Cambridge Assessment International Education

Cambridge Pre-U

CANDIDATE NAME									
CENTRE NUMBER						CANDIDATE NUMBER			

5166160763

CHEMISTRY **9791/02**

Paper 2 Part A Written **May/June 2022**

2 hours 15 minutes

You must answer on the question paper.

You will need: Data booklet

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, use appropriate units and use an appropriate number of significant figures.

INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].

This syllabus is regulated for use in England, Wales and Northern Ireland as a Cambridge International Level 3 Pre-U Certificate.

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

DC (ST/CT) 309169

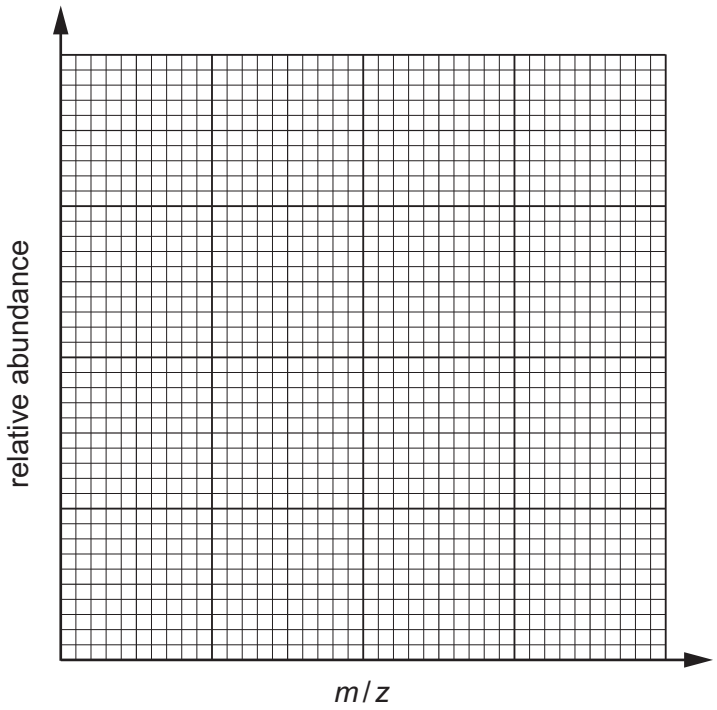
1 This question is about elements which are used in the manufacture of mobile phones.

(a) Complete the electronic configuration of an atom of arsenic.

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

(b) There are two naturally occurring isotopes of antimony, ^{121}Sb and ^{123}Sb.

(i) The relative atomic mass of antimony is 121.8. Draw the mass spectrum of antimony. Indicate the scale on the *x*-axis.



[2]

(ii) Complete the table to give the number of protons, neutrons and electrons in a $^{123}Sb^{3+}$ ion.

	number of protons	number of neutrons	number of electrons
$^{123}Sb^{3+}$			

[1]

(c) The Period 3 elements magnesium, aluminium, silicon and phosphorus are all used in mobile phones. Some data about these elements are given in the table.

element	first ionisation energy / kJ mol^{-1}	melting point / °C
Mg	736	650
A*l*	577	660
Si	786	1410
P	1060	44

(i) Explain why:

- there is an increase in first ionisation energy from aluminium to silicon to phosphorus

.....

.....

.....

- there is a decrease in first ionisation energy from magnesium to aluminium.

.....

.....

..... [5]

(ii) Write an equation for the third ionisation energy of aluminium. Include state symbols.

..... [2]

(iii) Describe, with the aid of a labelled diagram, the bonding in magnesium.

.....

..... [3]

(iv) Draw the structure of a molecule of white phosphorus.

[1]

(v) Explain in terms of structure and bonding why silicon has a high melting point.

.....

.....

.....

..... [3]

(d) Oxygen and carbon are examples of elements which exist as different allotropes.

(i) State what is meant by the term *allotrope*.

..... [1]

(ii) Write an equation for the equilibrium between the two allotropes of oxygen.

..... [1]

[Total: 20]

2 Urea, $(NH_2)_2CO$, is manufactured in large quantities. It has a melting point of 133 °C.

Urea is manufactured using a two-step process.

step 1 the formation of an ionic solid, ammonium carbamate

$$2NH_3 + CO_2 \longrightarrow NH_4CNH_2O_2$$

step 2 the decomposition of ammonium carbamate

$$NH_4CNH_2O_2 \longrightarrow (NH_2)_2CO + H_2O$$

The overall reaction is given.

$$2NH_3 + CO_2 \longrightarrow (NH_2)_2CO + H_2O$$

(a) Define the term *standard enthalpy change of formation*.

.....

.....

..... [2]

(b) Use the data in the table to calculate the standard enthalpy change for the overall reaction.

compound	standard enthalpy change of formation / kJ mol^{-1}
H_2O	–285.8
$(NH_2)_2CO$	–333.1
NH_3	–45.9
CO_2	–393.5

Show your working.

$\Delta_r H^{\ominus}$ = ... kJ mol^{-1} [2]

(c) The standard enthalpy change for the reaction in **step 2**, $\Delta_r H^{\ominus}$(step 2), is +23.1 kJ mol^{-1}. Use this information along with your answer to **(b)** to calculate the standard enthalpy change for the reaction in **step 1**.

$\Delta_r H^{\ominus}$(step 1) = ... kJ mol^{-1} [1]

(d) A solution of urea is used in some diesel vehicles. At the high temperatures in the exhaust it decomposes to produce gaseous ammonia which decreases nitrogen oxide pollutants.

(i) Suggest **one** reason why the amount of nitrogen oxides in exhaust emissions should be decreased.

..... [1]

(ii) Ammonia reacts with nitrogen oxides to form harmless products.
Write the equation for the reaction between ammonia and nitrogen monoxide, NO.

..... [1]

(iii) Suggest **one** advantage of using a solution of urea as a source of gaseous ammonia rather than gaseous ammonia itself.

..... [1]

(e) NO can also be removed from exhaust gases by reaction with carbon monoxide.

$$2NO(g) + 2CO(g) \rightarrow N_2(g) + 2CO_2(g)$$

Explain, by reference to oxidation numbers, why this reaction is a redox reaction. Identify the element oxidised and the element reduced.

.....

.....

..... [2]

(f) Draw the displayed formula of urea, $(NH_2)_2CO$.

[1]

(g) In ammonium carbamate, the carbon in the carbamate ion, $CNH_2O_2^-$, is bonded to two oxygen atoms and one nitrogen atom.

Describe the change in geometry at the carbon atom and the change in the OCO bond angle during **step 1**.

step 1 $2NH_3 + CO_2 \rightarrow NH_4CNH_2O_2$

geometry before ..... after .....

bond angle before .....° after .....°

[2]

(h) When ammonia dissolves in water, a small amount reacts with the water.

(i) Write the equation for the equilibrium when aqueous ammonia reacts with water.

..... [1]

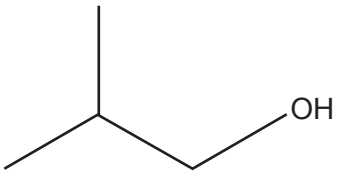
(ii) Explain why ammonia acts as a base in this reaction.

..... [1]

[Total: 15]

3 Compound **Y**, $C_4H_{10}O$, and ethanol can both be used as fuels.

(a) The skeletal formula of **Y** is shown.



State the systematic name of **Y**.

..... [1]

(b) The standard enthalpy change of combustion of **Y** and of ethanol are given in the table.

fuel	standard enthalpy change of combustion / kJ mol^{-1}
Y	–2668.3
ethanol	–1371.2

The equation for the complete combustion of ethanol is shown.

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

(i) Write the equation for the complete combustion of **Y**.

..... [1]

(ii) Use the data in the table to calculate the energy released per mole of carbon dioxide produced for each reaction.
Show your working and give your answers to the nearest kJ mol^{-1}.

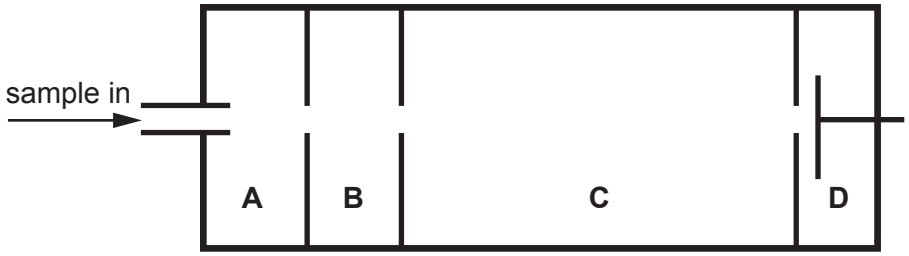
energy released per mole of CO_2 for **Y** ..... kJ mol^{-1}

energy released per mole of CO_2 for ethanol ..... kJ mol^{-1}
[2]

(iii) State why a fuel that releases more energy per mole of CO_2 produced has a lower environmental impact.

..... [1]

(c) A simplified diagram of a time-of-flight mass spectrometer is shown. It is divided into four sections, labelled **A** to **D**.



(i) Describe how ions are formed from the sample molecules in **A**.

.....

..... [1]

(ii) State what happens to the ions in **B**.

..... [1]

(iii) Explain why a vacuum is maintained in the mass spectrometer.

.....

..... [1]

(iv) Explain why the ions separate in **C** and arrive at detector **D** at different times.

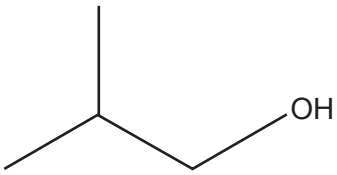
.....

.....

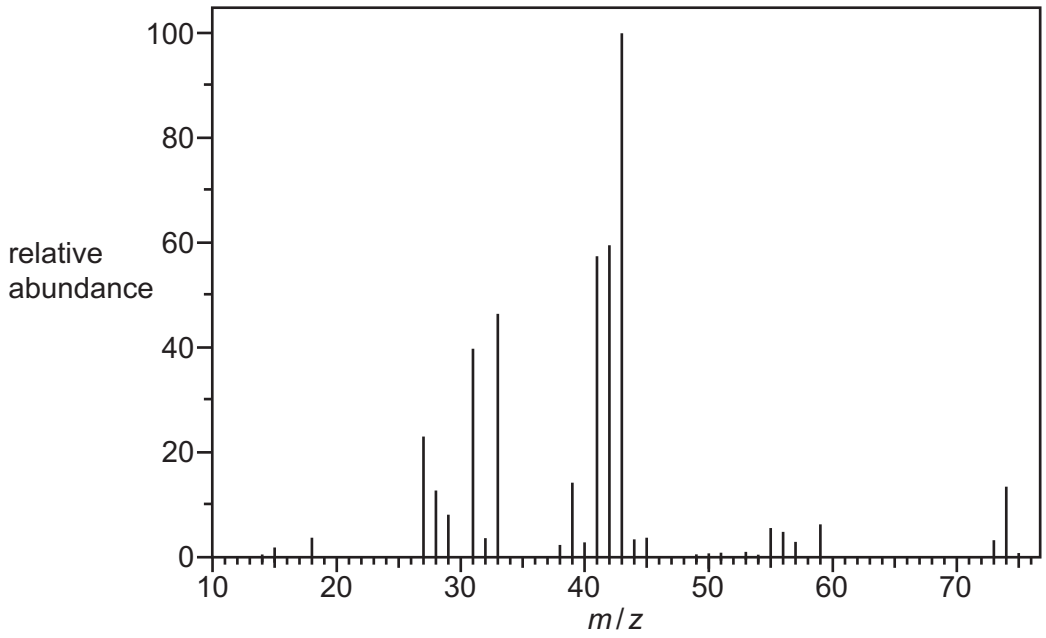
.....

..... [3]

Y



(d) The mass spectrum of **Y** is shown.



(i) Suggest what causes the peak at $m/z = 75$.

..... [1]

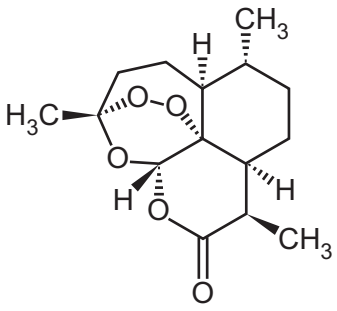
(ii) Write the equation for the formation of the species causing the peak at $m/z = 43$ from the molecular ion.

..... [3]

[Total: 15]

4 Artemisinin is a natural product and antimalarial drug discovered by Tu Youyou who later received the Nobel Prize for her work.

artemisinin



(a) The molecular formula of artemisinin is $C_nH_{22}O_5$.
Deduce the value of n.

..... [1]

(b) Explain why artemisinin does not form hydrogen bonds with other artemisinin molecules.

.....

..... [1]

(c) Artemisinin contains a peroxide bridge, –O–O–, which gives rise to its antimalarial properties. The –O–O– bond in artemisinin also features in a hydrogen peroxide molecule. Hydrogen peroxide decomposes according to the following equation.

$$2H_2O_2(l) \longrightarrow 2H_2O(l) + O_2(g) \qquad \Delta_r H = -196\,kJ\,mol^{-1}$$

(i) Determine the bond energy of the O=O bond in O_2, using the data in the table.

bond	bond energy / kJ mol^{-1}
O–O	146
O–H	464

Show your working.

bond energy of O=O bond in O_2 = ... kJ mol^{-1} [2]

(ii) The actual bond energy of O=O bond in O_2 is 498 kJ mol^{-1}.
Give **one** reason why this value is different from that calculated in **(c)(i)**.

.....

..... [1]

(d) The double bond in the oxygen molecule, O_2, consists of a σ bond and a π bond.

By considering the overlap of the 2p atomic orbitals, explain why the σ-bonding molecular orbital is lower in energy than the π-bonding molecular orbitals.

.....

.....

.....

..... [3]

(e) The bond orders of some oxygen species are given.

oxygen species	bond order
O_2	2
O_2^-	1.5
O_2^{2-}	1

Predict which of these three species has the longest bond and which has the strongest bond.

longest bond ..... strongest bond ..... [1]

(f) The minimum energy required to excite an electron in O_2 to the next highest energy level is $92\,kJ\,mol^{-1}$.
Use the relevant equation in the *Data Booklet* to calculate the frequency of radiation required to excite an electron in O_2 to the next highest energy level.

Show your working.

frequency = ... s^{-1} [2]

(g) The reaction of sodium peroxide with carbon dioxide can be used to generate oxygen.

$$2Na_2O_2(s) + 2CO_2(g) \rightarrow 2Na_2CO_3(s) + O_2(g)$$

(i) It is estimated that a person needs 550 dm^3 of O_2 each day.
Calculate the mass, in kg, of Na_2O_2 required to generate this volume of O_2 at room temperature and pressure.

Show your working.

..... kg [3]

(ii) Calculate the atom economy of this reaction.

..... % [1]

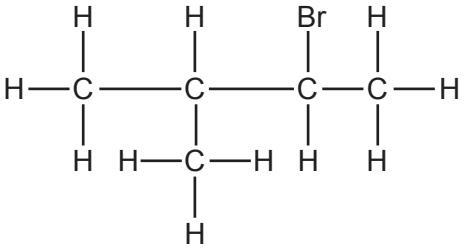
(iii) All Group 1 peroxides react with CO_2 in the same way as Na_2O_2. A Group 1 peroxide is used to convert CO_2 to O_2 in a spacecraft.
Suggest which Group 1 peroxide would be preferred for this conversion in a spacecraft.
Give a reason for your answer.

.....

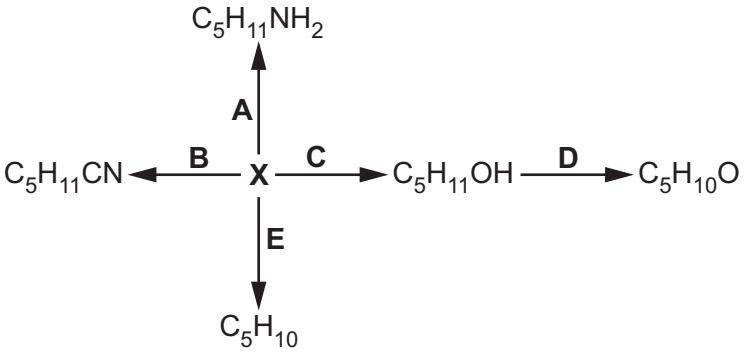
..... [1]

[Total: 16]

5 The structure of compound **X**, $C_5H_{11}Br$, is shown.



A series of reactions of **X** is shown.



(a) Draw the skeletal formula of **X**.

[1]

(b) Complete the table for reactions **B** to **E**.

reaction	substitution reaction	elimination reaction	change in functional group level
A	✓	✗	✗
B			
C			
D			
E			

[4]

(c) Draw the structure of two products of reaction **E**. Name these products.

name	name .....

[2]

(d) Write the equation for reaction **B**.

..... [1]

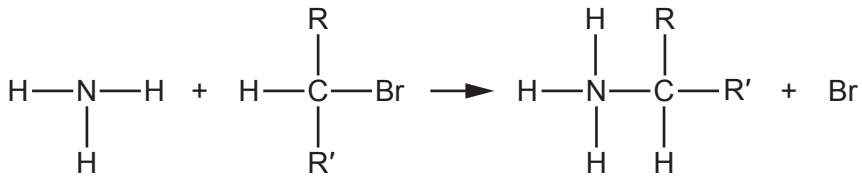
(e) In reaction **A**, compound **X** reacts with ammonia in ethanol.

(i) Ammonia acts as a nucleophile in reaction **A**. Explain the term *nucleophile*.

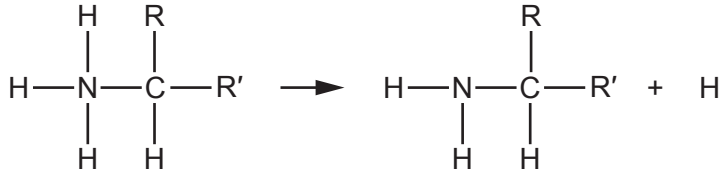
..... [1]

(ii) Two possible steps in the mechanism for reaction **A** are shown. The alkyl groups are represented by R and R′. No charges are shown. Complete the reaction mechanism by adding relevant dipoles, curly arrows, missing charges and lone pairs of electrons.

step 1



step 2



[5]

(iii) Suggest a reason why reaction **A** gives a low yield of primary amine.

.....

..... [1]

(f) Suggest the identity of the reagent which will reverse reaction **C**.

..... [1]

[Total: 16]

6 The presence of Pb^{2+} ions in drinking water is a health hazard. Smartphone nanocolorimetry (SNC) is proposed as a field method of determining the concentration of Pb^{2+} ions.

The method consists of the following steps.

step 1 Add $5.00 \times 10^{-3}\,cm^3$ of a drinking water sample to $5.00 \times 10^{-3}\,cm^3$ of $0.0500\,mol\,dm^{-3}$ potassium chromate(VI), $K_2CrO_4(aq)$, and mix thoroughly.
A precipitate of yellow lead(II) chromate(VI), $PbCrO_4$, is formed from the Pb^{2+} ions.

step 2 Immediately transfer $5.00 \times 10^{-4}\,cm^3$ of the mixture from **step 1** onto a microscope slide and allow to dry.

step 3 Wash the solid formed on the microscope slide in **step 2** with distilled water and leave to dry.

step 4 Take a photograph with a smartphone of the solid on the microscope slide after **step 3**. The greater the concentration of Pb^{2+} ions, the more intense the resultant yellow colour. The intensity of the yellow colour is measured on the smartphone and compared to a calibration curve.

(a) Describe how $100.0\,cm^3$ of $0.0500\,mol\,dm^{-3}$ $K_2CrO_4(aq)$ could be prepared from $K_2CrO_4(s)$ in a laboratory.

Include in your answer the names of the apparatus to be used and any relevant measurements to be taken during the preparation of the solution.

.....

.....

.....

.....

.....

.....

.....

.....

.....

..... [4]

(b) Write an ionic equation for the reaction occurring in **step 1**.
Include state symbols.

..... [1]

(c) K_2CrO_4 is corrosive. State one precaution, other than wearing a lab coat and goggles, that should be taken when handling K_2CrO_4.

..... [1]

(d) Give **two** reasons for thorough mixing before **step 2**.

reason 1 .....

reason 2 .....
[2]

(e) Suggest why the solid is washed with distilled water in **step 3**.

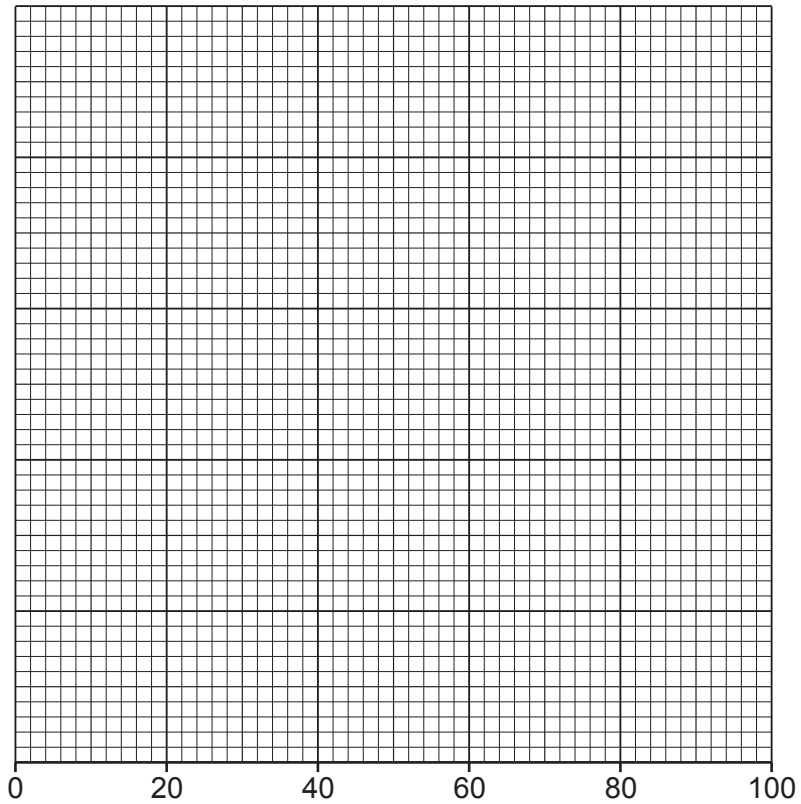
..... [1]

(f) The concentration of Pb^{2+} ions is measured in parts per billion by mass, ppb.

The method is used on standard solutions in order to obtain a calibration curve. The results are given in the table.

concentration of Pb^{2+} / ppb	yellow intensity
0	0
10	400
20	1270
50	5450
70	10 300
100	23 400

(i) Complete the axes for the calibration graph. Plot yellow intensity on the *y*-axis against concentration of Pb^{2+} on the *x*-axis in order to obtain the calibration curve.



[3]

(ii) A sample of drinking water gave a yellow intensity of 9000. Use your calibration curve to estimate the concentration of Pb^{2+} in this sample.

concentration of Pb^{2+} ions ..... ppb [1]

(iii) The maximum concentration of Pb^{2+} in water that is considered safe to drink is 1.37 ppb by mass.
Calculate the maximum concentration, in $mol\,dm^{-3}$, of Pb^{2+} in water that is considered safe to drink.
The density of water is $1.00\,g\,cm^{-3}$. Show your working.

.....$mol\,dm^{-3}$ [2]

(g) Aqueous barium ions, $Ba^{2+}(aq)$, also react with $K_2CrO_4(aq)$ to form a yellow precipitate.

A water sample known to contain 68 ppb Pb^{2+} also contains some Ba^{2+}. When this water sample was analysed using SNC, the concentration of Pb^{2+} was found to be 71 ppb.

Calculate the percentage uncertainty in the estimate of the concentration of Pb^{2+} for this sample due to the presence of Ba^{2+}.

..... % [1]

(h) Another sample of drinking water contains carbonate ions.

Suggest how aqueous carbonate ions can be removed from this sample of drinking water. Include an equation in your answer.

.....

..... [2]

[Total: 18]

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