1. $NO(g)$, $H_2(g)$, $N_2(g)$ and $H_2O(g)$ exist in equilibrium:

$$2NO(g) + 2H_2(g) \rightleftharpoons N_2(g) + 2H_2O(g)$$

At room temperature and pressure, the equilibrium lies well to the right-hand side.

Which of the following could be the equilibrium constant for this equilibrium?

A. 1.54×10^{-3} mol dm^{-3}
B. 6.50×10^{2} mol dm^{-3}
C. 1.54×10^{-3} dm^3 mol^{-1}
D. 6.50×10^{2} dm^3 mol^{-1}

Your answer ☐

[1]

2(a). Iodine, I_2, is a grey-black solid that is not very soluble in water.
Equilibrium 1 is set up with the equilibrium position well to the left.

$$I_2(s) \rightleftharpoons I_2(aq) \qquad \textbf{Equilibrium 1}$$

Solid iodine is much more soluble in an aqueous solution of potassium iodide, KI(aq), than in water.
Equilibrium 2 is set up.

$$I_2(aq) + I^-(aq) \rightleftharpoons I_3^-(aq) \qquad \textbf{Equilibrium 2}$$

A student dissolves I_2 in KI(aq).
The resulting 200 cm^3 equilibrium mixture contains:

4.00×10^{-5} mol $I_2(aq)$
9.404×10^{-2} mol $I^-(aq)$
1.96×10^{-3} mol $I_3^-(aq)$.

Calculate K_c for **equilibrium 2**.

Give your answer to an **appropriate** number of significant figures.

K_c = ... units .....**[4]**

(b). The student adds an excess of aqueous silver nitrate, $AgNO_3(aq)$, to the equilibrium mixture.

Predict what would be observed.

Explain the observations in terms of both **equilibrium 1** and **equilibrium 2** and any species formed.

[4]

3. Peroxycarboxylic acids are organic compounds with the COOOH functional group.

Peroxyethanoic acid, CH_3COOOH, is used as a disinfectant.

i. Suggest the structure for CH_3COOOH.
The COOOH functional group must be clearly displayed.

[1

ii. Peroxyethanoic acid can be prepared by reacting hydrogen peroxide with ethanoic acid.
This is a heterogeneous equilibrium.

$H_2O_2(aq) + CH_3COOH(aq) \rightleftharpoons CH_3COOOH(aq) + H_2O(l)$ $K_c = 0.37$ $dm^3\ mol^{-1}$

iii.

A 250 cm^3 equilibrium mixture contains concentrations of 0.500 mol dm^{-3} $H_2O_2(aq)$ and 0.500 mol dm^{-3} $CH_3COOH(aq)$.

Calculate the amount, in mol, of peroxyethanoic acid in the equilibrium mixture.

amount = ---------- mol **[3**

4(a). Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **equilibrium 18.1**.

$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ **Equilibrium 18.1**

Write an expression for K_c for this equilibrium and state the units.

K_c =

Units = ... **[2]**

(b). A chemist mixes together nitrogen and oxygen and pressurises the gases so that their total gas volume is 4.0 dm^3.

- The mixture is allowed to reach equilibrium at constant temperature and volume.

- The equilibrium mixture contains 0.40 mol NO and 0.80 mol O_2.
- Under these conditions, the numerical value of K_c is 45.

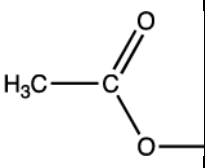
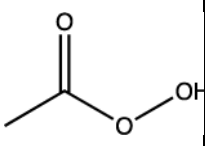
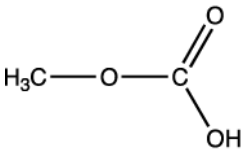
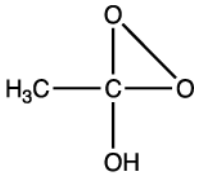
Calculate the amount, in mol, of NO_2 in the equilibrium mixture.

amount of NO_2 = ... mol **[4]**

END OF QUESTION paper

Mark scheme

Question	Answer/Indicative content	Marks	Guidance
1	D	1	
	Total	**1**	
2 a	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF K_c = 104 dm^3 mol^{-1} award 4 marks:** ***3 for calculation of 104 from data, 1 for units*** ..... **Equilibrium concentrations (mol × 5)** **(1 mark)** I_2 = 4.00 × 10^{-5} × **5** = 2.00 × 10^{-4} (mol dm^{-3}) **AND** I^- = 9.404 × 10^{-2} × **5** = 0.4702 (mol dm^{-3}) ✓ **AND** I_3^- = 1.96 × 10^{-3} × **5** = 9.80 × 10^{-3} (mol dm^{-3}) **Calculation of K_c and units** **(3 marks)** $K_c = \frac{[I_3^-(aq)]}{[I_2(aq)] \times$ = 104 ✓ **Must be 3 SF** dm^3 mol^{-1} **OR** mol^{-1} dm^3 ✓	4	***FULL ANNOTATIONS MUST BE USED*** ..... Throughout, at least **3SF** but **ALLOW** absence of trailing zeroes e.g. for 9.80 × 10^{-3}**ALLOW** 9.8 × 10^{-3} **FOR I^-** 0.4702, **ALLOW** 0.47(0) (mol dm^{-3}) still → 104 for calc State symbols **not** required in K_c expression **ALLOW ECF** from incorrect concentrations Any **ECF** value **MUST** be to **3 SF** for K_c value ..... **COMMON ERRORS** **104.2 → 104.2109741 (calc)** > *3 SF* **2 marks + units** **521** *no × 5 for concs* **2 marks + units** **521.1 → 521.0548703** as above and > 3SF **1 mark + units** **2610** ÷ *5 instead of × 5 for concs* **2 marks + units** **9.60 × 10^{-3}** K_c upside down, correct concs **2 marks + units** **1.92 × 10^{-3}** K_c upside down, no × *5 for concs* **1 mark + units** **NOTE**: With K_c upside down, units become mol dm^{-3} by **ECF** **Examiner's Comments** This question was about equilibrium, set in the context of the solubility of iodine.

					Most candidates are comfortable with calculations of equilibrium constants. The correct numerical answer of 104 and units of $dm^3\ mol^{-1}$ were seen often. The commonest calculation error was use of the equilibrium moles, rather than concentrations, giving 521. This question asked for the final value to be expressed to the most appropriate number of significant figures. Candidates should use the least significant number of significant figures in the provided data, in this case 3. Many candidates lost a mark by using more than 3 significant figures (e.g. 104.2 and 104.21). Answer: $K_c = 104\ dm^3\ mol^{-1}$
	b		Ag^+ / silver nitrate reacts with I^- to form AgI / silver iodide **OR** $Ag^+ + I^- \rightarrow AgI$ ✓ yellow precipitate / solid forms ✓ **Equilibrium 2** shifts to the left ✓ **Equilibrium 1** shifts to left **AND** I_2 comes out of solution / less I_2 dissolves / I_2 precipitates / black solid / grey solid / violet solid ✓	4	***FULL ANNOTATIONS MUST BE USED*** ..... **DO NOT ALLOW** cream **OR** cream73–yellow **ALLOW** just 'yellow' if supported by AgI(s) somewhere **Examiner's Comments** This question was about equilibrium, set in the context of the solubility of iodine. This part required candidates to apply their knowledge and understanding of equilibria to a novel situation. Candidates were expected to predict that $Ag^+(aq)$ and $I^-(aq)$ ions would react together to form AgI(s), a yellow precipitate, shifting equilibrium 2 to the left. Equilibrium 1 would then shift to the left forming solid iodine. Responses in terms of equilibrium 2 were seen far more often than for Equilibrium 1.
			Total	**8**	
3	i		 **ALLOW** skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous, e.g. 	**1**	**ALLOW**  **OR**  Structure must include OH as part of COOOH group **ALLOW** $-O^-\ H^+$ in structure **Examiner's Comment:** This part was attempted well, with many providing a structure containing the correct COOOH functional group. The mark scheme did allow alternatives provided that the three O atoms were bonded to the C atom, e.g. $H_3C\text{-}O\text{-}COOH$
		i i	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 0.023(125) (mol) award	**3**	**If there is an alternative answer, check for any ECF credit** **……** **ALLOW** $0.37 = \frac{[CH_3COOOH]}{0.500 \times 0.500}$

		3 marks for calculation …… …… …… ***K_c expression*** $(K_c =) \frac{[CH_3C($ $[H_2O_2]\,[C$ **[CH_3COOH]** = 0.37 × 0.500 × 0.500 = 0.0925 (mol dm^{-3}) ✓ *Subsumes K_c expression* ***n*(CH₃COOH)** $= 0.0925 \times \frac{250}{1000}$		**ALLOW ECF** but **ONLY** if 0.37 **AND** 0.5 × 0.5 have been used **Common errors** **0.076** **2 marks** *Use of $[CH_3COOOH]^2$* **0.675** **2 marks** *Use of 0.5 for $[H_2O]$ on K_c* **0.169** **2 marks** *Inverted K_c* **0.338** **1 mark** *Inverted K_c AND 0.5 for $[H_2O]$* **5.78×10^{-3}** **2 marks** $\times \frac{250}{1000}$ *before $[CH_3COOH]$* **Examiner's Comment:** Many candidates obtained the correct answer but water was often seen in the K_c expression. Candidates then assigned arbitrary values to the concentration of the water, often the same as CH_3COOH, unity, or even 55.6 from 1000/18. The mark scheme allowed some credit by use of error carried forwards. Answer: 0.023 mol
		Total	**4**	
4	a	$K_c = \frac{[NO_2]^2}{[NO]^2\,[O_2]}$ Units = $dm^3\ mol^{-1}$ ✓	**2**	Must be square brackets **IGNORE** state symbols **ALLOW** $mol^{-1}\ dm^3$ **ALLOW** mol dm^{-3} as ECF from inverted K_c expression **Examiner's Comments** The expression and the units were almost universally known by the candidates.
	b	**FIRST CHECK THE ANSWER ON THE ANSWER LINE IF answer = 1.2 (mol) award 4 marks** **Unless otherwise stated, marks are for correctly calculated values.**	**4**	***ANNOTATIONS MUST BE USED*** For **all** parts, **ALLOW** numerical answers from 2 significant figures up to the calculator value Ignore rounding errors after second significant figure 1st mark is for realising that concentrations need to be calculated. **ALLOW ECF** **Correct numerical answer with no working would score all previous calculation marks**

			Working shows how values have been derived. $[NO] = \frac{0.40}{4.0} =$ **AND** $[O_2] = \frac{0.80}{4.0} = 0$ $[NO_2]^2 = 45 \times 0.102 \times 0.20$ **OR** = 0.09(0) ✓ $[NO_2] = \sqrt{(45 \times 0.10^2 \times 0.20)}$ **OR** = 0.3(0) (mol dm^{-3}) ✓ amount $NO_2 = 0.30 \times 4 = 1.2$ (mol) ✓		Making point 2 subsumes point 1 Making point 3 subsumes points 2 and 1 Common errors 9.6 = 3 marks mol of NO and O_2 used 0.36 = 3 marks mol of NO_2 calculated from $[NO_2]^2$ 2.4 = 2 marks mol of NO and O_2 used and no mol of NO_2 calculated **Examiner's Comments** There were three steps to this calculation: Conversion of molar quantities of NO and O_2 to molar concentrations. Insertion into the K_c expression and determination (via a square root calculation) of the molar concentration of NO_2. Conversion of the molar concentration of NO_2 to a molar quantity. Steps 1 and/or 3 of the calculation were occasionally omitted but if the calculation was presented in a coherent manner, even here, partial credit was awarded.
			Total	**6**	