Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

5154508959

CHEMISTRY **9701/22**

Paper 2 AS Level Structured Questions **October/November 2023**

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **20** pages. Any blank pages are indicated.

DC (LK/SG) 308426/4

1 The elements silicon, phosphorus and sulfur are in Period 3 of the Periodic Table.

(a) **(i)** Describe the variation in atomic radius from silicon to sulfur.

.... [1]

(ii) The melting point of silicon is 1410 °C. The melting point of sulfur is 113 °C.

Explain this difference.

....

....

....

.... [3]

(b) Table 1.1 shows some properties of the elements Si to S.

The first ionisation energy of P is **not** shown.

Table 1.1

property	Si	P	S
total number of electrons in s subshells			
total number of electrons in p subshells			
first ionisation energy / kJ mol^{-1}	786		1000
formula of most common chloride	$SiCl_4$	PCl_5	SCl_2

(i) Complete Table 1.1 to show the total number of s and p electrons in an atom of Si, P and S.

[2]

(ii) Construct an equation to represent the first ionisation energy of Si.

.... [1]

(iii) Three possible values for the first ionisation energy of P are given.

619 kJ mol^{-1} **893 kJ mol^{-1}** **1060 kJ mol^{-1}**

Circle the correct value.

Explain your choice, including a comparison of your chosen value to those of Si and S.

....

....

....

....

....

.... [4]

(iv) $SiCl_4$ and PCl_5 each react with water, forming misty fumes.

Identify the chemical responsible for the misty fumes.

.... [1]

(v) Predict the shape of the SCl_2 molecule.

.... [1]

[Total: 13]

2 NO and NO_2 react at 25 °C to give N_2O_3 as shown in the equation.

$$NO(g) + NO_2(g) \rightleftharpoons N_2O_3(g) \qquad \Delta H = -7.2\,kJ\,mol^{-1}$$

The reaction is reversible and reaches equilibrium in a closed system.

(a) Fig. 2.1 shows how the rate of the forward reaction changes with time.

Initially, the rate of the reverse reaction is zero.

Complete Fig. 2.1 to sketch how the rate of the **reverse** reaction changes with time.

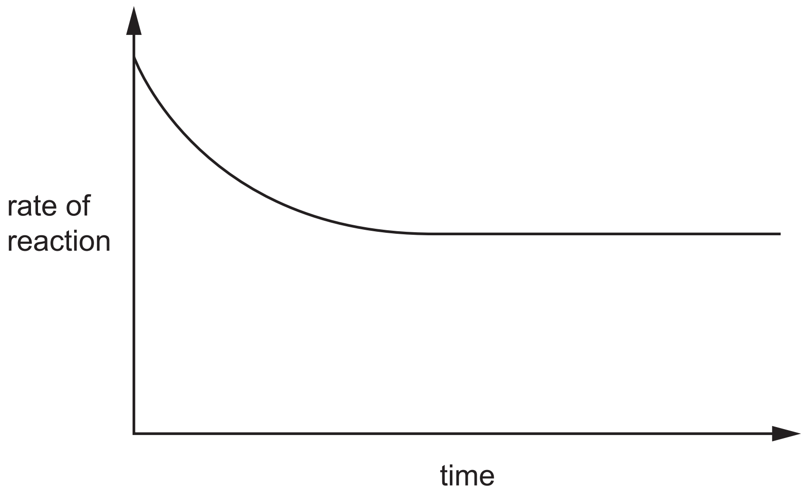

Fig. 2.1

[1]

(b) State how the position of equilibrium changes, if at all, when the reaction takes place at 100 °C.

Explain your answer.

Assume the pressure remains constant.

....

....

....

.... [2]

(c) Table 2.1 shows the composition of an equilibrium mixture of NO(g), NO_2(g) and N_2O_3(g) at 101 kPa.

Table 2.1

gas	number of moles at equilibrium / mol
NO	0.605
NO_2	0.605
N_2O_3	0.390

Calculate K_p, the equilibrium constant with respect to partial pressures.

Deduce the units of K_p.

K_p = ... units .... [3]

(d) Identify one natural process and one man-made process that cause the formation of atmospheric NO and NO_2.

natural process ....

man-made process .... [2]

(e) NO_2 is a brown gas that can be used to form nitric acid.

(i) NO_2 is a free radical.

Define free radical.

.... [1]

(ii) NO_2 has a catalytic role in the oxidation of atmospheric sulfur dioxide.

Write equations to show the catalytic role of NO_2 in this oxidation.

....

.... [2]

(iii) State **one** environmental consequence of the oxidation of atmospheric sulfur dioxide.

.... [1]

(f) A student titrates nitric acid with a base to form a solution containing aqueous magnesium nitrate.

(i) Identify a base that the student could use.

.... [1]

(ii) The student evaporates the water to obtain magnesium nitrate solid. When this solid is heated it decomposes.

Write an equation for the decomposition of magnesium nitrate.

.... [1]

(iii) State how the thermal stability of Group 2 nitrates changes down the group.

.... [1]

[Total: 15]

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3 Phosphoric(V) acid, H_3PO_4, is used in both inorganic and organic reactions.

(a) H_3PO_4 is made in a two-step process from phosphorus.

step 1 Phosphorus reacts with an excess of oxygen to form a white solid.

step 2 The white solid then reacts with water to form H_3PO_4.

(i) Write an equation for each step.

step 1 ....

step 2 ....
[2]

(ii) H_3PO_4 is a weak Brønsted–Lowry acid.

Define weak Brønsted–Lowry acid.

....

....

.... [2]

(b) H_3PO_4 is also formed in the process shown in reaction 1.

reaction 1 $4H_3PO_3 \rightarrow 3H_3PO_4 + PH_3$

Table 3.1 shows some relevant thermodynamic data.

Table 3.1

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
H_3PO_3	–972
H_3PO_4	–1281
PH_3	+9

(i) Define enthalpy change of formation.

....

....

.... [2]

(ii) Use the data in Table 3.1 to calculate the enthalpy change, ΔH_r, of reaction 1.

ΔH_r = ... $kJ\,mol^{-1}$ [2]

(iii) Explain why reaction 1 is a disproportionation reaction.

Explain your reasoning with reference to relevant oxidation numbers.

....

....

.... [2]

(c) Fig. 3.1 shows a reaction scheme that involves H_3PO_4 in several reactions.

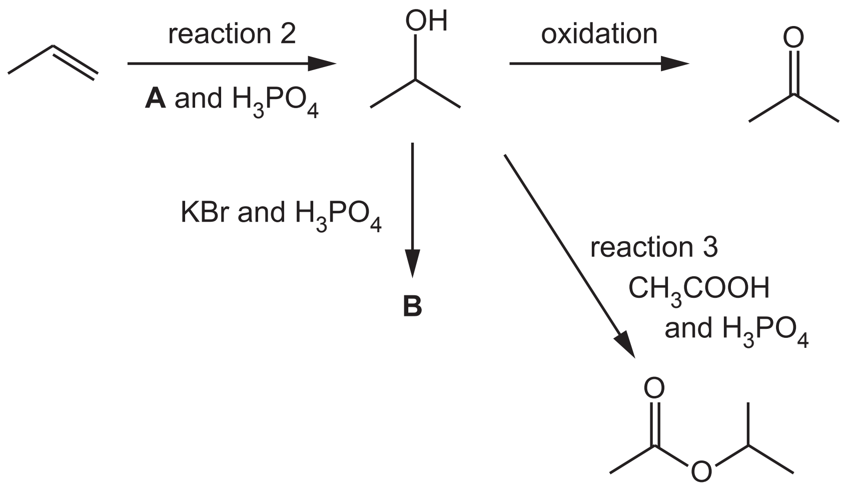


Fig. 3.1

(i) Identify **A**, which reacts with propene in the presence of H_3PO_4 in reaction 2.

.... [1]

(ii) Draw the structure of **B**.

[1]

(iii) Name the type of reaction that occurs in reaction 3.

.... [1]

(iv) Reaction 3 is monitored using infrared spectroscopy. It is not possible to use the O—H absorption frequency to monitor the reaction.

Use Table 3.2 to identify a suitable bond whose absorption frequency can be used to monitor the progress of reaction 3.

State the change you would see in the infrared spectrum during reaction 3.

bond ....

change in infrared spectrum ....

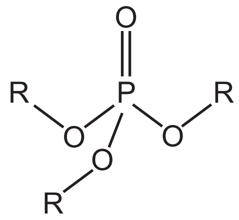
....
[2]

Table 3.2

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers) / cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C–H	alkane	2850–2950

(d) H_3PO_4 also reacts with alcohols to form organophosphates.

Organophosphates are compounds similar to esters. They have the general structure shown in Fig. 3.2.



R = alkyl group

Fig. 3.2

(i) Complete the equation to suggest the products of the reaction of H_3PO_4 with methanol, CH_3OH.

$H_3PO_4 + 3CH_3OH \rightarrow$ .... [1]

(ii) Compound **T** is a simple organophosphate.

The mass spectrum of **T** shows a molecular ion peak at m/e = 182. This peak has a relative intensity of 12.7.

The relative intensity of the M+1 peak is 0.84.

Deduce the number of carbon atoms in **T**.
Hence suggest the molecular formula of **T**.

Assume that phosphorus and oxygen exist as single isotopes.

Show your working.

number of carbon atoms in **T** = ...

molecular formula of **T** = ...
[3]

[Total: 19]

4 Lactic acid, $CH_3CH(OH)COOH$, and pyruvic acid, $CH_3COCOOH$, both contain two functional groups.

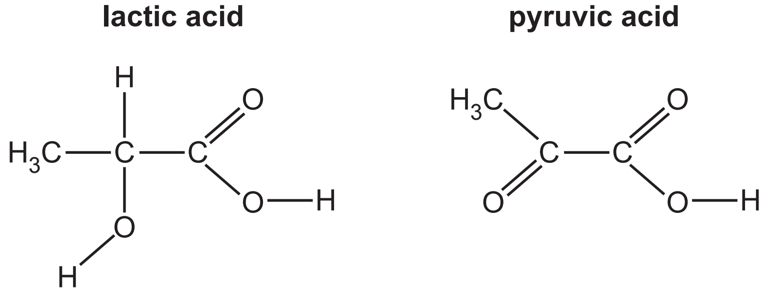


Fig. 4.1

(a) (i) Explain why lactic acid exists as optical isomers.

....

....

.... [1]

(ii) Give the systematic name of lactic acid.

.... [1]

(iii) Lactic acid forms hydrogen bonds with water.

Complete Fig. 4.2 to show the formation of a hydrogen bond between one molecule of lactic acid and one molecule of water.

Label the hydrogen bond. Show any relevant dipoles and lone pairs of electrons.

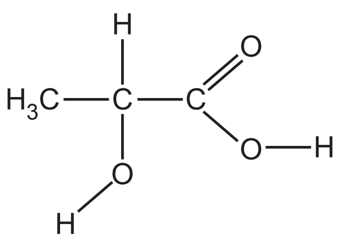


Fig. 4.2

[3]

(b) Two possible syntheses of pyruvic acid are shown in Fig. 4.3 and Fig. 4.4.

Each synthesis has a total of three steps.

Fig. 4.3

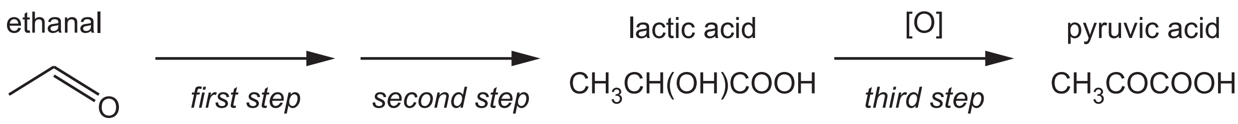


Fig. 4.4

(i) Complete the diagram in Fig. 4.5 to show the mechanism for the reaction of propene with Br_2.

Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

Fig. 4.5

[3]

(ii) Write an equation for the oxidation of lactic acid to pyruvic acid, the third step of Fig. 4.4.

Use [O] to represent one atom of oxygen from an oxidising agent.

$CH_3CH(OH)COOH$ + ... [1]

(iii) Complete Table 4.1 to give details of the reagents and conditions used in each of the two syntheses shown in Fig. 4.3 and Fig. 4.4.

Table 4.1

		synthesis from propene (shown in Fig. 4.3)	synthesis from ethanal (shown in Fig. 4.4)
reagents and conditions used	*first step*	Br_2	
	second step		
	third step		

[4]

[Total: 13]

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Important values, constants and standards

molar gas constant	R = 8.31 J K^{-1} mol^{-1}
Faraday constant	F = 9.65 × 10^{4} C mol^{-1}
Avogadro constant	L = 6.022 × 10^{23} mol^{-1}
electronic charge	e = –1.60 × 10^{-19} C
molar volume of gas	V_m = 22.4 dm^{3} mol^{-1} s.t.p. (101 kPa and 273 K) V_m = 24.0 dm^{3} mol^{-1} at room conditions
ionic product of water	K_w = 1.00 × 10^{-14} mol^{2} dm^{-6} (at 298 K (25 °C))
specific heat capacity of water	c = 4.18 kJ kg^{-1} K^{-1} (4.18 J g^{-1} K^{-1})

The Periodic Table of Elements

Key

atomic number
atomic symbol
name
relative atomic mass

Group

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –