SECTION A

Answer ALL the questions in this section. You should aim to spend no more than 20 minutes on this section. For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 The reaction between carbon monoxide and hydrogen reaches a dynamic equilibrium.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(a) Which of these statements about a dynamic equilibrium is **not** true?

(1)

☒ **A** The forward rate of reaction is equal to the backward rate of reaction.

☒ **B** The concentrations of the products and reactants do not change.

☒ **C** The concentrations of the products and reactants are equal.

☒ **D** The equilibrium can be approached from either direction.

(b) The K_c expression for the above reaction is

(1)

☒ **A** $K_c = \dfrac{[CH_3OH]}{[CO] \times [H_2]^2}$

☒ **B** $K_c = \dfrac{[CO] \times 2[H_2]}{[CH_3OH]}$

☒ **C** $K_c = \dfrac{[CO] \times [H_2]^2}{[CH_3OH]}$

☒ **D** $K_c = \dfrac{[CH_3OH]}{[CO] \times 2[H_2]}$

(Total for Question 1 = 2 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

2 Hydrogen and iodine, both with an initial concentration of 0.010 mol dm^{-3}, were allowed to react. At equilibrium, the concentration of hydrogen iodide was 0.0030 mol dm^{-3}.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

K_c is calculated using the values

	$H_2(g)$ / mol dm^{-3}	$I_2(g)$ / mol dm^{-3}	$HI(g)$ / mol dm^{-3}
☒ **A**	0.0070	0.0070	0.0030
☒ **B**	0.0040	0.0040	0.0030
☒ **C**	0.0040	0.0040	0.0060
☒ **D**	0.0085	0.0085	0.0030

(Total for Question 2 = 1 mark)

3 The reaction below reached a dynamic equilibrium from an initial mixture of all four substances P, Q, R and S in aqueous solution.

$$P + Q \rightleftharpoons R + S$$

The following data were obtained.

Substance	Concentration at equilibrium / mol dm^{-3}
P	0.050
Q	0.040
R	0.020
S	0.010

K_c for the equilibrium is

☒ **A** 0.10

☒ **B** 0.33

☒ **C** 3.00

☒ **D** 10.0

(Total for Question 3 = 1 mark)

4 The Haber process is used to make ammonia from nitrogen and hydrogen at 450 °C.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92.0 \text{ kJ mol}^{-1}$$

(a) If the partial pressures of these gases were measured in atm, the units of the equilibrium constant K_p will be

(1)

☒ **A** atm

☒ **B** atm^2

☒ **C** atm^{-2}

☒ **D** atm^{-1}

(b) When the temperature of the system is increased

(1)

☒ **A** K_p decreases.

☒ **B** K_p increases.

☒ **C** K_p stays the same.

☒ **D** K_p first decreases and then increases.

(Total for Question 4 = 2 marks)

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5 In high performance liquid chromatography, HPLC, which of these factors does **not** affect the time taken for a component to pass through the column?

☒ **A** Type of detector

☒ **B** Material of stationary phase

☒ **C** Particle size of stationary phase

☒ **D** Temperature of column

(Total for Question 5 = 1 mark)

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6 When equimolar amounts of the solutions below are mixed, which forms a buffer solution with a pH less than 7?

☒ **A** Hydrochloric acid and sodium chloride

☒ **B** Ethanoic acid and sodium ethanoate

☒ **C** Sodium hydroxide and sodium chloride

☒ **D** Ammonia and ammonium chloride

(Total for Question 6 = 1 mark)

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7 The pH of a 1.5 mol dm^{-3} solution of hydrochloric acid, HCl(aq), is

☒ **A** −1.50

☒ **B** −0.18

☒ **C** 0.18

☒ **D** 1.50

(Total for Question 7 = 1 mark)

8 Which of these solid substances is likely to have the greatest standard entropy? Use of the data booklet is not required.

☒ **A** SnO

☒ **B** SnO_2

☒ **C** $SnBr_2$

☒ **D** $SnBr_4$

(Total for Question 8 = 1 mark)

Question 9: N/A

Question 10: N/A

Question 11: N/A

Question 12: N/A

Question 13: N/A

14 The equation for the enthalpy of hydration for a magnesium ion is

☒ **A** $Mg^{2+}(s) + aq \rightarrow Mg^{2+}(aq)$

☒ **B** $Mg^{2+}(g) + aq \rightarrow Mg^{2+}(aq)$

☒ **C** $Mg^{2+}(aq) \rightarrow Mg^{2+}(g) + aq$

☒ **D** $Mg^{2+}(aq) \rightarrow Mg^{2+}(s) + aq$

(Total for Question 14 = 1 mark)

Question 15: N/A

Question 16: N/A

Question 17: N/A

Question 18: N/A

Question 19: N/A

20 The exothermic reaction between carbon monoxide and hydrogen can be used industrially to make methanol. The process is carried out at 250 °C and between 50 and 100 atm.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(a) Explain why increasing the pressure increases the yield of methanol. Give **one** disadvantage of increasing the pressure.

(2)

(b) The reaction gives a greater equilibrium yield at 100 °C than at 250 °C.

(i) Explain, in terms of the entropy change of the surroundings and the total entropy change of the reaction, why this is so.

A calculation is **not** required.

(2)

(ii) Explain why the reaction is, nevertheless, carried out at 250 °C.

(1)

(c) Given that the reaction is an equilibrium, suggest **two** ways in which the atom economy of this process could be maximised without changing the temperature or pressure.

(2)

(Total for Question 20 = 7 marks)

21 This question is about the kinetics of the reaction between bromoethane and aqueous hydroxide ions.

(a) The results of an experiment to find the initial rate of the reaction are shown in the table below.

$[CH_3CH_2Br]$ / mol dm^{-3}	$[OH^-]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
0.100	0.150	1.54×10^{-6}

The rate equation for the reaction is

$$\text{rate} = k[CH_3CH_2Br][OH^-]$$

(i) Calculate the value of k. Give your answer to three significant figures and include units.

(3)

(ii) Calculate the initial rate if the concentrations of both reactants were changed to 0.020 mol dm^{-3}.

(1)

(b) (i) State the order of the reaction.

(1)

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(ii) The mechanism for this reaction can be inferred from the rate equation. Draw the transition state formed in the reaction between bromoethane and hydroxide ions.

(2)

(c) The rate constant for the reaction between bromoethane and hydroxide ions was determined at five different temperatures. The results are shown in the table below.

Temperature (T) / K	1/Temperature (1/T) / K^{-1}	Rate constant, k	ln k
293	3.41×10^{-3}	5.83×10^{-5}	−9.75
303	3.30×10^{-3}	1.67×10^{-4}	−8.70
313	3.19×10^{-3}	5.26×10^{-4}	−7.55
323	3.10×10^{-3}	1.36×10^{-3}	−6.60
333		3.77×10^{-3}	

(i) Complete the missing values in the table.

(2)

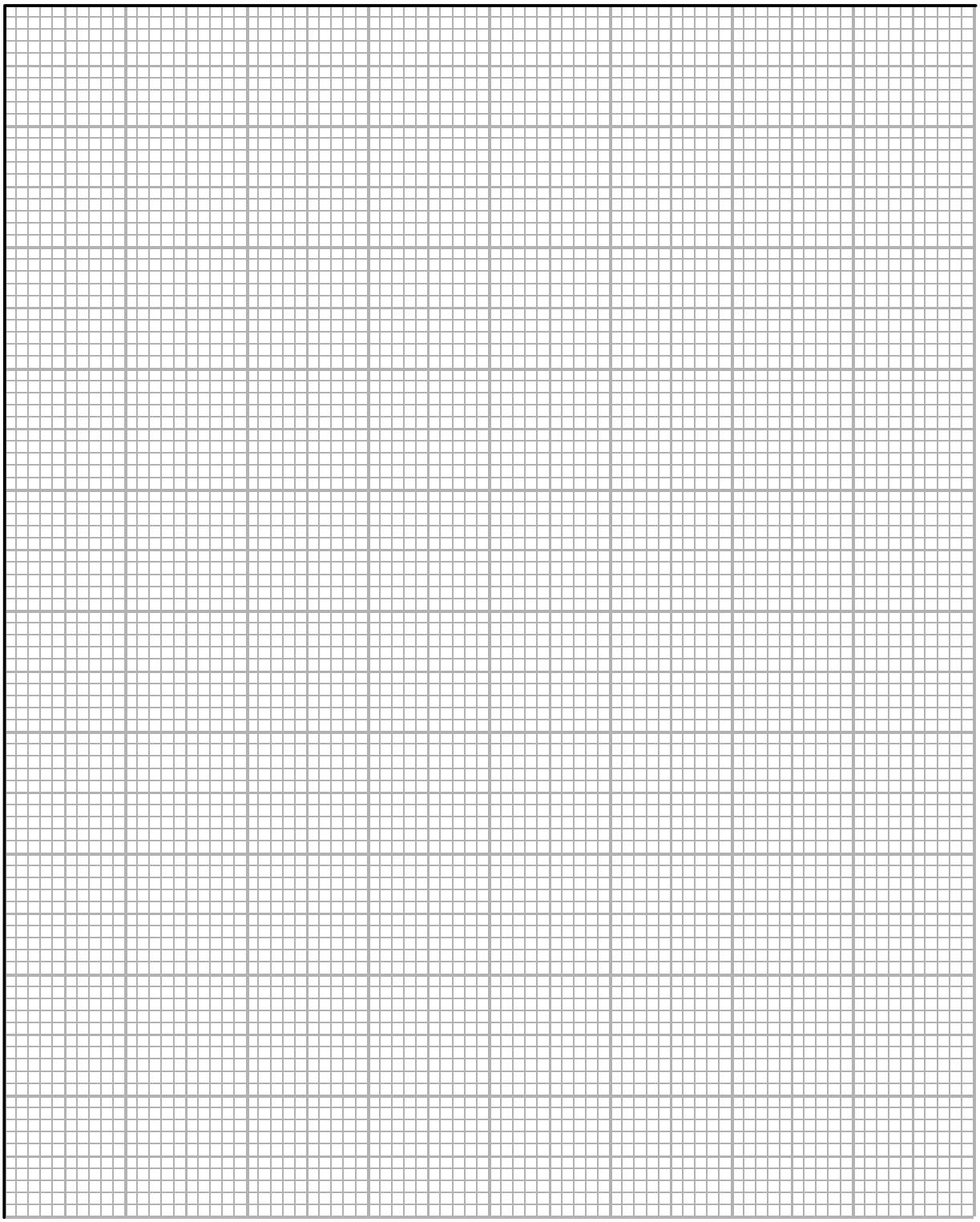
(ii) Plot a graph of ln k against 1/T. Calculate the gradient of your graph and use this to calculate the activation energy, E_A. The Arrhenius equation can be expressed as

$$\ln k = \frac{-E_A}{R} \times \left(\frac{1}{T}\right) + \text{a constant}$$

[Gas constant, R = 8.31 J K^{-1} mol^{-1}]

(5)

$1/T/K^{-1}$



ln *k*

(Total for Question 21 = 14 marks)

TOTAL FOR SECTION B = 49 MARKS

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

22 The hydrocarbon butane can be cracked to form propene and methane by passing it over a heated aluminium oxide catalyst at a temperature of 700 K. The equation for the reaction is

$$C_4H_{10}(g) \rightarrow C_3H_6(g) + CH_4(g) \qquad \Delta H = +71.9 \text{ kJ mol}^{-1}$$

(a) (i) Use page 20 of the data booklet to complete the table below.

(1)

Hydrocarbon	$S^{\ominus}$/ J mol^{-1} K^{-1}
$C_4H_{10}(g)$	+310.1
$C_3H_6(g)$	+266.9
$CH_4(g)$	

(ii) Calculate the standard entropy change of the system, $\Delta S^{\ominus}_{system}$, for this reaction. Include a sign in your answer.

(2)

(iii) Was the sign for your answer as you expected? Fully justify your answer.

(2)

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(iv) Calculate the entropy change of the surroundings, $\Delta S_{surroundings}$, at 700 K.

Include a sign and units in your answer.

Use this value and your answer to (ii) to explain why butane cracks into propene and methane at this temperature.

(3)

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(v) Calculate the minimum temperature needed for this reaction to be thermodynamically feasible.

(3)

(b) The aluminium oxide behaves as a heterogeneous catalyst. Explain both what is meant by the term **heterogeneous** and how, in terms of activation energy, the catalyst is able to speed up the reaction.

(3)

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(Total for Question 22 = 14 marks)

23 The bubble bath 'Colour Change Matey' has amongst its ingredients the weak acid benzoic acid, as well as the indicator bromocresol green. When it is added to bath water, its colour changes from yellow to blue.

(a) (i) Write the K_a expression for the dissociation of benzoic acid, C_6H_5COOH.

(1)

(ii) Use the data on page 18 of the data booklet to calculate the pH of a solution of benzoic acid, C_6H_5COOH, of concentration 0.0025 mol dm^{-3}.

(2)

*(b) Use the data on page 19 of the data booklet, and your answer to (a)(ii), to suggest why the bubble bath changes colour when it is diluted by being added to the bath water.

(4)

(Total for Question 23 = 7 marks)

Answer ALL the questions in this section. You should aim to spend no more than 20 minutes on this section. For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒

24 In the reaction of manganate(VII) ions with reducing agents in strongly acidic solution, the half-reaction for the reduction is

☒ **A** $MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$

☒ **B** $MnO_4^- + 4H^+ + 5e^- \rightarrow Mn^{2+} + 2H_2O$

☒ **C** $MnO_4^- + 8H^+ + 3e^- \rightarrow Mn^{2+} + 4H_2O$

☒ **D** $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

(Total for Question = 1 mark)

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25 In the titration of iodine with standard sodium thiosulfate solution, starch is often used as an indicator. The starch should **not** be added until nearly all the iodine has reacted because

☒ **A** it is decomposed by high concentrations of iodine.

☒ **B** the blue complex formed is bleached by high concentrations of iodine.

☒ **C** the blue complex formed with high concentrations of iodine is insoluble and does not re-dissolve as more thiosulfate is added.

☒ **D** the starch reacts with the thiosulfate ions being added.

(Total for Question = 1 mark)

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26 The conditions needed for the $E^{\ominus}$ value of the standard hydrogen electrode to be exactly 0 V are

☒ **A** 1 mol dm^{-3} solution of hydrogen ions, 1 atm pressure of hydrogen, 25 °C.

☒ **B** 1 mol dm^{-3} solution of hydrogen ions, 1 atm pressure of hydrogen, room temperature.

☒ **C** 1 mol dm^{-3} solution of hydrogen ions, laboratory pressure of hydrogen, 25 °C.

☒ **D** 0.1 mol dm^{-3} solution of hydrogen ions, 1 atm pressure of hydrogen, 25 °C.

(Total for Question = 1 mark)

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27 The electrode potential for a cell can be used to calculate the equilibrium constant for the cell reaction. This is because

☒ **A** $E^{\ominus}_{cell}$ is proportional to $\ln K$.

☒ **B** $E^{\ominus}_{cell}$ is proportional to K.

☒ **C** $\ln E^{\ominus}_{cell}$ is proportional to $\ln K$.

☒ **D** $\ln E^{\ominus}_{cell}$ is proportional to K.

(Total for Question = 1 mark)

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28 Which of the following successive ionization energies (values in kJ mol^{-1}) could have come from a transition element?

☒ **A** 496 4563 6913 9544 13352 16611 20115 25941

☒ **B** 590 1145 4912 6474 8144 10496 12320 14207

☒ **C** 717 1509 3249 4940 6985 9200 11508 18956

☒ **D** 2081 3952 6122 9370 12177 15239 19999 23069

(Total for Question = 1 mark)

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29 Which of the following gives the electronic configuration for chromium and for the Cr^{3+} ion?

		Cr	Cr^{3+}
☒	**A**	$[Ar]3d^4 4s^2$	$[Ar]3d^3 4s^0$
☒	**B**	$[Ar]3d^5 4s^1$	$[Ar]3d^2 4s^1$
☒	**C**	$[Ar]3d^5 4s^1$	$[Ar]3d^3 4s^0$
☒	**D**	$[Ar]3d^4 4s^2$	$[Ar]3d^1 4s^2$

(Total for Question = 1 mark)

30 Glycine, H_2NCH_2COOH, is a solid that has a melting temperature of about 250 °C, and it is very soluble in water. This is because of the

☒ **A** formation of intermolecular hydrogen bonds in the solid and hydrogen bonds with water.

☒ **B** formation of $H_3N^+CH_2COO^-$ ions which interact strongly with each other in the solid and with water.

☒ **C** dissociation of the molecule to form $H_2NCH_2COO^-$ and H^+ ions in the solid and the solution.

☒ **D** protonation of the molecule to form $H_3N^+CH_2COOH$ ions in both the solid and the solution.

(Total for Question = 1 mark)

S

Answer ALL the questions. Write your answers in the spaces provided.

31 Brass is an alloy of copper, zinc and, in some cases, other metals too. There are over 30 varieties of brass for different applications.

The amount of copper in a brass can be found as follows:

- A weighed sample of brass is reacted with the minimum amount of concentrated nitric acid.
- The solution is neutralized, a portion of it pipetted into a conical flask, and excess potassium iodide solution is added.
- The iodine produced is titrated with a solution of sodium thiosulfate of known concentration.

(a) The ionic equation for the reaction between copper metal and concentrated nitric acid is shown below.

$$Cu(s) + 2NO_3^-(aq) + 4H^+(aq) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 2H_2O(l)$$

(i) Give the oxidation numbers of the copper and nitrogen in both the reactants and products.

(2)

Copper: from ..... **to** .....

Nitrogen: from ..... **to** .....

(ii) Write the two half-equations that can be combined to give the ionic equation shown above.

(2)

(iii) Explain why the standard electrode potentials for the two ionic half-equations that you have written give an incorrect value for E_{cell} for this reaction as described above.

(2)

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(b) The solution produced contains a mixture of zinc ions and copper ions.

(i) State TWO observations that you would **see** if concentrated ammonia solution were to be added, drop by drop, to the solution until in excess.

(2)

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(ii) Copper ions can be separated from the zinc ions in the solution by adding sodium hydroxide solution in excess, followed by filtration of the mixture.

Write equations, including state symbols, for the THREE reactions that occur.

(3)

Equation 1

Equation 2

Equation 3

*(iii) Give examples of amphoteric behaviour and ligand exchange, by reference to the reactions of zinc compounds.

(3)

(c) A sample of Admiralty Brass of mass 3.00 g was treated with nitric acid and made up to a neutral solution of volume 250 cm^3. Excess potassium iodide was added to 25.0 cm^3 portions of this solution, and the liberated iodine was titrated with sodium thiosulfate solution, concentration 0.100 mol dm^{-3}. The mean titre was 33.10 cm^3.

(i) Write the ionic equation for the reaction between thiosulfate ions and iodine.

(1)

*(ii) The equation for the reaction between copper(II) ions and iodide ions is shown below.

$$2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$$

Hence calculate the percentage by mass of copper in Admiralty Brass. Give your answer to **three** significant figures.

(6)

(iii) When setting up the burette, a student failed to fill the jet of the burette. Explain the effect that this would have on the value of the first titre.

If this first titre was included in the calculation of the mean titre, what effect would this have on the value for the percentage of copper in the brass?

(2)

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(Total for Question 31 = 23 marks)