SO_2	H_2O	C	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			

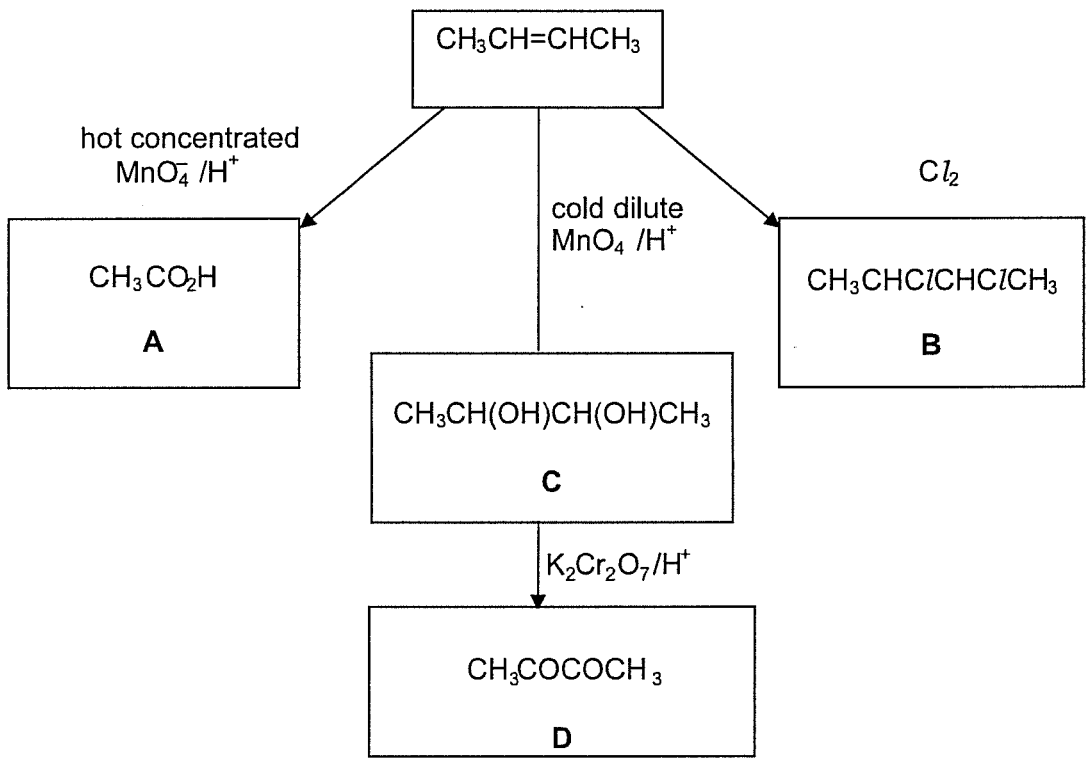
compound
damage [2]

28. M/J 12/P23/Q4

(a) high temperature and high pressure
high temperature and catalyst [2]

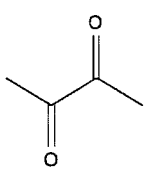
(b) $C_{12}H_{26} \rightarrow C_4H_8 + C_8H_{18}$ **or**
$C_{12}H_{26} \rightarrow 2C_4H_8 + C_4H_{10}$ [1]

(c)



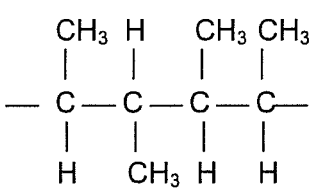
[4]

(d) (i)



(ii) compound **B**
compound **C** [3]

(e)



allow any orientation of CH_3... groups [1]

(f) (i) $CH_2=CH—CH=CH_2$
allow $CH_3CHOHCH=CH_2$ and $CH_3C\equiv CCH_3$

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(ii) $CH_2BrCHBrCHBrCH_2Br$
allow $CH_3CBr_2CBr_2CH_3$ from $CH_3CHOHCH{=}CH_2$
allow $CH_3CHOHCHBrCH_2Br$ from $CH_3C{\equiv}CCH_3$

(iii) electrophilic addition
both words required

[3]

29. M/J 12/P21/Q4

(a) **(i)** $C_2H_5OH \rightarrow C_2H_4 + H_2O$

(ii) elimination **or** dehydration

(iii) phosphoric acid **or** concentrated sulfuric acid
sulfuric acid must be 'concentrated'
allow aluminium oxide

[3]

(b)

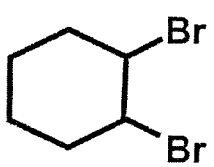
	with HBr	**with MnO_4**
colour at start	colourless	purple **or** pink
colour after reaction	colourless	colourless **or** decolourised
structural formula of product	CH_3CH_2Br	$HOCH_2CH_2OH$

with hydrogen bromide
from colourless **to** colourless **both** colours required
do not allow 'clear' instead of colourless
CH_3CH_2Br
with potassium manganate(VII)
from purple/pink **to** colourless/decolourised **both** colours required
$HOCH_2CH_2OH$

[4]

(c) **(i)** C_6H_{10}

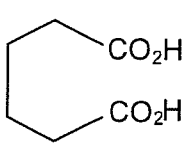
(ii)



accept answers which have $-CH_2-$ in the ring

(iii) electrophilic addition

(iv)



or

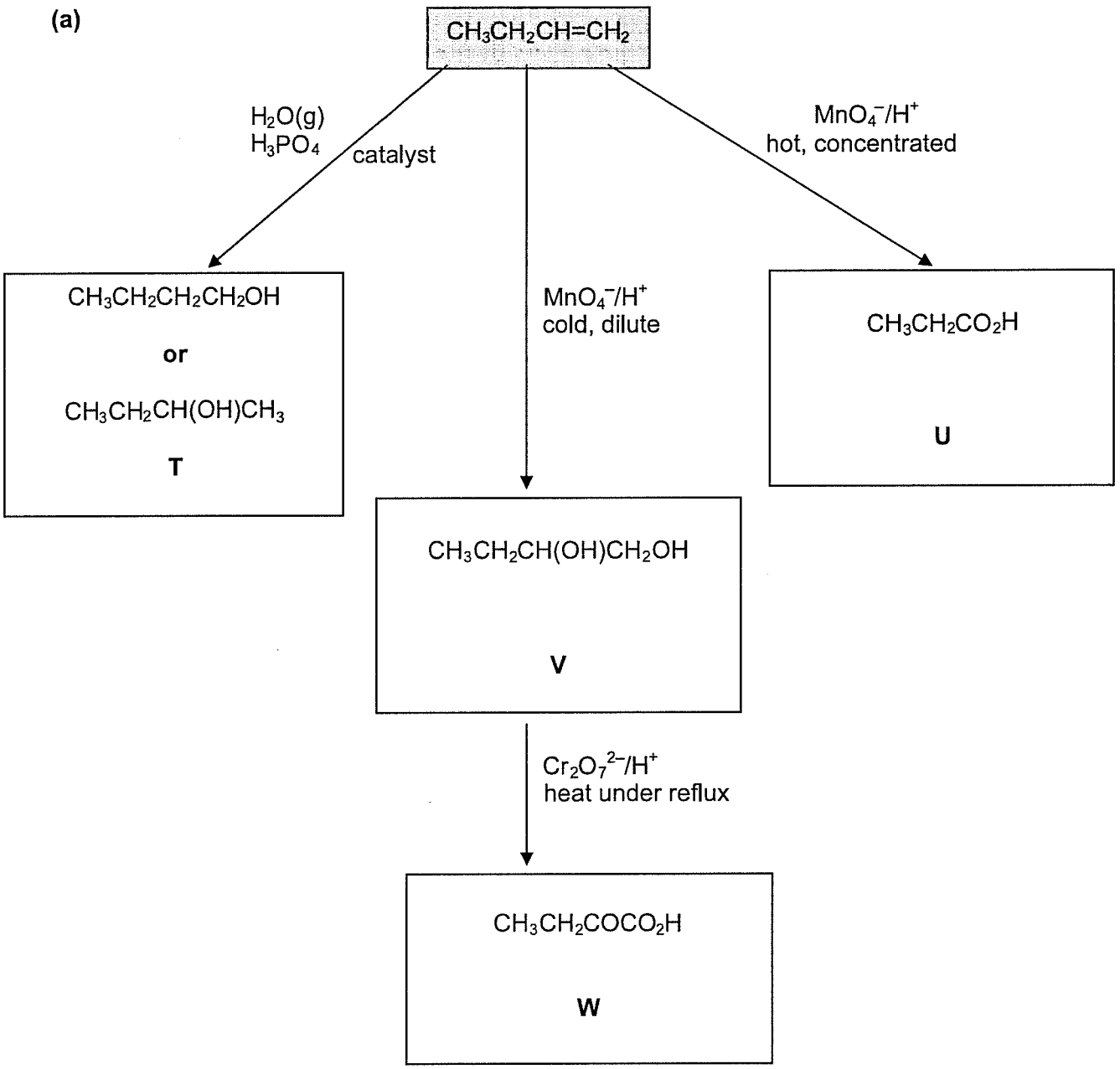
$HO_2C(CH_2)_4CO_2H$ **or**
$HO_2CCH_2CH_2CH_2CH_2CO_2H$
accept answers which have $-CH_2-$ in the ring

[5]

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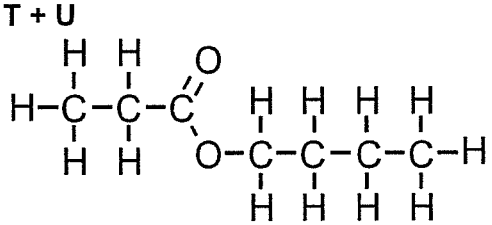
30. O/N 11/P22/Q4

(a)



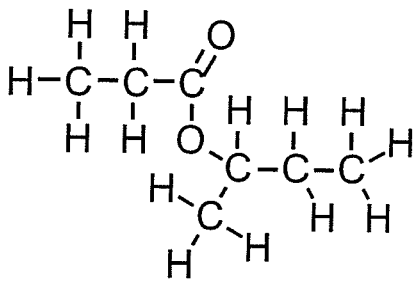
correct **T**
correct **U**
correct **V**
correct > CO group in **W**
correct $-CO_2H$ group in **W** [5]

(b) T + U



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or



correct structures
correctly displayed ester group

[2]

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A Level

Unit 15
HALOGEN COMPOUNDS

Chemistry Paper-2
Topical Workbook
Article Number: 232

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Unit 15: Halogen Compounds

1. M/J 20/P22/Q4

(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**.

[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]

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(iv) Give the names of **P** and **R**.

..... [2]

2. M/J 19/P23/Q5

Halogenoalkanes react with a number of different reagents in nucleophilic substitution reactions.

(a) A sample of potassium cyanide dissolved in ethanol is added to a sample of 1-bromobutane, $CH_3(CH_2)_3Br$, and heated under reflux. A nucleophilic substitution reaction occurs and compound **A** is formed.

(i) Name compound **A**.

..... [1]

(ii) What is meant by the term *nucleophile*?

..... [1]

(iii) Identify the nucleophile in this reaction.

..... [1]

(iv) Explain why this reaction is described as a substitution reaction.

..... [1]

(b) State the reagent(s) and conditions needed for $CH_3(CH_2)_3Br$ to react to form $CH_3(CH_2)_3NH_2$.

reagent(s) .....

conditions .....[2]

(c) Equal amounts of three different halogenoalkanes are added to three separate test-tubes. An equal amount of aqueous silver nitrate and ethanol is added to each test-tube. The time taken for a precipitate to form is recorded for each halogenoalkane.

halogenoalkane	time taken for precipitate to form / s
$(CH_3)_3CCl$	460
$(CH_3)_3CBr$	190
$(CH_3)_3CI$	40

(i) Describe and explain the trend in reactivity of the different halogenoalkanes shown in this experiment.

.....

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

(ii) All three halogenoalkanes tend to react via the S_N1 mechanism.

Explain why the S_N1 mechanism is favoured.

.....

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.....

..... [3]

(iii) Identify a halogenoalkane which tends to react with an aqueous solution of silver nitrate and ethanol via the S_N2 mechanism.

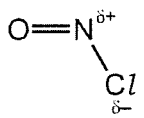
..... [1]

3. MAR 19/P22/Q1/e

Nitrogen, N_2, is the most abundant gas in the Earth's atmosphere and is very unreactive.

(a) Nitrosyl chloride, NOCl, is a reactive gas that is sometimes formed when NO reacts with Cl_2.

nitrosyl chloride



NOCl is a strong electrophile and readily undergoes an addition reaction with alkenes.

Complete the diagram to show the mechanism of the electrophilic addition reaction of NOCl with ethene.

Include all necessary charges, lone pairs and curly arrows, and the structure of the organic intermediate.

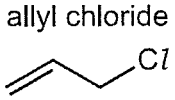


[2]

4. MAR 19/P22/Q4

Allyl chloride is an important chemical used in the manufacture of plastics, pharmaceuticals and pesticides.

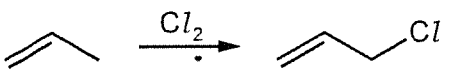
allyl chloride



(a) Give the systematic name of allyl chloride.

..... [1]

(b) Allyl chloride can be produced by many different methods. The most common method is chlorination of propene which proceeds via a free-radical substitution mechanism.



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(i) The initiation step in this reaction is the formation of chlorine radicals ($Cl^{\bullet}$) from Cl_2 molecules.
State the conditions required to initiate this reaction.

..... [1]

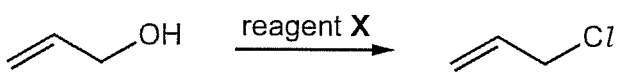
(ii) The propenyl radical, $CH_2{=}CHCH_2^{\bullet}$, is formed in the first propagation step of the reaction.
Write an equation to show the formation of $CH_2{=}CHCH_2^{\bullet}$ in this propagation step.

..... [1]

(iii) Explain why the free-radical substitution reaction gives a low yield of allyl chloride.

..... [1]

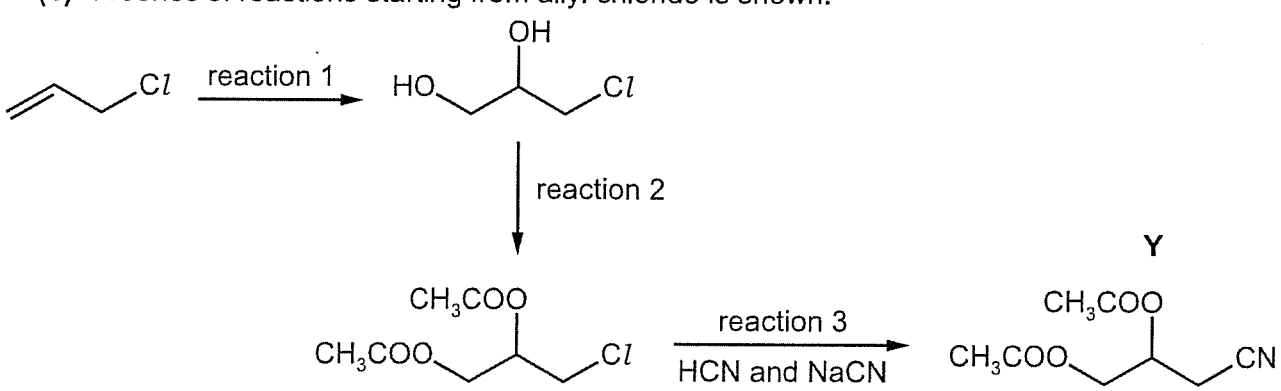
(iv) Allyl chloride can also be formed by the following substitution reaction.



Suggest the identity of reagent **X**.

..... [1]

(c) A series of reactions starting from allyl chloride is shown.



(i) Suggest a reagent that can be used in reaction 1.

..... [1]

(ii) In reaction 2, the organic product of reaction 1 is mixed with concentrated H_2SO_4 and an organic acid, and then heated under reflux.

State the role of the concentrated H_2SO_4. Identify the organic acid used.

role of the concentrated H_2SO_4 .....

identity of the organic acid ..... [2]

(iii) State the name of the mechanism that occurs in reaction 3.

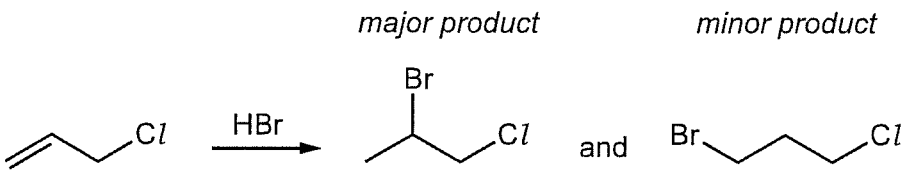
..... [1]

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(iv) The organic product of reaction 3 is **Y**.
Y can be hydrolysed using excess aqueous H_2SO_4 to form **Z**.
The molecular formula of **Z** is $C_4H_8O_4$.
Draw the structure of **Z**.

[2]

(d) 2-bromo-1-chloropropane, $CH_3CHBrCH_2Cl$, is the major product of the reaction of allyl chloride with HBr.

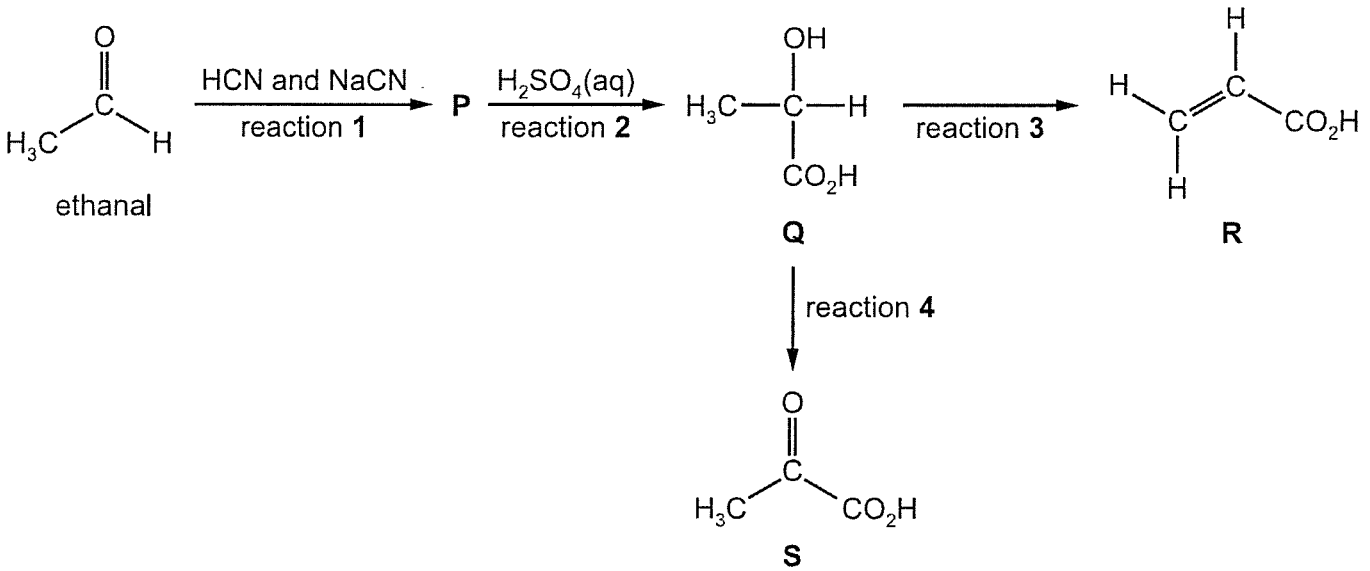


Explain why 2-bromo-1-chloropropane is the major product of this reaction.

.....

..... [2]

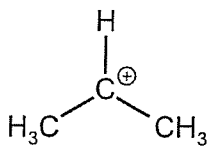
5. O/N 18/P22/Q4/d,e(i)
The diagram shows a reaction sequence starting from ethanal.



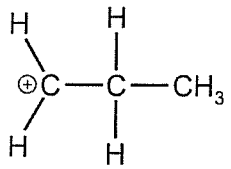
(a) Compound **Z**, $H_2C{=}CHCH_3$, is produced from **R**.
Z can be used in a two-step process to produce 2-aminopropane.

(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**.

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intermediate **I**



intermediate **II**

Explain why intermediate **I** is more likely to form than intermediate **II**.

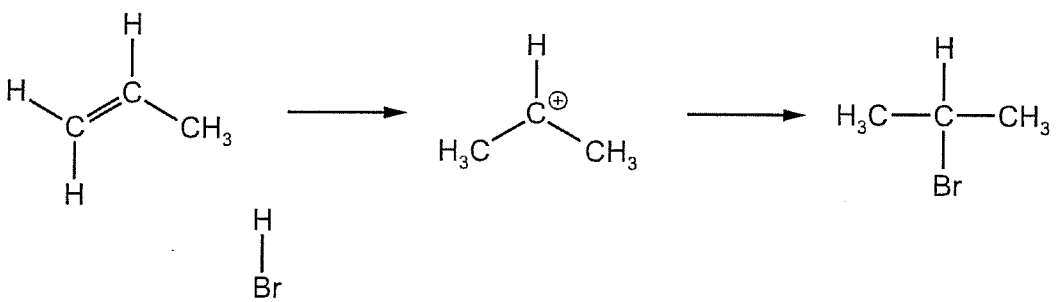
.....

..... [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.

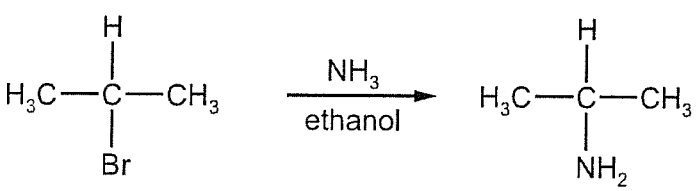
Z **T**



[3]

(iii) **T** can then be converted to 2-aminopropane.

T



2-aminopropane

Name the mechanism for this conversion.

..... [1]

(b) (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.

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6. O/N 18/P21/Q3/c, O/N 18 /P23/Q3/c

Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example $CHCl_3$.

(a) $CHClF_2$ is also used to produce the monomer tetrafluoroethene, C_2F_4.

This monomer can be used to produce poly(tetrafluoroethene), PTFE.

(i) State the type of polymerisation that occurs during the production of PTFE.

..... [1]

(ii) Draw the repeat unit of PTFE.

[1]

(iii) Suggest why PTFE is used as a coating for cooking pans.

..... [1]

(iv) Waste disposal can cause litter problems.

State two **other** difficulties associated with the disposal of PTFE.

1 .....

2 ..... [2]

7. M/J 18/P22/Q3/a,b

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]

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8. M/J 18/P21/Q2

Crude oil is a complex mixture of hydrocarbon molecules.

The hydrocarbon molecules in crude oil are separated by fractional distillation. Fractional distillation is used because the different hydrocarbon molecules in crude oil have different boiling points.

(a) Explain why the hydrocarbon molecules in crude oil have different boiling points.

.....

..... [2]

(b) Some of the hydrocarbon molecules obtained from crude oil are processed further by cracking.

Suggest why some hydrocarbon molecules are processed further by cracking.

..... [1]

(c) Cracking one mole of dodecane, $C_{12}H_{26}$, produces two moles of ethene and one mole of another hydrocarbon molecule.

(i) Write the equation for this cracking reaction.

.....[1]

The ethene can be used in the production of poly(ethene).

(ii) Give the full name of the process used to produce poly(ethene) from ethene.

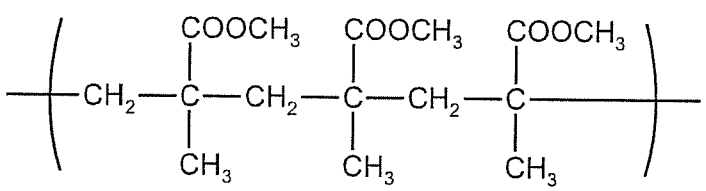
..... [1]

(iii) Give **two** reasons why poly(ethene) should be reused or recycled rather than just thrown away.

.....

..... [2]

(iv) Part of a polymer chain, produced by the same type of process as poly(ethene), is shown.



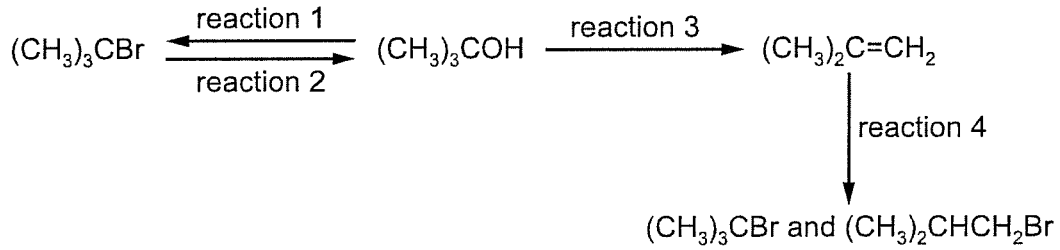
Give the **displayed** formula of the monomer used to produce this polymer.

[2]

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9. O/N 17/P22/Q4/d(ii),(iii)

Some reactions are shown, based on methylpropan-2-ol, $(CH_3)_3COH$.



(a) (i) 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]

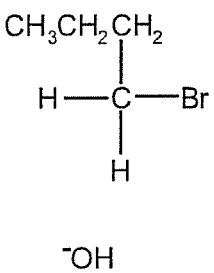
(ii) State the difficulty associated with the disposal of poly(alkenes).

..... [1]

10. MAR 17/P22/Q3/b,c(iii,iv,v)

(a) Complete the reaction scheme to show the mechanism of the reaction of 1-bromobutane with OH (aq) to produce **R**.

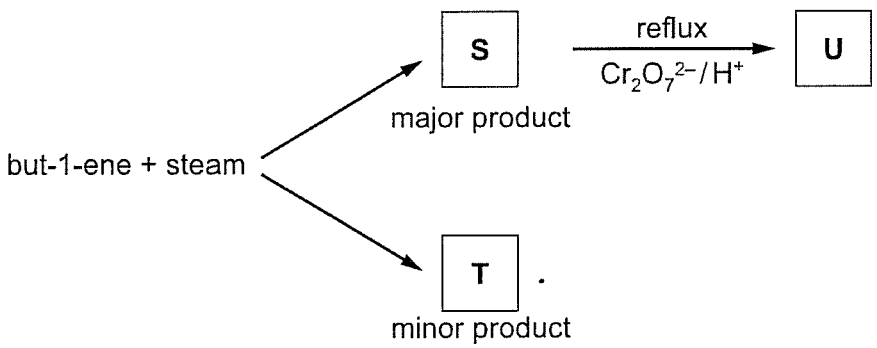
Include all necessary charges, dipoles, lone pairs and curly arrows and the structure of **R**.



^-OH

[3]

(b) But-1-ene reacts with steam as shown to form a mixture of two structural isomers, **S** and **T**.



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S can be oxidised with acidified potassium dichromate(VI) to form compound **U**.
S and **U** both react with alkaline aqueous iodine.

(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**.

S

T

U

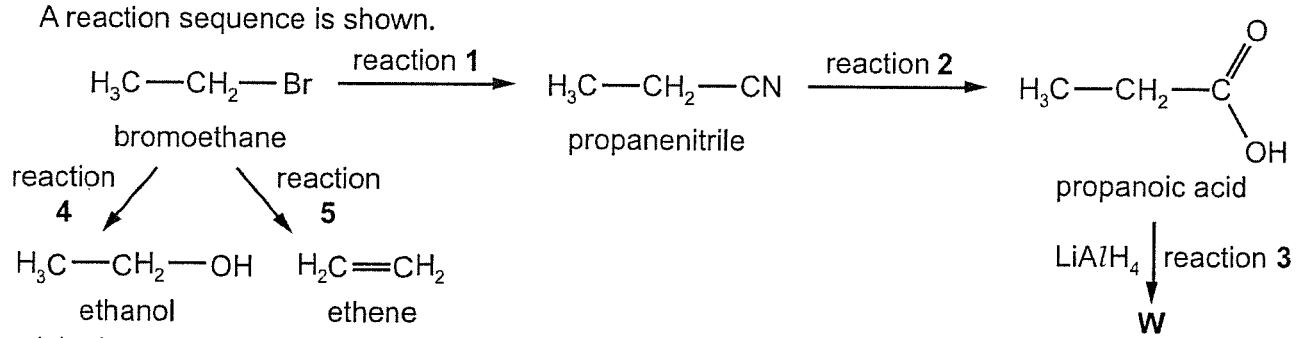
[3]

(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.

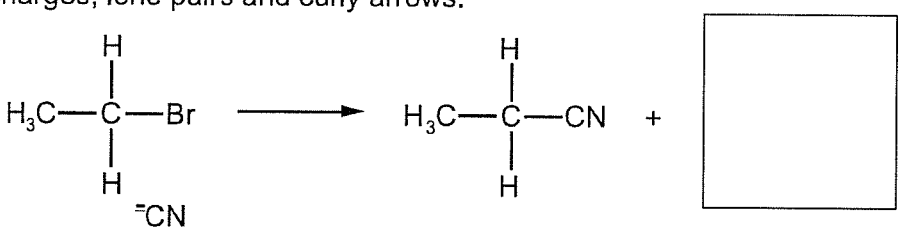
..... [1]

11. 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.



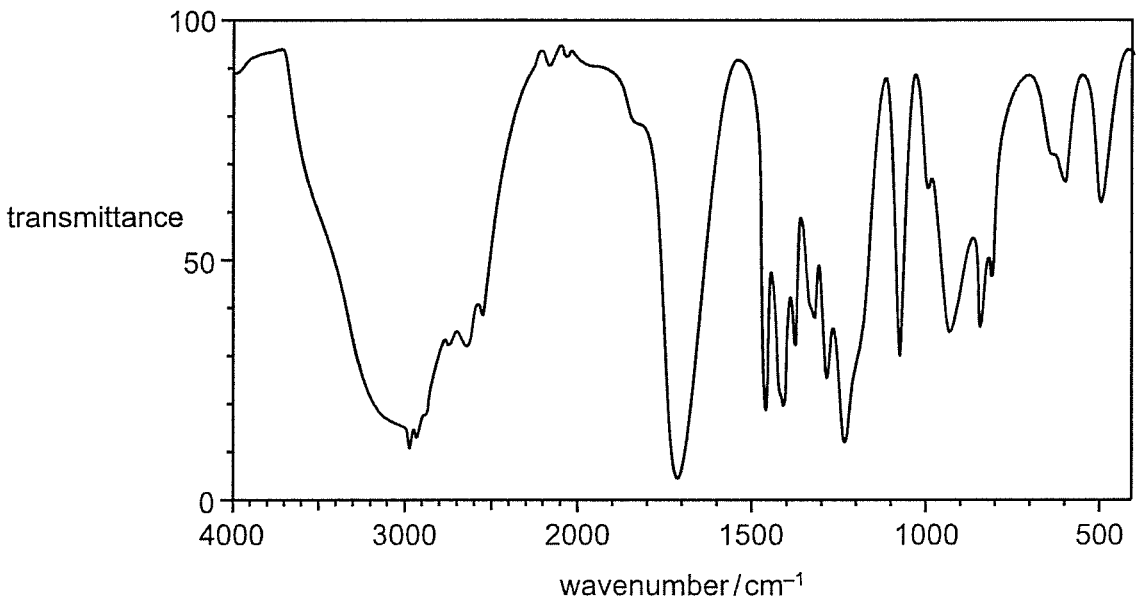
[2]

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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]

(ii) Draw the skeletal formula of the organic product of this reaction.

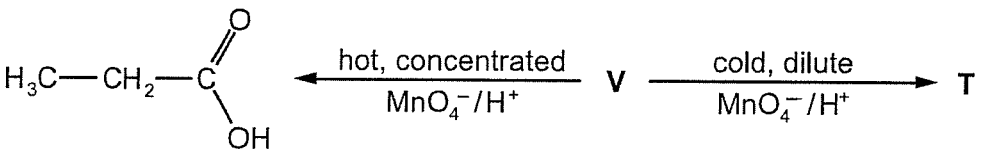
[1]

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(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**.

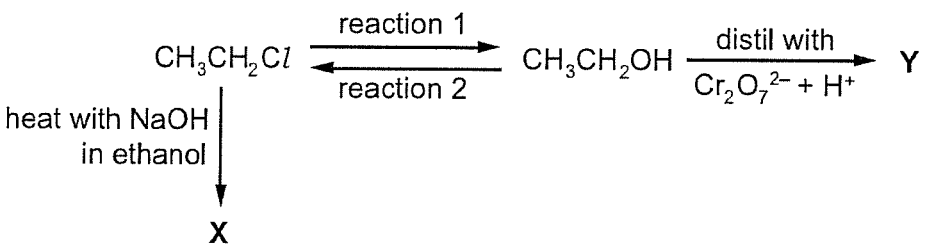
V ..... **T** ..... [2]

(ii) Identify the types of stereoisomerism shown by **V** and **T**.

V ..... **T** ..... [2]

12. 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]

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(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]

13. 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**.

$$C_2H_5Cl \xrightarrow{\text{reaction 1}} \mathbf{X} \xrightarrow{\text{reaction 2}} C_2H_6$$

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(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]

14. 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.

.....

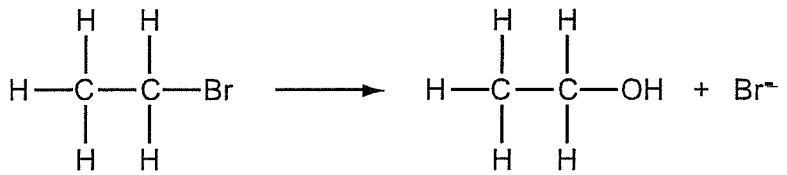
..... [2]

(c) (i) Give the full name of the mechanism for the reaction between aqueous sodium hydroxide and bromoethane.

..... [2]

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(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]

15. M/J 13/P22/Q1/c

Ammonium sulfate is a fertiliser which is manufactured by the reaction between ammonia and sulfuric acid.

(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

(ii) Describe as fully as you can what type of reaction occurs with ammonia.

..... [4]

16. O/N 10/P23/Q4

Although few halogenoalkanes exist naturally, such compounds are important as intermediates in organic reactions and as solvents.

The bromoalkane **B** has the following composition by mass: C, 29.3%; H, 5.7%; Br, 65.0%.
The relative molecular mass of **B** is 123.

(a) Calculate the molecular formula of **B**.

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[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)**.

(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]

17. 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.

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(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.

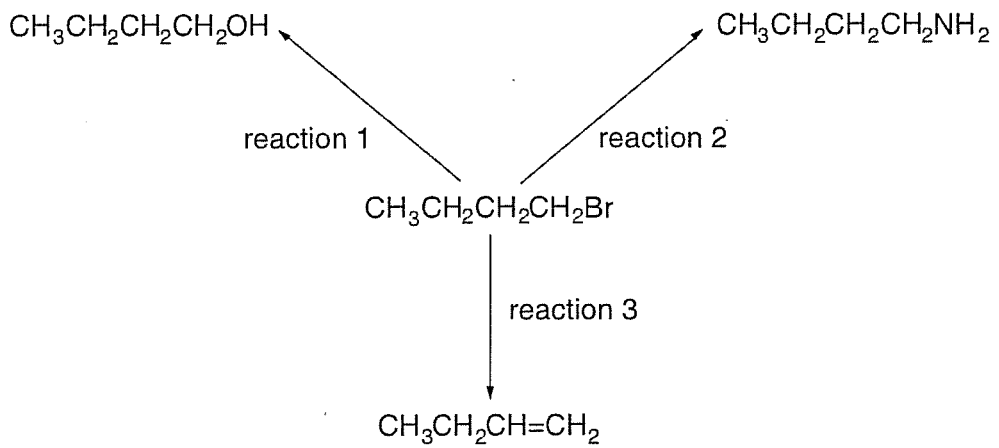
.....

..... [2]

18. 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.



(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?

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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]

(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]

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Answers Section

1. M/J 20/P22/Q4

(a) (i) Bromine / Br **1**

(ii) $Ag^+(aq) + X^-(aq) \rightarrow AgX(s)$ OR $Ag^+(aq) + Br^-(aq) \rightarrow AgBr(s)$ **1**

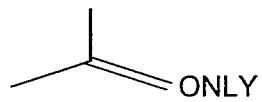
(iii) **M1** *reagent* **2**
Add (aqueous) ammonia
M2 *expected result*
EITHER (Dilute ammonia) – partial amount precipitate dissolves OR
not much precipitate dissolves **OR** add concentrated ammonia–precipitate dissolves

(b) (i) $CH_3CH_2CH_2CH_2CH_2Br$ **1**

(ii) **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+

(c) (i) elimination **1**

(ii) $C_4H_9Cl + NaOH \rightarrow C_4H_8 + NaCl + H_2O$ **1**

(iii)  **1**
ONLY

(iv) **M1** 2-chloro(-2-)methylpropane **2**
M2 1-chloro(-2-)methylpropane
ALLOW in any order

2. M/J 19/P23/Q5

(a) (i) pentanenitrile **1**

(ii) a lone pair / electron pair donor **1**

(iii) $(:)CN^-$ / $^-(:)CN$ / cyanide ion **1**

(iv) Br (atom) is replaced (with / by CN / nitrile) **1**

(b) **M1** *reagent* **2**
Ammonia
M2 *conditions*
heat with under pressure / heat in a sealed tube

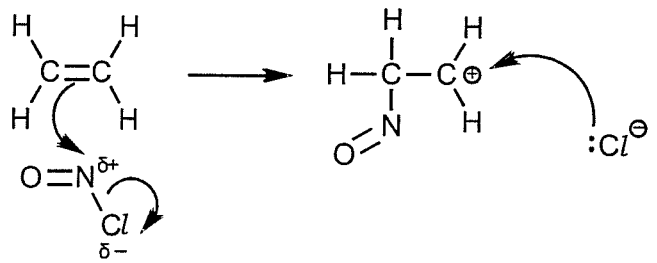
(c) (i) **M1** Increasing reactivity from $Cl \rightarrow Br \rightarrow I$ **2**
M2 Due to decreasing strength of C-X bond (from C-C*l* to C-Br to C-I)
OR
Less energy needed to break C-X (from C-C*l* to C-Br to C-I)

(ii) **M1** tertiary/ 3° halogenoalkane **3**
M2 (carbo)cation / intermediate is stable
M3 due to (3) electron releasing/donating methyl groups / + I
groups (attached to central C) OR (positive) inductive effect of the
(three) methyl groups /

(iii) *Any* **formula / name** for *any* **primary** halogenoalkane i.e. 1-chlorobutane **1**
/ 1-bromobutane / 1-iodobutane

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3. MAR 19/P22/Q1/e

(a)  **2**

M1 curly arrow from C=C to $N^{\delta+}$
AND curly arrow from N—C*l* to $C^{\delta-}$
M2 intermediate
AND curly arrow from lone pair on Cl^- to C(+)

4. MAR 19/P22/Q4

(a) 3-chloroprop-1-ene **1**

(b) (i) ultra-violet (light) /sun(light) **1**

(ii) $CH_2{=}CHCH_3 + Cl^\bullet \rightarrow CH_2{=}CHCH_2^\bullet + HCl$
OR $C_3H_6 + Cl^\bullet \rightarrow C_3H_5^\bullet + HCl$ **1**

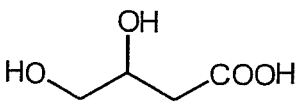
(iii) free-radical (substitution) reactions are uncontrolled
OR further chlorination / substitution occurs **1**

(iv) $SOCl_2$ OR PCl_5 OR PCl_3 OR c(oncentrated) HCl **1**

(c) (i) cold, dilute acidified $KMnO_4$ / potassium manganate(VII) **1**

(ii) M1 catalyst
M2 ethanoic acid / CH_3CO_2H **2**

(iii) nucleophilic substitution / S_N2 **1**

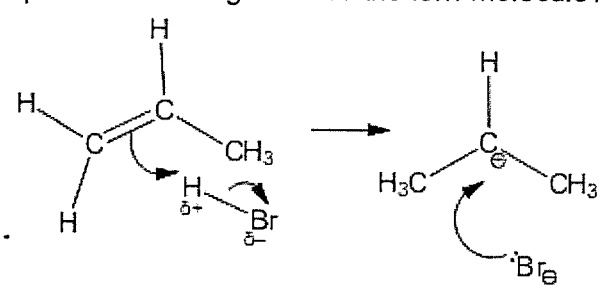
(iv)  **2**

M1 hydrolysed nitrile on straight-chain 4C backbone
M2 3,4-diol

(d) M1 major product formed from more stable intermediate / carbocation **2**
OR
(intermediate has) 2°carbocation which is (more) stable
M2 (positive) inductive effect / (+)I of alkyl groups (on the intermediate)

5. O/N 18/P22/Q4/d,e(i)

(a) (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**

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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]

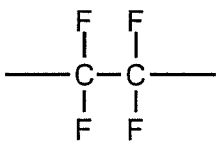
(iii) nucleophilic substitution **1**

(b) (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]

6. O/N 18/P21/Q3/c, O/N 18/P23/Q3/c

(a) (i) addition **1**

(ii)  **1**

(iii) molecule unreactive / inert **1**

(iv) non-biodegradable **2**
creates toxic/ harmful gases / HF / CO_2 / CO **if burnt**

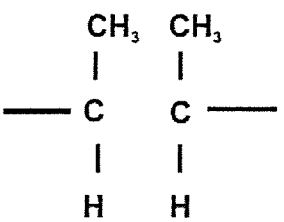
7. M/J 18/P22/Q3/a,b

(a) (i) combustion **1**

(ii) $C_8H_{18} + 12½O_2 \rightarrow 8CO_2 + 9H_2O$
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**

8. M/J 18 /P21/Q2

(a) Different (hydrocarbon) molecules have different numbers of electrons **1**
so different strengths / numbers / amount of VdW / IMFs / id-id **1**

(b) Produces more useful / more valuable / higher demand substances / alkanes / alkenes **1**

(c) (i) $C_{12}H_{26} \rightarrow 2C_2H_4 + C_8H_{18}$ **1**

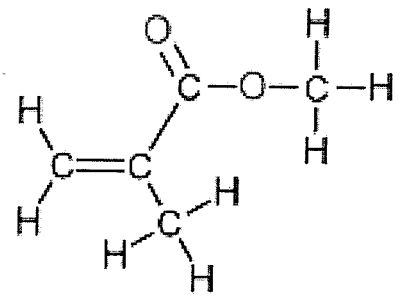
(ii) addition polymerisation **1**

(iii) *two from* **2**
save space in landfill
avoid litter
prevent eyesore
non-biodegradable

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conserves non-renewable resources
harmful incineration products
harmful to wildlife

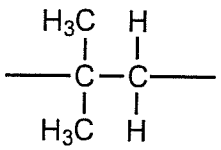
(iv)



correct monomer 1
fully displayed 1

9. O/N 17 /P22/Q4/d(ii),(iii)

(a) (i) addition 1



2

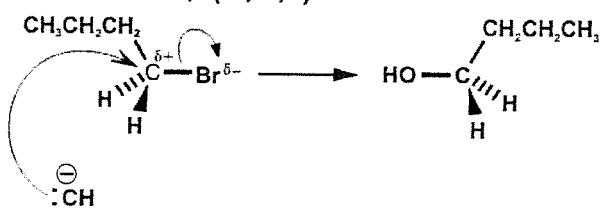
marking points:

- correct number of tetravalent carbon atoms in backbone, with extension bonds
- correct groups on backbone carbon atoms **and** only one repeat unit

(ii) not/non- biodegradable / harmful combustion products 1

10. MAR 17/P22/Q3/b,c(iii,iv,v)

(a)



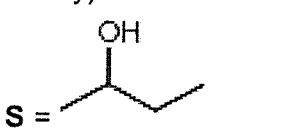
3

lone pair on O **AND** curly arrow from O to C of C–Br
dipole on C–Br **AND** curly arrow from C–Br to Br
product (butan-1-ol)

(b) (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

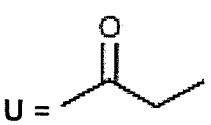
(ii)



1



1



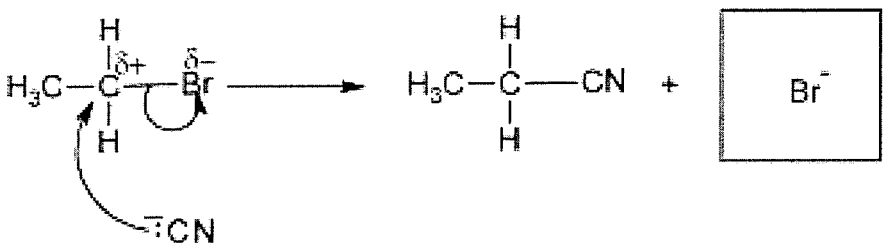
1

(iii) $CH_3CHOHCH_2CH_3 + [O] \rightarrow CH_3COCH_2CH_3 + H_2O$ 1

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11. M/J 16/P21/Q5

(a)



M1 = lone pair on C of CN− AND curly arrow from lone pair to C of C—Br

M2 = correct dipole on C—Br, curly arrow from C—Br bond to Br AND Br^- [2]

(b) (i) reduction [1]

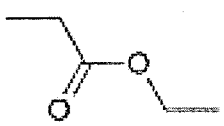
(ii) disappearance of peak/dip/trough/absorption at 1680–1730
due to (loss of) C=O
OR
peak at 3200–3650
due to (alcohol) O—H (formation) [2]

(c) (i) sodium/potassium hydroxide
aqueous [2]

(ii) ethanol

(d) (i) (conc) H^+ / (conc) acid / (conc)H_2SO_4 / (conc)H_3PO_4 1

(ii)



1

(iii) ethyl propanoate 1

(e) (i) **V** = $CH_3CH_2CHCHCH_2CH_3$ / $CH_3CH_2CH{=}CHCH_2CH_3$
T = $CH_3CH_2CH(OH)CH(OH)CH_2CH_3$ [2]

(ii) **V** = geometric(al) / *cis-trans* / *E–Z*
T = optical [2]

12. O/N 15/P23/Q4, O/N 15/P21/Q4

(a) (i) $CH_3CH_2OH + HCl \rightarrow CH_3CH_2Cl + H_2O$ [2]
or
$CH_3CH_2OH + PCl_5 \rightarrow CH_3CH_2Cl + HCl + POCl_3$
or
$CH_3CH_2OH + SOCl_2 \rightarrow CH_3CH_2Cl + HCl + SO_2$

(ii) NaOH/KOH
warm/heat/reflux AND aqueous [2]

(b) (i) $CH_2{=}CH_2$ / ethane / C_2H_4 / CH_2CH_2

(ii) White ppt / solid / suspension

(iii) $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl\,(s)$ [1]

(c) (i) CH_3CHO / ethanal

(ii) CH_3CH_2OH higher bpt than CH_3CHO ora
due to hydrogen bonding in ethanol / stronger IMFs
prevents further oxidation owtte [3]

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13. 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]

(ii) UV / High T / sunlight [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]

(b) (i) ethene [1]

(ii) KOH / NaOH [1]

ethanolic **AND** heat / reflux [1]

(iii) H_2 **AND** Pt or Ni (catalyst) [1]

14. M/J 14/P23/Q4/c,d,e,f

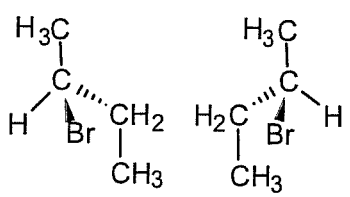
(a) (i) $CH_3CH_2CH_2CH_2Br$ primary

$CH_3CH_2CHBrCH_3$ secondary

$(CH_3)_2CHCH_2Br$ primary

$(CH_3)_3CBr$ tertiary [4]

(ii) 2-bromobutane



[3]

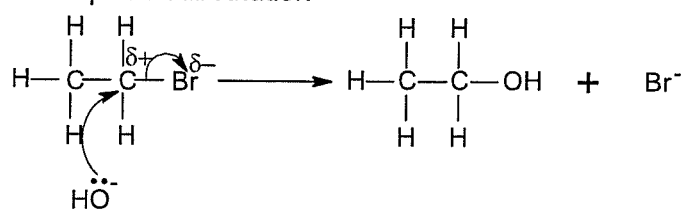
(b) halide ions liberated (by hydrolysis of halogenoalkanes)form precipitate with Ag^+

OR $Ag^+ + X \rightarrow AgX$

order due to decreasing bond strength (C – I < C – Br < C – C*l*) **[2]**

(c) (i) nucleophilic substitution [2]

(ii)



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M1 = curly arrow from lone pair on OH^- ;
M2 for curly arrow from C-Br bond to Br **AND** dipole [2]

(d) (i) inert or volatile owtte [1]

(ii) destroy ozone
(in stratosphere) C–C*l* bond broken by UV /free radicals produced [2]

15. M/J 13/P22/Q1/c

(a) (i) **with concentrated sulfuric acid**
$ClCH_2CH{=}CHCl$
with ammonia
$H_2NCH_2CH(OH)CH_2NH_2$

(ii) nucleophilic
substitution [4]

16. 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]

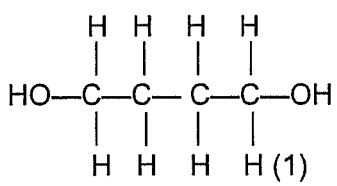
(b) (i) mechanism must be S_N2
dipole on C-Br bond **or**
central C atom shown with $\delta+$ (1)
attack on C atom by lone pair of OH^-
not from negative charge (1)
transition state formed **with** negative charge shown (1)
Br leaves/NaBr formed (1)

(ii) C_2H_4 /ethane (1)

(iii) ethanol/C_2H_5OH (1)

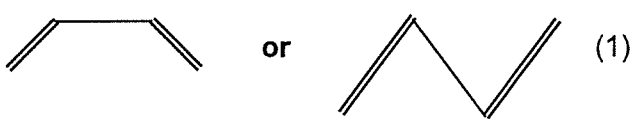
(iv) elimination (1) [7]

(c) (i)



(1)

(ii) **must** be skeletal



(1) [2]

17. O/N 10/P23/Q5

(a) AgC*l*/silver chloride (1) [1]

(b) white (1) [1]

(c) 1-iodobutane (1) [1]

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(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]**

18. 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]**

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A Level

Unit 16
HYDROXY COMPOUNDS

Chemistry Paper-2
Topical Workbook
Article Number: 232

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Unit 16: Hydroxy compounds

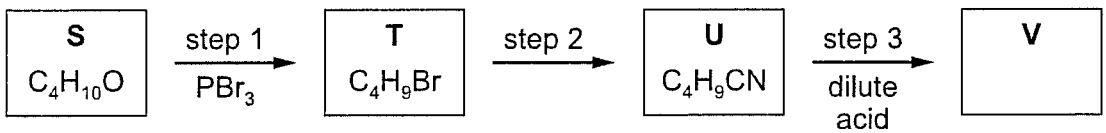
1. M/J 21/P22/Q5

S is a secondary alcohol with molecular formula $C_4H_{10}O$.

(a) Draw the displayed formula of **S**.

[1]

(b) **S** is converted to **V** in a three-step reaction sequence.



In step 1, the secondary alcohol **S** reacts with PBr_3 to produce **T**, which has molecular formula C_4H_9Br.

(i) Give the systematic name of **T**.

..... [1]

(ii) Name the type of reaction that occurs in step 1.

..... [1]

(iii) State the reagent(s) and conditions for step 2.

.....

..... [2]

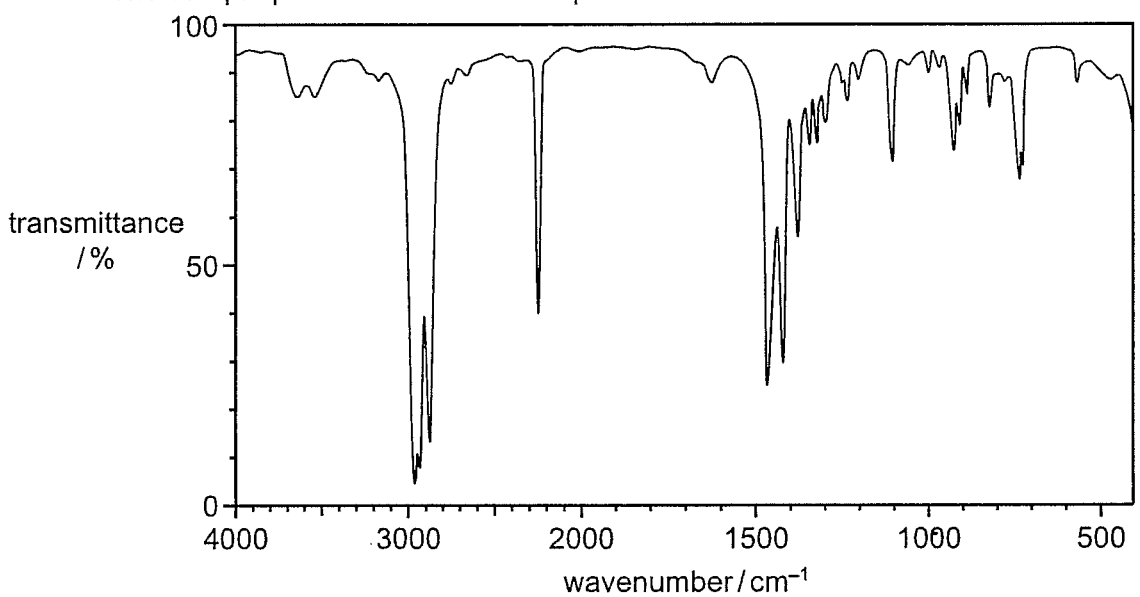
(iv) Step 3 involves heating C_4H_9CN with dilute acid to form **V**.

Complete the equation for this reaction.

$$.....C_4H_9CN + ...H^+ + ...H_2O \rightarrow .....$$ [2]

(v) An unlabelled sample contains either **S**, **T** or **U**.

The sample produces the infrared spectrum shown.



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Explain how this spectrum confirms that the unknown sample contains **U**.
In your answer identify **one** relevant absorption in the infrared spectrum and the bond that corresponds to this absorption in the region above 1500 cm^{-1}.

..... [1]

2. M/J 21/P23/Q2

Methanol, CH_3OH, is soluble in water because it forms hydrogen bonds with water molecules.

(a) Draw a fully labelled diagram to show how a hydrogen bond forms between a water molecule and a methanol molecule.

[3]

(b) Methanol has a melting point of –97.6 °C and a boiling point of 64.7 °C.
A sample of pure liquid methanol is added to a flask and then sealed. The sealed flask is left for several days at constant temperature. The vapour pressure is then measured as 17 kPa.

(i) Describe what is meant by the term *vapour pressure of methanol.*

.....

..... [2]

(ii) Explain why some of the liquid becomes a vapour.

..... [1]

(iii) Suggest and explain why the vapour pressure of water at room temperature is lower than the vapour pressure of methanol at room temperature. Refer to the correct intermolecular forces in your answer.

.....

..... [2]

(c) Methanol is made by reacting carbon monoxide with hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

Carbon monoxide and hydrogen react at 1.0×10^7 Pa and 200 °C. Eventually the reaction mixture reaches dynamic equilibrium.
The table shows the amounts of each species present in the mixture.

	CO(g)	$H_2(g)$	$CH_3OH(g)$
initial amount/mol	1.0	2.0	0
equilibrium amount/mol	0.030	0.060	0.97

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(i) Explain what is meant by *dynamic equilibrium*.

.....

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

(ii) Calculate the partial pressure of methanol vapour at equilibrium under these conditions. Show your working.

..... Pa [2]

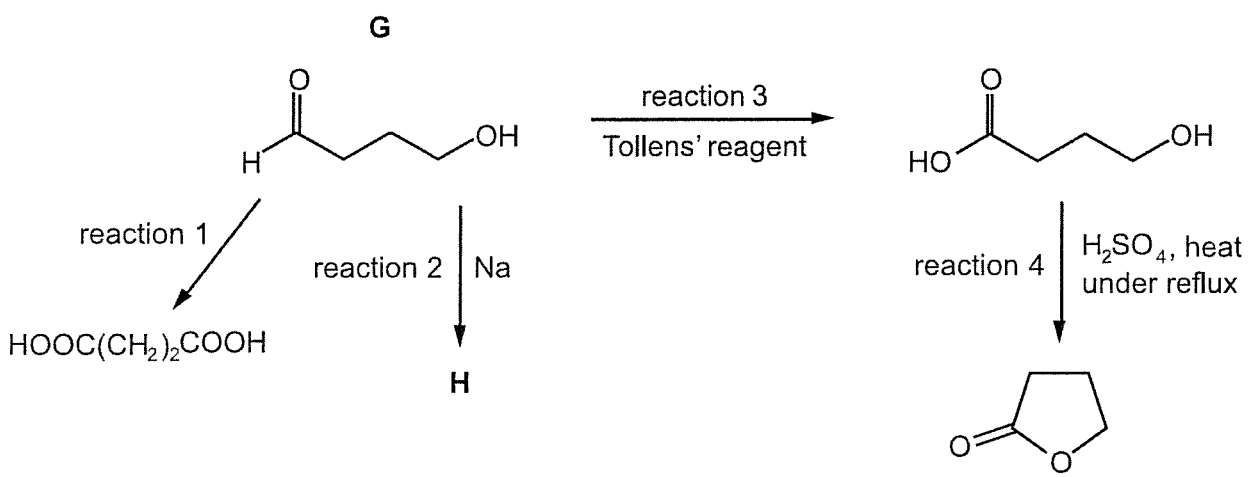
(iii) Write an expression for the equilibrium constant, K_p, for this reaction. State the units in your answer.

K_p =

units = ... [2]

3. O/N 20/P22/Q4

Some reactions of compound **G** are shown.



(a) (i) State the type of reaction that occurs in reaction 1.

..... [1]

(ii) Suggest the reagent(s) and conditions required for reaction 1.

.....

..... [2]

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(iii) Draw the structure of the organic product, **H**, from reaction 2.

[1]

(iv) State what you would observe in reaction 3.

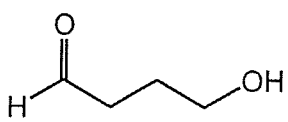
..... [1]

(v) Give the type of reaction shown by reaction 4.

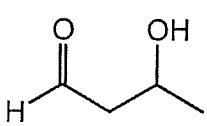
..... [1]

(b) **G** and **J** are structural isomers of each other.

G



J



(i) Name the type of structural isomerism shown by **G** and **J**.

..... [1]

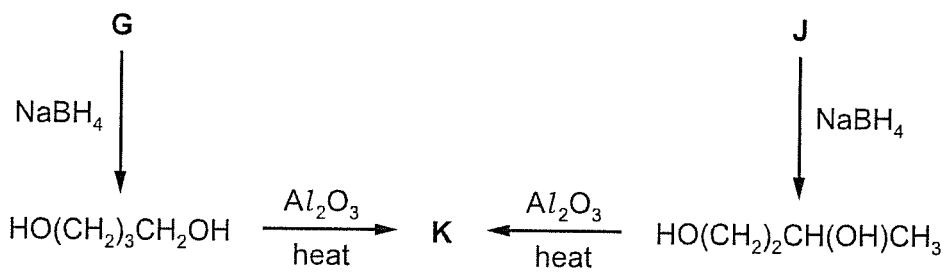
(ii) Suggest **one** chemical test that can distinguish **G** from **J**. Give the result of the test with each compound.

test .....

result with **G** .....

result with **J** .....[2]

In the reaction schemes below, **G** and **J** are converted into organic compound **K**.



(iii) State the role of $NaBH_4$ in the reactions with **G** and **J**.

..... [1]

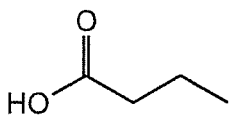
(iv) Identify the organic product **K**.

..... [1]

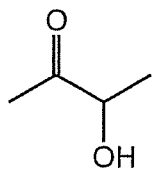
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(c) **P** and **Q** have the same molecular formula as **G**.

P



Q



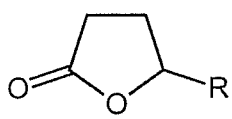
Complete the table with the expected observations for the reactions of **P** and **Q** with the named reagents.

reagent	result with **P**	result with **Q**
Br_2(aq)		
2,4-dinitrophenylhydrazine		
aqueous sodium carbonate		

[3]

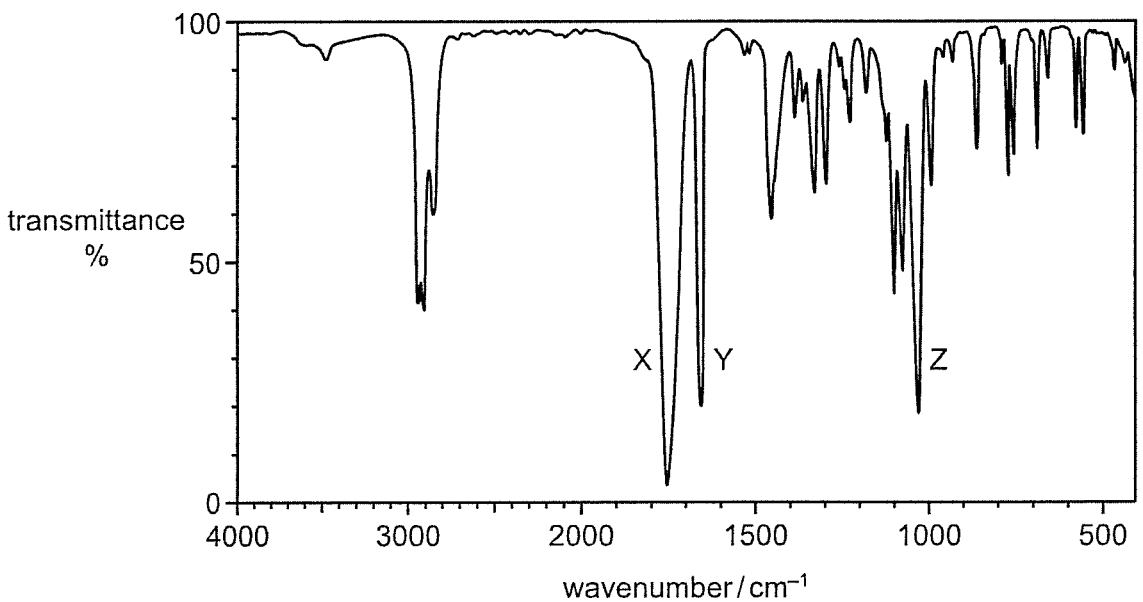
(d) The structure of compound **L** is shown. R represents a hydrocarbon chain.

L



A student was asked to deduce the full structure of **L**.

The student analysed **L** using infrared spectroscopy. The following spectrum was obtained.



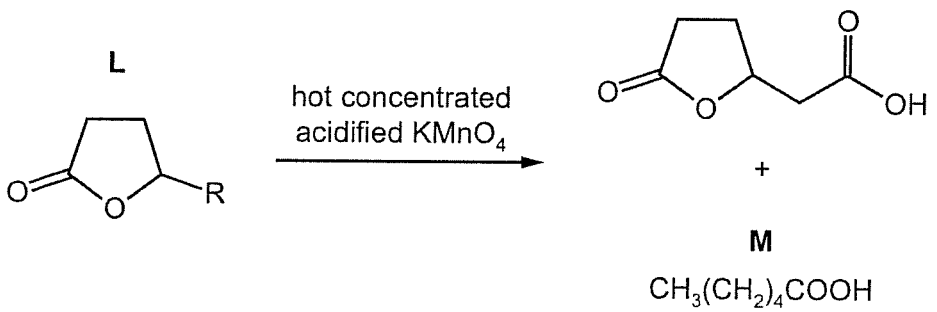
(i) Identify the bonds responsible for the absorptions marked X and Z.

X .....

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Z ..... [1]

Absorption Y shows that **L** has a C=C bond present in the R group.
The student decided to treat **L** with hot concentrated acidified potassium manganate(VII). The products of the reaction are shown.



(ii) Name **M**.

..... [1]

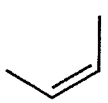
(iii) Use the information in **(d)** to deduce the molecular formula of **L**.

molecular formula of **L** = ... [1]

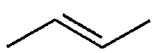
4. M/J 20/P23/Q5

C, **D** and **E** are isomers of each other.
They are made by passing an alcohol vapour over an aluminium oxide catalyst.

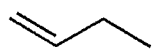
C



D



E



(a) (i) Name the type of reaction occurring.

..... [1]

(ii) Draw the displayed formula of the alcohol used in this reaction.

[2]

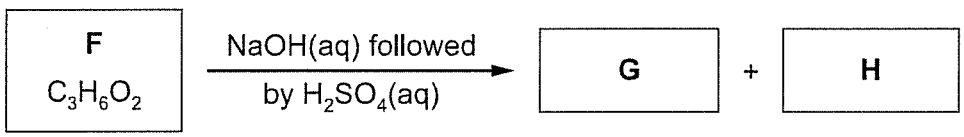
(iii) Name the isomers **C**, **D** and **E**.

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isomer	name
C	
D	
E	

[2]

(b) **F** is an organic molecule which has the molecular formula $C_3H_6O_2$.
When **F** is heated with NaOH(aq) followed by H_2SO_4(aq) the products **G** and **H** are made.



Separate samples of **G** and **H** are added to

- Na_2CO_3(aq)
- sodium metal
- alkaline aqueous iodine.

The observations are described in the table.

reagent(s)	**G**	**H**
Na_2CO_3(aq)	colourless bubbles of gas produced	no visible reaction
Na(s)	colourless bubbles of gas produced	colourless bubbles of gas produced
alkaline aqueous iodine	no visible reaction	yellow precipitate forms

(i) Complete the table to identify the functional groups present in **F**, **G** and **H**.

	functional group
F	
G	
H	

[3]

(ii) Name the yellow precipitate formed when alkaline aqueous iodine reacts with **H**.

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

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(iii) Draw the structures of **G** and **H**.

G	H

[2]

5. O/N 19/P22/Q3

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]

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(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.

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.

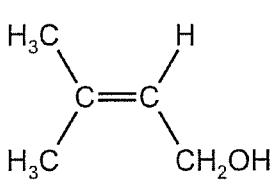
.....

..... [2]

6. O/N 19/P22/Q4

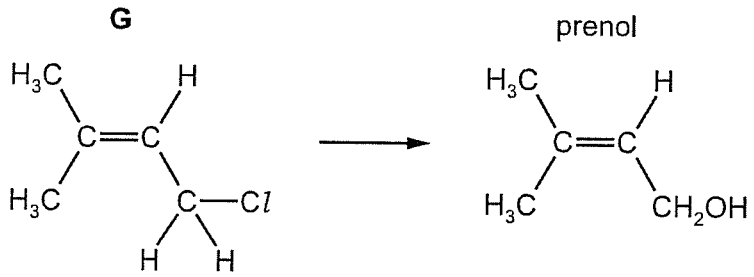
Prenol is a naturally occurring organic molecule found in many fruits. It contains both an alkene and an alcohol functional group.

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.

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[2]

(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]

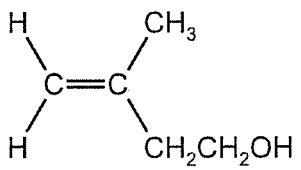
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(ii) Prenol can be polymerised to form poly(prenol).
Draw **one** repeat unit of poly(prenol).

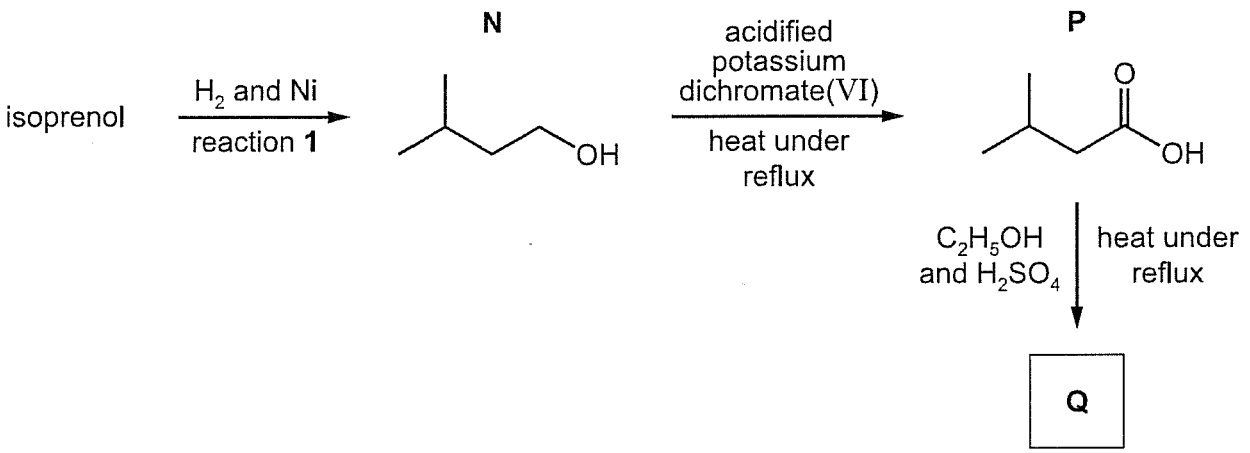
[1]

(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]

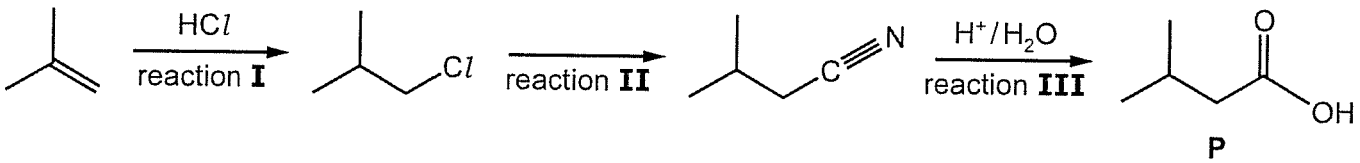
(iii) Draw the **skeletal** formula of **Q** and suggest one commercial use of **Q**.

Q

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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–Cl 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]

7. O/N 18/P21/Q3/b, O/N 18/P23/Q3/b

(a) $CHClF_2$ was used as an alternative to chlorofluorocarbons (CFCs). $CHClF_2$ should no longer be used because it was found to contribute to the *enhanced greenhouse effect*

(i) Give the meaning of the term *enhanced greenhouse*

..... [1]

(ii) Explain how $CHClF_2(g)$ may contribute to this effect.

.....

..... [2]

(iii) Suggest another environmental problem associated with the use of $CHClF_2$.

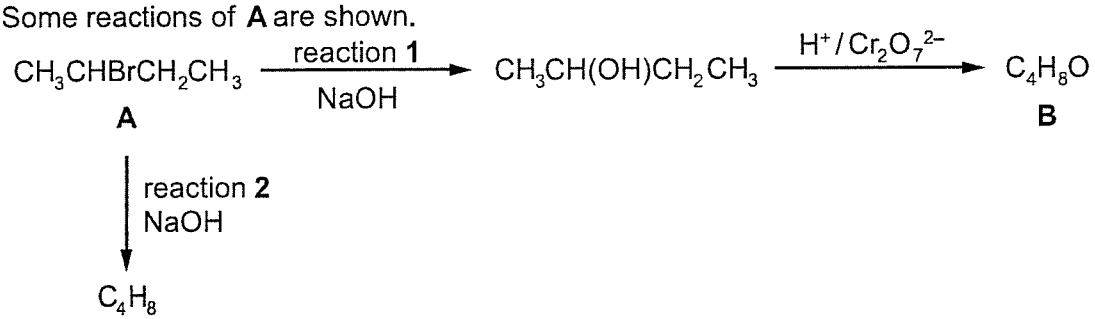
..... [1]

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8. M/J 18/P23/Q4

A is $CH_3CHBrCH_2CH_3$

(a) Some reactions of **A** are shown.



(i) Name **A**.

..... [1]

(ii) Name the class of compound to which **B** belongs.

..... [1]

(b) There are three structural isomers of **A**.
Draw the structures of these three isomers of **A**.

[2]

(c) Reaction **1** occurs by two different mechanisms at the same time.
These mechanisms are referred to as S_N1 and S_N2.

(i) State what the letters 'S' and 'N' represent in the abbreviation S_N1.

S .....

N ..... [1]

(ii) Complete the S_N1 mechanism for reaction **1**.
Include the structure of the intermediate and all necessary charges, dipoles, lone pairs and curly arrows.



[3]

(d) The S_N1 mechanism for reaction **1** is repeated using $CH_3CHClCH_2CH_3$ or $CH_3CHICH_2CH_3$ in place of the $CH_3CHBrCH_2CH_3$.

State and explain how the rates of these two reactions will compare with the rate of the original reaction using $CH_3CHBrCH_2CH_3$.

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.....

.....

..... [3]

(e) Reaction **2** uses the same reagent as reaction **1**, but under different conditions.
State **two** differences in the conditions needed to ensure that reaction **2** is more likely to take place than reaction **1** when this reagent is added.

.....

..... [2]

9. M/J 18/P21/Q4/d

(a) The reaction of methylpropene, $(CH_3)_2CCH_2$, with hydrogen bromide, HBr, produces a mixture of two halogenoalkanes.

One of the halogenoalkanes, 2-bromo-2-methylpropane, is formed as the major product while 1-bromo-2-methylpropane is formed in small quantities.

(i) Complete the mechanism to show the reaction of methylpropene with HBr to form the **major** product.

Include the structure of the intermediate and all necessary charges, dipoles, lone pairs and curly arrows. The structure of 2-bromo-2-methylpropane is not required.



[4]

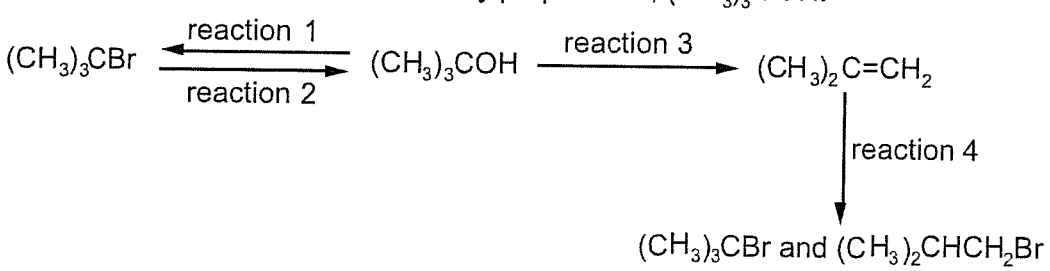
(ii) Explain why 2-bromo-2-methylpropane is the major product of this reaction.

.....

..... [2]

10. O/N 17/P22/Q4/c(ii)

Some reactions are shown, based on methylpropan-2-ol, $(CH_3)_3COH$.



(a) 1-bromobutane is a structural isomer of the product of reaction 1.

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(i) 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.

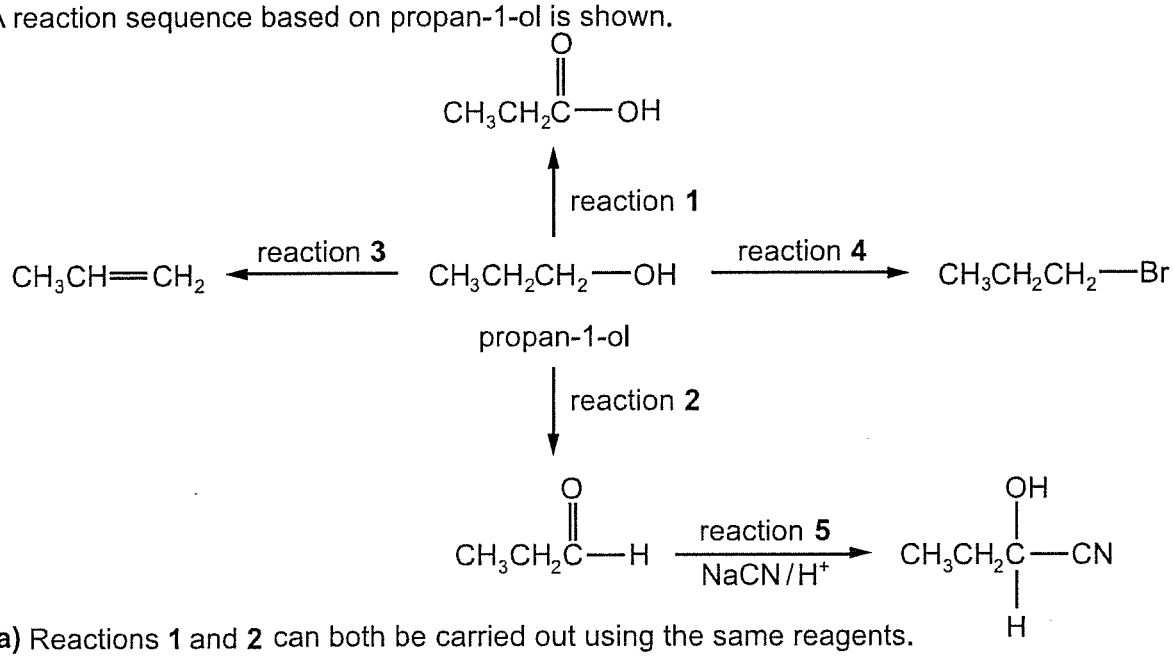
mechanism .....

explanation .....

..... [3]

11. 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** .....

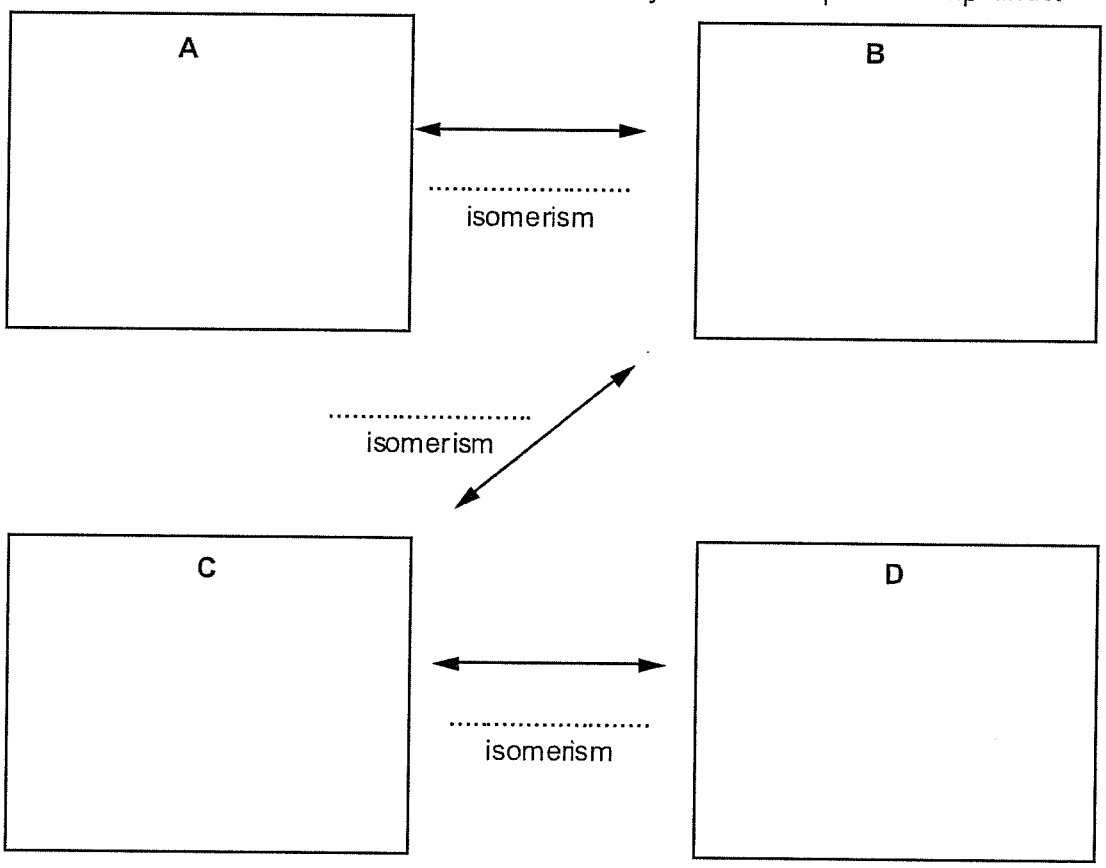
reaction **4** ..... [2]

12. M/J 15/P21/Q4

There are four alcohols, **A**, **B**, **C** and **D**, which are structura 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 mo ecular 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.

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(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

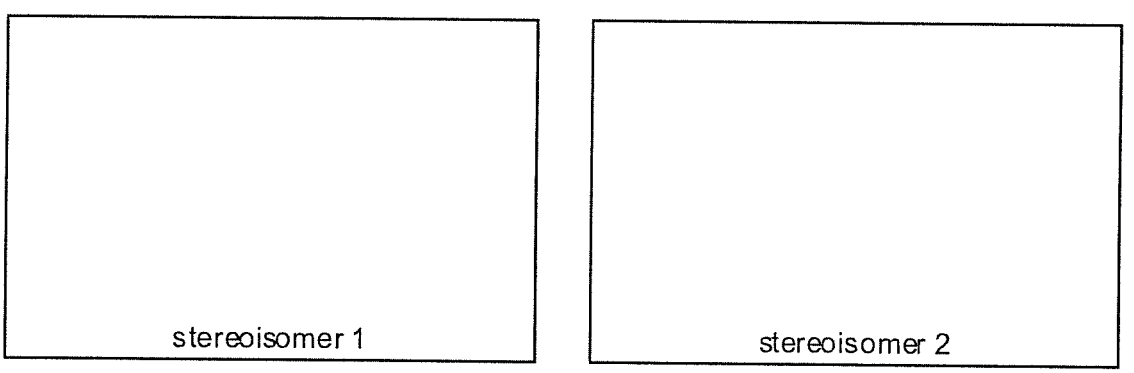
.... [2]

(ii) State which of these two isomers shows stereo somerism. Explain why this molecules capable of showing stereoisomerism.

.....

..... [2]

(iii) Draw **displayed** formulae to show the two stereoisomers.



[2]

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13. 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	

[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.

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alcohol	
product 1	
product 2	

[2]

14. 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	

[5]

(b) Draw the **displayed formula** of the organic compound formed when crotyl alcohol is reacted with cold, dilute acidified potassium manganate(VII).

[1]

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15. 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]**

(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) .....

condition(s) .....

(ii) Allyl alcohol and propanal are isomers.
What form of isomerism do they display?

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

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(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]

16. 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).

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	

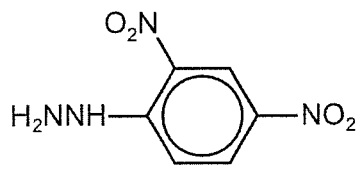
(ii) During some of the reactions in **(i)** a colour change occurs.
Complete the table below for any such reactions, stating the letter of the reaction and what the colour change is.

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reaction	colour at the beginning of the reaction	colour at the end of the reaction

[10]

(b) 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.

(ii) Suggest the colour of the organic product.

..... [2]

17. M/J 12/P23/Q3/c,d

(a) DME and ethanol are isomers with the molecular formula C_2H_6O.

(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]

18. ON 11/P23/Q2/b

When 0.42g 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 1.32g of CO_2 and 0.54g 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.

(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]

19. 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]

(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?

.....

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(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]

20. 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

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]

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(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**.

(ii) What type of reaction occurs when **Z** is formed from **X**?

..... [2]

21. 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]

22. 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]

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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]

(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 (*).

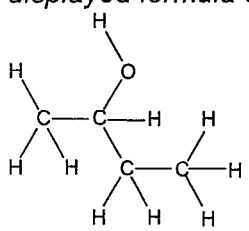
[3]

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Answers Section

1. M/J 21/P22/Q5

(a) *displayed formula of butan-2-ol structure with O—H shown* **1**



(b) (i) 2-bromobutane **1**

(ii) substitution **1**

(iii) *reagent* **1**
M1 NaCN or KCN
conditions **1**
M2 ethanolic AND heat (under reflux)

(iv) (1) C_4H_9CN + (1)H^+ + 2H_2O → (1)$C_4H_9CO_2H$ + (1)NH_4^+ ✓✓ **1**
correct organic product showing carboxylic acid functional group
M1 $C_4H_9CO_2H$ / C_4H_9COOH
M2 balanced equation with a $C_5H_{10}O_2$ or equivalent structure as product **1**

(v) 2200 2250 (cm^{-1} due to) C≡N / triple bond between C and N. **1**

2. M/J 21/P23/Q2

(a) **M1** H-bond between an O and an H in OH groups in water and methanol molecules **1**
M2 minimum three partial charges (in sequence) over one water and **1**
one methanol molecule, *i.e.*: **1**
M3 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

(b) (i) **M1** (methanol) gas (particles / molecules) in equilibrium with liquid **1**
M2 (methanol) gas (particles) exert a pressure **1**
(on the walls of a container / on the surface of the liquid)

(ii) (liquid) particles (at the surface) have enough energy (to overcome attractive forces / evaporate / to become a vapour) **1**

(iii) **M1** (liquid) H_2O molecules are held by stronger **hydrogen bonding** **1**
OR it takes more energy to break the **hydrogen bonds** between water molecules (in the liquid state)
OR each water molecule forms two **hydrogen bonds** (whereas methanol can (only) form one per molecule
M2 fewer H_2O liquid molecules (able to) escape / become gaseous **ora** **1**

(c) (i) **M1** rates of forward and reverse / backward reactions are equal **1**
M2 closed / sealed system / container OR **1**
no change in measurable properties / no change in macroscopic properties

(ii) **M1** mol fraction = 0.97 / (0.030 + 0.060 + 0.97) = 0.97 / 1.06 = (0.9151) **1**
M2 M1 × $1.0 \times 10^7 = 9.2 \times 10^6$(Pa) ✓✓ **1**

(iii) *expression for* K_p
M1 $K_p = p(CH_3OH) / p(CO) \times p(H_2)^2$ **1**
M2 units = Pa^{-2} **1**

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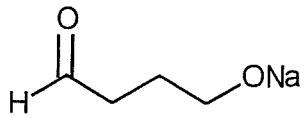
3. O/N 20/P22/Q4

(a) (i) oxidation **1**

(ii) **M1:** potassium dichromate[(VI)] **2**

M2: acid(ified) AND (heat under) **reflux**

(iii) *structure of **H***



OR $CHO(CH_2)_2CH_2O^-Na^+$ **1**

(iv) (formation of) silver mirror / ppt **1**

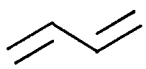
(v) esterification **1**

(b) (i) positional (isomerism)/ regioisomerism **1**

(ii) **M1:** add aqueous alkaline iodine **2**

M2: G no change **AND J** yellow ppt

(iii) reducing agent **1**

(iv) (1,3-)butadiene OR buta(-1,3-)diene OR  **1**

3

(c)

reagent	result with P	result with Q
$Br_2(aq)$	no change / **stays** orange	no change / **stays** orange
2,4-DNPH	no change	orange ppt
Na_2CO_3	effervescence	no change

Award one mark for every two correct observations.

(d) (i) X is C=O **AND** Z is C—O **1**

(ii) hexanoic acid **1**

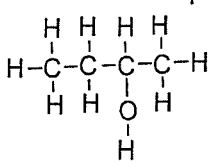
(iii) $C_{12}H_{20}O_2$ **1**

4. M/J 20 /P23/Q5

(a) (i) dehydration **1**

(ii) **M1** correct identification of butan-2-ol **2**

M2 correct displayed formula including correct connectivity of C–O–H



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(iii) **2**

isomer	name
C	cis but-2-ene
D	trans but-2-ene
E	but -1-ene

2 marks for 3 correct names
1 mark for 2 correct names

(b) (i) **3**

	Functional group
F	**M1** Ester / $RCOOR^{(')}$ / $RCO_2R^{(')}$
G	**M2** Carboxyl / carboxylic acid / RCOOH
H	**M3** Alcohol / hydroxy / R-OH

(ii) triiodomethane **1**

(iii) **M1 G** = HCOOH / HCO_2H **2**
M2 H = C_2H_5OH

5. O/N 19/P22/Q3

(a) (i) green gas fades **1**
OR
white solid / white powder / white smoke / white fumes

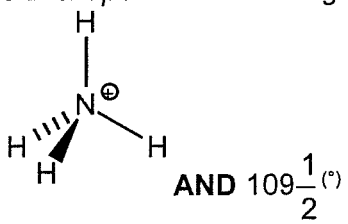
(ii) hydrolysis **1**

(iii) **2**
- ∝ P goes from 0 to (+)5 / (+)V
- ∞ 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 $109\frac{1}{2}^{(\circ)}$

(iii) fertilisers **1**

(c) (i) $C_2H_5OH + PCl_5 \rightarrow C_2H_5Cl + POCl_3 + HCl$ **1**

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(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

OR

M1: phosphoric acid is a weak / not an oxidising agent

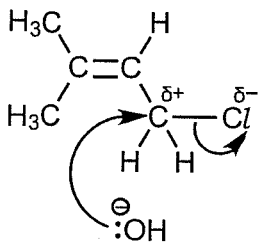
M2: (so) does not react with iodide (where M2 is dependent on M1 here)

(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)

6. O/N 19/P22/Q4

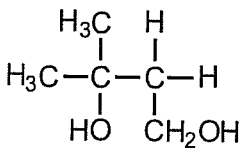
(a) **2**



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**



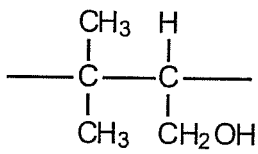
(ii) $(CH_3)_2CHCH(OH)CH_2OH$ **1**

(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**

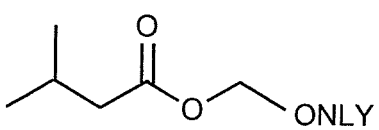
(ii) **1**



(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

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(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

7. O/N 18 /P21/Q3/b, O/N 18 /P23/Q3/b

(a) (i) **Human activity** creates / additional / more/increase / thicker layer in greenhouse gas(es) / $CHClF_2$ **OR** **1**
Human activity has an impact on climate change / temperature at earth's surface / temperature of sea **2**

(ii) **M1** traps (more)heat

M2 (in the atmosphere leading to) greater global warming or wtte **1**

(iii) ozone depletion / thinning

8. M/J 18 /P23/Q4

(a) (i) 2-bromobutane **1**

(ii) ketone **1**

(b) **2**

$(CH_3)_3CBr$	$(CH_3)_2CHCH_2Br$	$CH_2BrCH_2CH_2CH_3$

3 correct = 2 marks
2 correct = 1 mark

(c) (i) S = substitution
N = nucleophilic **1**

(ii)



M1 = dipole and curly arrow
M2 = intermediate carbocation IGNORE CH_2CH_3 shown as C_2H_5
M3 = OH^- with lone pair and curly arrow from lone pair to the 'C' **3**

(d)
- C_4H_9Cl slower (than C_4H_9Br)
- C_4H_9I faster (than C_4H_9Br)
- C–Cl bond stronger than C–Br OR C–Cl 340 C–Br 280
- C–I bond weaker then C–Br OR C–Br 280 C–I 240

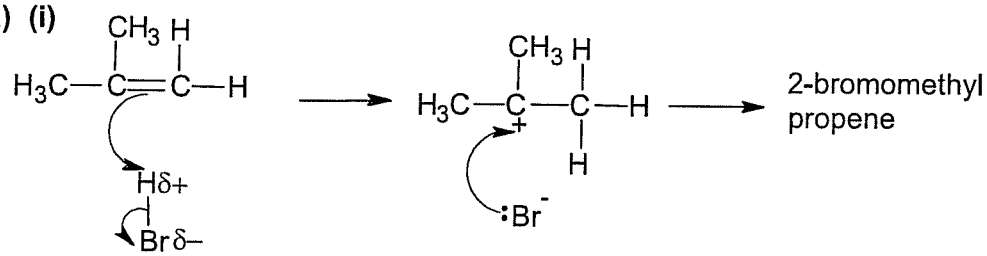
1 mark for each point, max 3 **3**

(e) ethanolic (instead of aqueous) **1**
hotter/higher temperature (heat under) reflux **1**

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9. M/J 18 /P21/Q4/d

(a) (i)



curly arrow from C=C to H **1**

correct dipole on HBr and curly arrow from bond of HBr to Br **1**

tertiary intermediate cation **1**

Br^- with curly arrow from lone pair **1**

(ii) (carbo)cation / tertiary ion / tertiary intermediate (more) stable (than primary) **1**

due to electron-releasing / (positive) inductive effect of more alkyl / methyl groups **1**

10. O/N 17 /P22/Q4/c(ii)

(a) (i) 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) **1**
AND limited (+)I / inductive effect / less electron donating (effect)

11. M/J 16/P22/Q5/a,b

(a) (i) acidified / H^+
AND
potassium / sodium dichromate **[1]**

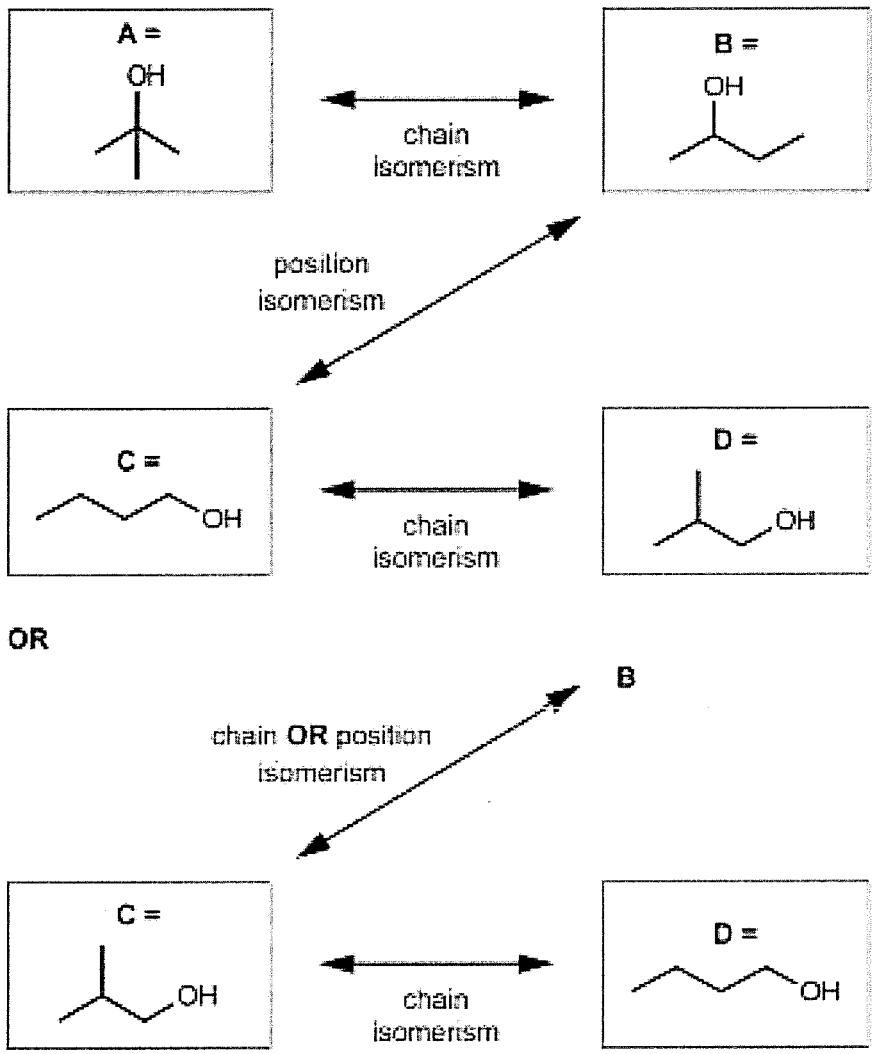
(ii) distillation (rather than reflux) **[2]**
(ensures aldehyde escapes) to avoid further oxidation / to avoid forming acid
/ as reflux causes further oxidation

(b) reaction 3 – (conc) H_2SO_4 / (conc) H_3PO_4 or A l_2O_3 / pumice / porcelain / porous pot / ceramic
AND heat
reaction 4 – KBr / NaBr with (conc) H_2SO_4 or (red)P and Br_2 / PBr_3
AND heat **[2]**

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12. M/J 15/P21/Q4

(a)



[1] [1] [1] [1] [1] [1] [7]

(b) (i) but-1-ene / 1-butene
but-2-ene / 2-butene [2]

(ii) but-2-ene **AND** two different groups on each carbon (of C=C)
double bond means no free rotation [2]

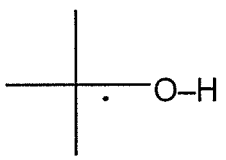
(iii)



and (either way round) [1+1] [2]

13. O/N 13/P23/Q5

(a)



(1) [1]

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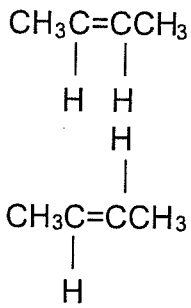
(b)

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]

14. M/J 13/P22/Q4/a,b

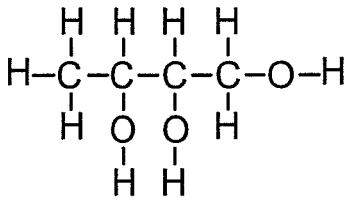
(a)

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]

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(b)



[1]

15. M/J 13/P23/Q5

(a) (i) $CH_2=CHCO_2H$

(ii) $BrCH_2CHBrCH_2OH$

(iii) product is $HOCH_2CH(OH)CH_2OH$
correct addition across >C=C<
original $-CH_2OH$ remains

(iv) HO_2CCO_2H [5]

(b) (i) nucleophilic substitution

(ii) oxidation [2]

(c) (i) step I
H_2
heat with Ni catalyst
step II
acidified $K_2Cr_2O_7$
heat **or** distil off product

(ii) structural isomerism
or
functional group isomerism [5]

(d) **both** oxidation **and** reduction have occurred **or**
disproportionation has taken place [1]

16. 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

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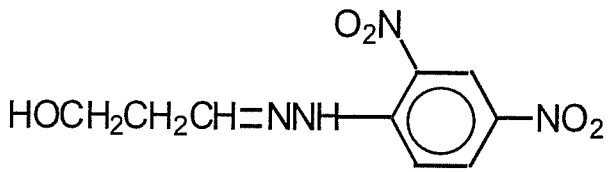
each correct answer gets (1) **(7 × 1)**

(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]**

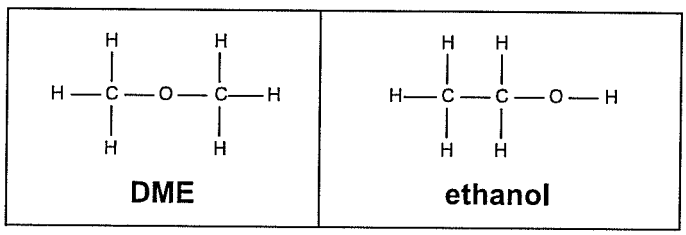
(b) (i)



(ii) red **or** orange **[2]**

17. M/J 12/P23/Q3/c,d

(a) (i)



both correct

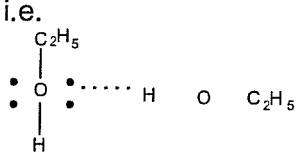
(ii) structural isomerism **or** functional group isomerism **[2]**

(b) (i) hydrogen bonds

(ii) lone pair on O atom of C_2H_5OH

correct dipole $O^{\delta-}—H^{\delta+}$ on bond in one molecule of ethanol

hydrogen bond shown between lone pair of an O atom and a hydrogen atom, i.e.



[4]

18. ON 11/P23/Q2/b

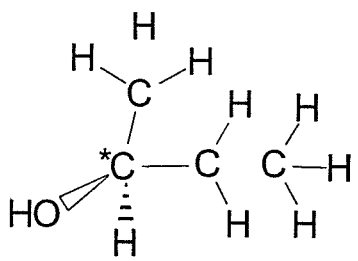
(a) (i) $C : H : O = \frac{64.86}{12} : \frac{13.50}{1} : \frac{21.64}{16}$

$= 5.41 : 13.50 : 1.35$

$= 4 : 10 : 1$

gives $C_4H_{10}O$

(ii)



correct compound **and** correct chiral C*

correct mirror object/ mirror image relationship in 3D

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(iii)

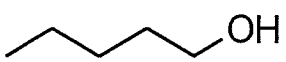
$CH_3CH_2CH_2CH_2OH$	$CH_3\underset{\displaystyle CH_3}{\overset{\displaystyle H}{\overset{\vert}{\underset{\vert}{C}}}}CH_2OH$	$CH_3\underset{\displaystyle CH_3}{\overset{\displaystyle OH}{\overset{\vert}{\underset{\vert}{C}}}}CH_3$
(1)	(1)	(1)

[7]

19. ON 11/P23/Q4

(a) (i) C_2H_5O

(ii)



[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

[3]

(c) (i) dehydration/elimination

(ii) conc. H_2SO_4 / P_4O_{10} / Al_2O_3 / H_3PO_4 / pumice

(iii) $CH_2{=}CHCH{=}CH_2$

allow $CH_2{=}C{=}CHCH_3$ [3]

(d) (i) $CH_3CH_2CH(OH)CH_2CH_3$

(ii) steam with H_3PO_4 catalyst **or**
conc. H_2SO_4 then water

only allow condition mark if reagent mark has been given

(iii) $Cr_2O_7^{2-}/H^+$ **or**
MnO_4^-/H^+ [4]

20. ON 11/P23/Q5

(a) **V** is HCHO [1]

(b) (i) ester

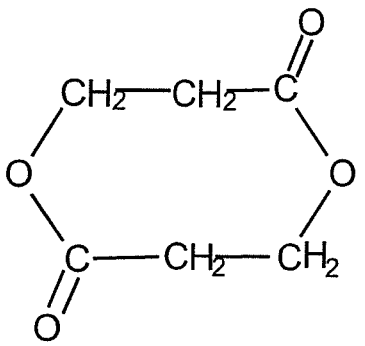
(ii) **W** is HCO_2CH_3 [2]

(c) (i) **X** is $HOCH_2CH_2CO_2H$

(ii) **Y** is $HO_2CCH_2CO_2H$ [2]

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(d) (i) **Z** is



(ii) esterification **or**
dehydration **or**
elimination **or**
condensation [2]

21. M/J 11/P21/Q2/b

(a) ethanol has hydrogen bonding, ethanethiol does not [1]

22. M/J 11/P23/Q5

(a) (i) $C_7H_{14}O_2$

(ii) one [2]

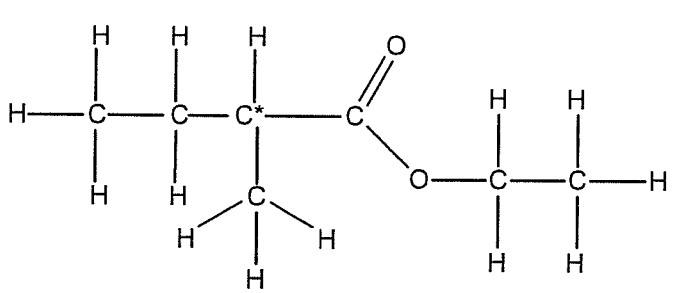
(b) (i) $Cr_2O_7^{2-}/H^+$
from orange
to green

(ii) 2-ethyl-3-methylbutanal/$(CH_3)_2CHCH(C_2H_5)CHO$/the corresponding aldehyde
partial oxidation of alcohol will produce aldehyde

(iii) reflux **because**
the alcohol must be fully oxidised [6]

(c) none
alcohol is tertiary
cannot be oxidised [3]

(d)



correct structure
fully displayed $-CO_2C_2H_5$ group (allow ecf on wrong esters)
correct chiral C atom (allow ecf on wrong esters) [3]

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A Level

Unit 17
CARBONYL COMPOUNDS

Chemistry Paper-2
Topical Workbook
Article Number: 232

Editorial Board

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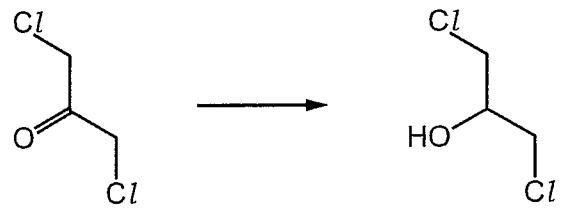
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Unit 17: Carbonyl Compounds

1. M/J 21/P23/Q4

(a) 1,3-dichloropropan-2-ol can be made by reacting **M**.

M 1,3-dichloropropan-2-ol



(i) Give the systematic name of **M**.

..... [1]

(ii) Name the functional group present in **M** that changes during this reaction.

..... [1]

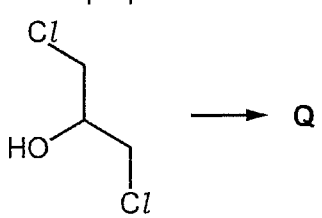
(iii) State a suitable reagent for this reaction.

..... [1]

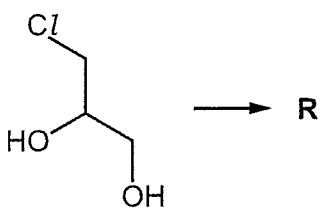
(b) Separate samples of 1,3-dichloropropan-2-ol and 3-chloropropane-1,2-diol are heated with excess acidified $Cr_2O_7^{2-}$ until there is no further reaction.

In each reaction, a different organic product, **Q** or **R**, is made.

1,3-dichloropropan-2-ol



3-chloropropane-1,2-diol



Q and **R** are tested separately with 2,4-dinitrophenylhydrazine solution, 2,4-DNPH, and sodium carbonate solution, $Na_2CO_3(aq)$.

Complete the table to give any relevant observations.

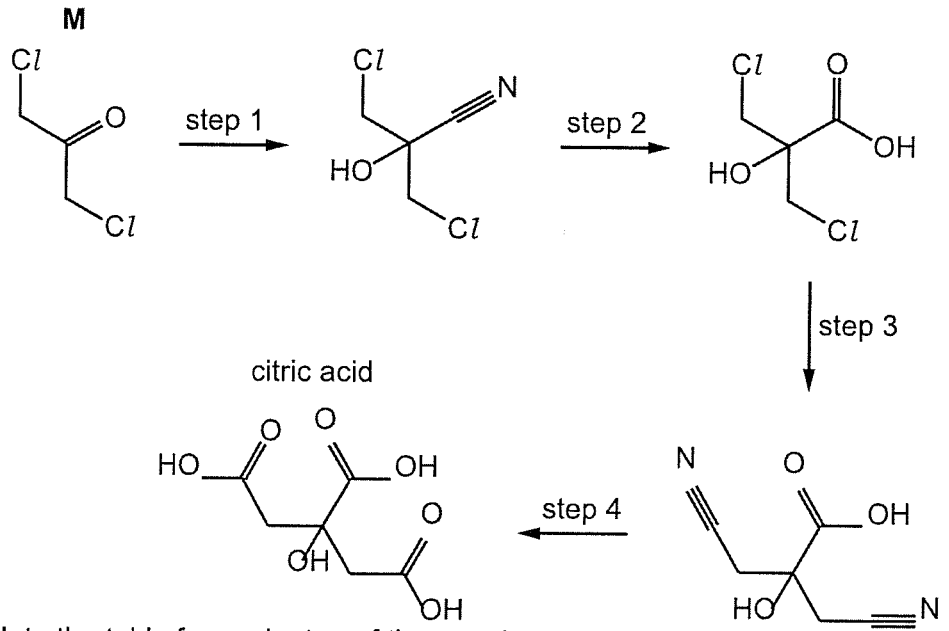
If no reaction occurs, write 'no visible change'.

reagent	observation with **Q**	observation with **R**
2,4-DNPH		
$Na_2CO_3(aq)$		

[4]

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(c) Citric acid can be made from **M** in a four-step reaction.



Complete the table for each step of the reaction sequence to identify:

- the reagents and conditions required
- the type of reaction.

step	reagent and conditions	type of reaction
1		
2	dilute sulfuric acid	
3		
4	dilute sulfuric acid	

[5]

2. O/N 19/P21/Q4, O/N 19/P23/Q4

$(CH_3)_3CCHO$ is used in the synthesis of some antibiotics.

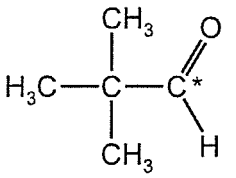
(a) (i) Give the name of $(CH_3)_3CCHO$.

.....

[1]

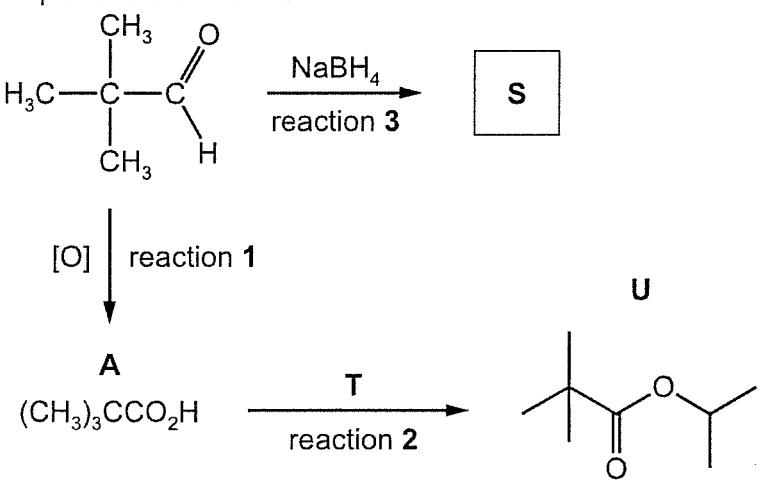
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(ii) State the hybridisation of the carbon atom labelled with an asterisk, *.



..... [1]

(b) Two reaction sequences are shown.



(i) Reaction **1** is an oxidation reaction.
Identify the reagent(s) and conditions for reaction **1**.

..... [1]

(ii) **A**, $(CH_3)_3CCO_2H$, is a solid at room temperature.
B, $CH_3CO_2(CH_2)_2CH_3$, is an isomer of **A**. **B** is a liquid at room temperature.
Explain the difference in the physical states of **A** and **B**, with reference to any intermolecular forces that may exist.

.....

.....

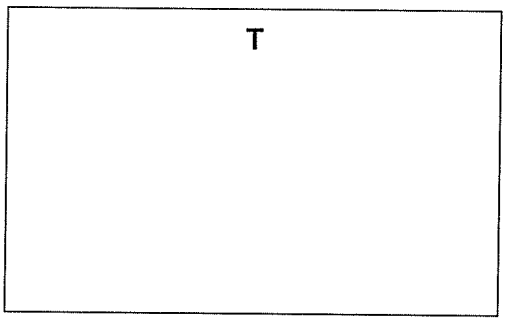
..... [3]

(iii) Give the balanced equation for the reaction of $(CH_3)_3CCHO$ with $NaBH_4$ to form **S**.
Use [H] to represent an atom of hydrogen provided by $NaBH_4$.

..... [1]

(iv) Draw the structure of the organic molecule **T** that reacts with **A**, $(CH_3)_3CCO_2H$, in reaction **2**, to form **U**.
Suggest a catalyst for reaction **2**.

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catalyst ..... [2]

(c) **X**, **Y** and **Z** are all isomers of $(CH_3)_3CCHO$.

A summary of some of the reactions and properties of **X**, **Y** and **Z** is shown in the table.

compound	observations with 2,4-DNPH	observations with Fehling's solution	principal absorptions in infra-red spectrum
X		no reaction	1715 cm^{-1}
Y		red precipitate	1730 cm^{-1}
Z	no reaction	no reaction	3200–3600 cm^{-1} 1630 cm^{-1} 1050 cm^{-1}

(i) **X** and **Y** each contains a carbonyl group.

Complete the table with the expected observations for the reactions of **X** and **Y** with 2,4-DNPH. **[1]**

(ii) Identify the functional group present in **Y** that causes the recorded observation with Fehling's solution.

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

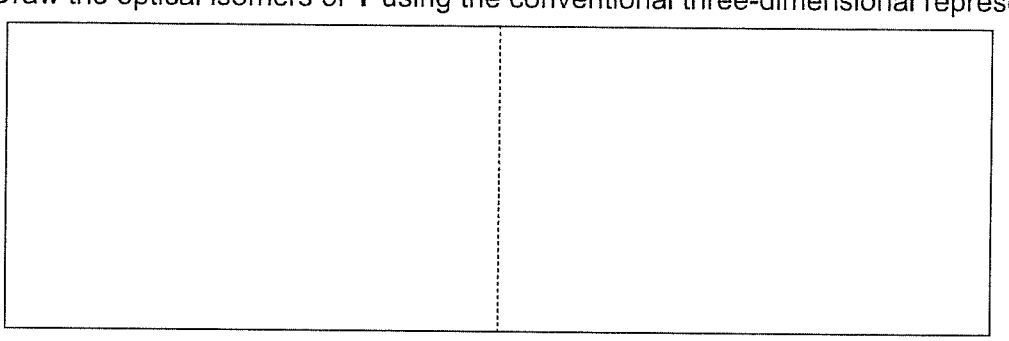
(iii) **Y** has a chiral centre and exists as a pair of optical isomers.

State what is meant by the term *chiral centre*.

.....

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

(iv) Draw the optical isomers of **Y** using the conventional three-dimensional representation.



[2]

Z, $C_5H_{10}O$, has a branched carbon chain. It shows geometrical isomerism.

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(v) Complete the table with the bond responsible for each of the principal absorptions seen in the infra-red spectrum of **Z**.

principal absorptions in infra-red spectrum	bond responsible
3200–3600 cm^{-1}	
1630 cm^{-1}	
1050 cm^{-1}	

[1]

(vi) Draw the skeletal formula of **Z**.

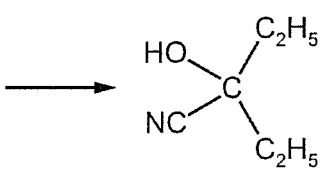
[3]

(vii) **X** contains a carbonyl group. **X** reacts with HCN, in the presence of a small amount of NaCN, to form $(C_2H_5)_2C(OH)CN$ as shown.

$$\mathbf{X} + HCN \rightarrow (C_2H_5)_2C(OH)CN$$

Draw the mechanism of the reaction of **X** with HCN.

- Draw the structure of **X** and the intermediate.
- Include all charges, partial charges, lone pairs and curly arrows.



[3]

(viii) State the role of NaCN in the reaction in **(c)(vii)**.

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

3. M/J 18/P21/Q4/a,b,c

X is $CH_3CH(OH)CH_2CH_3$.

(a) The reaction between **X** and alkaline aqueous iodine produces a yellow precipitate.

(i) Give the name of the compound formed as a yellow precipitate in this reaction.

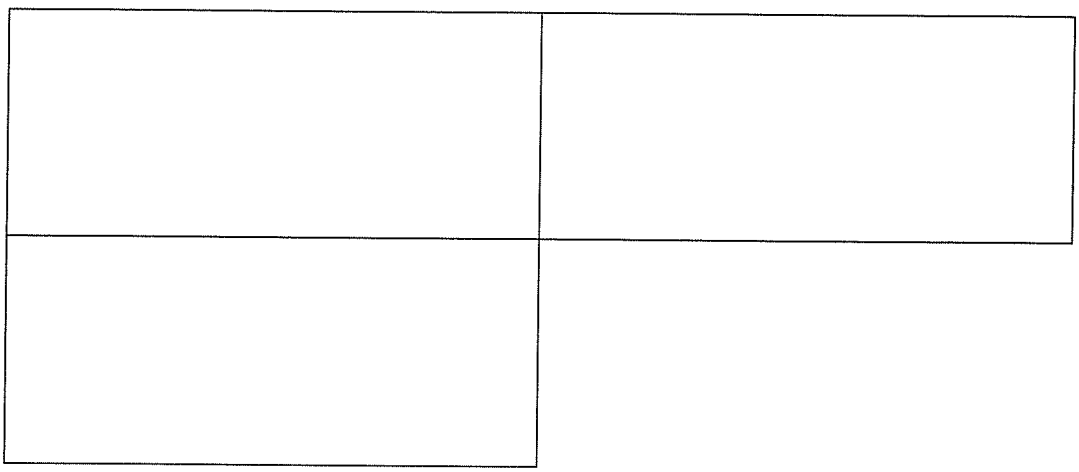
..... **[1]**

(ii) Give the name of **X**.

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

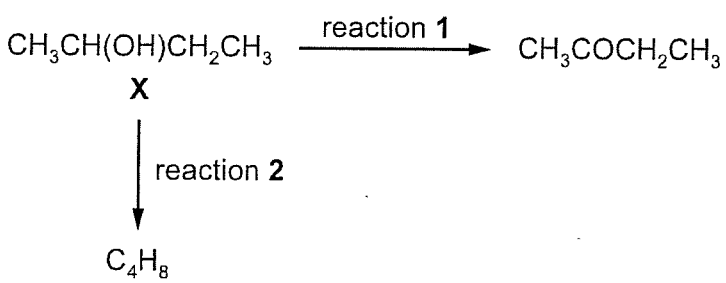
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(b) There are three structural isomers of **X** that are alcohols.
Draw the structures of these three isomers of **X**.



[2]

(c) Two reactions of **X** are shown.



(i) Identify the type of reaction involved in reaction **1**.

..... [1]

(ii) Identify the reagents for reaction **1**.

..... [1]

(iii) Reaction **2** can be carried out by passing the vapour of **X** over hot aluminium oxide.
The product of reaction **2**, C_4H_8, is actually a mixture of three isomers.
Give the full names of the three isomers formed by reaction **2**.

1 .....

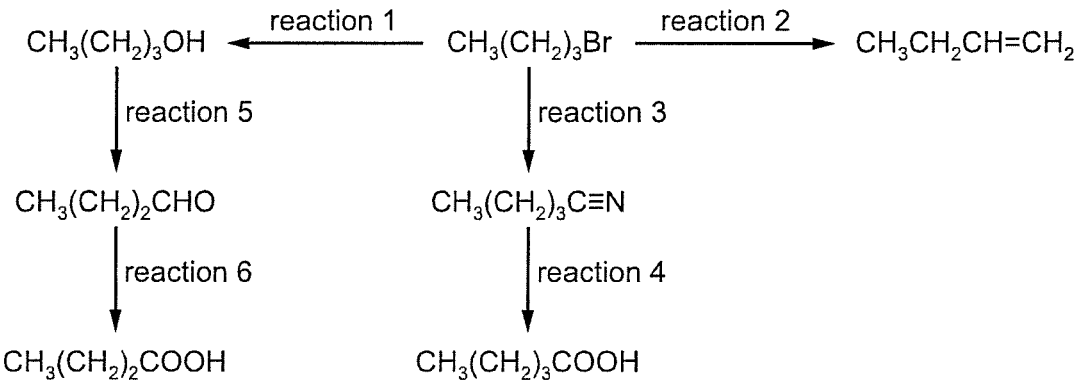
2 .....

3 ..... [3]

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4. O/N 17/P21/Q3/c(ii), O/N 17/P21/Q3/c(ii)

Some reactions based on 1-bromobutane, $CH_3(CH_2)_3Br$, are shown.



(a) 2-bromo-2-methylpropane is a tertiary halogenoalkane that is a structural isomer of 1-bromobutane.

(i) 2-bromo-2-methylpropane is treated with the same reagents as in reaction 1.
Methylpropan-2-ol is formed.
Identify the mechanism for this reaction.
Explain why this reaction proceeds via a different mechanism from that of reaction 1.

mechanism .....

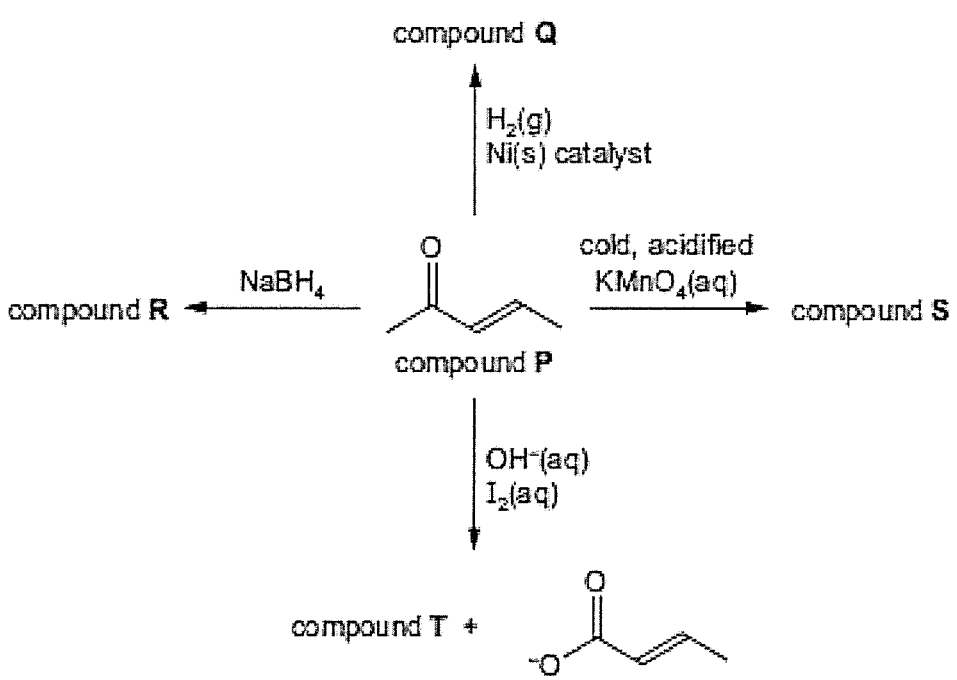
explanation .....

.....

[3]

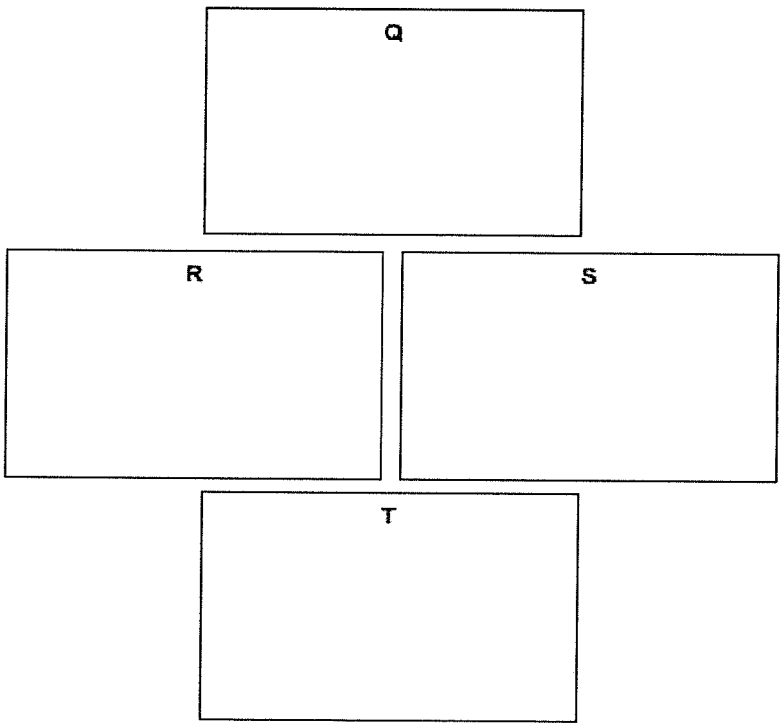
5. MAR 16/P22/Q5

Some reactions of compound P, C_5H_8O, are shown.



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(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)?

.....

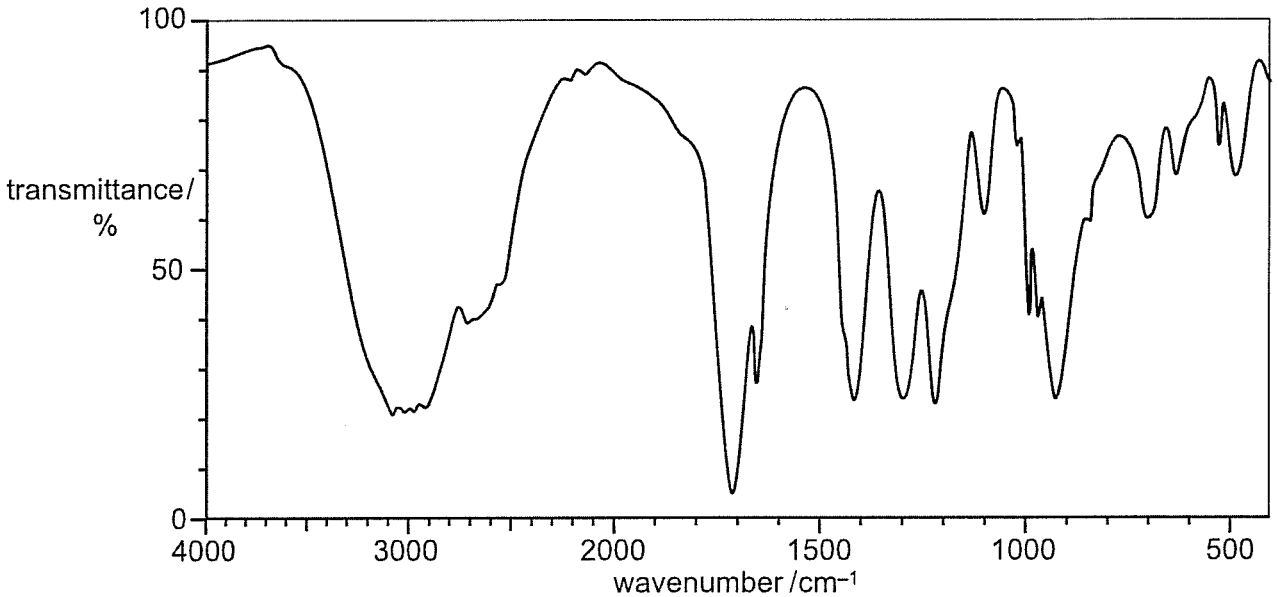
[1]

(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**

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Use the information given to suggest a structure for compound U.
Explain your answer.

[4]

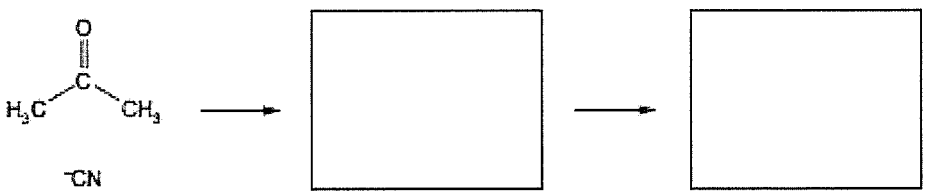
6. MAR 16/P22/Q3/d

(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]**

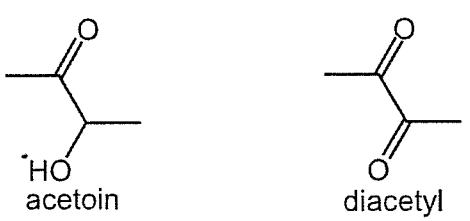
(ii) Complete the diagram to show the mechanism of the reaction of hydrogen cyanide with propanone.
Draw the structure of the intermediate and the product of the reaction.
Include all relevant charges, partial charges, curly arrows and lone pairs.



[5]

7. 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.



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(a) Give the systematic name for acetoin.

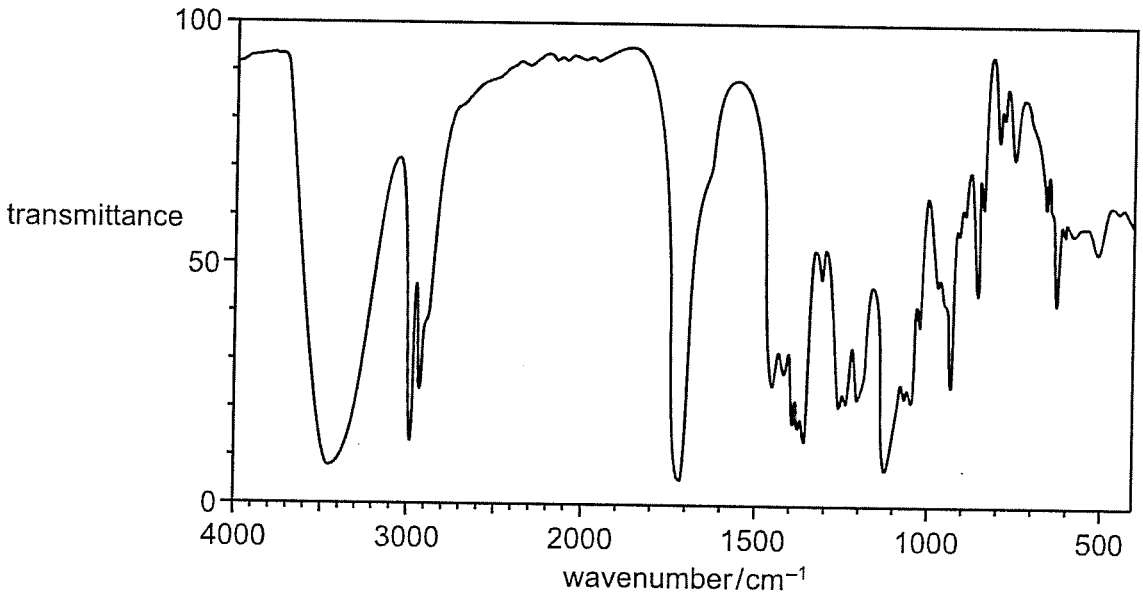
..... [1]

(b) Identify the reagents and conditions necessary for the conversion of acetoin into diacetyl.

.....

..... [2]

(c) The infra-red spectrum for acetoin is shown.



(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]

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(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.

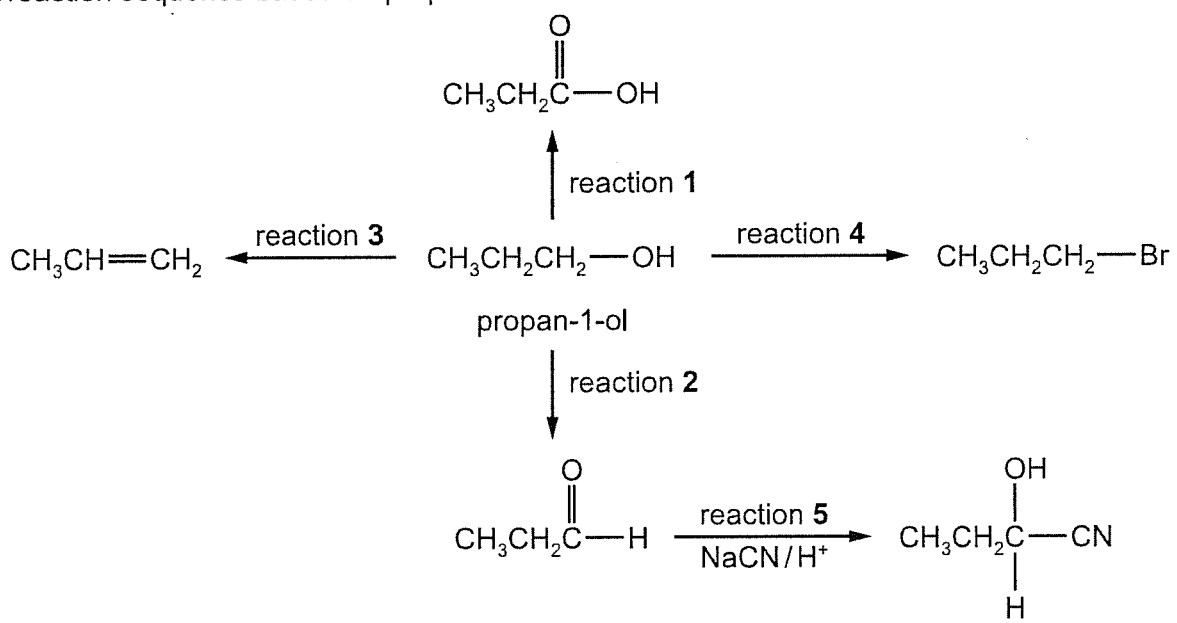
.....[1]

(iv) Draw the two stereoisomers from **(iii)** using the conventional representation.

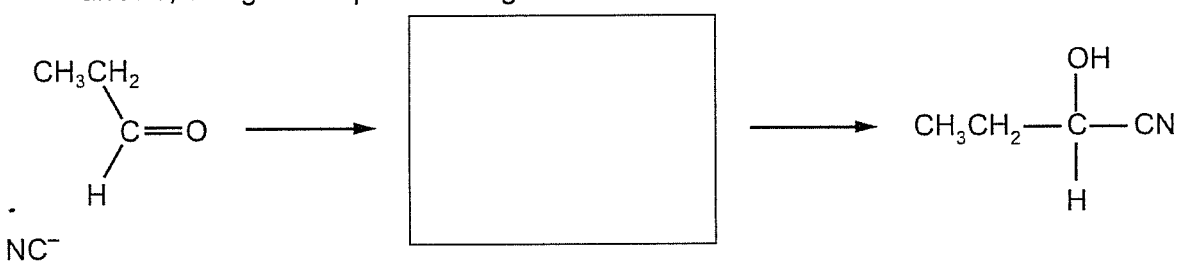
[2]

8. M/J 16/P22/Q5/c

A reaction sequence based on propan-1-ol is shown.



(a) (i) Complete the reaction mechanism for reaction 5. Include all relevant lone pairs, curly arrows, charges and partial charges.



[4]

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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]

9. 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.

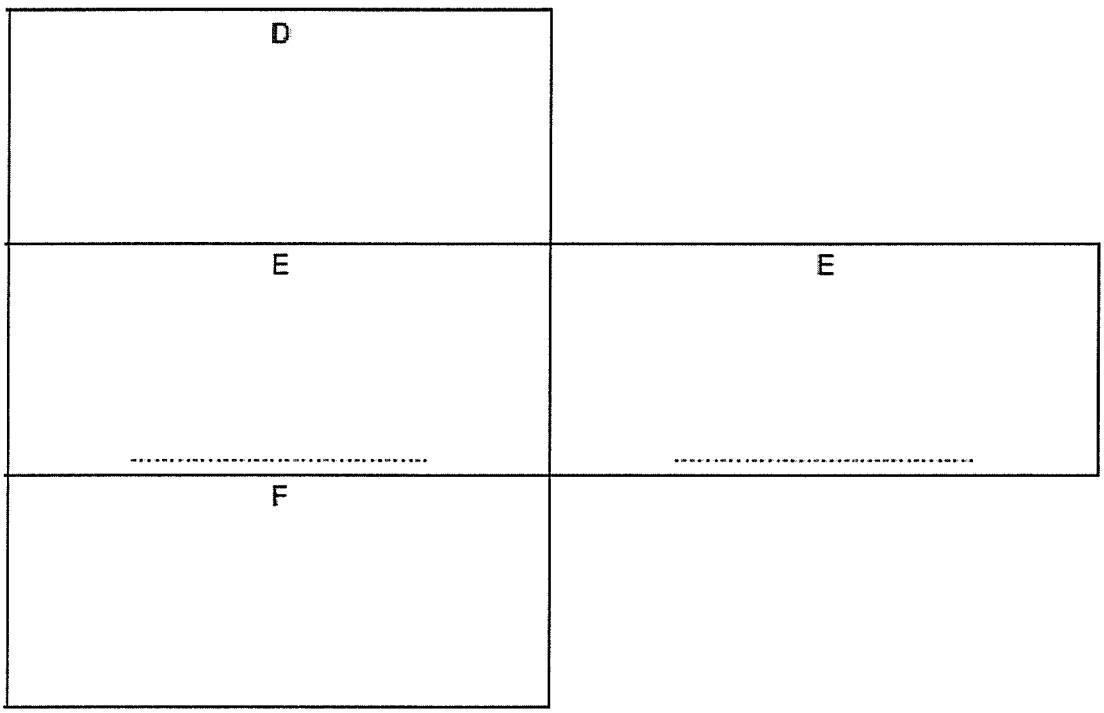
E shows geometrical isomerism. Only D has a branched chain.

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.

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[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 + ... $\rightarrow$ ..... [1]

(ii) reaction with $NaBH_4$

C_3H_6O + ... $\rightarrow$ ..... [1]

10. M/J 15/P22/Q4

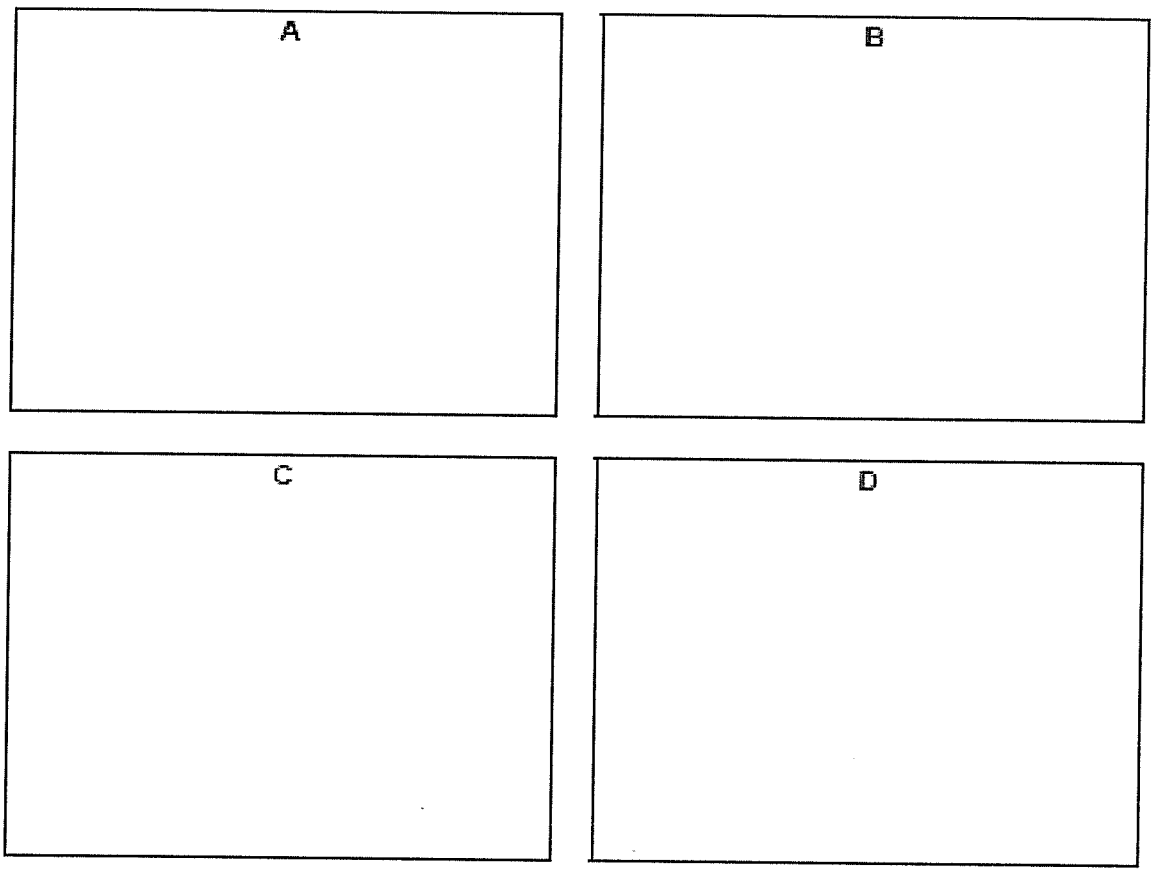
There are seven structural isomers with the molecular formula $C_5H_{10}O$ that are carbonyl compounds. Four of these are aldehydes.

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.

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[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]**

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(ii) Describe a test that would give the same result with all seven carbonyl isomers of $C_5H_{10}O$.

.....

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

11. 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.

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 .....

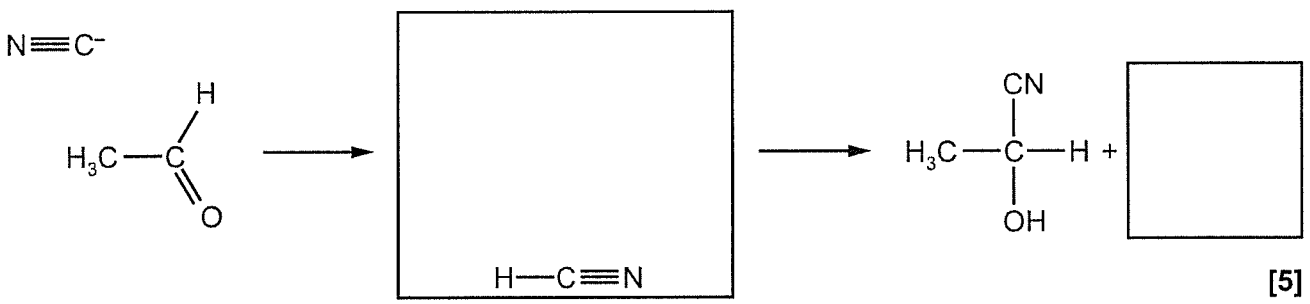
.....

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]**

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12. M/J 13/P23/Q4

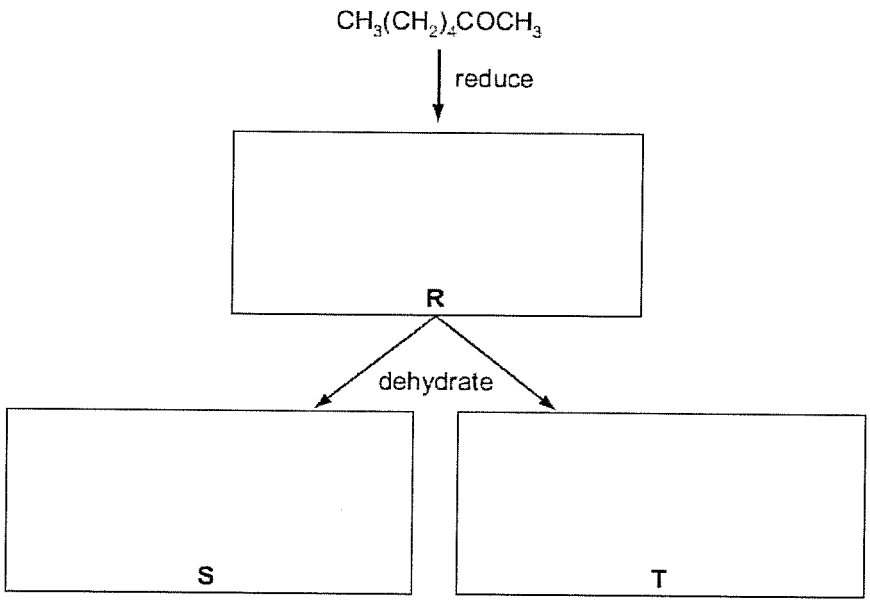
Compound Q, heptan-2-one, is found in some blue cheeses.

$CH_3(CH_2)_4COCH_3$

compound Q

(a) Compound **Q** may be reduced to **R**.
Compound **R** may be dehydrated to give two different products, **S** and **T**.

(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

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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]**

13. M/J 13/P22/Q4/d,e

(a) Crotyl alcohol is obtained from crotonaldehyde, $CH_3CH=CHCHO$.

(i) Describe one test that would confirm 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]

14. 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 reflux with acidified 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.

(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**?

.....

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(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]

15. 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]

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(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.

[3]

16. 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 flammable 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**.

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H	J	K

In addition to being structural isomers of each other, some of the possible structures for **H**, **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 (*).

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[8]

17. 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.

pair 1		
pair 2		

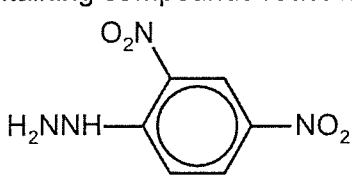
(ii) These four isomers of X show two types of stereoisomerism.
State which type of isomerism each pair shows.

pair 1 .....

pair 2 ..... [6]

18. 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]

19. 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]

20. 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.

[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]

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21. 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 identified 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]

(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.

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(ii) Give the structural formula of the compound formed when X is heated under reflux with acidifi ed $K_2Cr_2O_7$.

[2]

22. 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

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(ii) State the reagents for each of the three steps you have chosen.

step 1.....

step 2.....

step 3..... **[5]**

23. M/J 11/P21/Q4

Ketones are widely used as solvents and as intermediates in the chemical industry.

Ketones contain the reactive keto group, $\rangle C=O$.

(a) Propanone, CH_3COCH_3, undergoes a reaction with hydrogen cyanide, HCN.

(i) What type of reaction is this?

.....

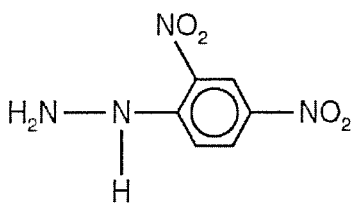
(ii) What reagents are used?

.....

(iii) Draw a diagram to show the dipole present in the propanone molecule.

[3]

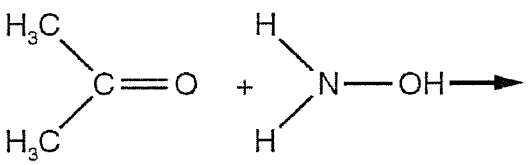
(b) Propanone reacts with 2,4-dinitrophenylhydrazine reagent.



2,4-dinitrophenylhydrazine

(i) Construct a balanced equation for the reaction between propanone and 2,4-dinitrophenylhydrazine.

(ii) A similar type of reaction occurs between propanone and hydroxylamine, NH_2OH. Draw the displayed formula of the organic product of this reaction.



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[3]

24. 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]

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]

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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]

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Answers Section

1. M/J 21/P23/Q4

(a) (i) 1,3-dichloropropan(-2-)one **1**

(ii) carbonyl / ketone **1**

(iii) $NaBH_4$ **OR** $LiAlH_4$ **1**

(b)

reagent	observation with **Q**	observation with **R**
2,4-DNPH	**M1** red / orange / yellow AND precipitate / solid / crystals	**M2** red / orange / yellow AND precipitate / solid / crystals
$Na_2CO_3(aq)$	**M3** no visible change	**M4** fizz / effervescence

4

(c)

step	reagent and conditions	type of rxn
1	**M1** HCN and (trace) KCN / NaCN	**M3** Addition
2	dilute sulfuric acid	**Hydrolysis**
3	**M2** KCN/NaCN in ethanol / alcohol	**M4** Substitution
4	dilute sulfuric acid	**Hydrolysis**

5

M5 type of reaction for step 2 AND step 4

2. O/N 19/P21/Q4, O/N 19/P23/Q4

(a) (i) (2,2–)dimethylpropanal **1**

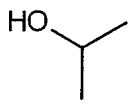
(ii) sp^2 **1**

(b) (i) acidified potassium dichromate**[(VI)] AND** heat under reflux **1**

(ii) **M1: A** has **H-bonding** (between molecules) **3**
M2: B only has dipole–dipole / **VdW** forces (between molecules)
M3: H-bonding is stronger / requires more energy to overcome

(iii) $(CH_3)_3CCHO + 2[H] \rightarrow (CH_3)_3CCH_2OH$ **1**

(iv) **2**



M1: / $CH_3CH(OH)CH_3$

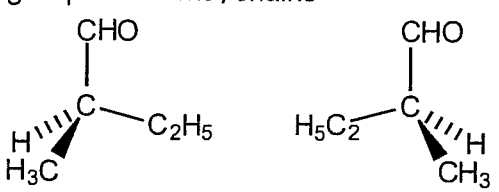
M2: H_2SO_4 / sulfuric acid

(c) (i) • orange / red / yellow precipitate **1**
• orange / red / yellow precipitate

(ii) Aldehyde **1**

(iii) has a carbon / atom attached / bonded to four different atoms / groups / groups of atoms / chains **1**

(iv) **2**



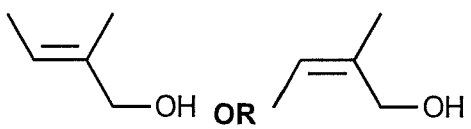
M1: Correct 3D representation
M2: Correct 3D representation of drawn enantiomer

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(v) **1**

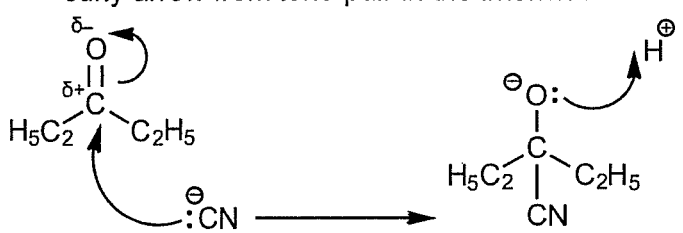
principal absorptions in the infra-red spectrum	bond responsible
3200–3600 cm^{-1}	RO-H / O-H
1630 cm^{-1}	C=C
1050 cm^{-1}	C—O

(vi) **3**



M1: skeletal alkene group **AND** C5 structure
M2: **one** alcohol group
M3: branched chain **AND** capable of geometrical isomerism

(vii) **M1:** Correct structure of **X** and correct dipole on C=O **3**
M2: curly arrow from C=O bond to O AND intermediate with CN attached and −ve charge on the O
M3: curly arrow from lone pair on CN^- to C(=O) in **X**
AND
curly arrow from lone pair in the intermediate to H^+



(viii) catalyst **1**

3. M/J 18/P21/Q4(a,b,c)

(a) (i) Iodoform / triiodomethane **1**

(ii) butan-2-ol **1**

(b) $CH_3CH_2CH_2CH_2OH$ **2**
$(CH_3)_3COH$
$(CH_3)_2CHCH_2OH$

(c) (i) oxidation / redox **1**

(ii) acidified / H^+ **AND** **1**
potassium / sodium dichromate((VI)) or formulae

(iii) *In any order:*
but-1-ene **1**
but-2-ene **1**
cis / *Z*- AND *trans* / *E*- **1**

4. O/N 17/P21/Q3/c(ii), O/N 17/P21/Q3/c(ii)

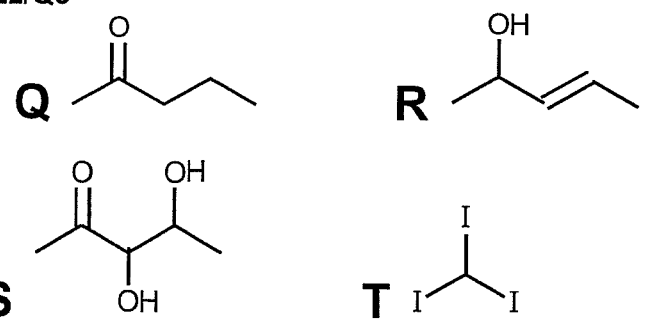
(a) (i) S_N / nucleophilic substitution **1**
$((CH_3)_3CBr$ / tertiary halogenoalkane) forms a stable (carbo)cation / stable intermediate **1**
(as charge density on cation is reduced) OR
(in) 1-bromobutane/primary halogenoalkane there is no (stable) (carbo)cation/ intermediate formed

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(because) there are (3 /more) alkyl / methyl groups AND (+) I / (greater) inductive effect **1**
OR
(because) there is only one / fewer alkyl /
methyl group(s) (compared to reaction with 2-bromo-2-methyl propane teriary halogenoalkane) AND limited (+) I/ (less) inductive effect

5. MAR 16/P22/Q5

(a) (i)

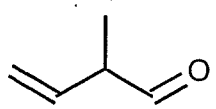


[4]

(ii) pent-3-en(e)-2-one
OR
3-penten-2-one [1]

(iii) red / orange / yellow precipitate / solid [1]

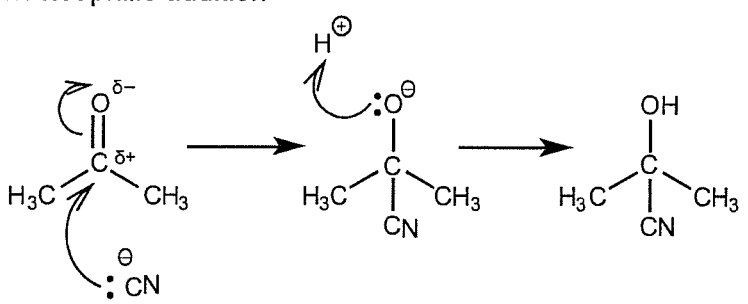
(b) *This question was discounted.*
M1 = decolourises bromine / 1500–1600 cm^{-1} = alkene
M2 = absorption at 1700cm^{-1} is C=O
AND
(very) broad absorption at 2500–3000 cm^{-1} is O—H = carboxylic acid
M3 = no cis-trans so terminal alkene [4]
OR
chiral so contains a carbon atom with 4 different groups attached
M4 = **U** is



6. MAR 16/P22/Q3/d

(a) (i) nucleophilic addition [1]

(ii)



[5]

correct dipole on carbonyl
curly arrow from lone pair on CN AND from C=O to O
correct intermediate
curly arrow from lone pair on O^- to H^+
correct product

7. M/J 16/P23/Q4

(a) 3-hydroxybutan(-2-)one [1]

(b) H_2/ $Cr_2O_7^{2-}$ or names
heat / reflux / warm [2]

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(c) (i) absorption at 1670–1740 C (=) O **[3]**
absorption at 2850–3000 C (-) H
absorption at 3200–3650 O (-) H

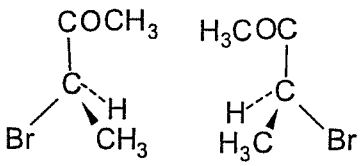
(ii) no absorption at 3200–3650 **[2]**
O-H disappears / no O-H bond in diacetyl

(d) (i) $CH_3COCH(=)CH_2$ **[1]**

(ii) one of the double-bonded C atoms / first C has 2H atoms attached **ora** **[2]**
so no cis-trans / *E-Z* / geometric(al) isomerism possible
OR
no chiral C
so mirror images superimposable / molecule not asymmetric

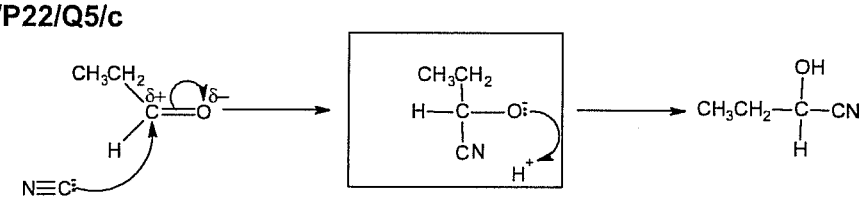
(iii) asymmetric / chiral C atom / carbon with four different groups / atoms attached **[1]**

(iv) **[2]**



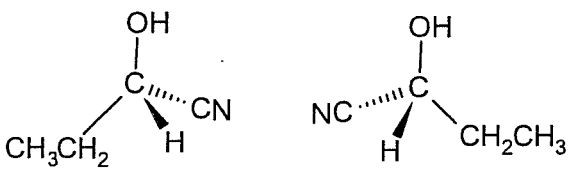
8. M/J 16/P22/Q5/c

(a) (i)



M1 = lone pair on C of CN^- AND curly arrow from lone pair to carbonyl carbon
M2 = dipole on C=O AND curly arrow to O from =
M3 = intermediate with negative charge
M4 = lone pair and curly arrow to H^+ **[4]**

(ii)

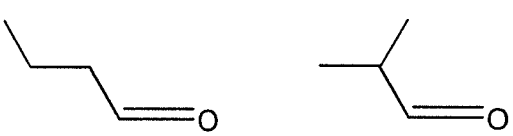


[2]

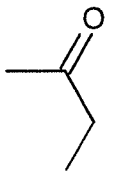
(iii) attack / attach from either side / above or below / from two directions because the carbonyl / molecule is planar / trigonal / flat / because of the shape of the molecule
OR
product is chiral / has a chiral carbon / has a carbon attached to four different groups / has a chiral centre asymmetric
(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) / doesn't distinguish between the two (optical isomers) / able to form either / chance of forming / able to form 50:50 **[2]**

9. M/J 15/P23/Q3

(a) (i) **A/B =**



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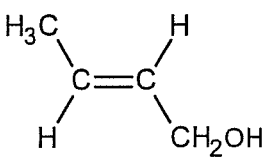
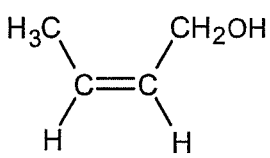
C = 

[3]

(ii) Chain **[1]**

(iii) Silver mirror/ppt/solid (black/grey) **[1]**

(b) (i)

D $CH_2=C(CH_3)CH_2OH$	
E  trans **OR** *E*	**E**  cis **OR** *Z*
F $H_2C=CHCH_2CH_2OH$	

[5]

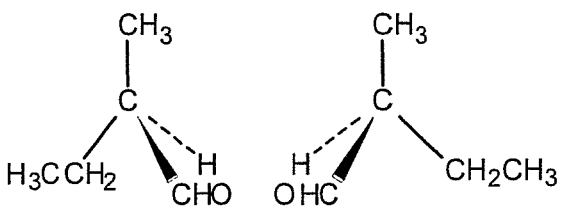
(ii) Hydrogen **[1]**

(c) (i) $C_3H_6O + [O] \rightarrow C_3H_6O_2$ **[1]**

(ii) $C_3H_6O + 2[H] \rightarrow C_3H_8O$ **[1]**

10. M/J 15/P22/Q4

(a) (i) **A** = $CH_3CH_2CH_2CH_2CHO$
B = $CH_3CH_2CH(CH_3)CHO$
C = $(CH_3)_2CHCH_2CHO$
D = $(CH_3)_3CCHO$ **[4]**

(ii)  **[2]**

(b) (i) Fehling's / Benedict's **OR** Tollens' **OR** dichromate **OR** manganate
Warm / heat
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 **[3]**

(ii) (2,4-)DNP(H) / Brady's reagent
Orange/ yellow / red-orange / yellow-orange ppt **[2]**

11. M/J 15/P21/Q3

(a) Bond breaking = C=O = 740
C–H = 410 = 1150 kJ

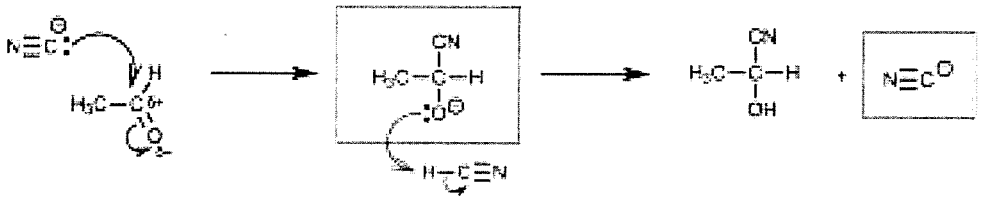
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Bond forming = C–C = 350
C–O = 360
O–H = 460 = 1170 kJ
Enthalpy change = 1150 – 1170 = **–20** kJ mol^{-1} [3]

(b) (i) Stereoisomerism = (molecules with the same molecular formula and) same structural formula but different spatial arrangements of atoms
Chiral centre = atom with four different atoms/groups attached [2]

(ii) (Planar) carbonyl so (equal chance of nucleophile) attacking either side [1]

(c) (i)

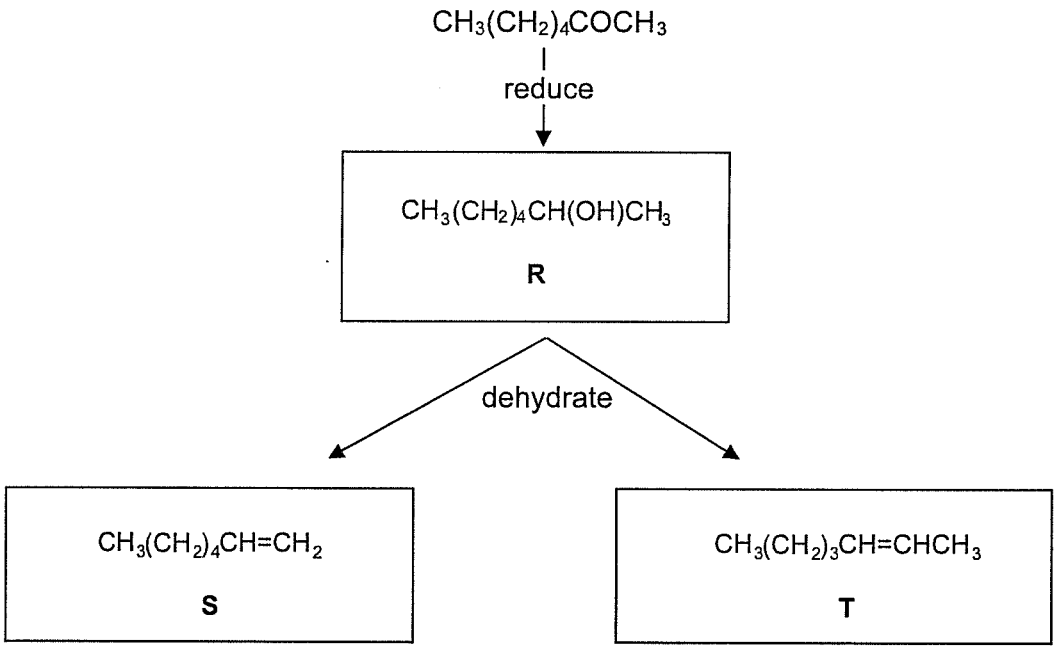


M1 = lone pair **AND** curly arrow from lone pair to carbonyl C
M2 = partial charges on C=O **AND** curly arrow from bond (=) to $O^{\delta-}$
M3 = structure of intermediate including charge
M4 = lone pair **AND** two correct curly arrows (from lone pair to H **AND** from H—C to C)
M5 = CN^- [5]

(ii) (CN^- regenerated so) catalyst [1]

12. 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
dehydration
P_4O_{10}/P_2O_5 **or** H_3PO_4 **or** conc. H_2SO_4 **or** Al_2O_3 [5]

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(b)

Tollens' reagent	NO REACTION
HCN	$CH_3(CH_2)_4C(OH)CH_3$ | CN
$K_2Cr_2O_7/H^+$	NO REACTION

[3]

(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
correct observation [2]

13. 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
observation

(ii) reduction **or** nucleophilic addiction [3]

(b) $C : H : O = \frac{73.7}{12} : \frac{12.3}{1} : \frac{14.0}{16}$

$= 6.14 : 12.3 : 0.875$

$= 7.01 : 14.1 : 1$

gives $C_7H_{14}O$
formula must be given [2]

14. M/J 13/P22/Q5/c,d,e

(a) (i) —CHO **or** aldehyde absent
(ii) >CO **or** carbonyl absent
(iii) $—CO_2H$ **or** carboxylic acid present [3]

(b) (i) CH_3CO_2H **or** ethanoic acid
(ii) **Y** above [2]

(c) none – no chiral carbon atoms present [1]

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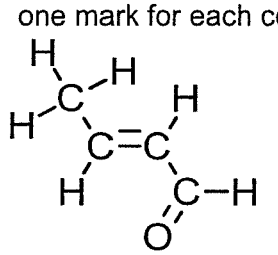
15. M/J 13/P21/Q5

(a)

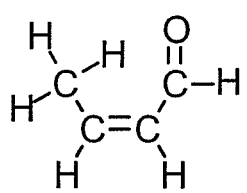
reaction	reagent	product
A	Br_2 in an inert organic solvent	$CH_3CHBrCHBrCHO$
B	PCl_3	NO REACTION
C	H_2 and Ni catalyst	$CH_3CH_2CH_2CH_2OH$
D	$NaBH_4$	$CH_3CH{=}CHCH_2OH$
E	$K_2Cr_2O_7/H^+$	$CH_3CH{=}CHCO_2H$

one mark for each correct answer **[5]**

(b)

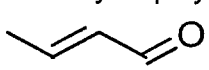


trans **or** E



cis **or** Z

two correct structures
both correctly labelled
correctly displayed -CHO group **[3]**

(c)  **[1]**

(d) (i) $CH_3CH(OH)CH(OH)CO_2H$

(ii) CH_3CO_2H
HO_2CCO_2H **[3]**

allow ecf on candidate's answer to E in **(a)**

16. O/N 12/P23/Q5

(a) (i)

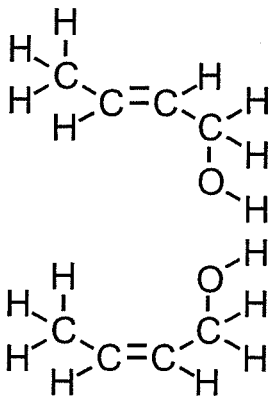
H	J	K
$CH_2{=}CHCH_2CH_2OH$	$CH_3CH_2COCH_3$	$CH_3CH_2CH_2CHO$

$CH_3CH{=}CHCH_2OH$

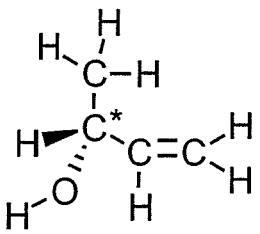
$CH_2{=}CHCH(OH)CH_3$

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(ii)



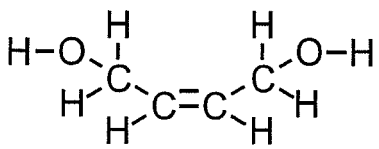
(iii)



[8]

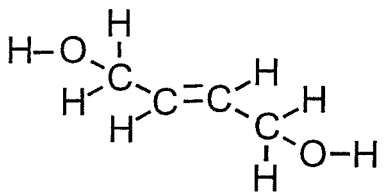
17. O/N 12/P21/Q5/b

(a) (i)



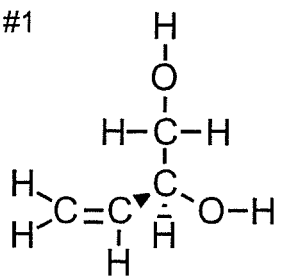
each correct structure gets

(ii) pair 1 geometrical **or** *cis-trans* **or** *E*/*Z* isomerism

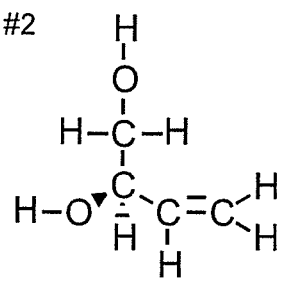


pair 2 optical isomerism – accept chiral compounds [6]

#1



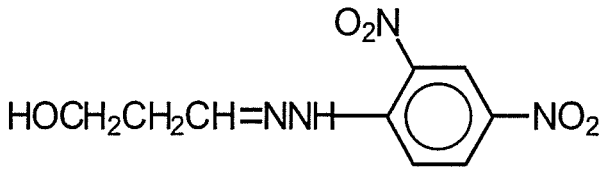
#2



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18. O/N 12/P22/Q4/b

(a) (i)



(ii) red **or** orange **[2]**

19. O/N 12/P22/Q5/a

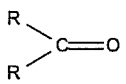
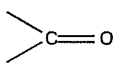
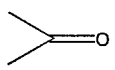
(a) (i) carboxylic acid **or** alcohol present **or**
carboxylic acid **and** alcohol present
not acid **or** carboxyl **or** hydroxyl

(ii) carboxylic acid **not** present **or**
only alcohol present

(iii) alkene **or** >C=C< present **[3]**

20. M/J 12/P22/Q4/c,d

(a) (i)


or

or

and **'ketone'**

(ii) **G** is $HOCH_2COCH_2OH$ as the minimum
allow the *gem* diol $CH_3COCH(OH)_2$ **[2]**

(b) (i) **H** is HO_2CCOCO_2H as the minimum

(ii) **J** is $HOCH_2CH(OH)CH_2OH$ as the minimum **[2]**

21. M/J 12/P21/Q5

(a) carboxylic acid **or** $-CO_2H$ **or** $-COOH$ **[1]**

(b) (i) alcohol

(ii) $n(H_2) = \frac{160}{24000} = 6.67 \times 10^{-3}$ mol

n(H atoms) $= 2 \times 6.67 \times 10^{-3}$ mol $= 1.33 \times 10^{-2}$ mol

(iii) $n(\mathbf{X}) = \frac{0.600}{90} = 6.67 \times 10^{-3}$ mol

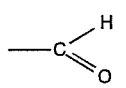
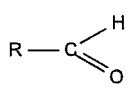
$n(\mathbf{X}) : n$(H atoms) $= 6.67 \times 10^{-3} : 1.33 \times 10^{-2}$

$= 1 : 2$

since each –OH group produces one H atom

there are two –OH groups **[4]**

(c) (i)


or


(ii) $HOCH_2CH(OH)CHO$ as the minimum
allow the *gem* diols $(HO)_2CHCH_2CHO$ **or** $CH_3C(OH)_2CHO$

(iii) $HOCH_2CH(OH)CO_2H$ or $HOCH_2CH(OH)CO_2^-$ **[3]**

(d) (i) $HOCH_2CH(OH)CH_2OH$

(ii) HO_2CCOCO_2H **[2]**

22. O/N 11/P22/Q5/a,c

(a) (i) **1** primary
alcohol **not** hydroxyl

2 aldehyde **not** carbonyl

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(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

[7]

(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]

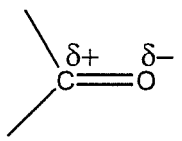
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23. M/J 11/P21/Q4

(a) (i) nucleophilic addition
both words are necessary

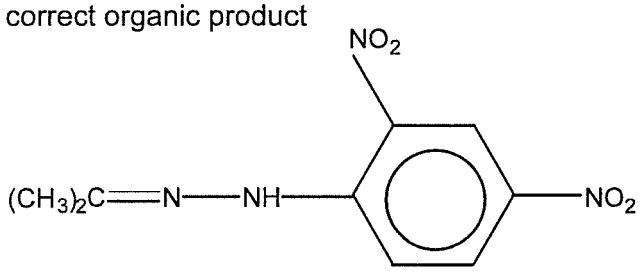
(ii) $NaCN$ and H_2SO_4 **or**
HCN plus CN^-
do not allow HCN on its own

(iii) correct δ+ **and** δ-, i.e.



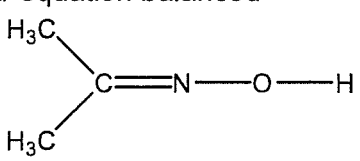
[3]

(b) (i) correct organic product



H_2O formed/ equation balanced [2]

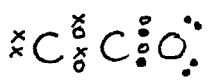
(ii)



[1]

24. O/N 10/P23/Q3

(a) (i) order of atoms **must** be C-C-O

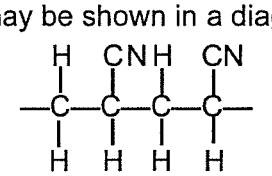


linear

(ii) a molecule or atom with an unpaired electron **or**
a species formed by the homolytic fission of a covalent bond

(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)

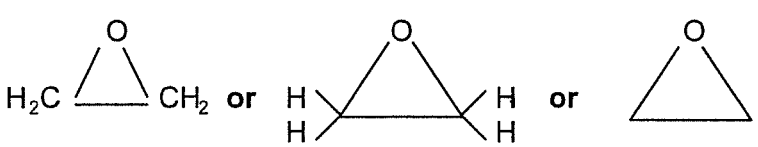


allow the structural formula —$CH_2CH(CN)CH_2CH(CN)$— (1)

(ii) addition [2]

(c) (i) CH_3CHO

(ii)



[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]

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A Level

Unit 18
CARBOXYLIC ACIDS AND DERIVATIVES

Chemistry Paper-2
Topical Workbook
Article Number: 232

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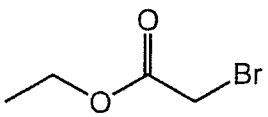
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Unit 18: Carboxylic acids and derivatives

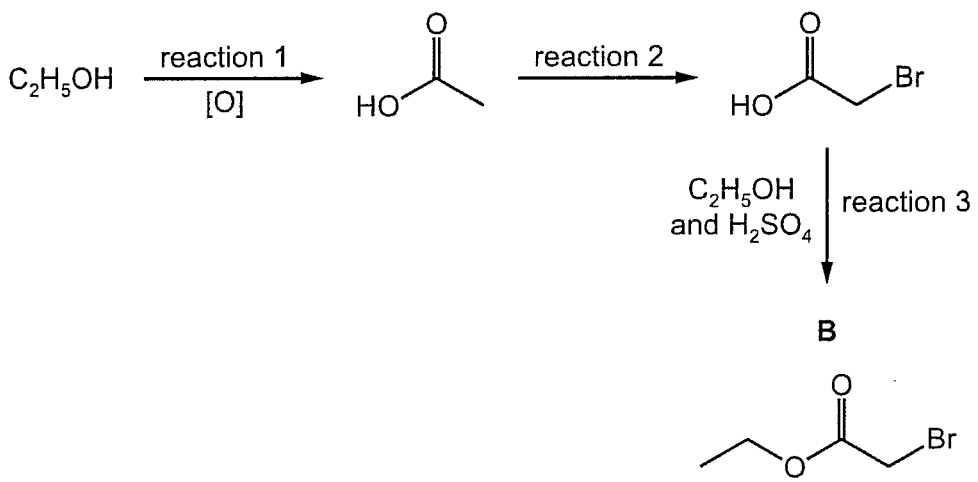
1. O/N 21/P21/Q4, O/N 21/P23/Q4

Compound **B** is a liquid with a fruity smell.

B



The reaction scheme shows how **B** can be made from ethanol, C_2H_5OH.



(a) (i) Reaction 1 is an oxidation reaction.
Give the reagent(s) and conditions required for reaction 1.

reagent(s) .....

conditions .....

.....
[2]

(ii) Construct an equation to represent reaction 1.
Use [O] to represent an oxygen atom from the oxidising agent in this reaction.

..... [1]

(iii) Suggest the type of reaction that occurs in reaction 2.

..... [1]

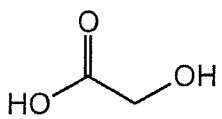
(iv) H_2SO_4 acts as a homogeneous catalyst in reaction 3.
Explain why H_2SO_4 is described as *homogeneous*.

..... [1]

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(b) Reaction 2 needs to take place in the absence of water to prevent formation of compound **C**.

C



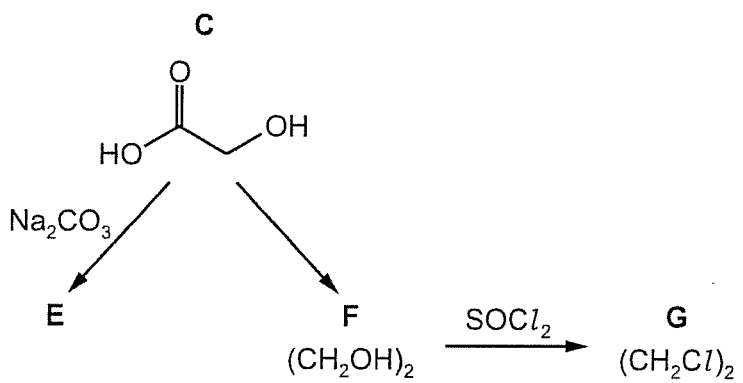
If **C** is present in the reaction mixture of reaction 3, a different compound, compound **D**, will also form. Compound **D** has two identical functional groups.
The infrared spectrum of **D** shows strong absorptions at 1100 cm^{-1} and 1720 cm^{-1}, but no absorption due to O–H bonds.
Use the *Data Booklet* to identify the functional group present in **D**.
Explain your answer as fully as you can.

.....

.....

..... [3]

(c) Some other reactions of **C** are shown.



(i) Draw the structure of **E**.

[1]

(ii) Suggest why $NaBH_4$ is not a suitable reagent to make **F**, $(CH_2OH)_2$, from **C**.
Explain your answer.

..... [1]

(iii) Construct an equation for the reaction of $(CH_2OH)_2$ with $SOCl_2$ to form **G**, $(CH_2Cl)_2$.

..... [1]

(d) Explain why **C** is very soluble in water.

..... [1]

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2. M/J 21/P21/Q1

Ethanedioic acid, HO_2CCO_2H, has a relative molecular mass of 90.0.

(a) (i) Explain what is meant by the term *relative molecular mass*.

.....

..... [2]

(ii) State the empirical formula of ethanedioic acid.

..... [1]

(iii) Calculate how many atoms of carbon are present in 0.18 g of ethanedioic acid, HO_2CCO_2H. Show your working.

atoms of carbon present = ... [3]

(b) Solid ethanedioic acid reacts with aqueous calcium ions to make a precipitate of calcium ethanedioate, CaC_2O_4.

CaC_2O_4 breaks down when heated to form calcium oxide, carbon dioxide and carbon monoxide.

(i) Construct an equation to represent the reaction of CaC_2O_4 when heated. Include state symbols.

..... [2]

(ii) Identify the type of reaction which occurs when CaC_2O_4 is heated.

..... [1]

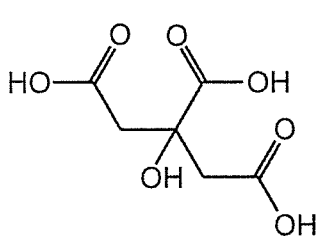
(iii) Identify another compound containing calcium ions which will also produce carbon dioxide and calcium oxide when it is heated.

..... [1]

3. M/J 21/P23/Q5

Compound **X** contains the same functional groups as citric acid.

citric acid

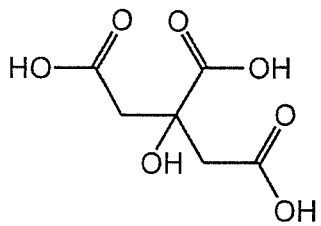


The table describes some of the similarities and differences between citric acid and compound **X**.

	citric acid	**X**
chiral centre	no	yes
reaction with Na	fizzing	fizzing
reaction with $H^+/Cr_2O_7^{2-}$	remains orange	orange to green

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(a) Complete the equation to show the reaction of excess sodium with citric acid. Show the skeletal structure of the product.



+ .....Na →

[3]

(b) (i) Use the information in the table to deduce the skeletal formula of **X**, $C_3H_6O_3$. Draw the skeletal formula of **X** in the box. Label the chiral centre of compound **X** with an asterisk (*).

[2]

(ii) Explain why compound **X** reacts with acidified $Cr_2O_7^{2-}$ but citric acid does not.

.....

..... [2]

(c) Compound **X** is one of a pair of stereoisomers.
Stereoisomerism occurs when a molecule has at least one of two key features.
State the two key features that give rise to stereoisomerism.

1 .....

.....

2 .....

..... [2]

(d) A structural isomer of compound **X** does not fizz when added to sodium.
Explain what is meant by *structural isomer*.

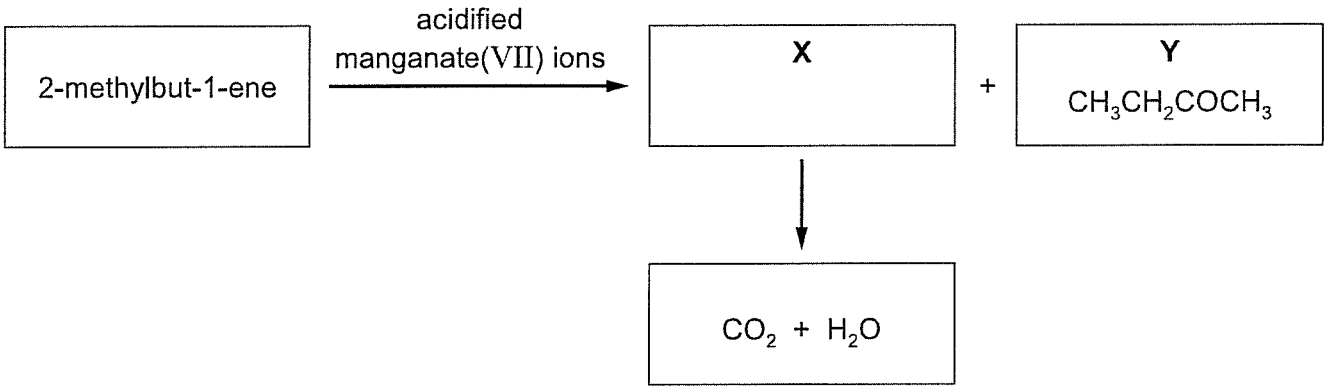
..... [1]

4. M/J 20/P21/Q6

2-methylbut-1-ene reacts with acidified manganate(VII) ions, under specific conditions, to produce two organic compounds **X** and **Y**.

X immediately reacts with the acidified manganate(VII) ions to form carbon dioxide and water. **Y** has the structural formula $CH_3CH_2COCH_3$.

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(a) Draw the skeletal formula of 2-methylbut-1-ene.

[1]

(b) **(i)** State the specific conditions required for the acidified manganate(VII) ions to react with 2-methylbut-1-ene in this way.

..... [1]

(ii) Name the type of reaction occurring to the functional group in 2-methylbut-1-ene in the reaction in **(b)(i)**.

..... [1]

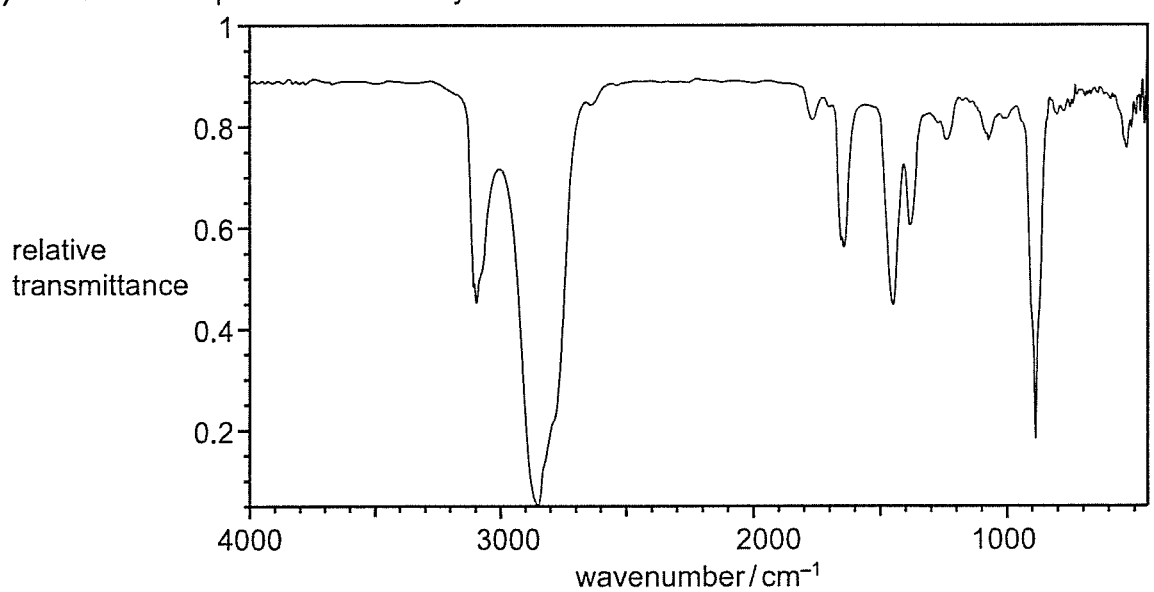
(c) Draw the structural formula of **X**.

..... [1]

(d) Describe a chemical test and the expected observation(s) to confirm the presence of the carbonyl functional group in **Y**.

..... [2]

(e) The infra-red spectrum of 2-methylbut-1-ene is shown.



Predict two main differences that would be seen between the spectra of **Y**, $CH_3CH_2COCH_3$, and of 2-methylbut-1-ene. Give reasons for your predictions.

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Your answer should refer only to the region of each spectrum **above 1500 cm^{-1}**.

.....

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

(f) Propanoic acid, $CH_3CH_2CO_2H$, is reduced by $LiAlH_4$.

(i) Write an equation to show this reaction. Use [H] to represent an atom of hydrogen from the reducing agent.

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

(ii) Name the organic product formed in this reaction.

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

(g) Organic compound **W** is an ester which is a structural isomer of propanoic acid.

(i) State the molecular formula of **W**.

..... [1]

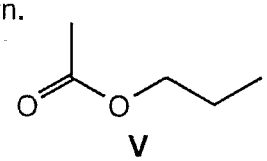
(ii) Draw a possible structure of **W**.

[1]

5. M/J 19/P22/Q5

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.

[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]

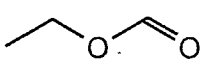
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(ii) State what additional information is required to determine the molecular formula of **W**.

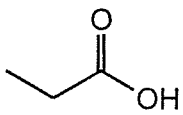
..... [1]

(c) Compounds **X**, **Y** and **Z** are shown. They all have the same molecular formula.

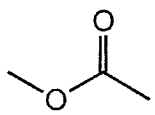
X



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.

experiment	observations
Na + **X**	
Na + **Y**	
Na + **Z**	

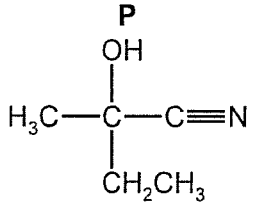
[2]

(d) Sodium carbonate solution reacts with methanoic acid.
Write the equation for this reaction.

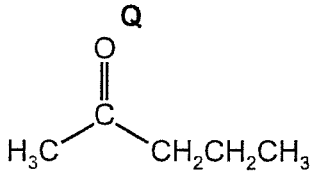
..... [1]

6. MAR 19/P22/Q3/a,b,c
P, **Q** and **R** all contain five carbon atoms.

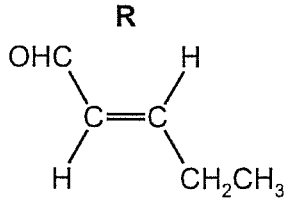
P



Q



R



A student carries out several tests to distinguish between **P**, **Q** and **R**.

(a) Complete the table, identifying any observations for the reaction of each reagent with **P**, **Q** and **R**.
If no reaction occurs, write 'no reaction'.

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reagent	observations with		
	P	**Q**	**R**
Na(s)			
2,4-DNPH	no reaction		
acidified $K_2Cr_2O_7$(aq)	no reaction		

[3]

(b) **Q** is reduced by $NaBH_4$.

Write an equation for the reaction of **Q** with $NaBH_4$.

In your answer, use [H] to represent $NaBH_4$.

$C_5H_{10}O$ + ... **[1]**

(c) **R** exists as a pair of stereoisomers.

Identify the type of stereoisomerism shown by **R** and draw the structure of the other stereoisomer.

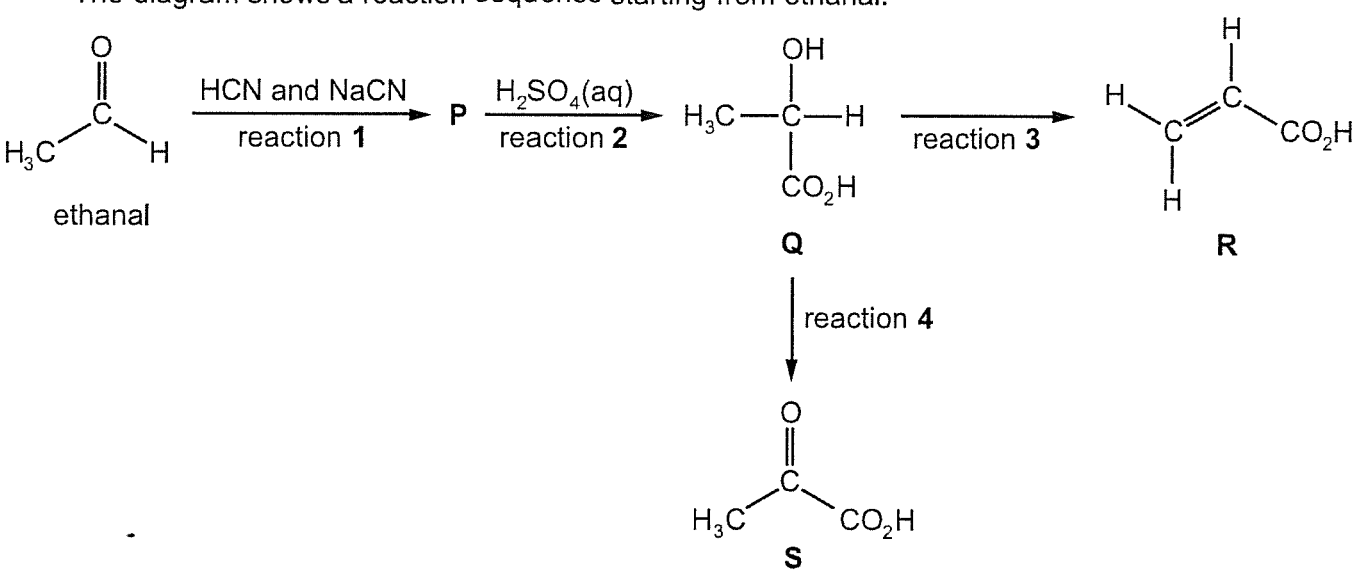
type of stereoisomerism .....

stereoisomer of **R**

[2]

7. O/N 18/P22/Q4/a

The diagram shows a reaction sequence starting from ethanal.



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(a) (i) Draw the **displayed** formula of **P**.

[1]

(ii) Name the type of chemical reaction that occurs in reaction **3**.

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

(iii) Write an equation to represent reaction **4**.

Use [O] to represent the oxidising agent.

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

(iv) State the reagents and conditions for reaction **4**.

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

8. O/N 18/P21/Q4/d, O/N 18/P23/Q4/d

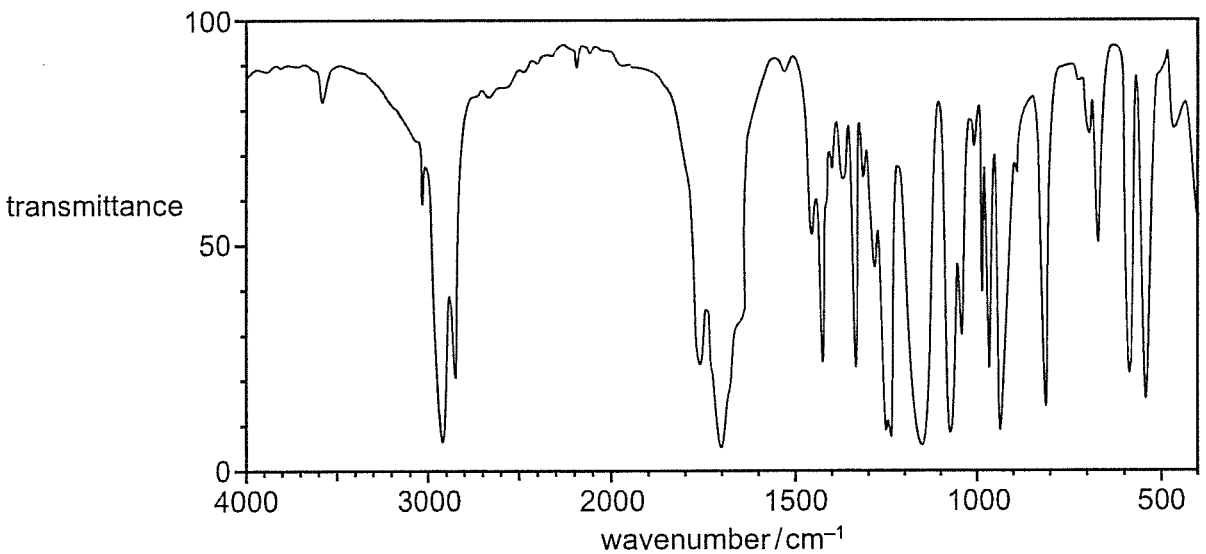
(a) When glycolic acid is heated in the presence of a sulfuric acid catalyst, a new compound, **Y**, $C_4H_4O_4$, is formed.

The equation for the reaction is given.

$$2CH_2(OH)CO_2H \rightarrow C_4H_4O_4 + 2H_2O$$

glycolic acid **Y**

(i) The infra-red spectrum of **Y** is shown.



State how this spectrum differs from an infra-red spectrum of glycolic acid. Explain your answer with particular reference to the peaks within the range 1500 – 4000 cm^{-1}.

.....

..... [2]

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(ii) Suggest a structure for **Y**.

[2]

9. M/J 18/P22/Q4

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]

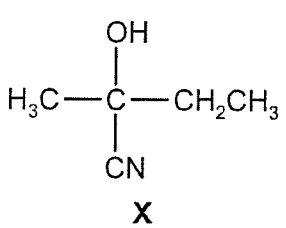
(b) There are two structural isomers of **W** that are also carbonyl compounds.
Draw the structures of these two isomers of **W**.

[2]

Two reactions of **W** are shown.

$CH_3COCH_2CH_3$ (**W**) —reaction **1**→ $CH_3CH(OH)CH_2CH_3$

W —reaction **2**→ **X**



X

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(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.

W 

[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]

(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]

10. MAR 17/P22/Q3/d(ii)

$CH_3(CH_2)_3CO_2H$ is a colourless liquid with an unpleasant odour.

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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}.

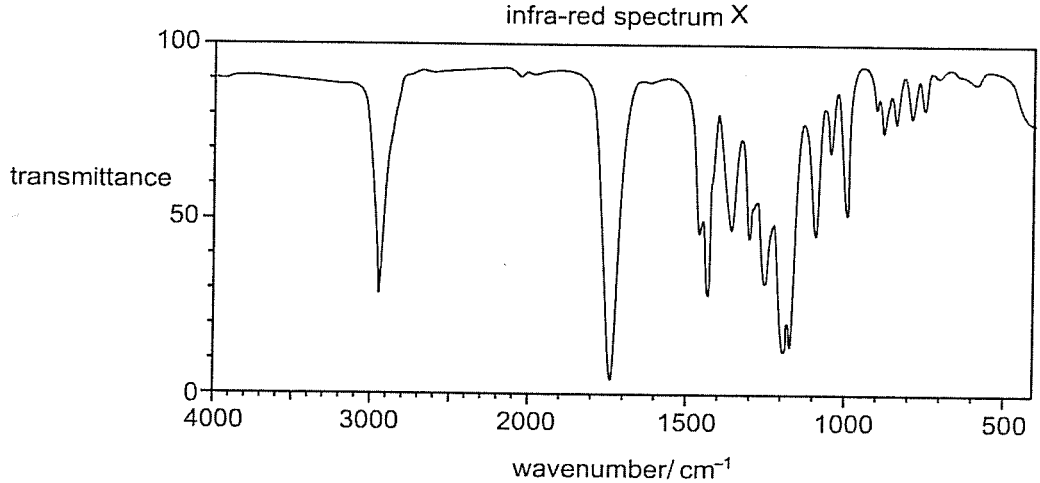
.....

.....

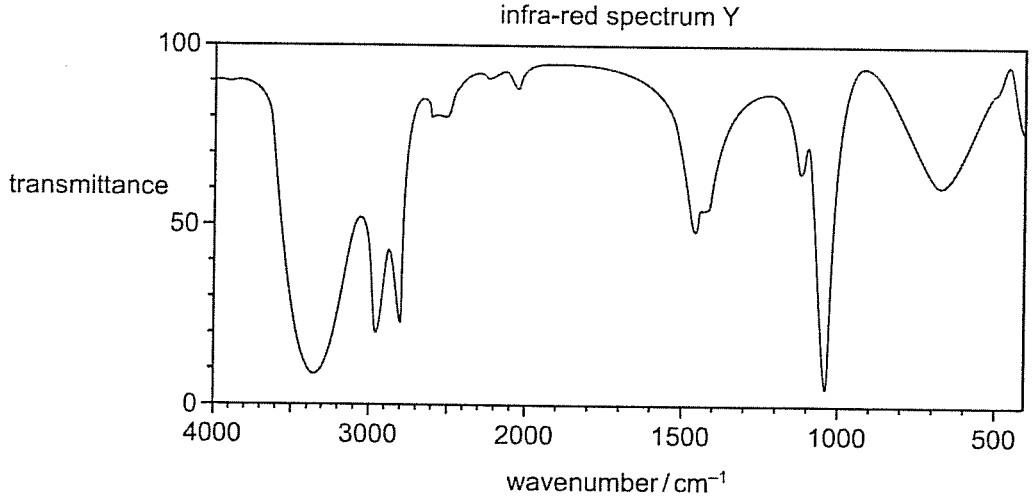
.....

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

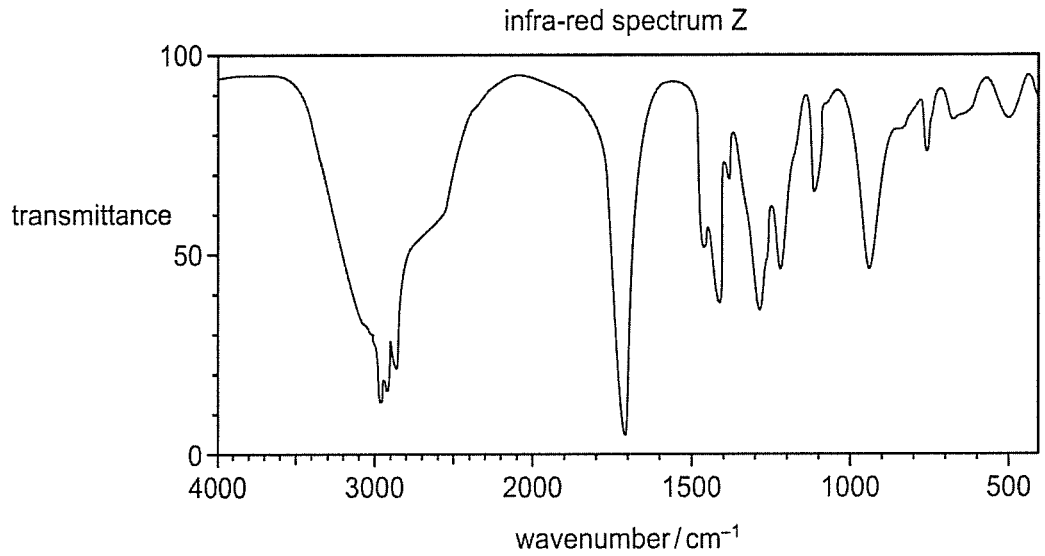
infra-red spectrum X



infra-red spectrum Y



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11. 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)**.

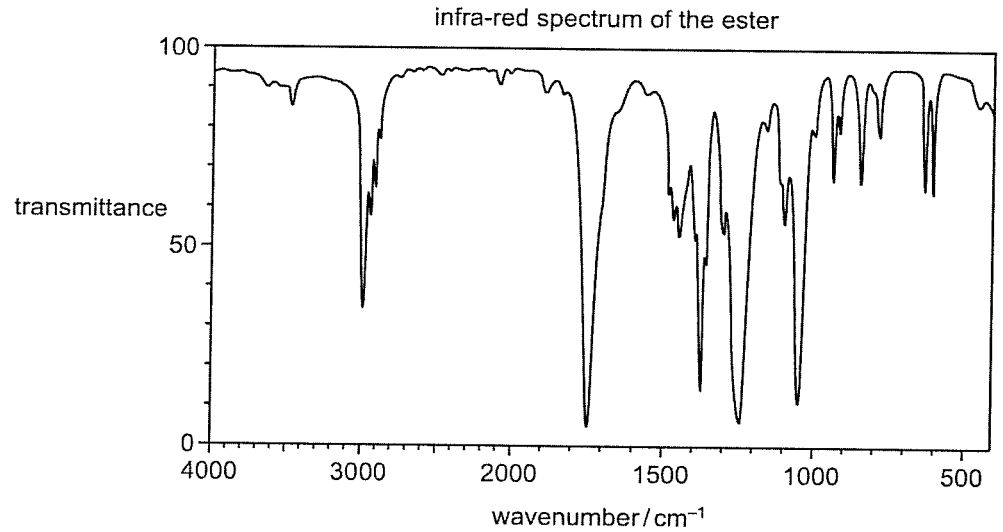
.....

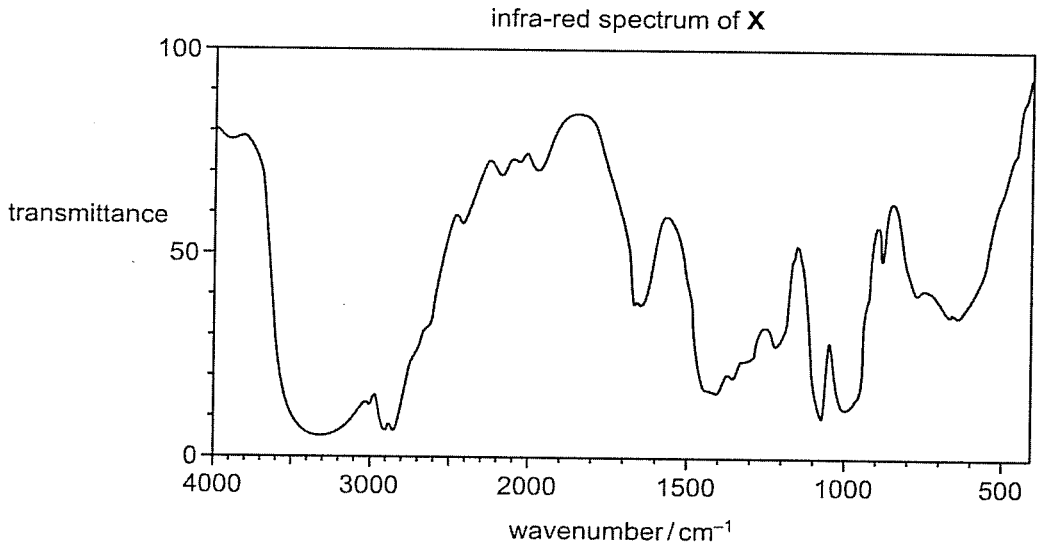
..... [2]

(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.

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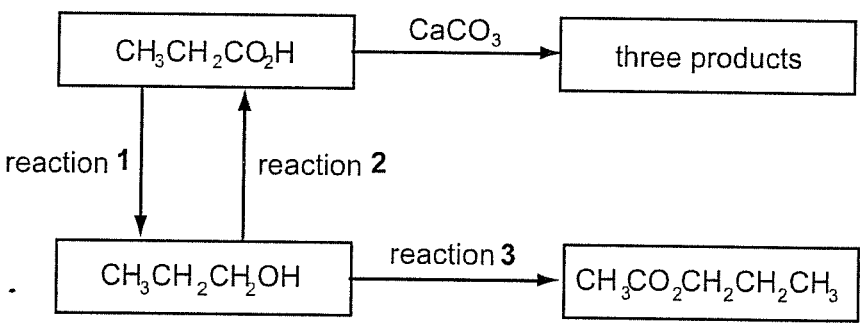
Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm^{-1}

.....

.....[3]

12. O/N 14/P21/Q4

A series of reactions based on propanoic acid is shown.



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(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]

13. 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.

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(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]

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

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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**

[2]

14. 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?

.....

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(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**

[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. M/J 13/P22/Q5/a,b

A student reacted together an alcohol and a carboxylic acid under appropriate conditions to

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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]**

(b) In the boxes below, draw the structural formulae of **four** isomers with this formula that are esters.

W	**X**
Y	**Z**

[4]

16. M/J 12/P22/Q3

Food additives are substances added to food to preserve the flavour or to improve its taste and appearance.

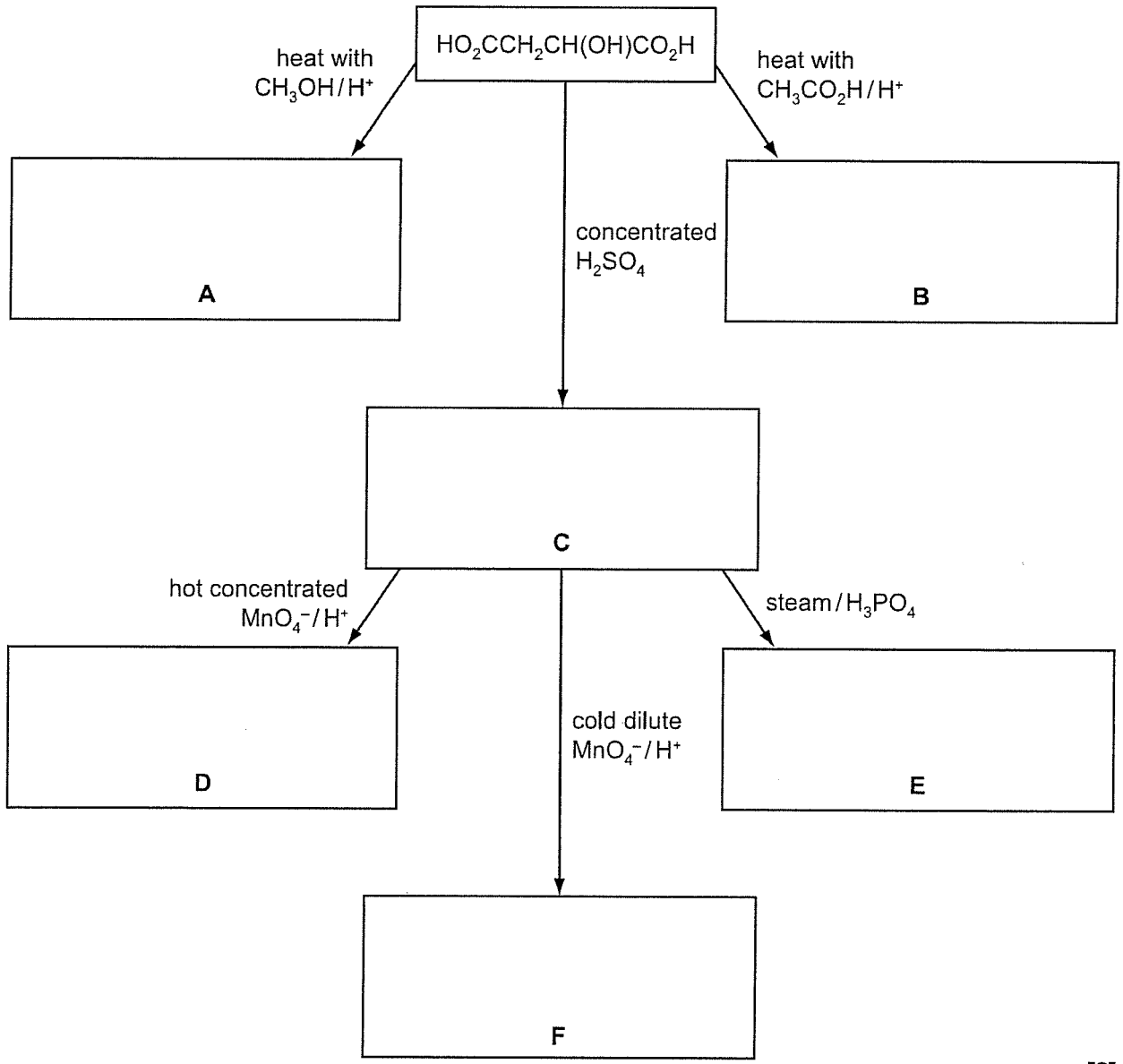
European Union legislation requires most additives used in foods to be labelled clearly in the list of ingredients, either by name or by an 'E number'. E296 is malic acid which occurs in unripe fruit.

Malic acid has the structural formula $HO_2CCH_2CH(OH)CO_2H$.

(a) Some reactions of malic acid are shown below.

In the boxes below, give the **structural** fórmulae of organic compounds **A** to **F**.

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[6]

(b) What *type of reaction* is **each** of the following conversions?

malic acid into **C** .....

C into **D** .....

C into **E** ..... [3]

(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.

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(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.

[3]

17. 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.

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reagent	alcohol R_2CHOH	aldehyde RCHO	carboxylic acid RCO_2H	ester RCO_2R'	ketone RCOR'
$NaHCO_3$					
Na					
$Cr_2O_7^{2-}/H^+$					

[5]

18. 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**.

[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]

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(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**

[2]

19. 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]

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(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**.

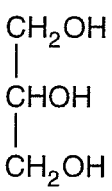
(ii) What type of reaction occurs when **Z** is formed from **X**?

..... [2]

20. 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, $CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2H$.

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(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]

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]

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Answers Section

1. O/N 21/P21/Q4, O/N 21/P23/Q4

(a) (i) potassium/sodium dichromate [(VI)] / $K_2Cr_2O_7$ / $Na_2Cr_2O_7$ acidified **AND** (heat) under reflux **2**

(ii) $C_2H_5OH + 2[O] \rightarrow CH_3CO_2H + H_2O$ **1**

(iii) substitution **1**

(iv) in the same phase / in same state **1**

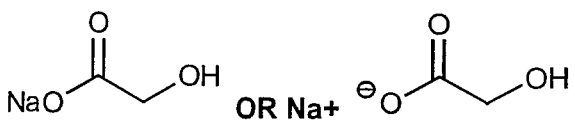
(b) **M1** ester **3**

M2 1100 cm^{-1} linked to C—O **AND** 1720 cm^{-1} linked to C=O

M3 No COOH / carboxylic acid and No OH / alcohol in D (but present in C)

OR

COOH / carboxylic acid and OH / alcohol reacted /lost (in C to form D)

(c) (i)  **1**

(ii) Not a strong (enough) reducing agent **1**

(iii) *Construct an equation* **1**

$(CH_2OH)_2 + SOCl_2 \rightarrow (CH_2Cl)_2 + SO_2 + H_2O$

(d) Forms hydrogen bonds **with water** **1**

2. M/J 21/P21/Q1

(a) (i) **option 1**

M1 the mass of a molecule OR the (weighted) average / (weighted) mean mass of the molecule(s) **1**

option 1 **1**

and

M2 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)

option 2

M1 mass of one mol of molecules

option 2

M2 relative / compared to 1 / 12 (the mass) of 1 mol of C-12 OR which one mol C-12 (atom / isotope) has a mass of (exactly) 12 g

(ii) CO_2H **1**

(iii) $0.18/90 \times 2 \times 6.02 \times 10^{23} = 2.408 \times 10^{21}$ (atoms) OR **$2.4(1) \times 10^{21}$** (atoms) **1**

M1 no mole ethanedioic acid $0.18 / 90 = 0.0020$

M2 no mole ethanedioic acid $\times 2$ $0.0020 \times 2 = 0.0040$ **1**

M3 no mole ethanedioic acid $\times 6.02 \times 10^{23}$ 2.4×10^{21} **1**

(b) (i) $CaC_2O_4(s) \rightarrow CaO(s) + CO_2(g) + CO(g)$ **1**

M1 correct formulae

M2 balancing equation AND state symbols. **1**

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(ii) (thermal) decomposition OR disproportionation 1

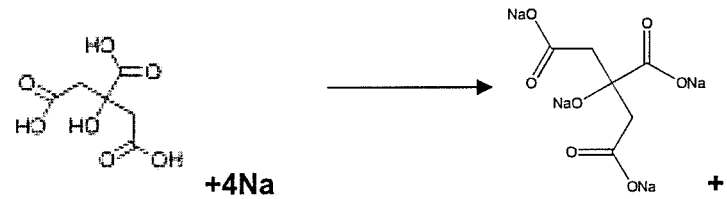
(iii) calcium carbonate / $CaCO_3$ 1

3. M/J 21/P23/Q5

(a) **M1** all 3 COOH form COONa / CO_2Na / COO Na^+ 1

M2 the OH group forms CONa / CO^-Na^+ 1

M3 equation describes H_2 as a product and equation balanced correctly 1

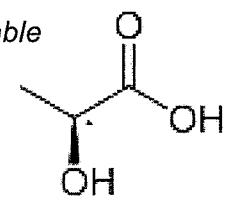


+4Na **+ $2H_2$** ✓✓✓

OR

$C(CH_2COOH)_2(COOH)(OH) + 4Na \rightarrow C(CH_2COONa)_2(COONa)(ONa) + 2H_2$ ✓✓✓

(b) (i) **M1** *skeletal formula of 2-hydroxypropanoic acid / similar chiral isomer that meet the criteria in table* 1



M2 chiral carbon marked with * 1

(ii) **M1** citric acid has a tertiary alcohol group so is not oxidised 1

M2 X has a secondary alcohol group which is oxidised (to a ketone) 1

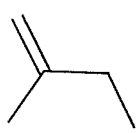
(c) **M1** chiral centre / non superimposable mirror image / has a C **attached** to 4 different groups 1

M2 C=C where each C is attached to (two) different groups 1

(d) (molecules / isomers with) the same molecular formula / same number of atoms of each element AND different structural formulae / different structures 1

4. M/J 20/P21/Q6

(a) 1



(b) (i) hot **AND** concentrated 1

(ii) oxidation 1

(c) *Structural formula of **X**:* 1
HCO_2H OR HCOOH

(d) **M1** *reagent* (2,4–) DNPH / (2,4)-dinitrophenylhydrazine

M2 *observation* yellow / orange / red precipitate 2

(e) *Predict **two** differences, with reasons, between spectra of **Y**, $CH_3CH_2COCH_3$ and 2-methylbut-1-ene (shown) first difference* 2

M1 absence of peak/ absorption at 3100 (cm^{-1}) as no longer any =C–H present (in **Y**)

second difference

M2 peak at 1650 (cm^{-1}) moves to the left to any value / range of

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values between 1670 and 1740) due to disappearance of C=C (in **Y**)
and appearance of C=O (in **Y**)
OR
absence of peak at 1650 (cm^{-1}) as no longer any C=C present (in **Y**)
AND
appearance of peak (in **Y**) at (any value / range of values) between
1670-1740(cm^{-1}) due to C=O

(f) (i) $CH_3CH_2CO_2H + 4[H] \rightarrow CH_3CH_2CH_2OH + H_2O$ **1**

(ii) propan-1-ol **1**
ALLOW propan-2-ol as error carried forward from **6f(i)**

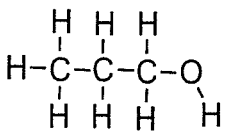
(g) (i) *Molecular formula of **W*** **1**
$C_3H_6O_2$

(ii) *Possible structure of **W*** **1**
CH_3COOCH_3 **OR** $HCOOCH_2CH_3$

5. M/J 19/P22/Q5

(a) (i) (n–)propyl ethanoate **1**

(ii) NaOH / sodium hydroxide **1**

(iii)  **1**

(iv) perfume / solvent **1**

(b) (i) **M1** *divide by A_r* C H O **1**
54.5 / 12 9.1 / 1 36.4 / 16

M2 *divide by smallest number* **1**
4.54 / 2.275 (= 2 OR 1.99) 9.1 / 2.275(=4) 2.275 / 2.275 (=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**

6. MAR 19/P22/Q3/a,b,c

(a) **3**

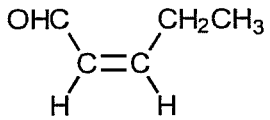
	P	Q	R
Na(s)	effervescence	no reaction	no reaction
2,4-DNPH	no reaction	orange ppt	orange ppt
acidified $K_2Cr_2O_7$(aq)	no reaction	no reaction	(turns) green

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(b) $C_5H_{10}O + 2[H] \rightarrow C_5H_{12}O$ **1**

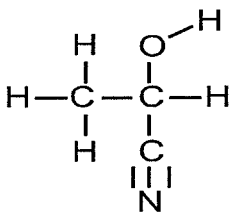
(c) **M1** geometric(al) **2**

M2



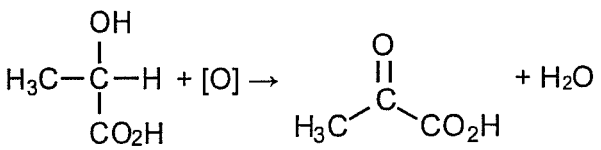
7. O/N 18/P22/Q4/a

(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**

8. O/N 18/P21/Q4/d, O/N 18/P23/Q4/d

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

Glycolic acid would have:

M1 2500–3000 due to RCO_2-H

M2 range within 3200–3650 due to RO–H

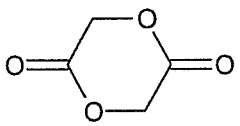
OR

Spectrum Y would NOT have:

M1 2500–3000 due to RCO_2-H

M2 range within 3200–3650 due to RO–H

(ii) **2**



M1 ANY ester group **AND** valid $C_4H_4O_4$ molecule

M2 correct cyclic structure

9. M/J 18/P22/Q4

(a) (i) iodoform / tri-iodomethane **1**

(ii) butanone **1**

(b) $CH_3CH_2CH_2CHO$ **1**

$(CH_3)_2CHCHO$ **1**

(c) (i) reduction **1**

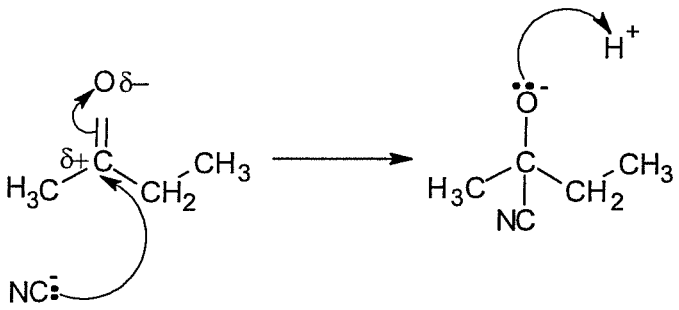
(ii) $NaBH_4$ / sodium borohydride **1**

OR

$LiAlH_4$ / lithium aluminium hydride

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(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**

10. 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]**

11. M/J 16/P22/Q4

(a) $CH_3CH_2CH_2COOH$ **[1]**

$(CH_3)_2CHCOOH$ / $CH_3CH(CH_3)COOH$ **[1]**

(b) (i) Two from

1. $CH_3CH_2COOCH_3$ 2. $CH_3COOCH_2CH_3$ 3 $HCOOCH_2CH_2CH_3$ **[1]**

(ii) correct acid + alcohol for either ester **[1]**
1. methanol + propanoic acid
2. ethanol + ethanoic acid

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3. propan-1-ol + methanoic acid
(conc)H_2SO_4/(conc)H_3PO_4 AND heat/warm/reflux [1]

(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]

12. O/N 14/P21/Q4

(a) $CH_3CH_2CO_2H + 4[H] \rightarrow CH_3CH_2CH_2OH + H_2O$ **[2]**

(b) (i) Oxidation

(ii) Sodium/potassium dichromate or correct formula
H^+/acidified and (heat under) reflux **[2]**

(c) $2\ CH_3CH_2CO_2H + CaCO_3 \rightarrow (CH_3CH_2CO_2)_2Ca + H_2O + CO_2$ **[2]**

(d) (i) CH_3CO_2H
warm/hot/high temperature/heat/reflux **AND** concentrated sulfuric acid **[2]**

(ii) water (or hydrogen chloride or ethanoic acid) [1]

13. O/N 13/P22/Q4, O/N 13/P21/Q4

(a) (i) $H_2X + 2NaOH \rightarrow Na_2X + 2H_2O$

(ii) $n(OH^-) = \dfrac{21.6 \times 0.100}{1000} = 2.16 \times 10^{-3}$ mol

(iii) $n(\mathbf{R}) = n(H_2X) = \dfrac{2.16 \times 10^{-3}}{2}$
$= 1.08 \times 10^{-3}$ mol in 25.0 cm^3

(iv) $n(\mathbf{R}) = 1.08 \times 10^{-3} \times \dfrac{250}{25.0} = 0.0108$ mol in 250 cm^3

(v) 0.0108 mol of **R** = 1.25 g of **R**
1 mol of **R** $= \dfrac{1.25 \times 1}{0.0108} = 115.7 = 116$ g **[5]**

(b) (i) M_r of **S** = 116
M_r of **T** = 134
M_r of **U** = 150 **all three** needed

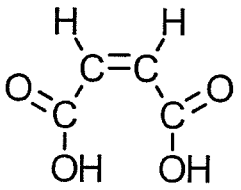
(ii) **S** **[2]**

(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
S into **U**
$KMnO_4$
cold dilute acidified **or** cold dilute alkaline
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 **[5]**

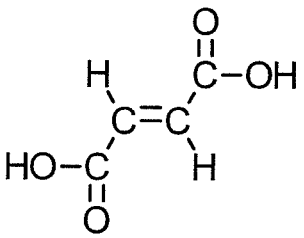
(d) **T** reacting with an excess of Na
$NaO_2CCH(ONa)CH_2CO_2Na$
U reacting with an excess of Na_2CO_3
$NaO_2CCH(OH)CH(OH)CO_2Na$ **[2]**

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(e)



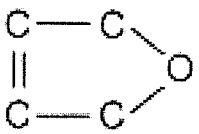
cis **or** Z



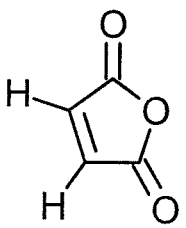
trans **or** E

two correct structures
correct labels **[2]**

(f) correct ring of C and O atoms, i.e.



correct compound, i.e.



(hydrogen atoms do not need to be shown) **[2]**

14. O/N 13/P23/Q4

(a) (i) structural **or** functional group isomerism

(ii) **R** primary alcohol **and** carboxylic acid – **not** 'acid'
S primary alcohol **and** ester
T primary alcohol **and** ester

(iii) **with Na_2CO_3**
carboxylic acid

(iv) **with Na**
alcohol **and** carboxylic acid **[6]**

(b) (i) $n(CO_2) = \frac{24.0}{24000} = 0.001$ mol

(ii) 0.002 mol of **Q** → 0.001 mol of CO_2
1 mol of **Q** → 0.5 mol of CO_2 **[2]**

(c) (i) $n(H_2) = \frac{48.0}{24000} = 0.002$ mol

(ii) 0.002 mol of **Q** → 0.002 mol of H_2
1 mol of **Q** → 1 mol of H_2 **[2]**

(d) **Q** is isomer **R**

with sodium carbonate

$2HOCH_2CH_2CO_2H + Na_2CO_3 \rightarrow 2\,HOCH_2CH_2CO_2Na + H_2O + CO_2$
correct products
balanced

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with sodium metal

$HOCH_2CH_2CO_2H + 2Na \rightarrow NaOCH_2CH_2CO_2Na + H_2$

correct products

balanced **[5]**

15. M/J 13/P22/Q5/a,b

(a) $C_4H_8O_2$ **[1]**

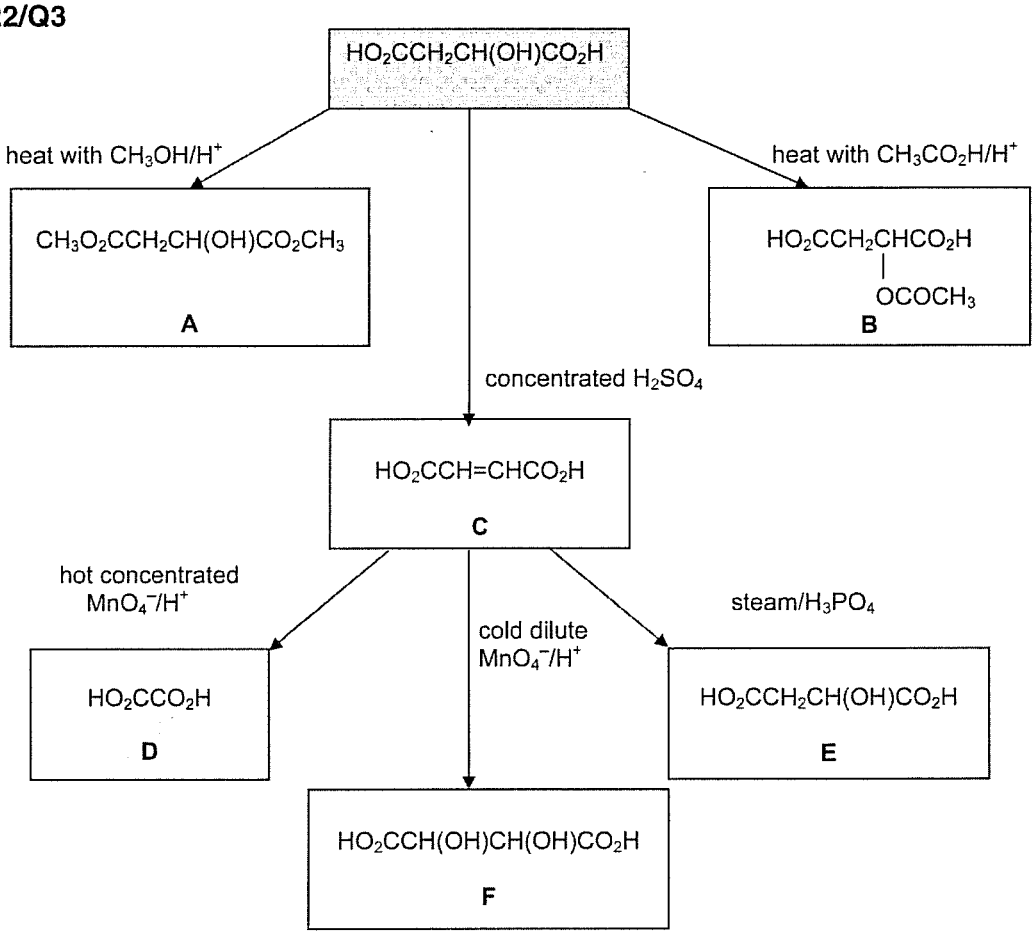
(b)

$HCO_2CH_2CH_2CH_3$ **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]

16. M/J 12/P22/Q3

(a)



give one mark for each correct compound **[6]**

(b) malic acid into **C** dehydration **or** elimination

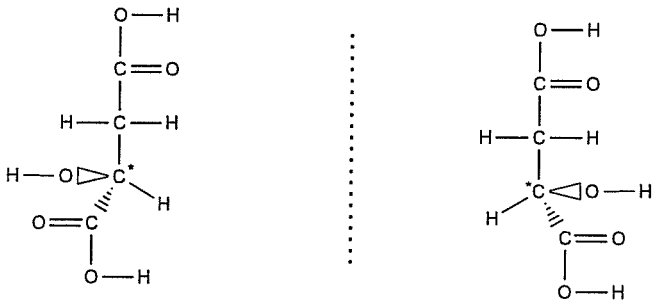
C into **D** oxidation

C into **E** addition **or** hydration **[3]**

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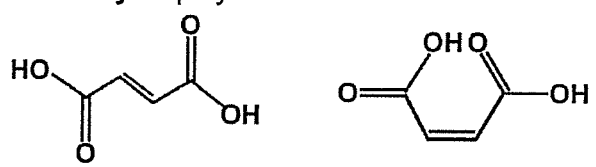
(c) solvents **or** perfumes **or** flavourings **[1]**

(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**
correct *cis* (or Z) **and** *trans* (or E) labels **[6]**

(e) $C : H : O = \frac{37.5}{12} : \frac{4.17}{1} : \frac{58.3}{16}$

$= 3.13 : 4.17 : 3.64$

$= 1 : 1.33 : 1.16$

$= 6 : 8 : 7$

empirical formula is $C_6H_8O_7$ **[3]**

17. M/J 12/P22/Q4/a

(a)

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]**

18. M/J 12/P23/Q5

(a) (i) CO_2/carbon dioxide

(ii) carboxylic acid **or** $-CO_2H$ **or** $-COOH$ **[2]**

(b) (i) dehydration **or** elimination

(ii) **H** contains >C=C< bond
H contains $-CO_2H$ group
H is $CH_2=CHCO_2H$ **[4]**

(c) $n(\mathbf{F}) = \frac{0.600}{90} = 6.67 \times 10^{-3}$ mol

F contains one –OH group and one $-CO_2H$ group
hence one mole of **F** produces one mole of H_2 with Na
$n(H_2) = 6.67 \times 10^{-3}$ mol
vol. of $H_2 = 6.67 \times 10^{-3} \times 24000$ cm^3
$= 160$ cm^3 at room temperature and pressure **[4]**

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(d) (i)

$HOCH_2CH_2CO_2H$	$CH_3CH(OH)CO_2H$
J	**K**

one isomer correct

(ii)

$HO_2CCH_2CO_2H$	CH_3COCO_2H
product from J	**product from K**

one oxidation product correct **[2]**

19. O/N 11/P23/Q5

(a) V is HCHO **[1]**

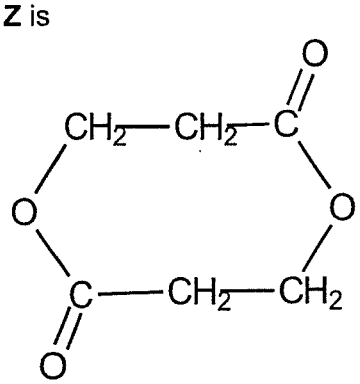
(b) (i) ester

(ii) **W** is HCO_2CH_3 **[2]**

(c) (i) **X** is $HOCH_2CH_2CO_2H$

(ii) **Y** is $HO_2CCH_2CO_2H$ **[2]**

(d) (i) **Z** is

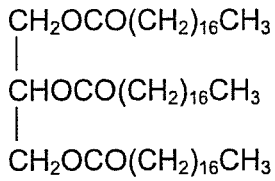


[1]

(ii) esterification **or**
dehydration **or**
elimination **or**
condensation **[2]**

20. M/J 11/P22/Q5/a,b,c

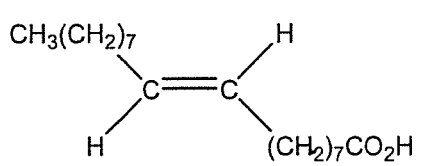
(a)



all three alcohol groups must be esterified **[1]**

(b) dilute HC*l* **or** dilute H_2SO_4 **or** dilute mineral acid **or** NaOH(aq) **followed by** dilute acid **[1]**

(c)



[1]

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Unit 19
ANALYTICAL TECHNIQUES

Chemistry Paper-2
Topical Workbook
Article Number: 232

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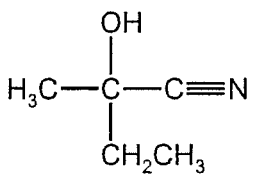
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Unit 19: Analytical Techniques

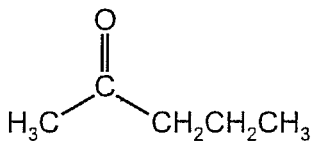
1. MAR 19/P22/Q3/d

P, **Q** and **R** all contain five carbon atoms.

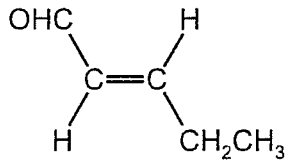
P



Q

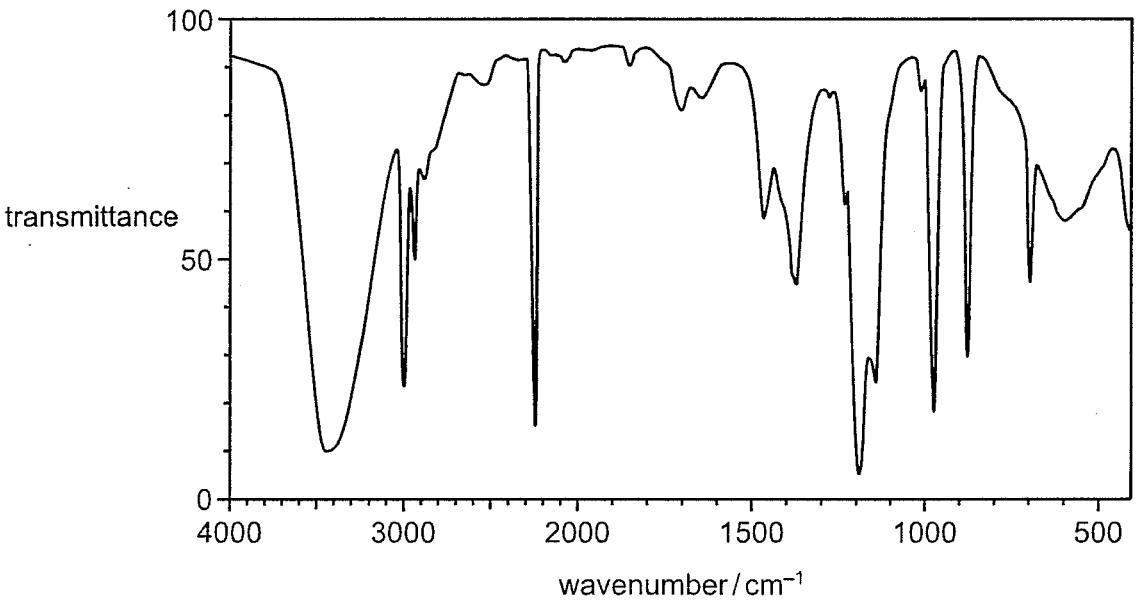


R



A student carries out several tests to distinguish between **P**, **Q** and **R**.

(a) The infra-red spectrum shown corresponds to one of **P**, **Q** or **R**.



Deduce which of the compounds, **P**, **Q** or **R**, produces this spectrum. Explain your reasoning. In your answer, identify any relevant absorptions in the infra-red spectrum and the bonds that correspond to these absorptions in the region **above** 1500 cm^{-1}.

compound .....

explanation .....

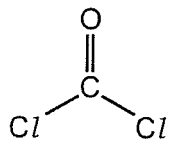
.....

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

2. O/N 18/P22/Q3/c

(a) A different trihalomethane, $CHCl_3$, reacts with O_2 to produce carbonyl dichloride. $HCl(g)$ is also released as a product of this reaction.

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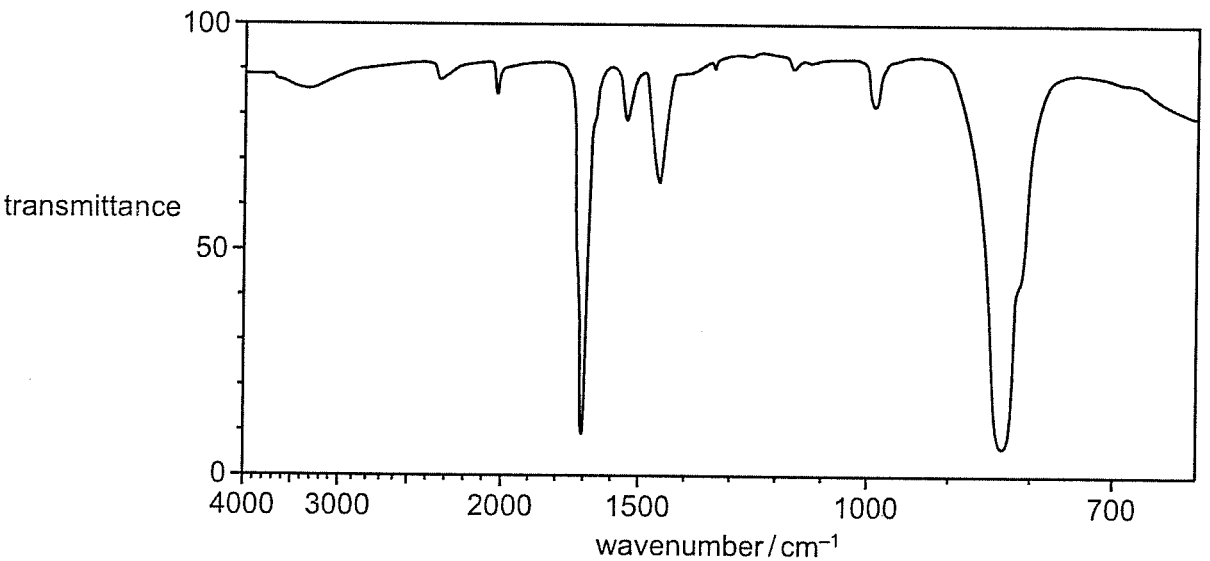


carbonyl dichloride

(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.



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]

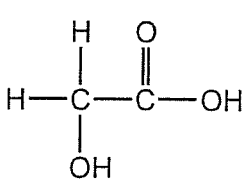
(iii) Suggest another difference between the infra-red spectra of $CHCl_3$ and carbonyl dichloride.

.....

..... [1]

3. O/N 18/P23/Q4/d

The structure of glycolic acid is shown.



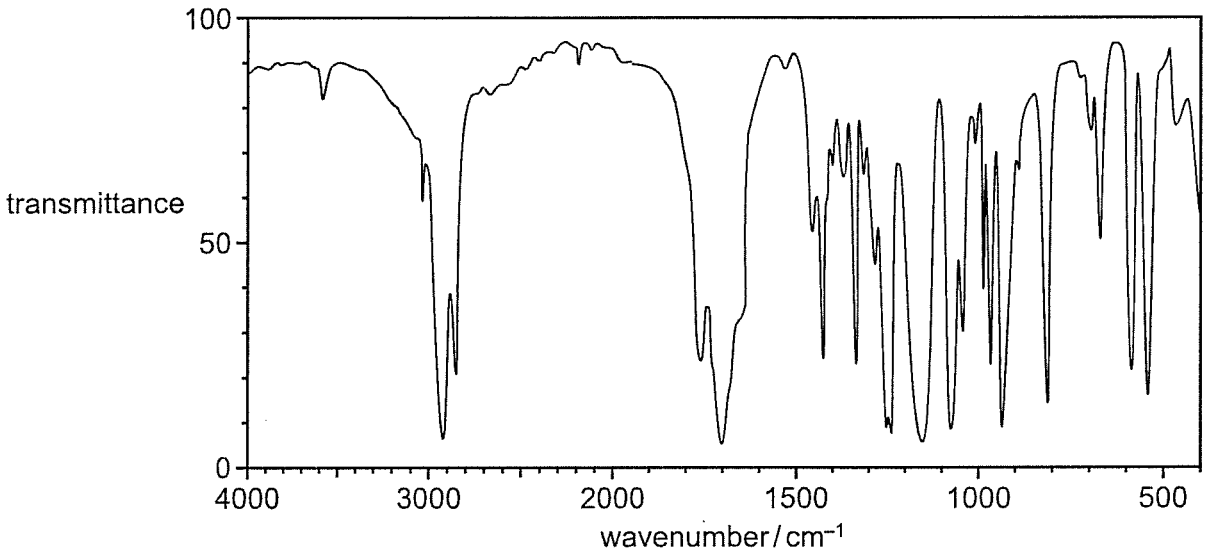
glycolic acid

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(a) When glycolic acid is heated in the presence of a sulfuric acid catalyst, a new compound, **Y**, $C_4H_4O_4$, is formed.
The equation for the reaction is given.

$$2CH_2(OH)CO_2H \rightarrow C_4H_4O_4 + 2H_2O$$
glycolic acid **Y**

(i) The infra-red spectrum of **Y** is shown.



State how this spectrum differs from an infra-red spectrum of glycolic acid. Explain your answer with particular reference to the peaks within the range 1500 – 4000 cm^{-1}.

.....

..... [2]

(ii) Suggest a structure for **Y**.

[2]

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Answers Section

1. MAR 19/P22/Q3/d

(a) **M1** compound **P** **3**

M2 (absorption at) 2250 cm^{-1} **AND** C≡N (stretch)

M3 (absorption at) 3100–3700 cm^{-1} **AND** O—H (stretch)

2. O/N 18/P22/Q3/c

(a) (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]

(iii) (It / $CHCl_3$ has a) peak at 2850–2950 (cm^{-1}) **1**

OR

carbonyl dichloride spectrum has no peak 2850–2950 (cm^{-1})

3. O/N 18/P23/Q4/d

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

Glycolic acid would have:

M1 2500–3000 due to RCO_2H

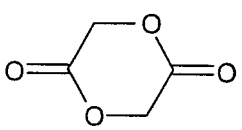
M2 range within 3200–3650 due to RO–H

OR

Spectrum Y would NOT have:

M1 2500–3000 due to RCO_2H

M2 range within 3200–3650 due to RO–H

(ii)  **2**

M1 ANY ester group **AND** valid $C_4H_4O_4$ molecule

M2 correct cyclic structure

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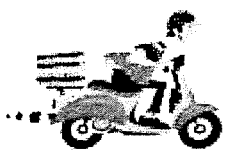
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