Cambridge Assessment International Education

Cambridge Pre-U

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

0123456789

CHEMISTRY **9791/02**

Paper 2 Part A Written **For examination from 2020**

SPECIMEN PAPER **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 specimen paper has been updated for assessments from 2020. The specimen questions and mark schemes remain the same. The layout and wording of the front covers have been updated to reflect the new Cambridge International branding and to make instructions clearer for candidates.

For Examiner's Use	
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Total	

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. Blank pages are indicated.

1 Magnesium powder is used to generate heat for battlefield soldiers wanting a hot drink.

9.0 g of magnesium powder is added to 30.0 g, an excess, of water.

$$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$$

(a) Calculate the amount, in mol, of magnesium.

.... mol [1]

(b) Calculate the mass of water that is in excess.

.... g [2]

(c) Calculate the volume of hydrogen gas, in dm^3, produced at room temperature and pressure.

.... dm^3 [1]

(d) Use the standard enthalpy change of formation data in the table to calculate the standard enthalpy change of reaction for magnesium reacting with water.

substance	$\Delta_f H^\ominus$ / kJ mol^{-1}
H_2O	−285.8
$Mg(OH)_2$	−924.5

.... kJ mol^{-1} [2]

(e) Calculate the heat energy, in kJ, released when 9.0 g of magnesium powder is added to 30.0 g of water.

.... kJ [1]

(f) When the magnesium powder and water are mixed, the temperature of the drink being heated can rise to 60 °C in about 10 minutes.

Calculate how much energy, in kJ, is required to heat 150 g of the drink from 15 °C to 60 °C. Assume that the specific heat capacity of the drink is $4.2\,J\,g^{-1}K^{-1}$.

.... kJ [1]

(g) How would using 9.0 g of magnesium **granules** affect the amount of energy released, and the temperature reached by the drink? Explain your answer.

....

....

.... [2]

(h) Exothermic reactions that do **not** produce hydrogen gas are being explored.

(i) One example is mixing calcium oxide with water. Write an equation for this reaction and give the approximate pH of the resulting solution.

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

(ii) Another example is the reaction of phosphorus(V) oxide with water. Write an equation for this reaction and give the approximate pH of the resulting solution.

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

(iii) Calcium oxide reacts with phosphorus(V) oxide to make calcium phosphate(V). Write an equation for this reaction.

.... [1]

[Total: 15]

2 **(a)** **(i)** What is meant by the term *bond energy*?

....

....

.... [3]

(ii) Use the bond energy data in the table to find the enthalpy change of reaction for the reaction between ethane and chlorine shown below.

$$C_2H_6(g) + 2Cl_2(g) \rightarrow C_2H_4Cl_2(g) + 2HCl(g)$$

bond	average bond energy / $kJ\,mol^{-1}$
C−C	347
C−H	413
Cl−Cl	243
C−Cl	346
H−Cl	432

[3]

(b) At low temperatures and pressures the alkali metals can exist as gaseous diatomic molecules. Recent research has investigated the mixing of gaseous diatomic molecules of different alkali metals (reported in *Science* 2010).

Spectroscopic techniques can be used to measure the bond energies of diatomic molecules. When measured in this way the values of bond energies are given in wavenumbers, which has the unit cm^{-1}.

Some values are shown in the table.

diatomic molecule	bond energy / cm^{-1}
K_2	4405
Rb_2	3966
KRb	4180

(i) Calculate the enthalpy change, in cm^{-1}, for the reaction between K_2 and Rb_2.

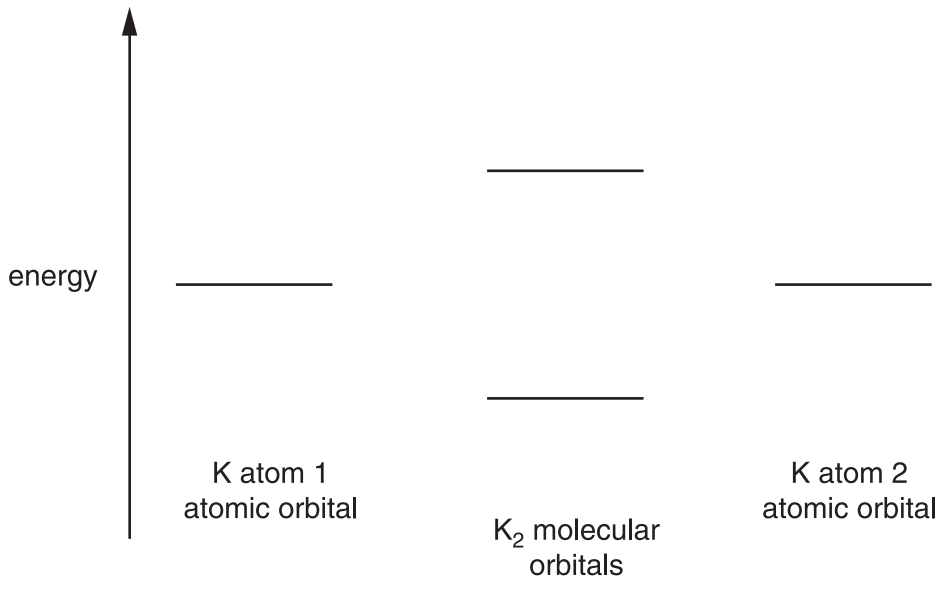
$$K_2(g) + Rb_2(g) \rightarrow 2KRb(g)$$

.... cm^{-1} [1]

(ii) Complete the electron configuration of a potassium atom.

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

(iii) If only the outer shell electrons are considered, the molecular orbital diagram for an alkali metal diatomic molecule is much like that for hydrogen, H_2. Label all the orbitals in the molecular orbital diagram for K_2 and include the electrons.



[3]

(iv) Explain why potassium has a greater first ionisation energy than rubidium.

....

....

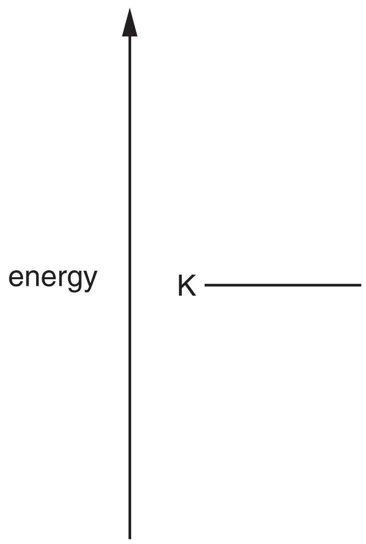
....

....

....

.... [3]

(v) Complete the molecular orbital diagram for KRb, showing relevant atomic and molecular orbitals. Only include outer shell orbitals. Label all the orbitals in your diagram.



[2]

(vi) Wavenumbers, $\overline{v}$, are converted into energy, E, using the equation

$$E = h\,c\,\overline{v}$$

where h is Planck's constant and c is the speed of light.

Using your answer to **(b)(i)**, work out the enthalpy change in $kJ\,mol^{-1}$ for the reaction between K_2 and Rb_2.

.... $kJ\,mol^{-1}$ [2]

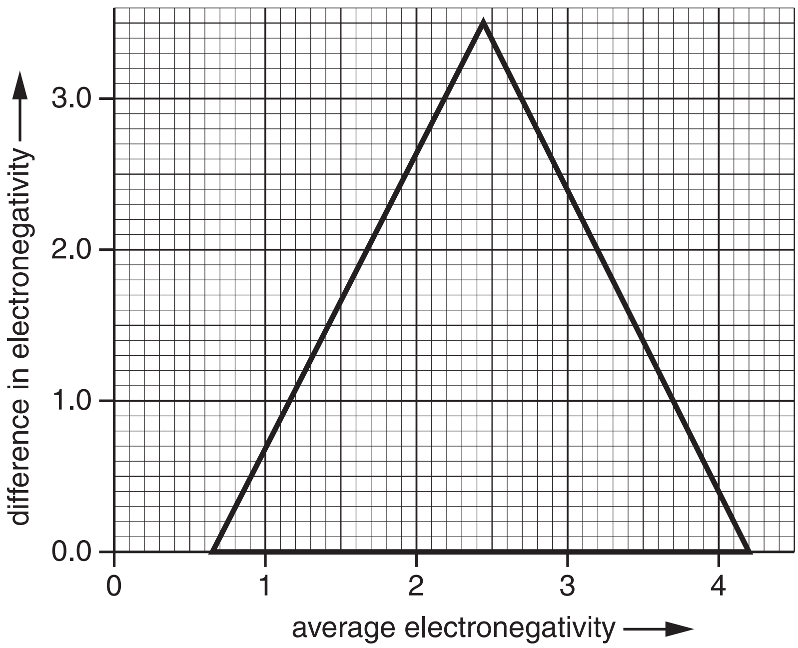
[Total: 18]

QUESTION 3 BEGINS ON PAGE 8

3 **(a)** Binary compounds such as cadmium sulfide, CdS, can be used to improve the efficiency of catalysts. The electronegativity values of cadmium and sulfur are shown in the table.

element	electronegativity
cadmium	1.52
sulfur	2.59

(i) Plot the position of CdS on the van Arkel triangle below.



[1]

(ii) Circle the option that best describes the bonding in CdS.

ionic **covalent** **metallic**

intermediate ionic-metallic **intermediate covalent-ionic**

intermediate covalent-metallic **intermediate covalent-ionic-metallic**

[1]

(b) Some bacteria can oxidise methane to carbon dioxide in the absence of oxygen. It has recently been reported that the mechanism involves a reaction between methane and nitrite ions in acidic conditions (reported in *Nature*, 2010).

The half-equation for the oxidation of methane is given.

$$CH_4 + 2H_2O \rightarrow CO_2 + 8H^+ + 8e^-$$

(i) Write a half-equation for the reduction of NO_2^- in acidic conditions to give N_2.

.... [2]

(ii) By combining the half-equations, or otherwise, balance the overall equation shown below.

..........CH_4 + ...NO_2^- + ...H^+ $\rightarrow$ ....CO_2 + ...N_2 + ...H_2O [1]

(iii) The oxidation of methane by nitrite ions is thermodynamically favourable but will not occur under standard laboratory conditions. Suggest briefly the role of bacteria in this reaction.

....

.... [1]

(c) Molybdenum can form many complex oxy-ions. It has been reported that a complex molybdenum oxyanion can self-assemble to a large doughnut-shaped structure with a 3.6 nm diameter (reported in *Science*, 2010). The oxyanion unit has the formula $[Mo_{36}O_{112}(H_2O)_{16}]^{8-}$.

(i) Calculate the oxidation state of molybdenum in this oxyanion unit.

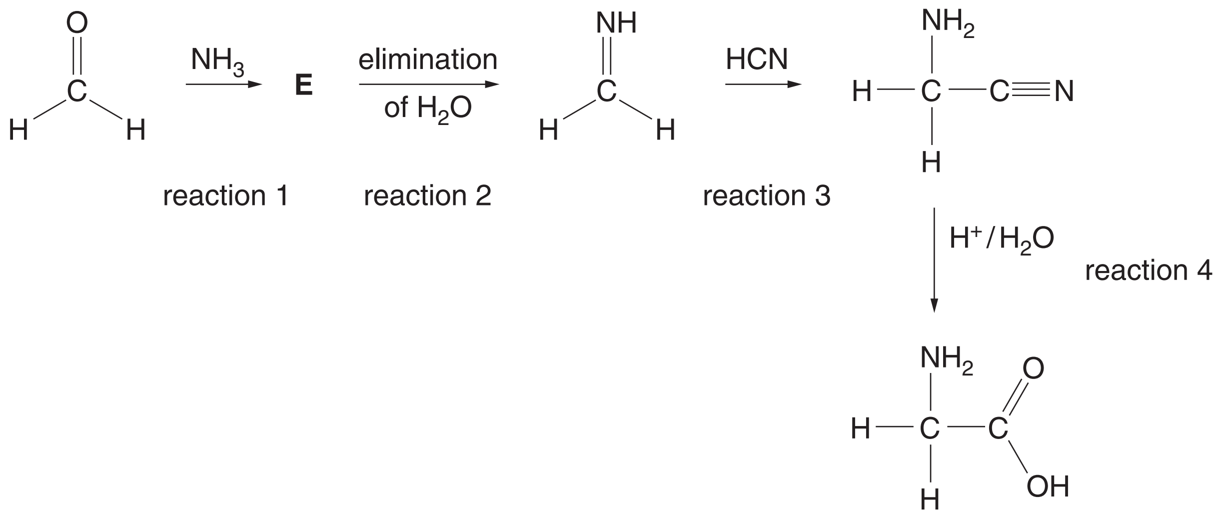
[1]

(ii) Give the empirical formula of the oxyanion unit.

.... [1]

[Total: 8]

4 The Strecker synthesis is a route to preparing amino acids. Glycine, 2-aminoethanoic acid, can be prepared from methanal in this way. This is shown in the four-reaction scheme below.



(a) Circle the atom in methanal that is attacked by the ammonia molecule. [1]

(b) What kind of reagent is ammonia, in the context of this synthesis?

.... [1]

(c) Suggest a structure for compound **E**.

[1]

(d) What type of reaction is reaction 3?

.... [1]

(e) The product of reaction 2 is an imine. Name a compound, which does not contain nitrogen, that undergoes a similar reaction with HCN.

.... [1]

(f) What type of reaction is reaction 4?

.... [1]

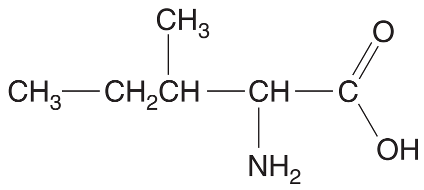
(g) State the functional group level of the carbon atom in methanal and the functional group level of this carbon atom in the product of reaction 2 and the product of reaction 3.

methanal ....

product of reaction 2 ....

product of reaction 3 .... [3]

(h) The amino acid shown is isoleucine, 2-amino-3-methylpentanoic acid.



Molecule **Z** can be used as the starting material to prepare this amino acid using a Strecker synthesis.

(i) Draw the structure of **Z**.

[1]

(ii) Name molecule **Z**.

.... [1]

(i) Alanine, 2-aminopropanoic acid, can be made in a similar way, but the synthesis produces a mixture of two optical isomers.

Draw the optical isomers of alanine.

[2]

[Total: 13]

5 **(a)** Chemists have recently established that four molecules of water are required for the dissociation of a single molecule of HCl (reported in *Science*, 2009).

Given that $1.00\,dm^3$ of water contains 55.6 mol of H_2O, calculate the maximum mass of hydrogen chloride, HCl, that should therefore dissociate in $1.00\,dm^3$ of water.

.... g [1]

(b) Commercial concentrated hydrochloric acid, $HCl(aq)$, fumes strongly on exposure to moist air and so is also known as 'fuming hydrochloric acid'.

$1.00\,cm^3$ of fuming hydrochloric acid was transferred with a graduated pipette to a $100\,cm^3$ volumetric flask. The volume was made up to $100\,cm^3$ with deionised water. The solution was labelled **F**. $10.0\,cm^3$ of solution **F** was neutralised by $24.75\,cm^3$ of $0.0500\,mol\,dm^{-3}$ of aqueous sodium hydroxide.

Calculate the concentration of HCl in the fuming hydrochloric acid in $mol\,dm^{-3}$. Give your final answer to **three** significant figures.

.... $mol\,dm^{-3}$ [4]

(c) Historically, hydrochloric acid, $HCl(aq)$, was produced by mixing concentrated sulfuric acid with sodium chloride and dissolving the gas produced in water.

(i) Write an equation for the production of gaseous hydrogen chloride by this method.

.... [1]

Hydrobromic acid, $HBr(aq)$, cannot be prepared in the same way as hydrochloric acid because a redox reaction occurs between hydrogen bromide and sulfuric acid.

(ii) Write a balanced equation for the reaction of hydrogen bromide with sulfuric acid.

.... [1]

(iii) Identify the oxidising agent in the reaction. Justify your answer using oxidation numbers.

....

....

.... [2]

(d) **(i)** State and explain the trend in bond strength for the gases hydrogen chloride, hydrogen bromide and hydrogen iodide, in that order.

....

.... [1]

(ii) State and explain the trend in acidic strength of hydrochloric acid, hydrobromic acid and hydroiodic acid.

....

....

.... [1]

(iii) Describe and explain the variation in boiling point of the gases hydrogen fluoride, hydrogen chloride, hydrogen bromide and hydrogen iodide.

....

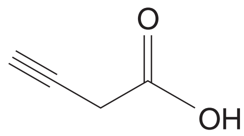
....

....

.... [2]

[Total: 13]

6 The molecule shown is but-3-ynoic acid.



(a) Give the molecular formula for but-3-ynoic acid.

molecular formula .... [1]

(b) Draw the structure and name an isomer of but-3-ynoic acid that contains the same functional groups.

structure

name .... [2]

(c) Work out the percentage composition (by mass) of the constituent elements in but-3-ynoic acid.

C .... % H .... % O .... % [2]

(d) Give the *m*/*z* value of the molecular ion peak in the mass spectrum of but-3-ynoic acid.

.... [1]

(e) **(i)** Describe the **two** most significant features that you would expect to see in the infra-red spectrum of but-3-ynoic acid.

....

....

.... [2]

(ii) Liquid samples for infra-red analysis are commonly prepared by placing them between two sodium chloride discs. Why could this approach not be considered for recording the IR spectrum of an aqueous solution of but-3-ynoic acid?

....

.... [1]

(f) Scientists recently isolated a novel, highly toxic and unstable molecule, **T**, from the poisonous Asian mushroom *Russula subnigricans* (reported in *Nature Chemical Biology*, 2009).

T is an isomer of but-3-ynoic acid. Its infrared spectrum indicates that **T** also contains a carboxylic acid group. Its carbon-13 NMR spectrum, however, only contains 3 signals.

Suggest a structure for **T**.

[1]

[Total: 10]

7 **(a)** Simple esters are flammable liquids. Flammability is affected by volatility. Write the following homologous series in order of boiling point, assuming molecular masses are similar.

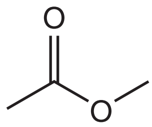
alcohols **alkanes** **esters**

highest boiling point ....

....

lowest boiling point .... [1]

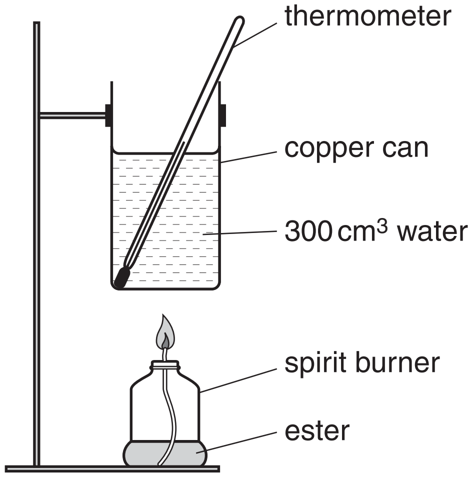
(b) The structure of methyl ethanoate, $C_3H_6O_2$, is shown below.



Write an equation for the complete combustion of methyl ethanoate.

.... [1]

(c) A student used the apparatus shown in the diagram to carry out experiments to determine the standard enthalpy change of combustion for ethyl ethanoate.



- mass of copper pot = 250 g
- volume of water = 300 cm^3

An initial experiment was carried out using methyl ethanoate. This ester was combusted in a spirit burner underneath a copper can so that the flame from the burner heated 300 cm^3 of water in the can. It was found that 0.980 g of ester was required to raise the temperature of the water in the can by 10.0 °C.

(i) Describe how this initial experiment was set up and carried out to collect the data that gave these results.

....

....

....

....

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....

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....

....

.... [6]

(ii) Calculate the total thermal energy in kJ gained by the water and the copper can in this initial experiment. The specific heat capacities of water and copper are 4.18 and $0.384\,\mathrm{J\,g^{-1}\,K^{-1}}$, respectively.

Take the density of water to be $1.00\,\mathrm{g\,cm^{-3}}$. Assume that the water and copper are in thermal equilibrium with each other. Express your answer to the appropriate number of significant figures.

.... [3]

(iii) The theoretical standard enthalpy change of combustion of methyl ethanoate is $-1592.1\,\text{kJ}\,\text{mol}^{-1}$. Calculate the total theoretical thermal energy in kJ released by the mass of methyl ethanoate combusted in this initial experiment.

.... kJ [2]

(iv) Heat losses are significant but can be taken into account by using the known value of $\Delta_c H^\ominus$ of $-1592.1\,\text{kJ}\,\text{mol}^{-1}$ for methyl ethanoate. A similar experiment with ethyl ethanoate produced the following results.

mass of ethyl ethanoate combusted = 0.948 g

increase in temperature of $300\,\text{cm}^3$ water = 11.5 °C

Calculate the most accurate possible value for the standard enthalpy change of combustion for ethyl ethanoate.

.... $\text{kJ}\,\text{mol}^{-1}$ [4]

(d) Outline **four** improvements that could increase the accuracy of the raw data recorded in these experiments.

....

....

....

....

....

....

....

....

....

.... [4]

(e) In terms of the ease of lighting and the appearance of the flame how does methyl ethanoate compare to decyl ethanoate ($CH_3COOC_{10}H_{21}$)?

ease of lighting ....

....

appearance of flame..

....
[2]

[Total: 23]

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