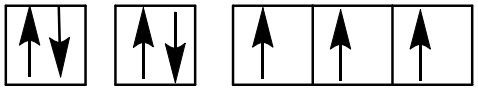
Mark Scheme

Question	Answer	Marks	Guidance
1	D	**1**	
2	D	**1**	

Mark Scheme

Question			Answer	Marks	Guidance
3	(a)		 ✓ 2s 2p ✓	2	**ALLOW** half headed arrows
	(b)		The forward reaction is exothermic, so an increase in temperature favours the backward reaction (*owtte*) ✓ therefore there will be more N_2 and H_2 **OR** less NH_3 in the equilibrium mixture, **AND** therefore the value of the equilibrium constant will decrease (*owtte*) ✓	2	**ALLOW** names of compounds **ALLOW** reactants/product instead of compounds 2nd mark only available if deduced from 1st mark **ALLOW ECF** for 2nd mark
	(c)		**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 2.37×10^{-6} kPa^{-2} award 5 marks **IF** answer = 2.37×10^{-6} with incorrect units award 4 marks At equilibrium, $n(H_2) = 0.300$ (mol) **AND** $n(NH_3) = 0.100$ (mol) ✓ $p(N_2) = \frac{0.400}{0.800} \times 500 = 250$ kPa **AND** $p(H_2) = \frac{0.300}{0.800} \times 500 = 187.5$ kPa **AND** $p(NH_3) = \frac{0.100}{0.800} \times 500 = 62.5$ kPa ✓ $K_p = \frac{p(NH_3)^2}{p(N_2) \times p(H_2)^3} = \frac{62.5^2}{250 \times 187.5^3}$ ✓ $= 2.37 \times 10^{-6}$ ✓ kPa^{-2} ✓	5	Final answer must be correct and have the correct units to score all five marks **ALLOW** calculator value for K_p correctly rounded to three or more significant figures. **If there is an alternative answer, check to see if there is any ECF credit possible using working below** Correct values substituted into correct expression for K_p gains first three marks.

Mark Scheme

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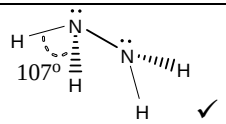
	(d)		**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 2580 (tonnes) award 3 marks $n(NH_3) = \frac{1.96 \times 10^{10}}{24}$ **OR** 8.167×10^8 (mol) **AND** $n(H_2) = \frac{8.167 \times 10^8}{2} \times 3 = 1.225 \times 10^9$ (mol) ✓ Mass of $H_2 = \frac{2.450 \times 10^9}{1 \times 10^6} = 2450$ (tonnes) ✓ Mass of H_2 for 95% yield = $\frac{2450 \times 100}{95} = 2580$ (tonnes) ✓	**3**	**If there is an alternative answer, check to see if there is any ECF credit possible using working below** **ALLOW** 2.58×10^3 tonnes **AW** 100% yield = 2.063×10^{10} dm^3 ✓ Amount of $NH_3 = 8.596 \times 10^8$ mol **AND** Amount of $H_2 = 1.289 \times 10^9$ mol ✓ Mass of H_2 = 2580 (tonnes) ✓ **ALLOW** 2579 (tonnes) (calculator answer rounded to nearest whole number)
	(e)	**(i)**	$2NH_3 + NaOCl \rightarrow N_2H_4 + NaCl + H_2O$ ✓	**1**	
		(ii)	 ✓ Bond angle 107° ✓	**2**	Diagram must attempt to show geometry around the nitrogen atom to be pyramidal **ALLOW** 106–108°
			Total	**15**	

Mark Scheme

Question	Answer	Marks	Guidance
4	B	1	**ALLOW** 0.426 in the box

Mark Scheme

Question			Answer	Marks	Guidance
5	(a)		$\Delta G = \Delta H - T\Delta S$ linked to $y = mx + c$ (somewhere) ✓ **gradient** = $-\Delta S$ ✓ **P:** ΔH / enthalpy change ✓ **Q**: (temperature) for reaction to be feasible/unfeasible **OR** (temperature) at which feasibility changes ✓	**4**	Could be: $\Delta G = -\Delta S\, T + \Delta H$ – sign required ALLOW ΔS = *–gradient* **ALLOW** 'point of feasibility' For Feasibility: **ALLOW** can take place/happen **OR** is spontaneous **IGNORE** 'minimum/maximum temperature'
	(b)	(i)	(Species have) different states/phases ✓	**1**	
		(ii)	(K_p =) $p(CO(g))^4$ ✓	**1**	Allow species without state symbols and without brackets, e.g. $p_{CO}{}^4$, $pp CO^4$, $P CO^4$, $p(CO^4)$ etc. **DO NOT ALLOW** square brackets
		(iii)	ΔG *at 25 C* $\Delta G = \Delta H - T\Delta S = 676.4 - (298 \times 0.7031)$ = (+) 467 (kJ mol^{-1}) **OR** (+) 466876 (J mol^{-1}) ✓ *Non-feasibility statement* Non-feasible when $\Delta G > 0$ **OR** $\Delta G > 0$ **OR** $\Delta H > T\Delta S$ ✓ *Minimum temperature* minimum temperature = $\frac{\Delta H}{\Delta S} = \frac{676.4}{0.7031}$ = 962(.0) K ✓	**3**	**IGNORE** units **ALLOW** (+) 467 up to calculator value of 466.8762 correctly rounded ECF for any positive value determined in M1 **ALLOW** 962 up to calculator value of 962.0253165 correctly rounded

Mark Scheme

Question			Answer	Marks	Guidance
		(iv)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = –110.5, Award 3 marks.** --- **Correct expression** $-13.5 = (4 \times -393.5) - (-1118.5 + 4 \times \Delta_f H(CO))$ ✓ **Correct subtraction using ΔH and $\Delta_f H(Fe_3O_4)$** $4 \times \Delta_f H(CO) = (4 \times -393.5) - (-1118.5) + 13.5$ $= -$**442(.0)** (kJ mol^{-1}) ✓ **Calculation of $\Delta_f H$(CO) formation** $\Delta_f H(CO) = -\frac{442}{4}$ = **–110.5** (kJ mol^{-1}) ✓	3	**For answer,** **ALLOW –111 (kJ mol^{-1})** --- **NOTE:** IF any values are omitted, **DO NOT AWARD** any marks. e.g. –393.5 OR –13.5 may be missing --- **Common errors** **(+)110.5** *wrong/omitted sign* **2 marks** **(+)184.625 / 184.63 / 184.6 / 185** *No $4CO_2$* **2 marks** **(+)738.5 / 739** *No $4CO_2$ and no CO/4* **1 mark** **–117.25 / –117.3 / –117** *Wrong cycle* **2 marks** **–469** *Wrong cycle, no CO/4* **1 mark** **(+)177.875 / 177.88 / 177.9 / 178** *Wrong cycle, no $4CO_2$* **1 mark** **–360.5** *Used 118.5* **2 marks** Any other number: **CHECK** for **ECF** from 1st marking point for expressions using **ALL** values with **ONE** error only e.g. one transcription error:, e.g.395.3 for 393.5
			Total	**12**	

Mark Scheme

Question			Answer	Marks	Guidance
6	(a)		**Conditions** Low/decreased pressure **AND** high/increased temperature ✓ **Pressure**: Right-hand/product side has more (gaseous) moles/molecules **OR** left-hand side/reactant side has fewer (gaseous) moles/molecules ✓ **Temperature**: (Forward) reaction is endothermic / takes in heat **OR** reverse reaction is exothermic / gives out heat ✓	**4**	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **DO NOT ALLOW** more atoms on right-hand side **OR** fewer atoms on left-hand side. **DO NOT ALLOW** incorrect shift direction
			Low pressure gives a slow rate **OR** High temperature uses a large amount of energy/fuel ✓		**ORA** **IGNORE** 'expensive' **IGNORE** use of catalyst
	(b)	(i)	(K_c =) $\frac{[SO_3]^2}{[SO_2]^2\,[O_2]}$ ✓ Units: $dm^3\ mol^{-1}$ ✓	**2**	**IGNORE** state symbols in K_c expression, even if wrong. For units, **ALLOW** $mol^{-1}\ dm^3$ **DO NOT ALLOW** dm^3/mol **NOTE**: If K_c upside down, units become $mol\ dm^{-3}$ by **ECF** No other **ECF** allowed for units.

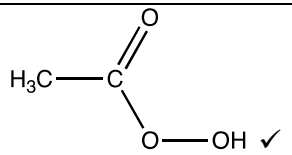
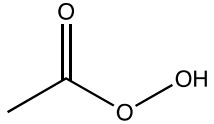
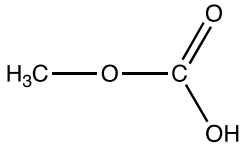
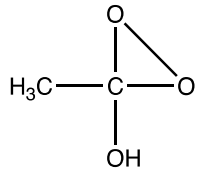
Mark Scheme

Question			Answer	Marks	Guidance
		(ii)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 2.45, Award **4 marks.** --- **Equilibrium concentrations (moles × 2.5) 1 MARK** SO_2 = 0.135 (mol dm^{-3}) **AND** O_2 = 0.0675 (mol dm^{-3}) ✓ **Calculation of [SO_3(g)] 2 MARKS** $[SO_3] = \sqrt{(K_c \times [SO_2]^2 \times O_2)}$ **OR** $\sqrt{((3.045 \times 10^4) \times 0.135^2 \times 0.0675)}$ ✓ = 6.12039291 (mol dm^{-3}) ✓ *Answer scores both [SO_3] marks automatically* **Calculation of *n*(SO_3) in 400 cm^3 1 MARK** *n*(SO_3) = 6.12039291/2.5 = 2.45 (mol) ✓ ***3SF required (Appropriate number)***	**4**	**FULL ANNOTATIONS NEEDED** **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below --- **ALLOW ECF** from incorrect concentrations of SO_2 and/or O_2 **ALLOW ECF** from incorrect [SO_3] **ALLOW 3 SF**, 6.12, up to calculator value of 6.12039291 correctly rounded. **Common errors** **37.5 1 mark** *No √for $[SO_3]^2$ and no scaling by 1/2.5* **15.0 2 marks** *No √for $[SO_3]^2$* **0.619 3 marks** *Use of mol of SO_2 and O_2* **1.55 2 marks** *No conc used and Use of mol of SO_2 and O_2*
			Total	**11**	

Mark Scheme

Question			Answer	Marks		Guidance
7	(a)	(i)	*(rate =)* k $[H_2O_2]$ $[I^-]$ ✓ $k = \frac{rate}{[H_2O_2]\,[I^-]} = \frac{2.00 \times 10^{-6}}{0.0100 \times 0.0100} = 0.02(00)$ ✓ units: $dm^3\ mol^{-1}\ s^{-1}$ ✓	**3**		**Square brackets required** **IGNORE** any state symbols **IGNORE** $[H^+]^0$ **ALLOW ECF** from incorrect rate equation **BUT** units must fit with rate equation used **ALLOW** $mol^{-1}\ dm^3\ s^{-1}$ **OR** in any order **NOTE** K_c expression with calculation and units **0 marks**
	(a)	(ii)	Plot graph using ln k **AND** $1/T$ ✓ (Measure) gradient ✓ *Independent mark* $E_a = (-)R \times$ gradient **OR** $(-)8.314 \times$ gradient ✓ • *Independent mark, even if variables for graph are incorrect* • *Subsumes 'gradient' mark*	**3**		**Unless otherwise stated, assume, that ln *k* is on y axis and 1/*T* is on x axis** **IGNORE** intercept **ALLOW** gradient = $(-)\frac{E_a}{R}$ --- **NOTE: ALLOW 'Inverse graph' (special case)** Plot graph of $1/T$ against ln k ✓ (Measure) gradient ✓ *Independent mark* $E_a = (-)\frac{R}{\text{gradient}}$ **OR** $(-)\frac{8.314}{\text{gradient}}$ **OR** gradient = $(-)\frac{R}{E_a}$ ✓ *Subsumes 'gradient' mark*

Mark Scheme

Question			Answer	Marks		Guidance
	(b)		**ALLOW** equilibrium sign in equations provided reactants on left **Reaction of H_2O_2 with MnO_2:** $H_2O_2 + MnO_2 + 2H^+ \rightarrow O_2 + Mn^{2+} + 2H_2O$ ✓ **Reaction of H_2O_2 with Mn^{2+}:** $H_2O_2 + Mn^{2+} \rightarrow MnO_2 + 2H^+$ ✓ **Use of *E* data** Use of *E* data to support equation(s) above or half direction of provided half equations (one including MnO_2) ✓ *Also look for evidence around half equations* MnO_2 regenerated/reformed ✓ *Must be linked to an equation showing MnO_2 as reactant and an equation showing MnO_2 as product*	**4**		**ALLOW** correct multiples **IGNORE** state symbols --- **ALLOW** uncancelled H_2O and H^+ $H_2O_2 + MnO_2 + \mathbf{4}H^+ \rightarrow O_2 + Mn^{2+} + 2H_2O$ **$+ 2H^+$** $H_2O_2 + Mn^{2+}$ **$+ 2H_2O + 2H^+$** $\rightarrow MnO_2 +$ **$4H^+ + 2H_2O$** ***Examples*** • More negative *E* moves to left **ORA** • Reduction half equation to the right **ORA** • Most positive *E* is reduced **ORA** • Calculated *E* cell = +0.81 V (*from top 2*) **OR** *+0.27 V (from bottom 2)* **ALLOW** combining of equations above to show that MnO_2 is used and reformed
	(c)	**(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

Mark Scheme

Question			Answer	Marks		Guidance
	(c)	(ii)	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 0.023(125) (mol) award 3 marks for calculation --- ***K_c expression*** $(K_c =) \frac{[CH_3COOOH]}{[H_2O_2]\,[CH_3COOH]}$ ✓ **$[CH_3COOOH]$** $= 0.37 \times 0.500 \times 0.500 = 0.0925$ (mol dm^{-3}) ✓ *Subsumes K_c expression* ***n*(CH_3COOOH)** $= 0.0925 \times \frac{250}{1000} = 0.023(125)$ (mol) ✓	**3**		**If there is an alternative answer, check for any ECF credit** --- **ALLOW** $0.37 = \frac{[CH_3COOOH]}{0.500 \times 0.500}$ **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 $[CH_3COOOH]$*
			Total	**14**		

Mark Scheme

Question	Answer	Marks	AO element	Guidance
8	B	1	AO1.2	

Mark Scheme

Question			Answer	Marks	Guidance
9	(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
	(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. Working shows how values have been derived.** $[NO] = \frac{0.40}{4.0} = 0.1(0)\ (mol\ dm^{-3})$ **AND** $[O_2] = \frac{0.80}{4.0} = 0.2(0)\ (mol\ dm^{-3})$ ✓ $[NO_2]^2 = 45 \times 0.10^2 \times 0.20$ **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) ✓	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** 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

Mark Scheme

Question			Answer	Marks	Guidance
	(c)	(i)	Exothermic **AND** K_p decreases as temperature increases ✓	1	**ALLOW** K_c for K_p **ALLOW** Equilibrium shifts to left hand side as temperature increases
	(c)	(ii)	***Equilibrium shift*** (Equilibrium position) shifts to right / forward / towards products ✓ ***Effect of increased pressure on K_p expression*** *R*atio (in K_p expression) decreases **OR** Denominator/bottom of K_p expression increases more (than numerator/top) ✓ ***Equilibrium shift (K_p expression)*** Ratio (in K_p expression) increases **to restore K_p** **OR** Numerator/top of K_p expression increases **to restore K_p** ✓	3	**FULL ANNOTATIONS NEEDED** **ALLOW** K_c for K_p throughout the response. **ALLOW** K_p (initially) decreases for second marking point **IF** K_p is seen to be restored later in the process. **ALLOW** more NO_2 / product formed to restore K_p **ALLOW** ratio adjusts to restore K_p
			Total	10	

Mark Scheme

Question			Answer	Marks	Guidance
10	(a)		**TAKE CARE: Correct final answer of –52.3 OR –52.25 can be obtained from two cancelling errors:** • Use of 50 for energy released (no ×2 of 50 for two solutions mixed) • No ÷ 2 in final step **–52.3 OR –52.25 would then be awarded 2 marks out of 4** --- ***Correctly calculates n(succinic acid)*** $= 0.400 \times \frac{50.0}{1000} = 0.02(00)$ (mol) ✓ ***Energy released in J OR kJ*** $= 100.00 \times 4.18 \times 5.0 = 2090$ (J) **OR** 2.090 (kJ) ✓ **Energy released, in kJ or J, for formation of 2 mol H_2O** $\pm \frac{2090}{0.0200} = \pm 104500$ (J) **OR** $\pm \frac{2.090}{0.0200} = \pm 104.5$ **OR** ± 105 (kJ) ✓ **$\Delta_{neut}H$ to 3 or more SF AND correct – sign** $= -\frac{104.5}{2} = -52.3$ **OR** – 52.25 kJ mol^{-1} ✓	**4**	**ALLOW ECF throughout** **DO NOT ALLOW** less than 3 SF **IGNORE** units --- **ALTERNATIVE METHOD** ***n(succinic acid)*** = 0.02(00) (mol) ✓ ***Energy released*** = 2090 (J) **OR** 2.090 (kJ) ✓ ***n*(H₂O) formed** = $2 \times 0.02(00) = 0.04(00)$ (mol) ✓ $\Delta_{neut}H = -\frac{2.090}{0.0400} = -52.3$ **OR** – 52.25 kJ mol^{-1} ✓
	(b)	**(i)**	Titration ✓	**1**	**IGNORE** type of titration
		(ii)	$(CH_2COOH)_2 + 2C_2H_5OH \rightleftharpoons (CH_2COOC_2H_5)_2 + 2H_2O$ ✓	**1**	**ALLOW** → instead of ⇌ sign **ALLOW** molecular formulae or hybrid formulae *Structures provided on QP* e.g. $C_4H_6O_4 + 2C_2H_6O \rightleftharpoons C_8H_{14}O_4 + 2H_2O$

Mark Scheme

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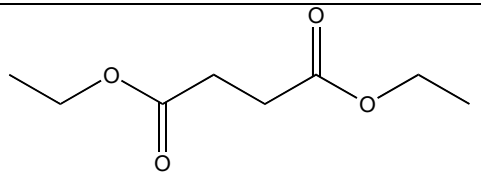
		(iii)	 ✓	**1**	**IGNORE** displayed formulae
		(iv)	Volume cancels **OR** Same number of moles on each side of equation ✓	**1**	**ALLOW** units cancel **ALLOW** (sum of) balancing numbers/coefficients on each side of equation are the same **OR** same number of (moles of) reactants and products **IGNORE** volume is the same; K_c has no units
		(v)	**Moles of equilibrium products** ***1 mark*** $n((CH_2COOC_2H_5)_2)$ = 0.0300 (mol) **AND** $n(H_2O)$ = 0.0600 (mol) ✓ **Moles of C_2H_5OH** ***1 mark*** $n(\mathbf{C_2H_5OH})$ = 0.150 – 0.060 = 0.0900 (mol) ✓ ***K_c* calculated** ***1 mark*** $= \frac{0.03 \times 0.06^2}{0.02 \times 0.09^2} = 0.667$ **OR** 0.67 ✓ **NOTE:** 0.02 must be used for *n*(succinic acid)	**3**	**ALLOW ECF** **ALLOW** 0.66, 0.666, etc. (**2 SF** and more) *Treated as meaning 0.6 recurring* **ALLOW** 2/3 **IGNORE** any units
			Total	**11**	

Mark Schemes

Question			Answer	Marks	AO element	Guidance
11	(a)	(i)	**More** energy is **released** by **forming** bonds than energy **required** when **breaking** bonds **OR** bond enthalpy of bonds being made is higher than bond enthalpy of bonds being broken ✓	1	1.2	Response needs link between **energy**, **breaking** and **making bonds** Eg 'bond breaking is endothermic' **AND** 'bond making is exothermic' **AND** 'exothermic change outweighs endothermic change' **IGNORE** more bonds made than broken
		(ii)	**FIRST CHECK ΔG** **If ΔG = –1010 (kJ mol^{-1}) award first 3 marks** ΔS = (2 × 248 + 2 × 70) – (2 × 206 + 3 × 205) = –391 (J K^{-1} mol^{-1}) **OR** –0.391 (kJ K^{-1} mol^{-1}) ✓ $\Delta G = \Delta H - T\Delta S$ = –1125 – (293 × –0.391) ✓ = –1010 (kJ mol^{-1}) ✓ Feasible **AND** ΔG < 0 **OR** ΔG is negative ✓	4	2.2 ×3 3.2 ×1	**ALLOW** ecf **ALLOW** –1010000 (J mol^{-1}) **ALLOW** 3 SF up to calculator value –1010.437 **Common errors** **ALLOW:** **Two** *calculation* marks for: –1117 to 3 SF up to calculator value of –1117.179865 (use of 20 instead of 293) (+)113438 (kJ mol^{-1}) or 113000, 113400, 113440 (mix of J and kJ) –1008 up to calculator value of –1008.482 (use of T = 298) –1018 up to calculator value of –1018.257 (use of T = 273) **ALLOW ECF** for from incorrect ΔG, eg Non feasible **AND** ΔG > 0 **OR** ΔG is +ve
	a	(iii)	**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = –20 (kJ mol^{-1}) award 3 marks**	3	2.2 ×3	

Mark Schemes

Question			Answer	Marks	AO element	Guidance
			Using Both $\Delta cH^{\ominus}$ values multiplied by 2 $2 \times (-296.8)$ **or** -593.6 **AND** $2 \times (-285.8)$ or -571.6 $(= -1165.2)$ ✓ *Use of –1125 and correctly processed:* $2\Delta_f H(H_2S) = [2 \times (-296.8) + 2 \times (-285.8)] - (-1125)$ $= -40.2$ (kJ mol^{-1}) ✓ *Division by 2* $\Delta_f H(H_2S) = -20$ (kJ mol^{-1}) ✓			First mark may be awarded from data on a cycle **ALLOW** – 20.1(0) **ALLOW ECF:** third mark is for dividing by 2 **and** use of all three values Common errors **Two** marks for (+)20(.1) **ALLOW** ecf if **no** multiplication by two occurred [(–296.8)+(–285.8)]–(–)1125 = (+)542.4 for 2nd mark Leading to $\Delta_f H(H_2S)$ = (+) 271(.2) for 3rd mark **ALLOW** –296.8 –285.8 = – 582.6 for 1st mark if –1125/2 **OR** – 562.5 is seen in 2nd mark
	(b)	**(i)**	$(K_p) = \dfrac{p(SO_3)^2(g)}{p(SO_2(g))^2 \times p(O_2(g))}$ ✓ atm^{-1} ✓	**2**	**1.2 ×2**	**ALLOW** species without state symbols and without brackets. e.g., pSO_3^2, $ppSO_3^2$, PSO_3^2, $p(SO_3)^2$ $(pSO_3)^2$etc. **DO NOT ALLOW** square brackets **ALLOW** atm as **ECF** if K_p is upside down **ALLOW** use of any pressure unit eg Pa^{-1} or kPa^{-1}

Mark Schemes

Question			Answer	Marks	AO element	Guidance
	b	(ii)	**FIRST CHECK THE ANSWER ON ANSWER LINE if answer = 27.2 award 5 marks** **----------** **Initial amounts** $n(SO_2) = (\frac{10.2}{24.0} =) 0.425$ (mol) **AND** $n(O_2) = (\frac{12}{32.0} =) 0.375$ (mol) ✓ **Equilibrium amounts in moles** $n(SO_2) = (0.425 - 0.350 =) 0.075$ (mol) **AND** $n(O_2) = (0.375 - 0.350/2 =) 0.200$ (mol) ✓ **Total moles** $n_{tot} = 0.625$ (mol) ✓ **Partial pressures** $pSO_2 = (\frac{0.075}{0.625} \times 2.50 =) 0.3$ (atm) **AND** $pO_2 = (\frac{0.2}{0.625} \times 2.50 =) 0.8$ (atm) **AND** $pSO_3 = (\frac{0.350}{0.625} \times 2.50 =) 1.4$ (atm) ✓ **K_p to 3 SF** $(K_p = \frac{1.4^2}{0.3^2 \times 0.8} =) 27.2$ (atm^{-1}) ✓	**5**	**2.6 ×5**	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below. *Common errors* Allow 4 marks for 1.45/1.46 (depending upon rounding) *Initial amounts* $n(SO_2) = 2 \times n(O_2)$ $n(O_2) = 0.375$ and $n(SO_2) = 0.75(0)$ *Equilibrium moles* $n(SO_2)$ 0.75 – 0.350 = 0.4(0) $n(O_2) = 0.2(0)$ *total moles* $n_{tot} = 0.95$ *partial pressures* $pSO_2 = 1.05$ $pO_2 = 0.526$ pSO3 = 0.921 Allow 4 marks for **15.1/15.0** *Initial amounts* $n(O_2) = 12/16 = 0.75$ *Equilibrium moles* $n(O_2) = 0.575$ *total moles* $n_{tot} = 1.00$ *partial pressures* $pSO_2 = 0.188$ $pO_2 = 1.438$ pSO3 = 0.88 **IGNORE** units

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	b	**(iii)**	(greater K_p value means) equilibrium position shifted to right/RHS ✓ Lower temperature because (forward) reaction is exothermic ✓	**2**	**3.2 ×2**	**ALLOW** greater/higher amount of SO_3/product **ALLOW** greater K_p means larger numerator
		(iv)	equilibrium position (far) to the right ✓	**1**	**3.2**	**ALLOW** (very) high yield of products or of SO_3 **ALLOW** reaction is nearly complete / irreversible **ALLOW** Forward reaction is (greatly) favored **ALLOW** (far) more product(s) than reactant(s) or **ALLOW** equilibrium (greatly) favours product

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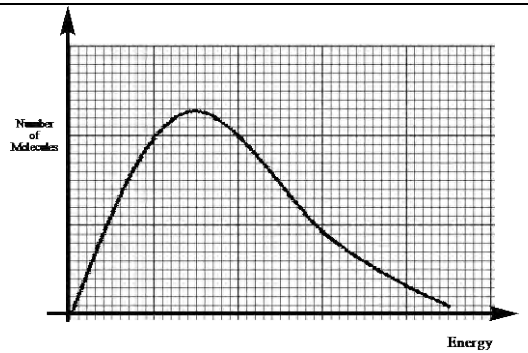
	(c)	(i)	 ***Correct drawing of Boltzmann distribution*** Curve starts within one small square of origin **AND** not touching the x axis at high energy ✓ ***Axes labels:*** y: (number of) molecules/particles **AND** x: (kinetic) energy ✓ ***Catalyst and activation energy*** Catalyst provides a lower activation energy **OR** E_c shown to the left of E_a on Boltzmann distribution ✓ ***Particles with $E > E_a$*** more or a greater proportion of molecules / particles / collisions have (energy above) activation energy (with catalyst) **OR** more molecules have enough energy to react **OR** greater area under curve above activation energy ✓	**4**	**1.1 ×4**	**DO NOT ALLOW** two curves *Confusion with effect of temperature* **DO NOT ALLOW** 'enthalpy' for x-axis label **DO NOT ALLOW** 'atoms' as y-axis label **ALLOW ECF** for atoms (instead of molecules/particles) if y axis labelled as 'atoms' **IGNORE** (more) successful collisions **IGNORE** response implying 'more collisions' *(confusion with effect of greater temperature)*
		(ii)	heterogeneous (catalyst) **AND** catalyst in a different phase/state (from other substances) ✓	**1**	**1.2**	**ALLOW** catalyst is a solid **AND** not a gas / everything else is a gas
			Total	**23**		

Mark Scheme

Question	Answer	Marks	AO element	Guidance
12	B	1	2.6	

Mark Scheme

Question			Answer	Marks	AO element	Guidance
13	(a)		High pressure **AND** low temperature ✓ Right-hand side has fewer (gaseous) moles/molecules **OR** left-hand side has more (gaseous) moles/molecules ✓ (Forward) reaction is exothermic/gives out heat **OR** reverse reaction is endothermic/takes in heat ✓	**3**	1.2×1 1.1×2	Marks are independent **ORA** throughout **ALLOW** RHS **ALLOW** suitable alternatives for RHS e.g. product side
	(b)		(Reaction can be carried out at) lower temperatures / lower energy demand ✓ Less (fossil) fuels burnt / less CO_2 emissions ✓	**2**	1.1×2	**ALLOW** lower pressures as alternative to lower temperature **ALLOW** reduced carbon footprint as alternative to less fuels burnt **ALLOW** different reactions can be used with greater atom economy / less waste **ALLOW** can reduce use of toxic substances

Mark Scheme

Question			Answer	Marks	AO element	Guidance
	(c)		**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer =** 25.55 kJ mol^{-1} **OR** 25550 J mol^{-1} **award first 4 marks** --- ΔS = 238 – (198 **+** 2 × 131) ✓ = –222 (J K^{-1} mol^{-1}) **OR** –0.222 (kJ K^{-1} mol^{-1}) ✓ $\Delta G = \Delta H - T\Delta S$ **OR** ΔG = –91 – (525 × –0.222) **OR** ΔG = –91000 – (525 × –222) ✓ = 25.55 kJ mol^{-1} **OR** 25550 J mol^{-1} ✓ (Reaction is) not feasible **AND** $\Delta G > 0$ ✓	**5**	2.2×4 3.2×1	**ALLOW ECF** **IGNORE** units at this stage Units for ΔG required **ALLOW** 26 kJ mol^{-1} **OR** 26000 J mol^{-1} up to calculator value.

Mark Scheme

Question			Answer	Marks	AO element	Guidance
	(d)		**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer =** 2.22 $\times$ 10^4 **award first 2 marks** --- ln $K_p = -\Delta G/RT = \frac{2.48 \times 10^4}{8.314 \times 298}$ = 10.01 ✓ K_p = 2.22 $\times$ 10^4 (**3SF required**) ✓ Units = atm^{-2} ✓	**3**	3.1×2 1.2×1	**ALLOW ECF** for transcription errors in first sum **ALLOW** 10 up to calculator value of 10.00979992 **ALLOW** 22200 **ALLOW** 2.20 $\times$ 10^4 **OR** 22000 (use of 10) **ALLOW** alternatives (k)Pa^{-2} **OR** N^{-2} m^4 **OR** $mmHg^{-2}$ **OR** PSI^{-2} **OR** bar^{-2} **Common errors for 1 mark:** 22400 (use of 8.31) 4.50 x 10^{-5} (use of -10.01)
			Total	**14**		

Mark Scheme

Question			Answer	Marks	AO element	Guidance
14	(a)	(i)	To keep [CH_3OH] (effectively) constant **OR** Zero order with respect to CH_3OH **OR** To ensure equilibrium is far to the right ✓	1	3.3	**ALLOW** Change in [CH_3OH] is negligible **ALLOW** rate is independent of [CH_3OH] **IGNORE** Methanol doesn't run out/is not limiting reagent.
		(ii)	One half-life $t_{½}$ between 102 and 110 (mins) Two half-lives calculated **OR** evidence on the graph of two half-lives **AND** constant half-life/values (means first order) ✓	2	3.1 3.2	 **ALLOW** any two combinations of positions, e.g. 5 and 2.5 **AND** 4 and 2 **AND** 3 and 1.5
		(iii)	**Using gradients** Evidence of tangent at $t = 0$ and intercept between 100 -140 (min) ✓ Correctly calculated gradient in the range of 2.9×10^{-5} to 4.0×10^{-5} (mol dm^{-3} min^{-1}) ✓ **OR** **Using half-life** *For* $t_{½} = 106$ *min*, $k = \frac{\ln 2}{t_{½}} = 0.00654$ (min^{-1}) ✓ rate $= 0.00654 \times 5 \times 10^{-3}$ $= 3.27 \times 10^{-5}$ (mol dm^{-3} min^{-1}) ✓	2	3.1×1 3.2×1	 **ALLOW ECF** from value of $t_{½}$ in **(a)(ii)**

Mark Scheme

Question			Answer	Marks	AO element	Guidance
	(b)		**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer =** 7.4 **award 4 marks** --- **Initial moles of reactants** **1 mark** $n(CH_3OH)_{initial} = \frac{9.6}{32} = 0.3$ (mol) **AND** $n(CH_3COOH)_{initial} = \frac{12}{60} = 0.2$ (mol) ✓ **Equilibrium moles** **2 marks** $n(CH_3COOH)$ reacted $= 0.2 - 0.03 = 0.17$ (mol) **AND** $n(CH_3OH)_{equil} = 0.3 - 0.17 = 0.13$ (mol) ✓ $n(CH_3COOCH_3)_{equil} = 0.17$ (mol) **AND** $n(H_2O)_{equil} = 0.17$ (mol) ✓ **K_c calculation** **1 mark** $K_c = \frac{0.17/V \times 0.17/V}{0.13/V \times 0.03/V} = 7.4$ ✓	**4**	1.2×1 2.8×3	**ALLOW** minimum of **2SF** throughout **ALLOW ECF** from initial moles **ALLOW ECF** from equilibrium moles Use of V not required but Kc expression must be correct **ALLOW** up to calculator answer of 7.41025641
			Total	**9**		