Question			Answer	Marks	Guidance
1	(a)		$(K_c =)\ \dfrac{[C_2H_2]\,[H_2]^3}{[CH_4]^2}$ ✓	1	Square brackets are **essential** State symbols **not** required. **IGNORE** incorrect state symbols
	(b)	(i)	amount of $H_2 = 3 \times 0.168$ $= 0.504$ (mol) ✓	1	

	(b)	**(ii)**	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 0.153 $mol^2\ dm^{-6}$, award **3 marks** **IF** answer = 0.153 with incorrect units, award **2 marks** --- **IF answer from 3(b)(i) for $n(H_2) \neq 0.504$, mark by ECF.** **Equilibrium concentrations** (from $n(H_2) = 0.504$ mol dm^{-3}) $[CH_4] = 2.34 \times 10^{-2}$ (mol dm^{-3}) **AND** $[C_2H_2] = 4.20 \times 10^{-2}$ (mol dm^{-3}) **AND** $[H_2] = 0.126$ (mol dm^{-3}) ✓ **Calculation of K_c and units** $K_c = \frac{4.20\times10^{-2}\times(0.126)^3}{(2.34\times10^{-2})^2} = 0.153$ ✓ $mol^2\ dm^{-6}$ ✓ **3 significant figures** are required	**3**	***FULL ANNOTATIONS MUST BE USED*** --- **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below --- **ALLOW** ÷ by 4 of equilibrium amounts in all expressions, i.e. **ALLOW** $[CH_4] = \frac{9.36\times10^{-2}}{4}$ mol dm^{-3} **AND** $[C_2H_2] = \frac{0.168}{4}$ mol dm^{-3} **AND** $[H_2] = \frac{0.504}{4}$ mol dm^{-3} ✓ **ALLOW ECF** from incorrect concentrations or from moles From moles: 9.36 $\times 10^{-2}$, 0.168 and 0.504, $K_c = 2.45$ by **ECF** **ALLOW** $dm^{-6}\ mol^2$ **DO NOT ALLOW** mol^2/dm^6 **ALLOW ECF** from incorrect K_c expression for both calculation and units --- **COMMON ECF** From **3(b)(i)** answer of 0.1404, $K_c = 3.32 \times 10^{-3}$ 2 marks + units $K_c = 0.0531$ No ÷ 4 throughout 1 mark + units
	(b)	**(iii)**	**Initial amount of CH_4** amount of $CH_4 = 9.36 \times 10^{-2} + 2 \times 0.168$ = 0.4296 **OR** 0.43(0) (mol) ✓	**1**	**NO ECF** possible (all data given in question)

(c)

Change	K_c	Equilibrium amount of C_2H_2 / mol	Initial rate
temperature increased	greater	greater	greater
smaller container	same	smaller	greater
catalyst added	same	same	greater
	✓	✓	✓

3

Mark by **COLUMN**

ALLOW obvious alternatives for greater/smaller/same, e.g.
increases/decreases;
more/less

(d)

ONE mark only
USE ONE TICK ONLY ✓
from **TWO** uses:

1. fuel cells
2. manufacture of margarine
OR hydrogenation of alkenes/unsaturated fats/unsaturated oils/unsaturated molecules
3. making of ammonia **OR** Haber process
4. making of HCl/hydrochloric acid
5. making of methanol

1

IGNORE just 'fuel'
IGNORE hydrogenation of margarine
ALLOW hydrogenation of fats/oils

DO NOT ALLOW explosives **OR** fertilisers

Total **10**

Question			er	Marks	Guidance
2	(a)		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 16.8 with 'no units', award **5 marks** --- At equilibrium, $n(I_2)$ **OR** $[I_2(g)]$ $= 4.00 \times 10^{-3} - 1.70 \times 10^{-3} = 2.30 \times 10^{-3}$ (mol / mol dm^{-3}) ✓ n(HI) **OR** [HI(g)] $= 2 \times 1.70 \times 10^{-3} = 3.40 \times 10^{-3}$ (mol / mol dm^{-3}) ✓ (K_c =) $\frac{(3.40 \times 10^{-3})^2}{3.00 \times 10^{-4} \times 2.30 \times 10^{-3}}$ ✓ **IGNORE** $K_c = \frac{[HI]^2}{[H_2]\,[I_2]}$ = 16.8 (**3 SF** required) ✓ no units ✓	5	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below --- **ANNOTATE WITH TICKS AND CROSSES, etc** **ALLOW ECF** throughout For **all** parts, **ALLOW** numerical answers from 3 significant figures up to the calculator value **ALLOW** omission of trailing zeroes, i.e. 3.40 as 3.4 but final numerical answer for K_c must be to 3 SF **ALLOW ECF** using incorrect values for $[I_2]$ **AND** [HI] **BUT** $[H_2]$ in K_c expression must be 3.00×10^{-4} (given in Q) **ALLOW ECF** from incorrect K_c expression for calculation to 3 SF and units **For 'no units' ALLOW 'none' (ORA) OR '—'** **DO NOT ALLOW** space to be left blank **Common errors:** Use of 1.70×10^{-3} for n(HI) (no factor of x 2) K_c = 4.19 (3SF) and no units: 4 marks Use of K_c expression used is upside down K_c = 0.0597 (3SF) and no units: 4 marks No square for $[HI]^2$ K_c = 4930 and dm^3 mol^{-1} 4 marks **Note:** different ECF units

<table>
<tr><th colspan="3">Question</th><th>er</th><th>Marks</th><th>Guidance</th></tr>
<tr><td></td><td>(b)</td><td>(i)</td><td>
<table>
<tr><th></th><th>$H_2(g)$</th><th>$I_2(g)$</th><th>I(g)</th></tr>
<tr><td>greater</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>smaller</td><td></td><td>✓</td><td></td></tr>
<tr><td>the same</td><td></td><td></td><td></td></tr>
</table>
Each column should have only one box ticked

Correct ticks for $H_2(g)$ AND $I_2(g)$ AND HI(g) two marks ✓✓
i.e. all three columns correct

Ticks for two of $H_2(g)$, $I_2(g)$ and HI(g) correct one mark ✓
i.e. two columns correct
</td><td>2</td><td>DO NOT ALLOW more than one box ticked in a column (response is a CON)</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>K_c is smaller
AND
(forward) reaction is exothermic OR ΔH is negative ✓</td><td>1</td><td>Link to ΔH/exothermic essential
ALLOW reverse reaction is endothermic
DO NOT ALLOW equilibrium shifts to the right (CON)</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>K_c is the same
AND
K_c is temperature dependent OR K_c is not changed by pressure ✓</td><td>1</td><td>ALLOW K_c is only changed by temperature
IGNORE same number of moles on both side</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>9</td><td></td></tr>
</table>

Question			Answer	Marks	Guidance
3	(a)	(i)	(K_c =) $\frac{[CO_2]^2\ [N_2]}{[CO]^2\ [NO]^2}$ ✓	1	Square brackets required for **ALL** four concentrations
		(ii)	$dm^3\ mol^{-1}$ ✓	1	**ALLOW** $mol^{-1}\ dm^3$

Question			Answer	Marks	Guidance
	(a)	(iii)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 0.95 award **4 marks** --- ***Equilibrium amounts:*** $n(CO) = 0.46 - 0.20 = 0.26$ mol ✓ $n(CO_2) = 0.2(0)$ mol ✓ $n(N_2) = 0.1(0)$ mol ✓ **K_c calculation** **Must** use calculated equilibrium amounts **AND** 0.25 $(K_c =) \dfrac{0.20^2 \times 0.10}{0.26^2 \times 0.25^2} = 0.95$ (dm^3 mol^{-1}) ✓	4	***ANNOTATIONS MUST BE USED*** **IF** there is an alternative answer, apply **ECF** by checking working for intermediate marks --- **APPLY ECF** from incorrect starting $n(CO)$ By **ECF**, $n(N_2) = n(CO_2)/2$ For **all** parts, **ALLOW** numerical answers from 2 significant figures up to the calculator value **Correct numerical answer with no working scores 4 marks** **ALLOW** calculator value: 0.946745562 down to 0.95 (2SF), correctly rounded, e.g. 0.947 **IGNORE** units, even if incorrect --- **Common errors** 1.89 3 marks use of $n(N_2) = 0.2(0)$ mol $(K_c =) \dfrac{0.20^2 \times 0.20}{0.26^2 \times 0.25^2} = 1.893491124$ (dm^3 mol^{-1}) ✓ 1.29 3 marks 0.45 and 0.46 swapped over $n(CO) = 0.45 - 0.21 = 0.24$ mol ✓ $n(CO_2) = 0.21$ mol ✓ $n(N_2) = 0.105$ mol ✓ $(K_c =) \dfrac{0.21^2 \times 0.105}{0.24^2 \times 0.25^2} = 1.28625$ (dm^3 mol^{-1}) ✓ 1.024 3 marks 0.45 used twice $n(CO) = 0.45 - 0.20 = 0.25$ mol ✓ $n(CO_2) = 0.2(0)$ mol ✓ $n(N_2) = 0.1(0)$ mol ✓ $(K_c =) \dfrac{0.20^2 \times 0.10}{0.25^2 \times 0.25^2} = 1.024$ (dm^3 mol^{-1}) ✓ 1.185 3 marks 0.46 used twice $n(CO) = 0.46 - 0.21 = 0.25$ mol ✓ $n(CO_2) = 0.21$ mol ✓ $n(N_2) = 0.105$ mol ✓ $(K_c =) \dfrac{0.21^2 \times 0.105}{0.25^2 \times 0.25^2} = 1.185408$ (dm^3 mol^{-1}) ✓

Question			Answer	Marks	Guidance
	(a)	(iv)	Mark **ECF** from **(iii)** **IF** K_c from **(iii)** < 1 equilibrium to left/towards reactants **OR** **IF** K_c from **(iii)** > 1 equilibrium to right/towards products ✓	1	**First look at K_c value for (iii) at bottom of cut** **----------** **ALLOW** favours reverse reaction For correct K_c value in **(iii)** of 0.95, **ALSO ALLOW** equilibrium position near to centre ✓
	(b)	(i)	K_c has decreased **AND** ΔH is negative **OR** (forward) reaction is exothermic ✓	1	Statement **AND** reason required for mark **ALLOW** for reason: reverse reaction is endothermic
		(ii)	**Effect of *T* and *P* on equilibrium** (increased) temperature shifts equilibrium to left **AND** (increased) pressure shifts equilibrium to right **AND** fewer (gaseous) moles on right-hand side ✓ **Overall effect on equilibrium** Difficult to predict relative contributions of two opposing factors ✓	2	**Reason ONLY** required for pressure Temperature and ΔH had been *required in (i)* **ALLOW** ratio of (gas) moles is 4:3 **ALLOW** opposing effects may not be the same size **ALLOW** effects could cancel each other out **ALLOW** effects oppose one another **DO NOT ALLOW** just 'it is difficult to predict equilibrium position' (*in question*) *For the 2nd mark, we are assessing the idea that we don't know which factor is dominant*
			Total	**10**	

Question			Answer	Marks	Guidance
4	(a)		$MnO_2 + 4OH^- \longrightarrow MnO_4^{2-} + 2H_2O$ **+ $2e^-$** ✓ $3H_2O + ClO_3^-$ **+ $6e^-$** ✓ $\longrightarrow 6OH^- + Cl^-$	2	**ALLOW** 'e': i.e. – sign not required
	(b)		**Role of CO_2** CO_2 reacts with H_2O forming an acid **OR** carbonic acid/H_2CO_3 forms **OR** CO_2 is acidic ✓ **Equation involving OH^-** $H_2CO_3 + OH^- \longrightarrow H_2O + HCO_3^-$ **OR** $H_2CO_3 + 2OH^- \longrightarrow 2H_2O + CO_3^{2-}$ **OR** $CO_2 + OH^- \longrightarrow CO_3^{2-} + H^+$ **OR** $CO_2 + OH^- \longrightarrow HCO_3^-$ **OR** $CO_2 + 2OH^- \longrightarrow CO_3^{2-} + H_2O$ **OR** $H^+ + OH^- \longrightarrow H_2O$ ✓ **Effect on equilibrium with reason** equilibrium shifts to right **AND** to restore OH^- ✓	3	***ANNOTATIONS MUST BE USED*** --- **ALLOW** equation: $CO_2 + H_2O \longrightarrow H_2CO_3$ **OR** $CO_2 + H_2O \longrightarrow H^+ + HCO_3^-$ **OR** $CO_2 + H_2O \longrightarrow 2H^+ + CO_3^{2-}$ **ALLOW** for 'restores OH^-' the following: 'makes more OH^-', 'OH^- has been used up' **DO NOT ALLOW** just 'equilibrium shifts to right'

Question	Answer	Marks	Guidance
(c)	**FOLLOW through stages to mark** --- **Moles in titration** $n(KMnO_4) = 0.0200 \times \frac{26.2}{1000} = 5.24 \times 10^{-4}$ mol ✓ $n(SO_3^{2-}) = 1.31 \times 10^{-3}$ mol ✓ **Scaling** $n(SO_3^{2-})$ in original 100 cm^3 $= 4 \times 1.31 \times 10^{-3} = 5.24 \times 10^{-3}$ mol ✓ **Mass** Mass of Na_2SO_3 in sample $= 126.1 \times 5.24 \times 10^{-3}$ g = 0.660764 g ✓ **Percentage** % $Na_2SO_3 = \frac{0.660764}{0.720} \times 100 = 91.8\%$ ✓	5	***ANNOTATIONS MUST BE USED*** ***AT LEAST 3 SF for each step*** --- **ECF** 2.5 x answer above **ECF** 4 x answer above **ECF** 126.1 x answer above **ALLOW** 0.661 g up to calculator value **ECF** $\frac{\text{calculated mass above}}{0.720} \times 100$ **ALLOW** 91.8% (1 DP) up to calculator value of 91.77277778 i.e. **DO NOT ALLOW** 92%
	ALLOW alternative approach based on theoretical content of Na_2SO_3 for last 2 marks **Theoretical amount, in moles, of Na_2SO_3 in sample** $n(Na_2SO_3) = \frac{0.720}{126.1} = 5.71 \times 10^{-3}$ mol ✓ **Percentage** % $Na_2SO_3 = \frac{5.24 \times 10^{-3}}{5.71 \times 10^{-3}} \times 100 = 91.8\%$ ✓		**COMMON ERRORS**: 36.8(1)% 4 marks no 2.5 factor 22.9(4)% 4 marks no scaling by 4 9.18% 3 marks no 2.5 and no x 4 Watch for random ECF %s for % from incorrect $M(Na_2SO_3)$, e.g. use of $M(SO_3^{2-})$ = 80.1 giving 58.3%
	Total	**10**	

Question			er	Mark	Guidance
5	(a)		**Temperature**: (Forward) reaction is exothermic **OR** gives out heat **OR** reverse reaction is endothermic **OR** takes in heat ✓ **Pressure**: Right-hand side has fewer number of (gaseous) moles ✓ **ORA** **Equilibrium** Lower temperature/cooling **AND** increasing pressure shifts (equilibrium position) to the right ✓	**3**	**ANNOTATE WITH TICKS AND CROSSES, etc** **ALLOW** K_c increases at lower temperatures **3rd mark** is for stating that **BOTH** low temperature and high pressure shift equilibrium to the right (Could be separate statements) **Note: ALLOW** suitable alternatives for 'to right', e.g.: towards NO_2 **OR** towards products **OR** in forward direction **OR** increases yield of NO_2/products **ALLOW** 'favours the right', as alternative for 'shifts equilibrium to right' **IGNORE** responses in terms of rate
	(b)		$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$ ✓ $2NO_2 + H_2O \longrightarrow HNO_3 + HNO_2$ ✓	**2**	**ALLOW** multiples, e.g. $2NH_3 + 2½O_2 \longrightarrow 2NO + 3H_2O$ **ALLOW** $\rightleftharpoons$ **OR** $\rightarrow$ in equations
	(c)	(i)	$(K_c =) \frac{[NO_2]^2}{[NO]^2\,[O_2]}$ ✓	**1**	Square brackets are **essential**

Question			er	Mark	Guidance
	(c)	(ii)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 45 dm^3 mol^{-1}, award **5 marks** **IF** answer = 45 with incorrect units, award **4 marks** --- **Equilibrium moles** 0.60 mol NO_2 ✓ 0.20 mol NO **AND** 0.40 mol O_2 ✓ **Equilibrium concentrations (equilibrium moles ÷ 2)** $[NO_2]$ = 0.30 mol dm^{-3} **AND** [NO] = 0.10 mol dm^{-3} **AND** $[O_2]$ = 0.20 mol dm^{-3} ✓ **Calculation of K_c and units** $K_c = \frac{0.30^2}{0.10^2 \times 0.20}$ = 45 ✓ dm^3 mol^{-1} ✓	**5**	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below --- **ANNOTATE WITH TICKS AND CROSSES, etc** **ALLOW ECF** throughout ***Alternative route if concs NO and O_2 calculated at start:*** **initial concentrations:** 0.40 mol dm^{-3} NO **AND** 0.35 mol dm^{-3} O_2 ✓ **Equilibrium concentrations:** $[NO_2]$ = 0.30 mol dm^{-3} ✓ [NO] = 0.10 mol dm^{-3} **AND** $[O_2]$ = 0.20 mol dm^{-3} ✓ For units, **ALLOW** mol^{-1} dm^3 **ALLOW ECF** using any incorrect values for **concentrations OR moles** of NO, O_2 AND NO_2 For **ECF**, **ALLOW** 2 significant figures up to calculator value correctly rounded **ALLOW ECF** from incorrect K_c expression for both calculation and units **Common ECFs worth less than 5 marks:** **22.5** not ÷2 3 marks + unit mark **1.61** 0.6 for NO_2 but 0.8 for NO and 0.7 for O_2 No mark for moles NO and O_2 3 marks + unit mark **0.804** As above but also no ÷2 No mark for moles NO and O_2 **AND** ÷2 2 marks + unit mark
			Total	**11**	

Question			Expected answers	Marks	Additional guidance
6	a		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** numerical value = 7.81×10^{-2} **OR** 0.0781 **AND** $[N_2O_4]$ = 0.2(00 mol dm^{-3} **AND** $[NO_2]$ =1.6(0), award 4 calculation marks and check for the mark for correct units --- **Equilibrium amount of N_2O_4** 0.400 mol N_2O_4 ✓ **Equilibrium concentrations** $[N_2O_4]$ = 0.200 mol dm^{-3} **AND** $[NO_2]$ = 1.60 mol dm^{-3} ✓ **K_c expression** $K_c = \frac{[N_2O_4]}{[NO_2]^2}$ (Square brackets **essential**) **OR** $\frac{0.200}{1.60^2}$ ✓ **Calculation** = 7.81×10^{-2} ✓ **Units** $dm^3\ mol^{-1}$ ✓	**5**	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below --- ***ANNOTATIONS MUST BE USED*** --- **ALLOW ECF** for equilibrium amounts ÷ 2 **ALLOW** 3 SF up to calculator value of 0.078125 correctly rounded **ALLOW ECF** using calculated equilibrium concentrations For units, **ALLOW** $mol^{-1}\ dm^3$ **ALLOW ECF** from incorrect K_c expression
			Common errors for 4 calculation marks **– Remember there is another mark for unit** 7.81×10^{-2} from wrong concs ✓✓ + units *look for $[N_2O_4]$ = 0.8 **AND** $[NO_2]$ = 3.2* 0.03906 ✓ ✓✓ + units *no conversion of both moles to concentration* 0.01953 ✓✓✓ + units *no conversion of NO_2 moles to concentration* 0.3125 ✓✓✓ + units *moles of N_2O_4 taken as 3.2/2* 12.8 ✓✓✓ + units: mol dm^{-3} *K_c expression upside down* 0.125 ✓✓✓ + units; **none** *$[NO_2]$ instead of $[NO_2]^2$* ***'No units' MUST be stated*** **0.15625 MARK BY ECF as there are many different routes to this answer**		

Question			Expected answers	Marks	Additional guidance
	b		***Each marking point is independent***		
			Effect on K_c K_c does not change (with pressure) ✓		**ALLOW** K_c **only** changes with temperature **IGNORE** K_c changes with temperature
			Comparison of conc terms after increase in pressure $[NO_2]^2$ increases more than $[N_2O_4]$ **OR** concentration (term) on bottom (of K_c) increases more that concentration (term) on top (of K_c) ✓		**ALLOW** $\frac{[N_2O_4]}{[NO_2]^2} < K_c$ **OR** $\frac{[N_2O_4]}{[NO_2]^2}$ decreases **IGNORE** K_c decreases
			Changes in concentrations linked to K_c (amount /concentration of) N_2O_4 increases **AND** (amount /concentration of) NO_2 decreases **AND** to maintain/restore ***K_c*** ✓	**3**	**ALLOW** top of K_c expression increases and bottom decreases until K_c is reached **ALLOW** equilibrium shifts to right to maintain/restore K_c **IGNORE** just 'restores equilibrium' ***K_c* IS REQUIRED** **IGNORE** just 'equilibrium shifts to right **IGNORE** le Chatelier response: 'equilibrium shifts to right' because there are fewer moles of gas on right-hand side
			Total	**8**	