



# Cambridge International AS & A Level

CANDIDATE  
NAME

--	--	--	--	--

CENTRE  
NUMBER

--	--	--	--	--

CANDIDATE  
NUMBER

--	--	--	--

**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.

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 <sup>-1</sup>	786		1000
formula of most common chloride	SiCl <sub>4</sub>	PCl <sub>5</sub>	SCl <sub>2</sub>

(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<sup>-1</sup>**

**893 kJ mol<sup>-1</sup>**

**1060 kJ mol<sup>-1</sup>**

Circle the correct value.

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

.....  
.....  
.....  
.....  
.....  
.....

[4]

(iv)  $\text{SiCl}_4$  and  $\text{PCl}_5$  each react with water, forming misty fumes.

Identify the chemical responsible for the misty fumes.

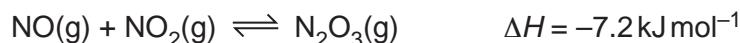
..... [1]

(v) Predict the shape of the  $\text{SCl}_2$  molecule.

..... [1]

[Total: 13]

2 NO and  $\text{NO}_2$  react at  $25^\circ\text{C}$  to give  $\text{N}_2\text{O}_3$  as shown in the equation.



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.

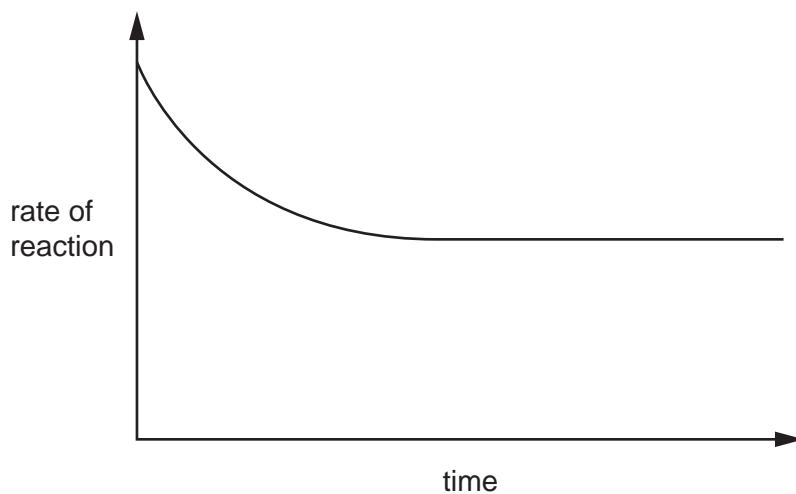


Fig. 2.1

[1]

(b) State how the position of equilibrium changes, if at all, when the reaction takes place at  $100^\circ\text{C}$ .

Explain your answer.

Assume the pressure remains constant.

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

(c) Table 2.1 shows the composition of an equilibrium mixture of  $\text{NO(g)}$ ,  $\text{NO}_2\text{(g)}$  and  $\text{N}_2\text{O}_3\text{(g)}$  at 101 kPa.

**Table 2.1**

gas	number of moles at equilibrium/mol
NO	0.605
$\text{NO}_2$	0.605
$\text{N}_2\text{O}_3$	0.390

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

Deduce the units of  $K_p$ .

$$K_p = \dots \text{ units} \dots \quad [3]$$

(d) Identify one natural process and one man-made process that cause the formation of atmospheric  $\text{NO}$  and  $\text{NO}_2$ .

natural process .....

man-made process .....

[2]

(e)  $\text{NO}_2$  is a brown gas that can be used to form nitric acid.

(i)  $\text{NO}_2$  is a free radical.

Define free radical.

..... [1]

(ii)  $\text{NO}_2$  has a catalytic role in the oxidation of atmospheric sulfur dioxide.

Write equations to show the catalytic role of  $\text{NO}_2$  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]

**BLANK PAGE**

3 Phosphoric(V) acid,  $\text{H}_3\text{PO}_4$ , is used in both inorganic and organic reactions.

(a)  $\text{H}_3\text{PO}_4$  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  $\text{H}_3\text{PO}_4$ .

(i) Write an equation for each step.

step 1 .....

step 2 .....

[2]

(ii)  $\text{H}_3\text{PO}_4$  is a weak Brønsted–Lowry acid.

Define weak Brønsted–Lowry acid.

.....  
.....  
.....

[2]

(b)  $\text{H}_3\text{PO}_4$  is also formed in the process shown in reaction 1.

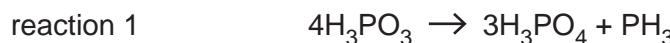


Table 3.1 shows some relevant thermodynamic data.

**Table 3.1**

compound	enthalpy change of formation, $\Delta H_f/\text{kJ mol}^{-1}$
$\text{H}_3\text{PO}_3$	-972
$\text{H}_3\text{PO}_4$	-1281
$\text{PH}_3$	+9

(i) Define enthalpy change of formation.

.....  
.....  
.....

[2]

(ii) Use the data in Table 3.1 to calculate the enthalpy change,  $\Delta H_r$ , of reaction 1.

$$\Delta H_r = \dots \text{ kJ mol}^{-1}$$

[2]

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

Explain your reasoning with reference to relevant oxidation numbers.

.....  
.....  
.....

[2]

10

(c) Fig. 3.1 shows a reaction scheme that involves  $\text{H}_3\text{PO}_4$  in several reactions.

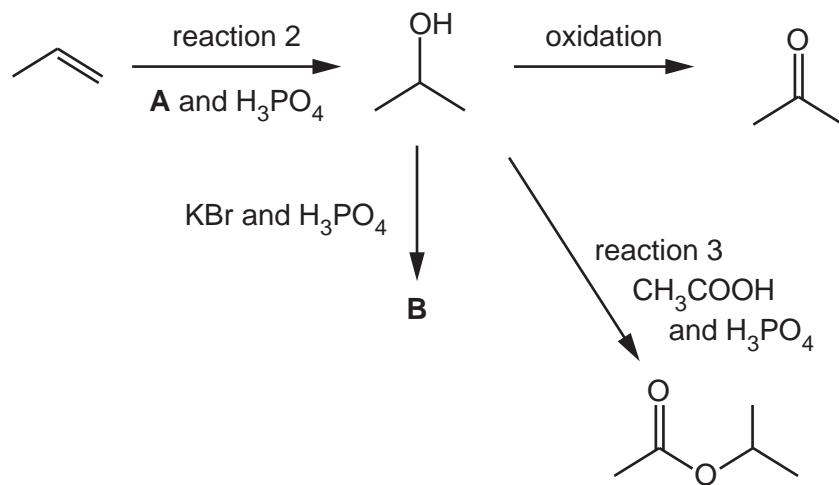


Fig. 3.1

(i) Identify **A**, which reacts with propene in the presence of  $\text{H}_3\text{PO}_4$  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 .....

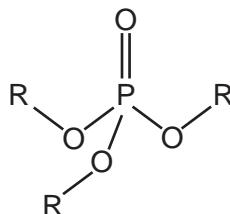
..... [2]

**Table 3.2**

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers)/cm <sup>-1</sup>
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)  $\text{H}_3\text{PO}_4$  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  $\text{H}_3\text{PO}_4$  with methanol,  $\text{CH}_3\text{OH}$ .



(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  $\text{M}+1$  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.

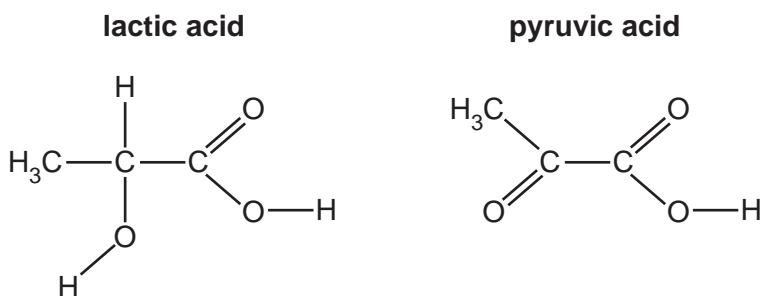
Show your working.

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

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

[Total: 19]

4 Lactic acid,  $\text{CH}_3\text{CH}(\text{OH})\text{COOH}$ , and pyruvic acid,  $\text{CH}_3\text{COCOOH}$ , 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.

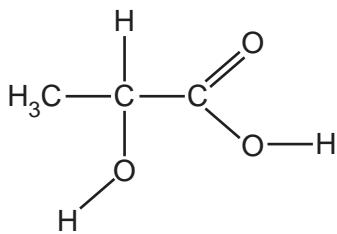
.....

[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]

## 14

(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.

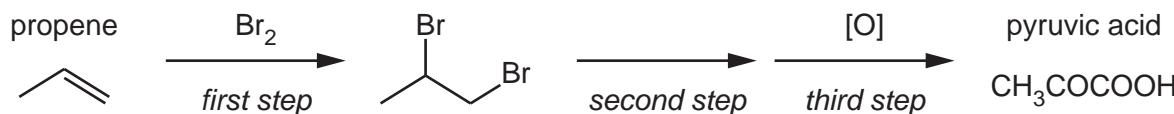


Fig. 4.3

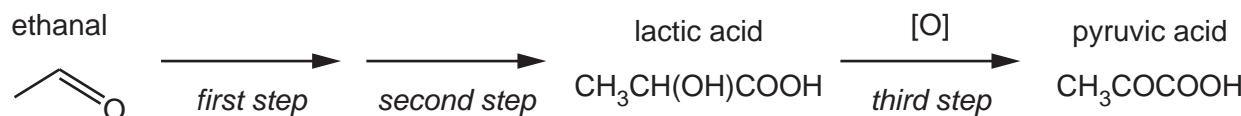


Fig. 4.4

(i) Complete the diagram in Fig. 4.5 to show the mechanism for the reaction of propene with  $\text{Br}_2$ .

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  $[\text{O}]$  to represent one atom of oxygen from an oxidising agent.



(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	<i>first step</i>	$\text{Br}_2$	
	<i>second step</i>		
	<i>third step</i>		

[4]

[Total: 13]







### Important values, constants and standards

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

# The Periodic Table of Elements

To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced online in the Cambridge Assessment International Education Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download at [www.cambridgeinternational.org](http://www.cambridgeinternational.org) after the live examination series.