57th INTERNATIONAL CHEMISTRY OLYMPIAD 2025

UK Round One

MARK SCHEME

Although we would encourage students to always quote answers to an appropriate number of significant figures, do not penalise students for significant figure errors. Allow where a student's answers differ slightly from the mark scheme due to the use of rounded/non-rounded data from an earlier part of the question.

In general, 'error carried forward' (referred to as ECF) can be applied. We have tried to indicate where this may happen in the mark scheme and where ECF is not allowed.

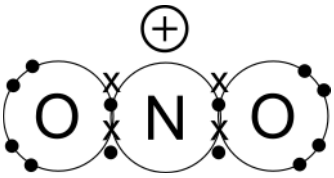
For answers with missing or incorrect units, penalise one mark for the first occurrence in **each** question and write **UNIT** next to it. Do not penalise for subsequent occurrences in the same question.

Organic structures are shown in their skeletal form, but also accept displayed formulae if the representation is unambiguous.

State symbols are not required for balanced equations and students should not be penalised if they are absent.

No half marks are to be awarded. One blank tick box has been included per mark available for each part. Please mark by placing a tick in each box if mark is scored.

Question	1	2	3	4	5	6	**Total**
Marks Available	8	9	20	12	19	15	**83**

1.	**This question is about clay pigeon shooting**	**Mark**
(a)	(i) $C_6H_7(OH)_3O_2 + 3HNO_3 \rightarrow C_6H_7(ONO_2)_3O_2 + 3H_2O$ *State symbols are not required. Accept multiples of this equation.*	☑
	(ii)  *An overall positive charge must be indicated for the mark.*	☑
(b)	$HNO_3 + H_2SO_4 \rightarrow H_2NO_3^+ + HSO_4^-$ *State symbols are not required. Accept multiples of this equation.* *Accept* $H^+ + HNO_3 \rightarrow H_2NO_3^+$	☑
(c)	$H_2NO_3^+ \rightarrow NO_2^+ + H_2O$ *State symbols are not required. Accept multiples of this equation.*	☑
(d)	$C_6H_7N_3O_{11} + {}^9/_4O_2 \rightarrow 6CO_2 + {}^7/_2H_2O + {}^3/_2N_2$ *State symbols are not required. Accept multiples of this equation.*	☑
(e)	$\Delta H^\ominus_c = 6 \times \Delta H^\ominus_f(CO_2) + 3.5 \times \Delta H^\ominus_f(H_2O) - \Delta H^\ominus_f(\text{cellulose trinitrate})$ $= (6 \times -393.5\ \text{kJ mol}^{-1}) + (3.5 \times -285.8\ \text{kJ mol}^{-1}) - (-653.1\ \text{kJ mol}^{-1})$ $= -2708.2\ \text{kJ mol}^{-1}$ *Answer must be negative for mark. ECF from part (d) can be awarded if stoichiometric coefficients for* CO_2, H_2O, *and cellulose trinitrate are off, but not if wrong chemical products are suggested, e.g. CO.*	☑
(f)	$C_6H_7N_3O_{11} \rightarrow {}^9/_2CO + {}^7/_2H_2O + {}^3/_2N_2 + {}^3/_2CO_2$ *State symbols are not required. Accept multiples of this equation.*	☑
(g)	$M_{(Cellulose\ trinitrate)} = 297.15\ \text{g mol}^{-1}$ $n_{(Cellulose\ trinitrate)} = \frac{5.00\ \text{g}}{297.15\ \text{g mol}^{-1}} = 0.01683\ \text{mol}$ $n_{(gas\ prodcued)} = 11 \times 0.01683\ \text{mol} = 0.1851\ \text{mol}$ $V_{(gas\ produced)} = \frac{nRT}{p} = \frac{0.1851\ \text{mol} \times 8.314\ \text{J K}^{-1}\ \text{mol}^{-1} \times 473\ \text{K}}{101325\ \text{Pa}}$ $V_{(gas\ produced)} = 7.18 \times 10^{-3}\ \text{m}^3$ *No marks if answer not given in* m^3 *as asked in question. If answer in part (f) is incorrect, allow ECF using* $n_{(gas\ produced)}$ *from part (f). Allow if student has used standard pressure of 1 bar rather than 1 atmosphere.*	☑
	Total out of 8	**8**

2.	This question is about BrAt		Mark
(a)	$$\text{number of atoms} = \frac{m_{(At)}}{M_{(At)}} \times N_A$$ $$= \frac{30\text{ g}}{219\text{ g mol}^{-1}} \times 6.022 \times 10^{23}\text{mol}^{-1} = 8 \times 10^{22}\text{ (atoms)}$$ *One significant figure is fine due to the error in the estimated mass. Atoms does not need to be explicitly written as is not an official unit.*		☑
(b)	**A** $CaMg_2Bi_2$		☑
(c)	**B:** $MgCl_2$ **C:** $CaCl_2$ *Both must be correct for mark. No credit if wrong way around.*		☑
(d)	x = 211 y = 85 *Both must be correct and the correct way around for mark.*		☑
(e)	$Bi + 4HNO_3 \rightarrow Bi(NO_3)_3 + 2H_2O + NO$ *State symbols are not required. Accept multiples of this equation.*		☑
(f)	**D** I_2 *One mark.*	**E** BrI *One mark. No ECF if **D** is incorrect.*	☑ ☑
(g)	$$z = \text{number of half lives}$$ $$m_t = m_0 \times \left(\frac{1}{2}\right)^z$$ $$z = log_{\frac{1}{2}}\left(\frac{m_t}{m_0}\right)$$ $$z = log_{\frac{1}{2}}\left(\frac{3.65 \times 10^{-3}\text{ g}}{3.60\text{ g}}\right) = 9.95$$ $$t = t_{1/2} \times z$$ $$t = \frac{433\text{ min}}{60\text{ min}} \times 9.95 = 72\ hours$$ *One mark can be awarded if they have correctly calculated this will be approximately 10 half-lives or have the equivalent algebraic expression. If answer is correct but not given in hours, then give one mark out of two. Do not penalise if answer has not been rounded to nearest hour.*		☑ ☑
		Total out of 9	**9**

3.	This question is about epoxides	Mark

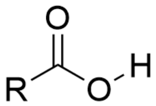
(a) $C_nH_{2n}O$

(b)

	60°	90°	104.5°	107°	109.5°	120°	180°
$C_2H_5OC_2H_5$					✓		
	✓						

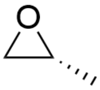
One mark each.

(c)

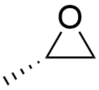


(d)

Stereoisomer 1

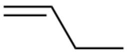
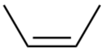
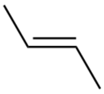
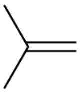
 *or* 

Stereoisomer 2

 *or* 

One mark for each correctly drawn stereoisomer. Two views of each have been shown above. If three structures are drawn maximum mark is one mark if the three structures contain the two correct answers. No marks if four or more structures drawn.

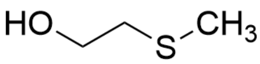
(e)

C_4H_8 isomer	1	2	3	4
		✓		
	✓			
		✓		
	✓			

All four isomers correct three marks. Three isomers correct two marks. Two isomers correct one mark. One isomer or no isomers correct zero marks.

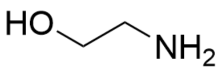
(f)

B

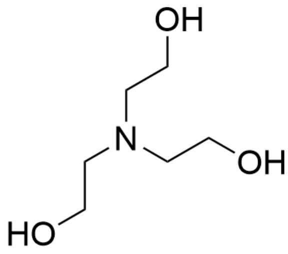
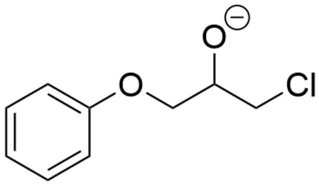
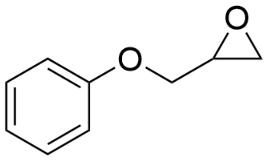
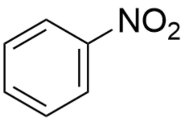
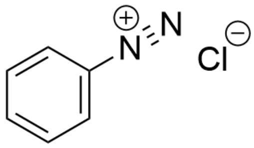
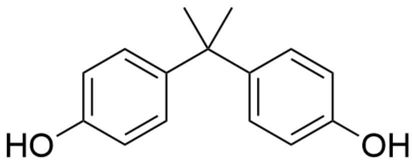


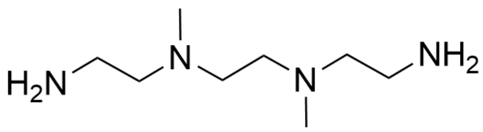
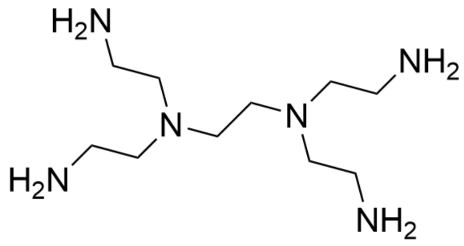
One mark.

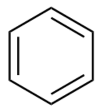
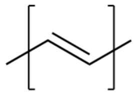
C



One mark.

	D  *One mark.*		☑
(g)	**[E$^-$]**  *Two marks. Accept if sodium salt is drawn. One mark if alcohol drawn in middle (i.e., not deprotonated).*	**F**  *One mark. ECF allowed from **E** for trivial errors but must contain an epoxide for mark.*	☑ ☑ ☑
(h)	**G**  *One mark.*	**H**  *One mark. Diazo group does not have to be drawn out in full, but if it is, the positive charge must be on the nitrogen that is directly attached to the benzene ring. Allow if only cation is drawn, and chloride is missing.*	☑ ☑ ☑
	I  *One mark.*		

(i)	**J**  *One mark.*	☑
	K  *One mark.*	☑
	Total out of 20	**20**

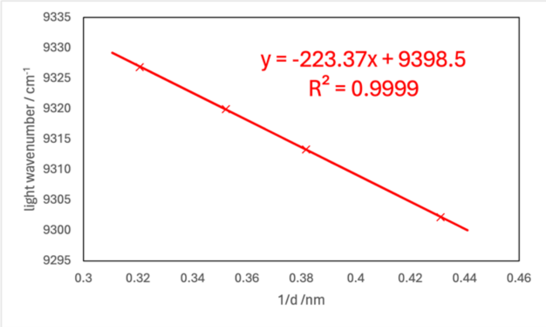
4.	**This question is about Raman spectroscopy**	**Mark**
(a)	$$\frac{n}{2}C_2H_2 + \frac{n}{4}O_2 \rightarrow C_n + \frac{n}{2}H_2O$$ *or* $2nC_2H_2 + nO_2 \rightarrow 4C_n + 2nH_2O$ *State symbols are not required. Accept multiples of this equation.*	☑
(b)	$$n_{C_2H_2} = \frac{pV}{RT} = \frac{101325\ \text{Pa} \times 40.00 \times 10^{-3}\ \text{m}^3}{8.314\ \text{J K}^{-1}\ \text{mol}^{-1} \times 298\ \text{K}} = 1.636\ \text{mol}$$ There are 2 C atoms in every C_2H_2. $$n_{C\ atoms,\ gas} = 1.636\ \text{mol} \times 2 = 3.272\ \text{mol}$$ $$n_{C\ atoms,\ nanotubes} = \frac{242 \times 10^{-3}\text{g}}{12.01\ \text{g mol}^{-1}} = 0.0201\ \text{mol}$$ $$yield = \frac{0.0201\ \text{mol}}{3.272\ \text{mol}} \times 100\% = 0.616\%$$ *Allow if determined from molar volume of gas of 24 dm^3 mol^{-1}.* $n_{C_2H_2} = 1.667\ mol \quad yield = 0.603\%$	☑
(c)	**A**  *Accept if drawn with a circle for delocalised electrons.*	☑
(d)	**B**  *Brackets must be drawn for mark but they do not have to be square brackets. Students do not need to write n after the brackets.*	☑
(e)	(i) $$f_1 = \frac{2.998 \times 10^8\ \text{m s}^{-1}}{5028.8 \times 10^{-10}\ \text{m}} = 5.962 \times 10^{14}\ \text{Hz}$$ $$f_X = \frac{2.998 \times 10^8\ \text{m s}^{-1}}{4358.3 \times 10^{-10}\ \text{m}} = 6.879 \times 10^{14}\ \text{Hz}$$ $$\Delta f_1 = (6.879 - 5.962) \times 10^{14}\ \text{Hz}$$ $$= 9.17 \times 10^{13}\text{Hz}$$	☑
	(ii) $$f_2 = \frac{2.998 \times 10^8\ \text{m s}^{-1}}{4683.9 \times 10^{-10}\ \text{m}} = 6.401 \times 10^{14}\ \text{Hz}$$ $$\Delta f_2 = (6.879 - 6.401) \times 10^{14}\ \text{Hz}$$ $$\Delta f_2 = 4.78 \times 10^{13}\ \text{Hz}$$ $$\frac{4.78 \times 10^{13}\ \text{Hz}}{2.998 \times 10^{10}\ \text{cm s}^{-1}} = 1600\ \text{cm}^{-1}$$	☑

(f)

	C≡C stretch	conjugated C=C stretch	C–H stretch	C–C stretch	O–H stretch
Line 1			✓		
Line 2		✓			

One mark each.

(g) (i)



Wavenumber of scattered light will be given by:

$$\nu_{scattered} = \nu_{irr} - \tilde{\nu} = \nu_{irr} - \frac{A}{d}$$

(making sure to double the radii to get the diameter)

Plotting wavenumber against $1/d$ (or doing linear regression or taking any two points) gives the gradient as –223 with units cm^{-1}/nm^{-1}.

A = 223 cm^{-1}/nm^{-1} (acceptable range is 201 – 245).

1 mark for A value; 1 mark for unit if A value correct (accept nm cm^{-1}, "dimensionless", or "no unit"). Award 1 mark total for 112 cm^{-1}/nm^{-1} AND if unit is correct (accept nm cm^{-1}, "dimensionless", or "no unit") (acceptable range is 101 – 123). There are no specific marks for drawing a graph.

(ii)

intercept = 9398.5 cm^{-1}

$$\lambda = \frac{1}{9395.1\text{cm}^{-1}} = 1.064 \times 10^{-4}\text{cm}$$

$$= 1064 \text{ nm}$$

(iii)

$$\tilde{\nu} = \frac{A}{d} = \frac{223 \text{ cm}^{-1}\text{nm}}{1.20 \text{ nm}} = 186 \text{ cm}^{-1}$$

$$\tilde{\nu}_{irr} = \frac{1}{4358.3 \times 10^{-10}\text{m} \times 10^{2}\text{cm m}^{-1}} = 22945 \text{ cm}^{-1}$$

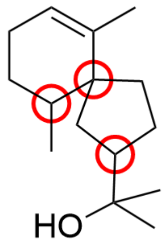
$$\tilde{\nu}_{\text{scatt}} = 22945 - 186 = 22759 \text{ cm}^{-1}$$

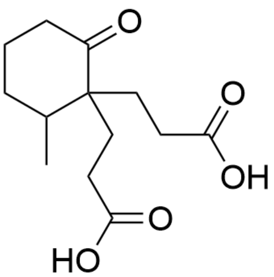
$$\lambda = \frac{1}{22759\text{cm}^{-1}} \times 10^{8}$$

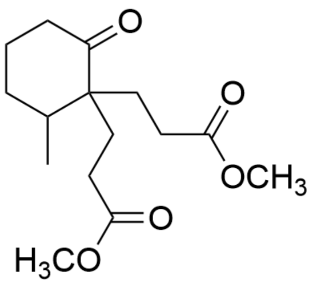
$$= 4394 \text{ Å}$$

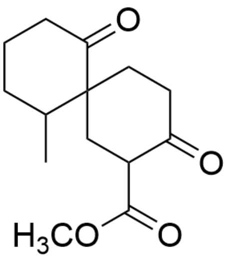
Allow ECF from part (g)(i).

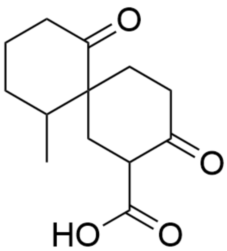
Total out of 12 **12**

<table>
<tr><th>5.</th><th colspan="2">This question is about agarwood</th><th>Mark</th></tr>
<tr><td>(a)</td><td colspan="2">

All three must be correct for mark. Any errors, omissions, or extra circles drawn then no marks.</td><td>☑</td></tr>
<tr><td>(b)</td><td>A


One mark for correct structure. The carboxylate anion/dianion or sodium salts are not accepted as these do not match the formula.</td><td>B


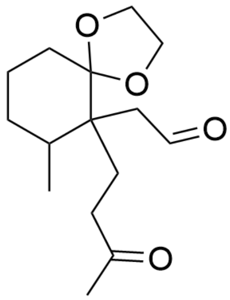
One mark for correct structure. ECF from A cannot be awarded as students also can work backwards from the anion shown.</td><td>☑
☑</td></tr>
<tr><td></td><td>C


One mark for correct structure. ECF from B cannot be awarded as students are given the intermediate before this.</td><td>[D]


One mark for correct structure. The carboxylate anion or lithium carboxylate salt should be accepted. ECF from C cannot be awarded as students also can work backwards from the product shown.</td><td>☑
☑</td></tr>
</table>

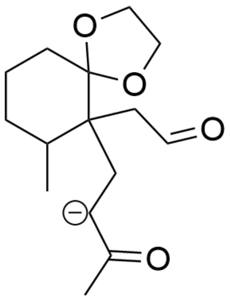
(c)

E

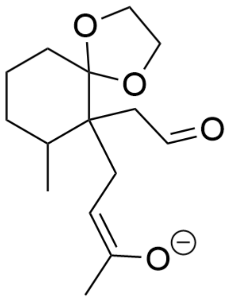


Two marks for correct structure. One mark can be awarded if two carbonyls have been formed and the alkene has gone but there are other mistakes in the structure (for example the carbonyls are in the wrong place). Structures which do not match the molecular formula score zero marks.

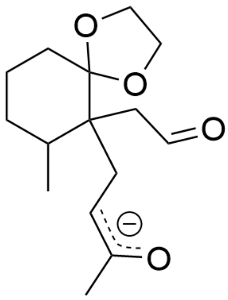
[F⁻]



or

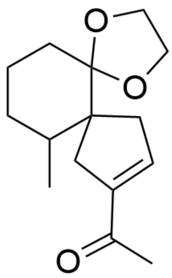


or



*One mark. ECF from **E** can be awarded. In case of ECF, structure drawn here must have been deprotonated at a position that could form a delocalised enolate.*

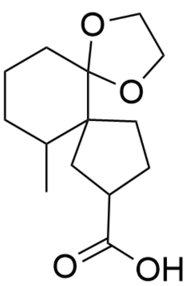
G



*Two marks for correct structure. ECF from **F⁻** cannot be awarded as students can work back from the product. One mark if double bond is in the five-membered ring but in the wrong place. Structures which do not match the molecular formula score zero marks.*

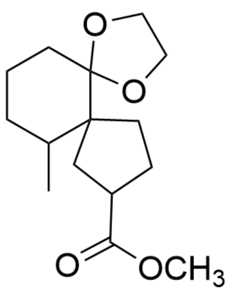
(d)

H



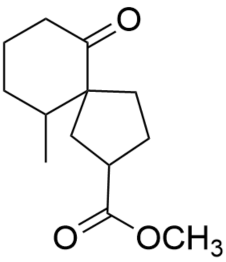
One mark. The carboxylate anion or sodium salt are not accepted as these do not match the formula.

I



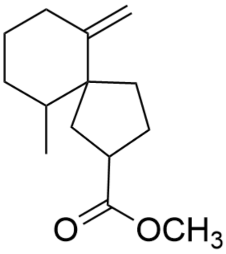
*Two marks for correct structure. ECF from **H** can be awarded. No partial credit for structure.*

J



*Two marks for correct structure. ECF from **I** can be awarded. Students may be tempted to hydrolyse the ester instead of the acetal here. However, this would be a reverse of the previous transformation and so would be illogical.*

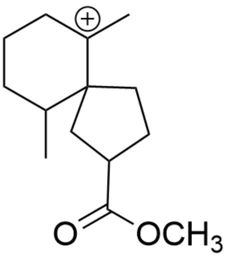
K



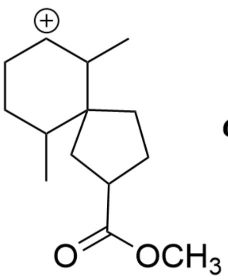
*One mark for correct structure. ECF from **I** can be awarded. Structures which do not match the molecular formula score zero marks. Although the Wittig reaction is an unusual transformation, the good students will have noticed this transformation in the earlier part of this question.*

☑ ☑ ☑

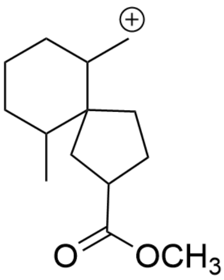
[L$^+$]



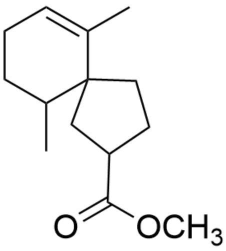
*Two marks for correct structure. ECF from **J** can be awarded. No marks if a cation has not been drawn. No marks if protonation is on oxygen. One mark should be given for either of the two cations below; the one on the left could eliminate to the product but cannot be formed from protonation of the starting material, and the one on the right can be formed from protonation of the starting material but cannot eliminate to the product.*



or



M



*One mark for correct structure. Structures which do not match the molecular formula score zero marks. The good students will have noticed that the isomerisation of the double bond from **K** to **M** is very similar to the one which happened earlier in the question. This is driven by the fact that more substituted double bonds are lower in energy/more stable.*

☑ ☑ ☑

Total out of 19 **19**

6.	**This question is about the iodination of ketones**	**Mark**

(a)

A	B	C	I_2	HI
✓				

Mark: ☑

(b)

(i)

$$rate = k_1[\mathbf{A}]$$

Mark: ☑

(ii)

$$gradient = \frac{600 \times 10^{-6}\ \mathrm{mol\ dm^{-3} s^{-1}}}{14\ \mathrm{mol\ dm^{-3}}}$$

$$gradient = 4.29 \times 10^{-5}\ \mathrm{s^{-1}}$$

$k_1 = 4.29 \times 10^{-5}\ \mathrm{s^{-1}}$ (acceptable range $4.08 \times 10^{-5} - 4.50 \times 10^{-5}$).

One mark for correct numerical value. One mark for correct units.

Mark: ☑ ☑

(c)

$$K_{eq} = \frac{k_1}{k_2}$$

$$\frac{[\mathbf{B}]}{[\mathbf{A}]} = \frac{k_1}{k_2}$$

$$[\mathbf{B}] = \frac{k_1[\mathbf{A}]}{k_2}$$

Mark: ☑

(d)

Starting with the expression given:

$$rate = k_3[\mathbf{B}][\mathrm{I_2}]$$

Using the expression for [**B**] from part (c):

$$rate = k_3\frac{k_1[\mathbf{A}]}{k_2}[\mathrm{I_2}]$$

$$Rate = \frac{k_1k_3[\mathbf{A}][\mathrm{I_2}]}{k_2}$$

or

$$Rate = K_{eq}k_3[\mathbf{A}][I_2]$$

Correct answer scores both marks. No partial credit.

Mark: ☑ ☑

(e)

$$[\mathbf{B}] = \frac{k_1[\mathbf{A}]}{k_2 + k_3[\mathrm{I_2}]}$$

$$rate = k_3[\mathbf{B}][\mathrm{I_2}]$$

$$Rate = \frac{k_1k_3[\mathbf{A}][\mathrm{I_2}]}{k_2 + k_3[\mathrm{I_2}]}$$

Correct answer scores both marks. No partial credit.

Mark: ☑ ☑

(f)

Statement	C	E
Product whose reaction pathway has a larger rate constant for the first step	✓	
Is the major product at high $[I_2]$	✓	
Product whose reaction pathway has a larger K_{eq}		✓
Is the major product a low $[I_2]$		✓

☑ ☑ ☑ ☑

One mark each. No ECF can be awarded.

(g) Setting the rates as equal:

$$rate_{Top\ Pathway} = rate_{Bottom\ Pathway}$$

$$\frac{k_1k_3[\mathbf{A}][\mathrm{I_2}]}{k_2 + k_3[\mathrm{I_2}]} = \frac{k_4k_6[\mathbf{A}][\mathrm{I_2}]}{k_5 + k_6[\mathrm{I_2}]}$$

$$k_1k_3(k_5 + k_6[\mathrm{I_2}]) = k_4k_6(k_2 + k_3[\mathrm{I_2}])$$

$$k_1k_3k_5 + k_1k_3k_6[\mathrm{I_2}] = k_2k_4k_6 + k_3k_4k_6[\mathrm{I_2}]$$

$$k_1k_3k_6[\mathrm{I_2}] - k_3k_4k_6[\mathrm{I_2}] = k_2k_4k_6 - k_1k_3k_5$$

$$[\mathrm{I_2}] = \frac{k_2k_4k_6 - k_1k_3k_5}{k_3k_6(k_1 - k_4)}$$

$$= \frac{[8.3 \times 2.9 \times 10^{-6} \times 5.2 \times 10^5 - (4.29 \times 10^{-5} \times 5.2 \times 10^5 \times 2.1 \times 10^{-2})]\ \mathrm{mol^{-1}dm^3s^{-3}}}{[5.2 \times 10^5 \times 5.2 \times 10^5 \times (4.29 \times 10^{-5} - 2.9 \times 10^{-6})]\ \mathrm{mol^{-2}dm^6s^{-3}}}$$

$$[\mathrm{I_2}] = 1.11 \times 10^{-6}\ \mathrm{mol\ dm^{-3}}$$

☑ ☑

Correct answer scores both marks. One mark if correct algebraic expression for $[I_2]$ but numerical evaluation done incorrectly. Allow ECF from part (b)(ii).

Total out of 15 **15**