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Baccalauréat International
Bachillerato Internacional

CHEMISTRY
HIGHER LEVEL
PAPER 2

Candidate session number

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Thursday 16 May 2013 (afternoon)

2 hours 15 minutes

Examination code

2	2	1	3	–	6	1	0	8

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the ***Chemistry*** *Data Booklet* is required for this paper.
- The maximum mark for this examination paper is *[90 marks]*.

SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

1. A student decided to determine the molecular mass of a solid monoprotic acid, HA, by titrating a solution of a known mass of the acid.

The following recordings were made.

Mass of bottle / g ± 0.001 g	1.737
Mass of bottle + acid HA / g ± 0.001 g	2.412

(a) Calculate the mass of the acid and determine its absolute and percentage uncertainty. *[2]*

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(b) This known mass of acid, HA, was then dissolved in distilled water to form a 100.0 cm^3 solution in a volumetric flask. A 25.0 cm^3 sample of this solution reacted with 12.1 cm^3 of a 0.100 mol dm^{-3} NaOH solution. Calculate the molar mass of the acid. *[3]*

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(Question 1 continued)

(c) The percentage composition of HA is 70.56% carbon, 23.50% oxygen and 5.94% hydrogen. Determine its empirical formula. *[2]*

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(d) Determine the molecular formula of HA. *[2]*

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(e) A solution of HA is a weak acid. Distinguish between a *weak acid* and a *strong acid*. *[1]*

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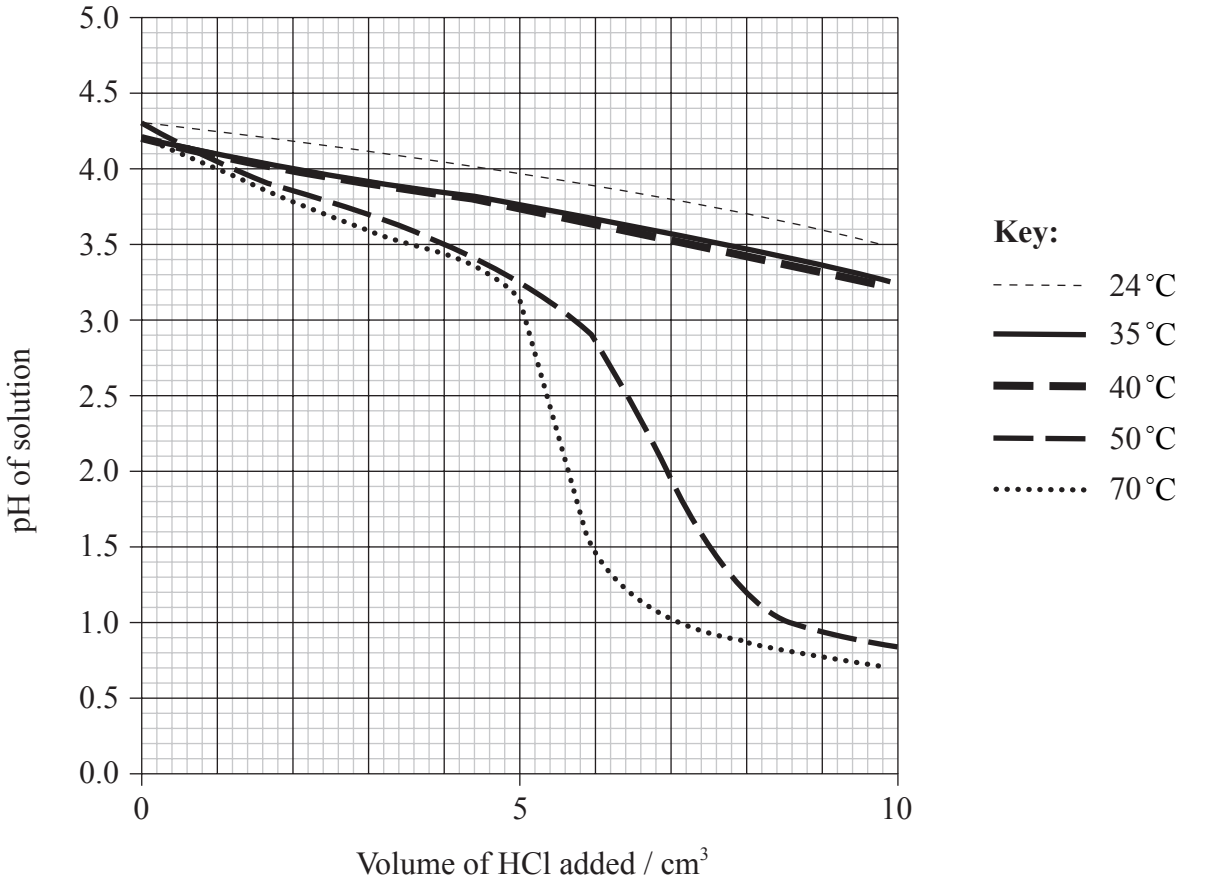
(This question continues on the following page)

(Question 1 continued)

(f) To investigate the effect of temperature on the effectiveness of a buffer solution, the student placed 20.0 cm^3 of the buffer solution in a water bath at 24 °C. He added small portions of hydrochloric acid, stirring after each addition, until a total of 10 cm^3 was added, and measured the pH continuously during the addition. The procedure was repeated at different temperatures and the results are shown in the following graph.



(This question continues on the following page)

(Question 1 continued)

(i) State what is meant by a *buffer solution*. *[2]*

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(ii) With reference to the graph on page 4, describe the effect of increasing temperature on the effectiveness of the buffer solution. *[2]*

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Please **do not** write on this page.

Answers written on this page
will not be marked.

2. Table 8 of the Data Booklet shows the atomic and ionic radii of the elements.

(a) Describe and explain the trend in atomic radius across period 3. *[3]*

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(b) A student formulates the following hypothesis: "If phosphorus were to form a positive ion, P^{3+}, its ionic radius would probably be between 110×10^{-12} m and 212×10^{-12} m." Evaluate this hypothesis. *[2]*

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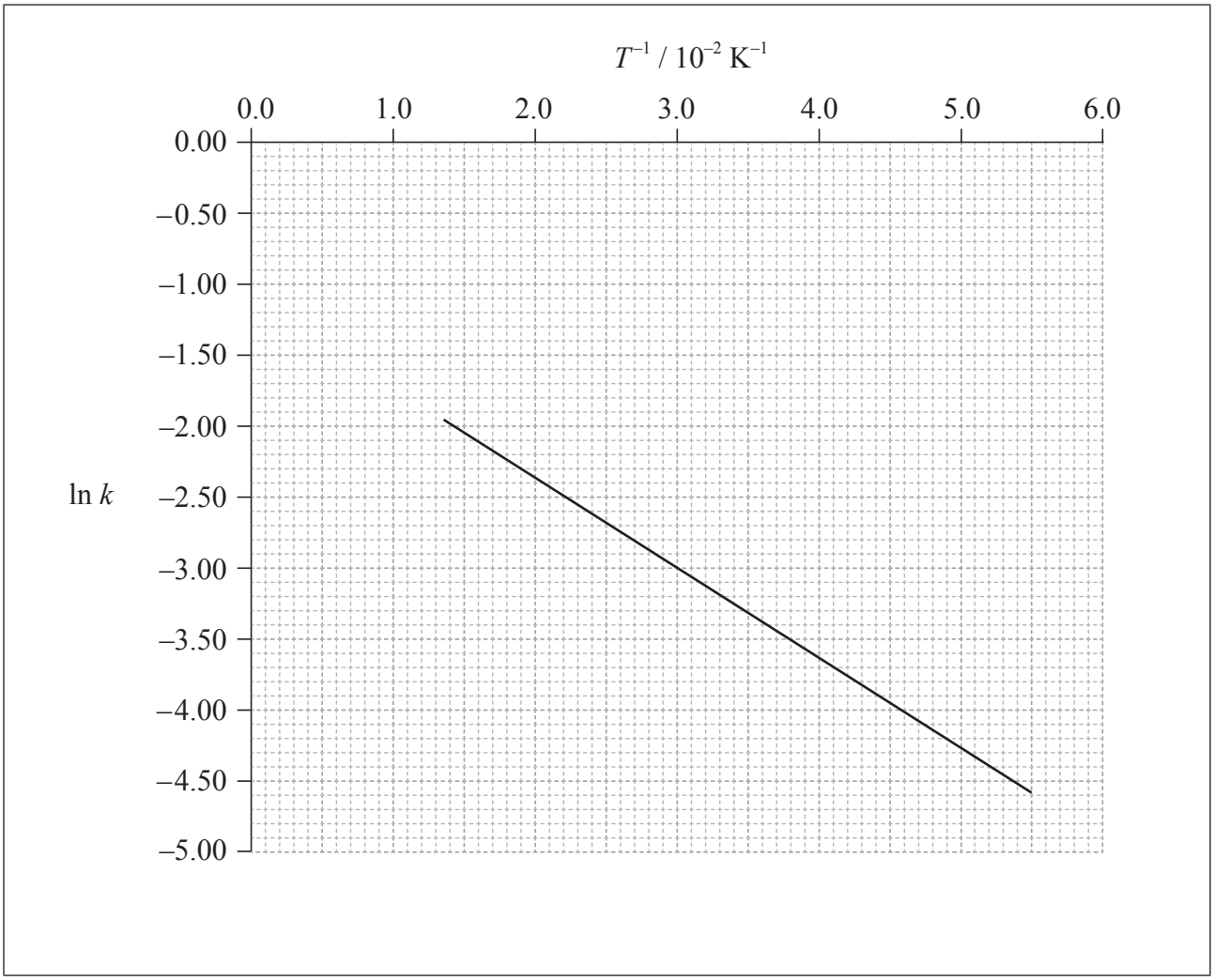
3. To determine the activation energy of a reaction, the rate of reaction was measured at different temperatures. The rate constant, k, was determined and ln k was plotted against the inverse of the temperature in Kelvin, T^{-1}. The following graph was obtained.



(a) Define the term *activation energy*, E_a. *[1]*

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(This question continues on the following page)

(Question 3 continued)

(b) Use the graph on page 8 to determine the value of the activation energy, E_a, in $kJ\,mol^{-1}$. *[2]*

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(c) On the graph on page 8, sketch the line you would expect if a catalyst is added to the reactants. *[1]*

4. Ethanedioic acid (oxalic acid), $(COOH)_2$, reacts with acidified potassium permanganate solution, $KMnO_4$, according to the following equation.

$$5(COOH)_2(aq) + 2MnO_4^-(aq) + 6H^+(aq) \rightarrow 10CO_2(g) + 2Mn^{2+}(aq) + 8H_2O(l)$$

The reaction is a redox reaction.

(a) Define *oxidation* in terms of electron transfer. *[1]*

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(b) Calculate the change in oxidation numbers of carbon and manganese. *[2]*

Carbon:

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. . . . . .

Manganese:

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(c) Identify the oxidizing and reducing agents. *[1]*

Oxidizing agent:

. . . . . .

Reducing agent:

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(This question continues on the following page)

(Question 4 continued)

(d) Deduce the half-equation involving ethanedioic acid. *[1]*

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(e) (i) The standard electrode potential for the half-equation involving ethanedioic acid is $E^{\ominus} = -0.49\,\text{V}$. Using Table 14 of the Data Booklet, calculate the standard electrode potential for the equation on page 10. *[2]*

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(ii) Explain the sign of the calculated standard electrode potential. *[1]*

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(f) Predict the sign of $\Delta G^{\ominus}$ for this reaction. *[1]*

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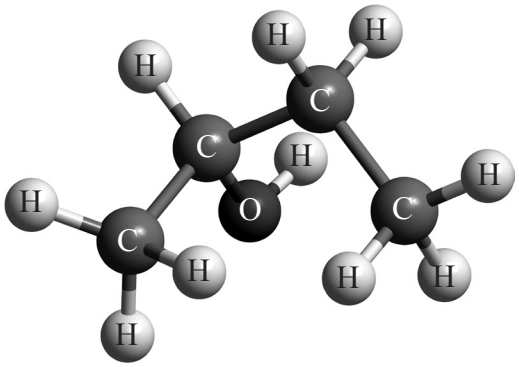
5. The following diagram shows the three-dimensional structure of a molecule.



(a) Apply IUPAC rules to state the name of this molecule. *[1]*

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(b) Deduce the structural formula of **two** isomers of the molecule above with the same functional group. *[2]*

(This question continues on the following page)

(Question 5 continued)

(c) Some organic nitrogen compounds have economic importance.

(i) Apply IUPAC rules to state the name of $CH_3CH_2CH_2NH_2$. *[1]*

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(ii) Describe, using an equation, how $CH_3CH_2CH_2NH_2$ can be prepared from a nitrile. *[1]*

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(iii) Some polymers can be produced by the reaction of amines and carboxylic acids. Identify what type of reaction this is. *[1]*

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(iv) State **one** important feature monomers must have to be able to produce such polymers. *[1]*

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(v) Outline the economic importance of this type of polymer. *[1]*

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SECTION B

*Answer **two** questions. Write your answers in the boxes provided.*

6. The element boron has two naturally occurring isotopes, ^{10}B and ^{11}B.

(a) (i) Define the term *isotopes of an element*. *[1]*

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(ii) Calculate the percentage abundance of **each** isotope, given that the relative atomic mass of B is 10.81. *[2]*

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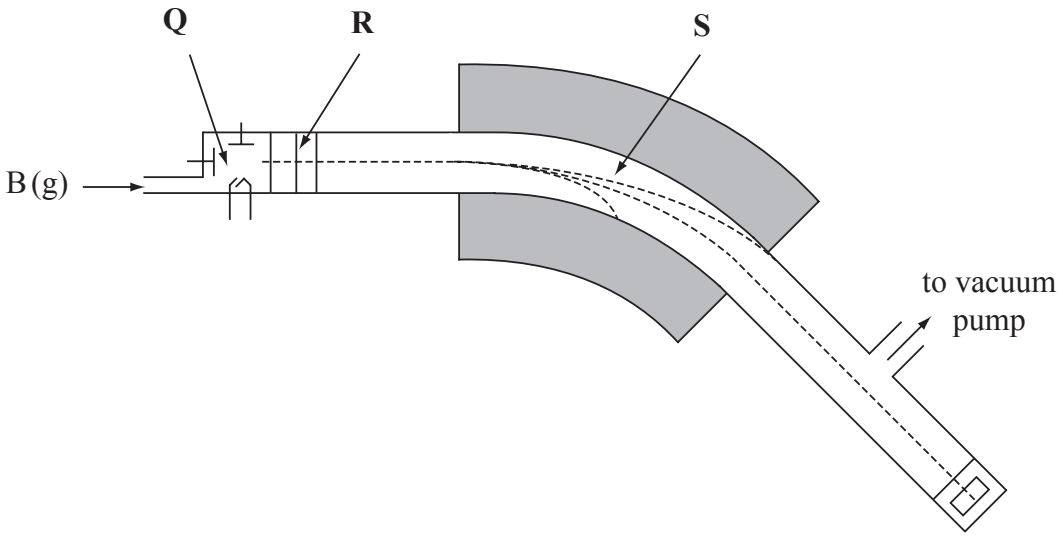
(Question 6 continued)

(b) The percentage abundance of the isotopes of boron can be determined with a mass spectrometer. The diagram shows the operation of a mass spectrometer.



(i) State the names of stages **R** and **S**. *[1]*

R: . . . . . .

S: . . . . . .

(ii) Identify the formula of the main ion formed in stage **Q**. *[1]*

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(iii) Identify the species that is used as the scale for the mass of the isotopes. *[1]*

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(This question continues on the following page)

(Question 6 continued)

(c) Phosphorus forms two chlorides, PCl_3 and PCl_5.

(i) Apply the Aufbau principle to state the **full** electron configuration for an atom of phosphorus. *[1]*

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(ii) Deduce the Lewis structures for PCl_3 and PCl_5. *[2]*

PCl_3	PCl_5

(iii) Predict the shapes and the bond angles in the two molecules. *[4]*

	PCl_3	**PCl_5**
Shape	. . . . .	. . . . .
Bond angles	. . . . .	. . . . .

(This question continues on the following page)

(Question 6 continued)

(iv) Identify the type of hybridization present in PCl_3. *[1]*

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(v) Compare the melting points of PCl_3 and PCl_5 and explain the difference. *[3]*

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(vi) Describe, using an equation, the reaction of PCl_5 with water. *[1]*

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(This question continues on the following page)

(Question 6 continued)

(d) (i) Define an *acid* according to the Lewis theory. *[1]*

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(ii) State and explain the acid–base character of PCl_3 according to the Lewis theory. *[2]*

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(e) Explain the delocalization of π electrons using the O_3 molecule as an example, including **two** facts that support the delocalization. *[4]*

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7. (a) Bromine is a member of group 7, the halogens.

(i) Explain the trend in reactivity of the halogens. *[3]*

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(ii) Deduce, using equations where appropriate, if bromine reacts with sodium chloride solution and with sodium iodide solution. *[2]*

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(b) Iron is a transition metal.

(i) Describe the bonding in metals and explain their malleability. *[3]*

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(Question 7 continued)

(ii) List **three** characteristic properties of transition elements. *[2]*

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(iii) Identify the type of bonding between iron and cyanide in $[Fe(CN)_6]^{3-}$. *[1]*

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(iv) Deduce the oxidation number of iron in $[Fe(CN)_6]^{3-}$. *[1]*

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(v) Draw the abbreviated orbital diagram for an **iron atom** using the arrow-in-box notation to represent electrons. *[1]*

(This question continues on the following page)

(Question 7 continued)

(vi) Draw the abbreviated orbital diagram for the **iron ion in $[Fe(CN)_6]^{3-}$** using the arrow-in-box notation to represent electrons. *[1]*

(c) Freshly prepared iron(II) bromide can be electrolysed both in the liquid state and in aqueous solution.

(i) Describe, using a diagram, the essential components of an electrolytic cell. *[3]*

(This question continues on the following page)

(Question 7 continued)

(ii) Describe the **two** ways in which current is conducted in an electrolytic cell. *[2]*

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(iii) Predict and explain the products of electrolysis of a **dilute** iron(II) bromide solution. *[4]*

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(This question continues on the following page)

(Question 7 continued)

(iv) Identify another product that is formed if the solution of iron(II) bromide is **concentrated**. *[1]*

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(v) Explain why this other product is formed. *[1]*

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8. To determine the enthalpy change of combustion of methanol, CH_3OH, 0.230 g of methanol was combusted in a spirit burner. The heat released increased the temperature of 50.0 cm^3 of water from 24.5 °C to 45.8 °C.

(a) (i) Calculate the enthalpy change of combustion of methanol. *[4]*

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(ii) Using the theoretical value in Table 12 of the Data Booklet, discuss the experimental result, including **one** improvement that could be made. *[3]*

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(This question continues on the following page)

(Question 8 continued)

(b) Methanol can be produced according to the following equation.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$

(i) Calculate the standard enthalpy change of this reaction, using the values of enthalpy of combustion in Table 12 of the Data Booklet. *[3]*

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(ii) Calculate the standard entropy change for this reaction, $\Delta S^{\ominus}$, using Table 11 of the Data Booklet and given:
$S^{\ominus}(CO) = 198\,J\,K^{-1}\,mol^{-1}$ and $S^{\ominus}(H_2) = 131\,J\,K^{-1}\,mol^{-1}$. *[1]*

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(iii) Calculate, stating units, the standard free energy change for this reaction, $\Delta G^{\ominus}$, at 298 K. *[2]*

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(This question continues on the following page)

(Question 8 continued)

(iv) Predict, with a reason, the effect of an increase in temperature on the spontaneity of this reaction. *[2]*

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(c) The manufacture of gaseous methanol from CO and H_2 involves an equilibrium reaction.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H^{\ominus} < 0$$

(i) Outline the characteristics of a chemical equilibrium. *[2]*

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(ii) Deduce the equilibrium constant expression, K_c, for this reaction. *[1]*

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(This question continues on the following page)

(Question 8 continued)

(iii) 1.00 mol of CH_3OH is placed in a closed container of volume 1.00 dm^3 until equilibrium is reached with CO and H_2. At equilibrium 0.492 mol of CH_3OH are present. Calculate K_c. *[3]*

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(d) State and explain the effect of the following changes on the equilibrium position of the reaction in part (c).

(i) Increase in temperature. *[2]*

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(ii) Increase in pressure. *[2]*

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9. But-2-ene belongs to the homologous series of the alkenes.

(a) (i) Outline **three** features of a homologous series. *[3]*

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(ii) Describe a test to distinguish but-2-ene from butane, including what is observed in **each** case. *[2]*

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(iii) 2-bromobutane can be produced from but-2-ene. State the equation of this reaction using structural formulas. *[1]*

(This question continues on the following page)

(Question 9 continued)

(iv) State what is meant by the term *stereoisomers*. *[1]*

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(v) Explain the existence of geometrical isomerism in but-2-ene. *[2]*

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(b) A bromoalkane, C_4H_9Br, reacts with a warm aqueous sodium hydroxide solution, NaOH.

(i) State the equation for the reaction of C_4H_9Br with NaOH. *[1]*

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(ii) Suggest what would happen to the pH of the solution as the reaction proceeds. *[1]*

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(This question continues on the following page)

(Question 9 continued)

(c) The time taken to produce a certain amount of product using different initial concentrations of C_4H_9Br and NaOH is measured. The results are shown in the following table.

Reaction	$[C_4H_9Br] / 10^{-2}$ mol dm^{-3}	$[NaOH] / 10^{-3}$ mol dm^{-3}	t / s
A	1.0	2.0	46
B	2.0	2.0	23
C	2.0	4.0	23

(i) Deduce the order of reaction with respect to C_4H_9Br and NaOH, using the data above. *[3]*

C_4H_9Br:

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

NaOH:

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(ii) Deduce the rate expression. *[1]*

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(iii) Based on the rate expression obtained in (c) (ii) state the units of the rate constant, k. *[1]*

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(This question continues on the following page)

(Question 9 continued)

(iv) Deduce whether C_4H_9Br is a primary or tertiary halogenoalkane. *[2]*

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(v) Determine the structural formula of C_4H_9Br. *[1]*

(This question continues on the following page)

(Question 9 continued)

(d) (i) Explain the mechanism for the reaction in (c), of C_4H_9Br with NaOH, using curly arrows to represent the movement of electron pairs. *[4]*

(ii) Halogenalkanes can react with NaOH via S_N1 and S_N2 type mechanisms. Explain why C_4H_9Br reacts via the mechanism described in (d) (i). *[1]*

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(iii) Identify the rate-determining step of this mechanism. *[1]*

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