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 Select the correct pH for each of the following solutions.

(a) 2 mol dm^{-3} nitric acid.

(1)

☒ **A** −2

☒ **B** −0.3

☒ **C** +0.3

☒ **D** +2

(b) 0.10 mol dm^{-3} barium hydroxide, $Ba(OH)_2$. $K_w = 1.0 \times 10^{-14}$ mol^2 dm^{-6}.

(1)

☒ **A** 13.0

☒ **B** 13.3

☒ **C** 13.7

☒ **D** 14.3

(c) A mixture of 20 cm^3 of 1.0 mol dm^{-3} hydrochloric acid and 10 cm^3 of 1.0 mol dm^{-3} sodium hydroxide.

(1)

☒ **A** 0

☒ **B** 0.30

☒ **C** 0.48

☒ **D** 7

(Total for Question 4 = 3 marks)

---

5 Ammonia reacts with water in a reversible reaction. Which are the Brønsted-Lowry bases?

☒ **A** H_2O and OH^-

☒ **B** NH_3 and OH^-

☒ **C** NH_4^+ and H_2O

☒ **D** NH_4^+ and NH_3

(Total for Question 5 = 1 mark)

---

16 Methanoic acid, HCOOH, is present in ant stings.

A scientist analyzed 25.0 cm^3 of an aqueous solution of methanoic acid, solution **Z**, by titrating it with dilute sodium hydroxide, NaOH(aq).

- 20.0 cm^3 of sodium hydroxide was required to neutralize the methanoic acid
- The equation for the neutralization of methanoic acid is

$$HCOOH(aq) + NaOH(aq) \rightarrow HCOONa(aq) + H_2O(l)$$

(a) (i) Give the expression for K_w, the ionic product of water.

(1)

(ii) The concentration of the sodium hydroxide, NaOH(aq), used in the titration was 0.00750 mol dm^{-3}.

Calculate the pH of the sodium hydroxide solution.

[K_w = 1.00 x 10^{-14} $mol^2\,dm^{-6}$]

(2)

(b) Use the equation for the reaction and the data from the titration to show that the concentration of the methanoic acid in solution **Z** was 6.00×10^{-3} mol dm^{-3}.

(2)

(c) Methanoic acid is a weak acid.

(i) Explain the term **weak acid**.

(2)

Weak ....

....

Acid ....

....

(ii) The equation for the dissociation of methanoic acid in aqueous solution is shown below.

$$HCOOH(aq) \rightleftharpoons HCOO^{-}(aq) + H^{+}(aq)$$

Write the expression for the acid dissociation constant, K_a, for methanoic acid.

(1)

*(iii) At 298 K, the acid in ant stings has a concentration of 6.00×10^{-3} mol dm^{-3} and a pH of 3.01.

Calculate the value of K_a for methanoic acid at 298 K.

State clearly any assumptions that you have made.

(4)

Calculation:

Assumption(s):

....

....

....

....

(Total for Question 16 = 12 marks)

17 Ethanoic acid and ethanol react together to form the ester ethyl ethanoate, $CH_3COOC_2H_5$, and water.

$$CH_3COOH(l) + CH_3CH_2OH(l) \rightleftharpoons CH_3COOCH_2CH_3(l) + H_2O(l)$$

(a) (i) Give the expression for K_c.

(1)

(ii) An equilibrium was reached when the amounts of substances shown in the table below were used.

Complete the table to show the amounts of each substance present at equilibrium.

(2)

Component	$CH_3COOH(l)$	$CH_3CH_2OH(l)$	$CH_3COOCH_2CH_3(l)$	$H_2O(l)$
Initial amount / mol	0.40	0.30	0.00	0.15
Equilibrium amount / mol	0.20			

(iii) Explain why K_c for this reaction has no units.

(1)

....

....

(iv) Calculate the numerical value of K_c.

(1)

(b) The esterification reaction above was carried out in the presence of hydrochloric acid as the catalyst.

State the effect on the equilibrium position and the rate of attainment of equilibrium if the concentration of the acid catalyst were to be increased.

(2)

....

....

....

....

Total = 7 marks

Section A

Answer **all** questions in the spaces provided.

1 (a) A mixture of 1.50 mol of hydrogen and 1.20 mol of gaseous iodine was sealed in a container of volume V dm^3. The mixture was left to reach equilibrium as shown by the following equation.

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

At a given temperature, the equilibrium mixture contained 2.06 mol of hydrogen iodide.

1 (a) (i) Calculate the amounts, in moles, of hydrogen and of iodine in the equilibrium mixture.

Moles of hydrogen ....

Moles of iodine ....

(2 marks)

1 (a) (ii) Write an expression for the equilibrium constant (K_c) for this equilibrium.

....

....

(1 mark)

1 (a) (iii) K_c for this equilibrium has no units.
State why the units cancel in the expression for K_c

....

....

(1 mark)

1 (a) (iv) A different mixture of hydrogen, iodine and hydrogen iodide was left to reach equilibrium at the same temperature in a container of the same volume.
This second equilibrium mixture contained 0.38 mol of hydrogen, 0.19 mol of iodine and 1.94 mol of hydrogen iodide.

Calculate a value for K_c for this equilibrium at this temperature.

....

....

....

....

(2 marks)

(Extra space) ....

....

1 (b) This question concerns changes made to the four equilibria shown in parts **(b) (i)** to **(b) (iv)**.
In each case, use the information in the table to help you choose from the letters **A** to **E** the best description of what happens as a result of the change described. Write your answer in the box.

Each letter may be used once, more than once or not at all.

	Position of equilibrium	**Value of equilibrium constant, K_c**
A	remains the same	same
B	moves to the right	same
C	moves to the left	same
D	moves to the right	different
E	moves to the left	different

1 (b) (i) Change: increase the temperature of the equilibrium mixture at constant pressure.

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H^\ominus = +52\ kJ\ mol^{-1}$

(1 mark)

1 (b) (ii) Change: increase the total pressure of the equilibrium mixture at constant temperature.

$3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H^\ominus = -92\ kJ\ mol^{-1}$

(1 mark)

1 (b) (iii) Change: add a catalyst to the equilibrium mixture at constant temperature.

$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H^\ominus = -41\ kJ\ mol^{-1}$

(1 mark)

1 (b) (iv) Change: add chlorine to the equilibrium mixture at constant temperature.

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g) \qquad \Delta H^\ominus = +93\ kJ\ mol^{-1}$

(1 mark)

10

3 Ammonia and ethylamine are examples of weak Brønsted–Lowry bases.

3 (a) State the meaning of the term *Brønsted–Lowry base*.

....

....
(1 mark)

3 (b) (i) Write an equation for the reaction of ethylamine ($CH_3CH_2NH_2$) with water to form a weakly alkaline solution.

....

....
(1 mark)

3 (b) (ii) In terms of this reaction, state why the solution formed is **weakly** alkaline.

....

....
(1 mark)

3 (c) State which is the stronger base, ammonia or ethylamine. Explain your answer.

Stronger base ....

Explanation ....

....

....

....
(3 marks)

(Extra space) ....

....

3 (d) Give the formula of an organic compound that forms an alkaline buffer solution when added to a solution of ethylamine.

....

(1 mark)

3 (e) Explain qualitatively how the buffer solution in part **(d)** maintains an almost constant pH when a small amount of hydrochloric acid is added to it.

....

....

....

....

(2 marks)

(Extra space) ....

....

9

Turn over for the next question

Do not write outside the box

4 (c) A 25.0 cm^3 sample of 0.620 mol dm^{-3} nitric acid was placed in a beaker and 38.2 cm^3 of 0.550 mol dm^{-3} aqueous sodium hydroxide were added.
Calculate the pH of the solution formed.
Give your answer to 2 decimal places.

The ionic product of water $K_w = 1.00 \times 10^{-14}$ $mol^2\ dm^{-6}$ at 25 °C.

....

....

....

....

....

....

....

....

....

....

(6 marks)

(Extra space) ....

....

....

....

....

....

Total for test = 52 marks