56th INTERNATIONAL CHEMISTRY OLYMPIAD 2024

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	**Total**
Marks Available	8	15	20	24	15	**82**

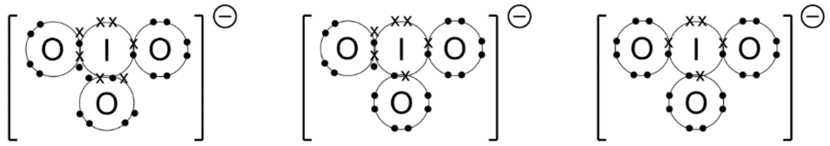
1.	This question is about Bronze				Mark
(a)	$[Ar]4d^{10}$	$[Ar]4d^{10}5s^1$	$[Kr]4d^{10}$	$[Kr]4d^{10}5s^1$ ✓	☑
(b)	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$		$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$		☑
	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$ ✓		$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^9$		
(c)	$volume = \frac{mass}{density}$ $volume = \frac{4600\ \text{g}}{10.5\ \text{g cm}^{-3}}$ $volume = 438\ \text{cm}^3 = 0.438\ \text{dm}^3 = 4.38 \times 10^{-4}\ \text{m}^3$ *Answer acceptable in cm³, dm³, or m³.*				☑
(d)	$density = \frac{4(M_{(Cu)} + y(M_{(Sn)} - M_{(Cu)}))}{5.93 \times 10^{-23}\ \text{cm}^3 \times N_A}$ $7.85\ \text{g cm}^{-3} = \frac{4(63.55 + y(118.71 - 63.55))\ \text{g mol}^{-1}}{5.93 \times 10^{-23}\ \text{cm}^3 \times 6.022 \times 10^{23}\ \text{mol}^{-1}}$ $7.85\ \text{g cm}^{-3} = \frac{(254.2 + 220.64y)\ \text{g mol}^{-1}}{35.71046\ \text{cm}^3\ \text{mol}^{-1}}$ $280.32711\ \text{g cm}^{-1} = (254.2 + 220.64y)\ \text{g cm}^{-1}$ $\frac{26.12711}{220.64} = y$ $y = 11.8\%$ *Do not accept 0.118; answer must be given as a percentage as specified in the question.*				☑
(e)	$a^2 + a^2 = (4r)^2$ $a^2 = 8r^2$ $a = 2\sqrt{2}r$ $a = 2\sqrt{2} \times 128 \times 10^{-12}\ \text{m}$ $a = 3.62 \times 10^{-10}\ \text{m}$ $a = 3.62 \times 10^{-8}\ \text{cm}$ *No mark to be awarded if answer not given in cm as this was asked for in the question. Note some students may also write answers in terms of surds (e.g.,* $256\sqrt{2} \times 10^{-10}\ \text{cm}$*). This should also be marked incorrect. Whilst the use of surds in maths is preferred as they are exact and it avoids rounding errors, the final value here is based on an experimentally determined atomic radius which has an assoicated error, and so the answer should be stated in decimal form.*				☑

(f)	$$volume = a^3$$ $$volume = (3.62 \times 10^{-8}\ \text{cm})^3$$ $$volume = 4.75 \times 10^{-23}\ \text{cm}^3$$ *Allow ECF from part (e). Incorrect units should only be penalised once per question, so if the answer was given in m in part (e) and m^3 here (instead of cm^3 as asked for), this answer can be marked correct.*	☑
(g)	$$atoms\ in\ unit\ cell = 8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$$ $$mass\ of\ Cu\ atoms\ in\ unit\ cell = \frac{4 \times 63.55\ \text{g mol}^{-1}}{6.022 \times 10^{23}\ \text{mol}^{-1}}$$ $$mass\ of\ Cu\ atoms\ in\ unit\ cell = 4.2212 \times 10^{-22}\ \text{g}$$ $$density = \frac{4.2226 \times 10^{-22}\ \text{g}}{4.75 \times 10^{-23}\ \text{cm}^3}$$ $$density = 8.89\ \text{g cm}^{-3}$$ *Correct answer scores both marks. One mark can be awarded if correct statement of number of atoms in a unit cell. Alternatively one mark can be awarded if number of atoms in a unit cell is incorrect but remainder of calculation is correct. Allow ECF from part (f). Incorrect units should only be penalised once per question, so if the answer was given in m in part (e) for example and g m^{-3} here (instead of g cm^{-3} as asked for), this answer can be marked correct.*	☑ ☑
	Total out of 8	**8**

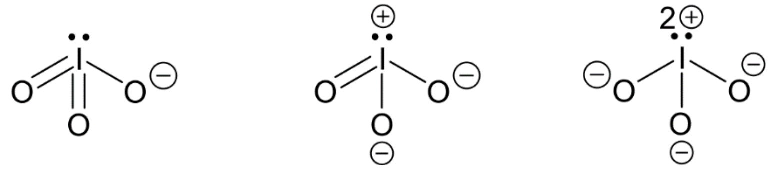
2.	This question is about iodate salts	Mark

(a) +5 ☑

(b)



preferred answer | also acceptable | also acceptable



Acceptable dot and cross diagrams are shown. The overall charge of −1 must be indicated for the mark. Equivalent Lewis structures with formal charges also acceptable. Note all oxygen atoms have eight electrons in outer shell in all acceptable forms; it is only the iodine atom that can expand the octet. ☑

(c)

<109.5°	109.5°	>109.5°
✓		

☑

(d)

$$mass\ of\ KIO_3\ needed = \frac{m_{KI}}{M_{(KI)}} \times M_{(KIO_3)}$$

$$= \frac{130\ \text{mg}}{(39.102 + 126.90)\ \text{g mol}^{-1}} \times (39.102 + 126.90 + (3 \times 16.00))\ \text{g mol}^{-1}$$

$$= 168\ \text{mg} = 0.168\ \text{g}$$

☑

(e) (i) $IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$

State symbols not required. Accept any multiple with correct stoichiometry. ☑

(ii)

redox	electrophilic substitution	elimination	disproportionation	polymerisation
✓				

☑

(f) $2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^-$

State symbols not required. Accept any multiple with correct stoichiometry. ☑

(g)

$$amount\ of\ IO_3^-\ in\ the\ aliquot = \frac{m_{mineral}}{M_{(mineral)}} \times \frac{V_{sample}}{V_{total}}$$

$$amount\ of\ IO_3^-\ in\ the\ aliquot = \frac{1.000\ \text{g}}{255.46\ \text{g mol}^{-1}} \times \frac{10.00\ \text{cm}^3}{100.0\ \text{cm}^3} = 3.9145 \times 10^{-4}\ \text{mol}$$

$$amount\ of\ I_2\ formed = 3.9145 \times 10^{-4}\ \text{mol} \times 3 = 1.1744 \times 10^{-3}\ \text{mol}$$

$$amount\ of\ thiosulfate\ that\ reacts = 1.1744 \times 10^{-3}\ \text{mol} \times 2 = 2.3487 \times 10^{-3}\ \text{mol}$$

$$volume\ of\ thiosulfate\ solution = \frac{2.3487 \times 10^{-3}\ \text{mol}}{0.1000\ \text{mol dm}^{-3}} = 0.02349\ \text{dm}^3 = 23.49\ \text{cm}^3$$

☑ ☑

Final answer scores both marks. Award one mark if the amount of I_2 formed is correct, or if amount of I_2 formed is incorrect but rest of calculation is done correctly using this incorrect amount. Allow ECF if working is correct here, but incorrect stoichiometric ratios are used that are consistent with equations written in parts (e)(i) and (f). Allow reasonable rounding in answers.

(h) Volume of thiosulfate solution that is needed to react with iodine formed by reaction of the metal ion with iodide:

$$V_{excess} = 27.40\ \text{cm}^3 - 23.49\ \text{cm}^3 = 3.91\ \text{cm}^3$$

Therefore, the amount of iodine formed by the reaction of the metal ion with iodide:

$$3.91\ \times 10^{-3}\ \text{dm}^3\ \times\ 0.1000\ \text{mol dm}^{-3} \times \frac{1}{2} =\ 1.955\ \times 10^{-4}\ \text{mol}$$

The amount of metal ion in the sample is the same as the amount of iodate ions in the sample calculated in part (g), therefore:

$$\frac{n_{I_2}}{n_{M^{n+}}} = \frac{1.955\ \times 10^{-4}\ \text{mol}}{3.9145\ \times 10^{-4}\ \text{mol}} =\ 0.49943 = 0.5$$

Therefore 0.5 mol of iodine are produced by the reaction of 1 mol of metal ion with excess iodide ions.

Final answer scores both marks. One mark can be awarded for correct calculation of amount of iodine formed. If they use the volume value given (15.67 cm^3), then the final answer is 1.5 mol of iodine per mol of metal ion. Allow ECF from part (g).

☑ ☑

(i)

+(n+3)	+(n+2)	+(n+1)	+(n)	+(n−1)	+(n−2)	+(n−3)
				✓		

As 0.5 mol of I_2 are produced by the reaction of 1 mol of M^{n+}, the oxidation state of the metal must have decreased by 1. If they used the incorrect volume value for part (g) given as 15.67 cm^3, then the correct answer here is +(n−3).

☑

(j) *Two correct ions are necessary to get the mark; one correct ion only scores no mark. If three or more ions given that include two correct answers can award mark.*

Expected answers (two of): HCO_3^-, CO_3^{2-}, HSO_3^-, SO_3^{2-}, NO_2^-.

Ions such as H^- can be credited as hydrides do give a gas upon reaction with acid, but it is worth discussing with students that these react with water, and no naturally occurring minerals contain the hydride ion.

Ions such as I^- or S^{2-} which could be oxidised, with concomitant reduction of HNO_3 to give NO_2 gas can be credited. It is worth noting that these reactions are most commonly demonstrated with concentrated nitric acid, and this result may not be seen with the 2 mol dm^{-3} HNO_3 in this question.

Ions such as NH_2^-, F^-, CN^- should not be credited. Although the protonated forms of these ions are gaseous, these gases are also highly water soluble, and it is likely no gas evolution would be observed.

☑

(k)	M^{n+}	Sc^{3+}	Fe^{2+}	Fe^{3+}	Cu^{+}	Cu^{2+}	Mg^{2+}	Ga^{2+}	Zn^{2+}	
						✓				☑
	Z^{m-}	F^{-}	Cl^{-}	Br^{-}	H^{-}	O^{2-}	OH^{-}	PO_4^{3-}	SO_3^{2-}	
							✓			☑

One mark for each correct identification. No marks for that ion if more than one box is ticked in a row.

As charge on iodate = −1, we know than (n+ + m−) = +1.

Remaining molar mass of mineral = 255.46 g mol^{-1} − 174.90 g mol^{-1} = 80.56 g mol^{-1}.

After this, students should look for a suitable molar mass combination. You may wish to point out to students that the presence of Cu^{2+} gives a characteristic colour to the mineral, however this knowledge is not needed to solve the problem.

Total out of 15 **15**

3. This question is about fuel-producing bacteria. **Mark**

(a) C_3H_6 ☑

Allow if drawn out as a structural formula.

(b) (i) $2C_3H_6 + 9O_2 \rightarrow 6CO_2 + 6H_2O$ ☑

State symbols not required. Accept any multiple with correct stoichiometry.

(ii)

$$(3 \times -393.5\ \mathrm{kJ\ mol^{-1}}) + (3 \times -285.8\ \mathrm{kJ\ mol^{-1}}) - y = -2091\ \mathrm{kJ\ mol^{-1}}$$

$$y = (3 \times -393.5\ \mathrm{kJ\ mol^{-1}}) + (3 \times -285.8\ \mathrm{kJ\ mol^{-1}}) + 2091\ \mathrm{kJ\ mol^{-1}}$$

$$y = 53.1\ \mathrm{kJ\ mol^{-1}}$$

☑

Do not award mark if value quoted as negative.

(iii)

$$\frac{-2091\ \mathrm{kJ\ mol^{-1}}}{3} = -697.0\ \mathrm{kJ\ mol^{-1}}$$

☑

Do not award mark if value quoted as positive.

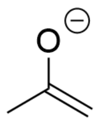
(iv)

$$\frac{-3951\ \mathrm{kJ\ mol^{-1}}}{6} = -658.5\ \mathrm{kJ\ mol^{-1}}$$

☑

Do not award mark if value quoted as positive unless already penalised for incorrect sign in part (iii).

(c)



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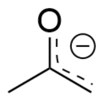


☑

A delocalised structure can be accepted.

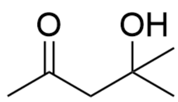
(d)

	The enolate intermediate acts a reducing agent; the iodomethane acts an oxidising agent.
	The enolate intermediate acts an oxidising agent; the iodomethane acts a reducing agent.
	The enolate intermediate acts an electrophile; the iodomethane acts a nucleophile.
✓	The enolate intermediate acts a nucleophile; the iodomethane acts an electrophile.
	The enolate intermediate acts an acid; the iodomethane acts a base.
	The enolate intermediate acts a base; the iodomethane acts an acid.

☑

Fourth box must be ticked for mark. If the first box has been ticked, then do not penalise for this. An argument can be made for the first statement depending on which electronegativity value of iodine is used, if students analyse the reaction as per the method in Q5. No marks if any other boxes ticked.

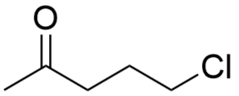
(e)



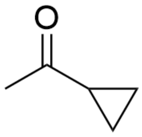
☑

(f) (i)

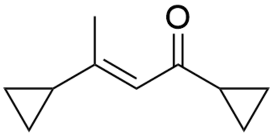
B



C

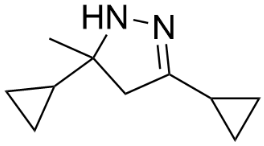


D

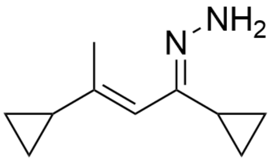


Both cis and trans or undefined stereochemistry acceptable for alkene.

E



Allow if drawn as enamine tautomer



Can award 1 mark for hydrazone

*One mark each for **B** and **C**. Two marks each for **D** and **E**. One mark can be awarded if the hydrazone is drawn for **E**. ECF can be awarded if a trivial error has been propagated but the transformation is correct **and the structure is consistent with the formula given**, for example an aldol reaction from **C** to **D**.*

(ii)

step 1	step 2	step 3	step 4	step 5
	✓	✓		

Both steps must be ticked and no other steps may be ticked in order to receive the mark.

(g)

oxidation	reduction	condensation	hydrolysis	isomerisation	elimination
	✓				

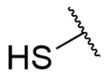
(h)

X

CO_2

One mark

Y



One mark

(i)

first enzyme required for process	second enzyme required for process	third enzyme required for process	last enzyme required for process
3	2	4	1

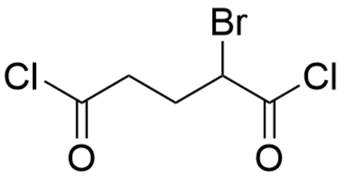
No partial marks. All four must be correct for the two marks.

Total out of 20 **20**

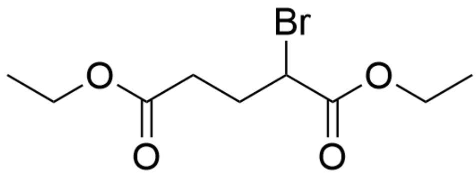
4.	This question is about the MRI contrast agent gadopiclenol	Mark

(a)

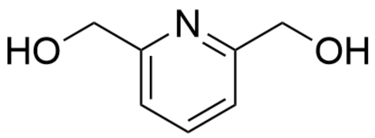
A



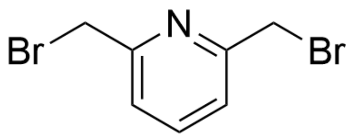
B



C



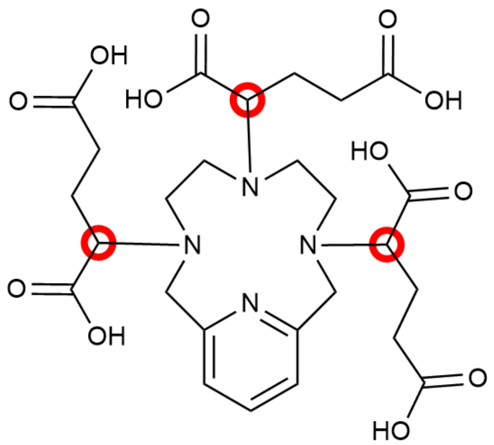
D



*One mark each. ECF can be awarded for **B** if a trivial error has been propagated but the transformation is correct (for example an extra CH_2 drawn in both). ECF can be awarded for **D** if a trivial error has been propagated but the transformation is correct **and the structure is consistent with the formula given**. Students may be initially surprised that the carboxylic acids can be reduced by $NaBH_4$ to give compound **C**, as it is typically taught that a stronger reducing agent such as $LiAlH_4$ is needed for this. $NaBH_4$ is sufficient in this case as the carboxyxlic acids are activated towards reduction by the electron withdrawing pyridine they are attached to.*

Mark: ☑ ☑ ☑ ☑

(b)

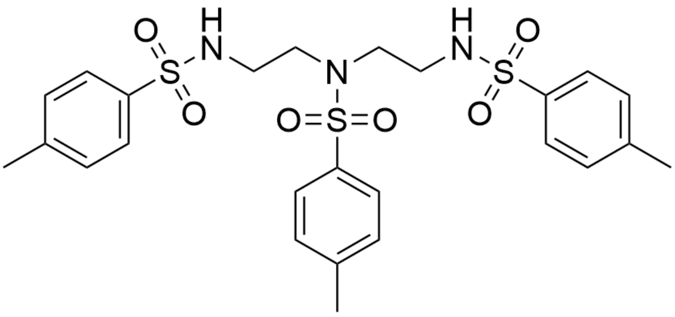


All three correct with no incorrect centres circled – two marks. One mark can be awarded for two correct centres circled only with no incorrect centres circled, or if three correct centres circled and one extra incorrect centre circled.

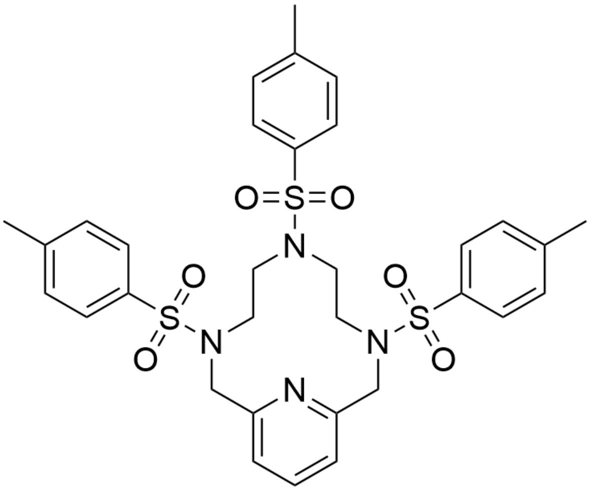
Mark: ☑ ☑

(c)

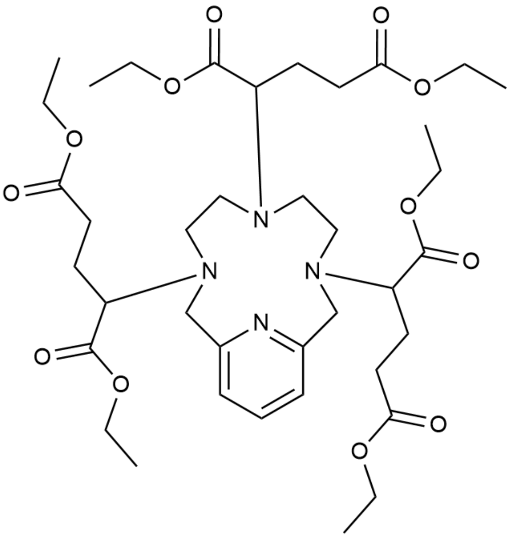
E



F



G



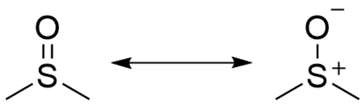
☑ ☑ ☑ ☑ ☑

*Two marks for **E**, two marks for **F**, one mark for **G**. ECF can be awarded for **F** if a trivial error has been propagated but the transformation is correct (for example a consistent error in the tosyl protecting group drawn in both). ECF cannot be given for **G** (from either **F** or **B**) as extra information is provided allowing students to work both forwards and backwards. Partial credit can be given for **E** and **F** if one trivial error has been made (such as extra CH_2 group or missing CH_3 group). Correct abbreviations such as Ts, Et, CO_2Et are allowed.*

(d)	Formula of gadopiclenol: $C_{35}H_{54}GdN_7O_{15}$ Molar mass of gadopiclenol $= (35 \times 12.01 + 54 \times 1.008 + 157.25 + 7 \times 14.01 + 15 \times 16.00)\ \mathrm{g\ mol^{-1}}$ $= 970.102\ \mathrm{g\ mol^{-1}}$ $\text{concentration of dose solution} = \frac{485.05\ \mathrm{g\ dm^{-3}}}{970.102\ \mathrm{g\ mol^{-1}}}$ $= 0.5000\ \mathrm{mol\ dm^{-3}}$ $\text{amount of gadolinium administered} = 0.5000\ \mathrm{mol\ dm^{-3}} \times 0.00600\ \mathrm{dm^3}$ $= 0.003000\ \mathrm{mol}$ $mass\ of\ gadolinium = 0.003000\ \mathrm{mol} \times 157.25\ \mathrm{g\ mol^{-1}}$ $= 0.472\ \mathrm{g} = 472\ \mathrm{mg}$ *Accept answer in either mg or g.*	☑
(e)	<table><tr><td>radiowave ✓</td><td>microwave</td><td>IR</td><td>visible</td><td>UV</td><td>X-ray</td><td>gamma ray</td></tr></table>*No calculation is required here as students should know that NMR operates with radiowave frequencies and that this is studying the same phenomenon.*	☑
(f)	$M = M_0\left(1 - e^{-\frac{t}{\tau}}\right)$ $M = M_0\left(1 - e^{-\frac{3\tau}{\tau}}\right)$ $M = M_0(1 - e^{-3})$ $M = M_0(0.9502)$ $M = 95.0\%\ of\ M_0$ *Answer must be quoted as a percentage to be awarded mark.*	☑
(g)	$[\text{gadopiclenol}] = 0.0500\ \mathrm{mol\ dm^{-3}}$ $[\text{water}] = \frac{1000\ \mathrm{g\ dm^{-3}}}{18.016\ \mathrm{g\ mol^{-3}}}$ $[\text{water}] = 55.506\ \mathrm{mol\ dm^{-3}}$ The molar fraction can be written in terms of concentration. $\chi = \frac{[\text{gadopiclenol}]}{[\text{water}]}$ $\chi = \frac{0.0500\ \mathrm{mol\ dm^{-3}}}{55.506\ \mathrm{mol\ dm^{-3}}}$ $\chi = 9.01\ \times 10^{-4}$ *Correct answer scores both marks. One mark can be given if the molar concentration of water has been calculated correctly. Alternatively one mark can be awarded if student is out by a power(s) of 10 only, for example writes 0.9.*	☑ ☑

(h)	$$\tau_e = \frac{k}{B^2}$$ $$\tau = \tau_c + \frac{k}{B^2}$$ $$\tau_1 = \tau_c + \frac{k}{{B_1}^2}$$ $${B_1}^2(\tau_1 - \tau_c) = k$$ $$\tau_2 = \tau_c + \frac{k}{{B_2}^2}$$ $${B_2}^2(\tau_2 - \tau_c) = k$$ $${B_1}^2(\tau_1 - \tau_c) = {B_2}^2(\tau_2 - \tau_c)$$ $${B_1}^2\tau_1 - {B_1}^2\tau_c = {B_2}^2\tau_2 - {B_2}^2\tau_c$$ $${B_2}^2\tau_c - {B_1}^2\tau_c = {B_2}^2\tau_2 - {B_1}^2\tau_1$$ $$\tau_c({B_2}^2 - {B_1}^2) = {B_2}^2\tau_2 - {B_1}^2\tau_1$$ $$\tau_c = \frac{{B_2}^2\tau_2 - {B_1}^2\tau_1}{({B_2}^2 - {B_1}^2)}$$ *The subscripts 1 and 2 are interchangeable in this equation. So this other expression is also correct.* $$\tau_c = \frac{{B_1}^2\tau_1 - {B_2}^2\tau_2}{({B_1}^2 - {B_2}^2)}$$	☑
(i)	$$r_c = ATe^{-\frac{\Delta H}{RT}}$$ $$\frac{1}{r_c} = \frac{1}{AT}e^{\frac{\Delta H}{RT}}$$ $$\tau_c = \frac{1}{q\chi} \times \frac{1}{r_c}$$ $$\tau_c = \frac{1}{q\chi} \times \frac{1}{AT}e^{\frac{\Delta H}{RT}}$$ $$T\tau_c = \frac{1}{q\chi A}e^{\frac{\Delta H}{RT}}$$ $$ln(T\tau_c) = \frac{\Delta H}{R} \times \frac{1}{T} + ln\left(\frac{1}{q\chi A}\right)$$ $$a = \frac{\Delta H}{R}$$ $$b = ln\left(\frac{1}{q\chi A}\right) = -ln(q\chi A)$$ *One mark for a and one mark for b. Marks can be awarded for the appropriate equation for $\ln(T\tau_c)$; a and b do not have to be stated explicitly.*	☑ ☑

(j)	$$y_1 = \frac{a}{T_1} + b \text{ and } y_2 = \frac{a}{T_2} + b$$ $$y_1T_1 - y_2T_2 = b(T_1 - T_2)$$ $$b = \frac{y_1T_1 - y_2T_2}{(T_1 - T_2)}$$ $$b = \frac{ln(T_1\tau_{c1})T_1 - ln(T_2\tau_{c2})T_2}{(T_1 - T_2)}$$ $$b = \frac{ln(275 \times 4.775 \times 10^{-4})275\ \text{K} - ln(280 \times 3.326 \times 10^{-4})280\ \text{K}}{(275 - 280)\ \text{K}}$$ $$b = \frac{-558.298 + 664.659}{-5}$$ $$b = -21.2722$$ $$b = -ln(q\chi A)$$ $$Aq\chi = e^{-b}$$ $$Aq\chi = e^{-b}$$ $$Aq\chi = 1.73 \times 10^9\ \text{K}^{-1}\text{s}^{-1}$$ *Correct answer scores all three marks. First mark can be awarded for correct expression that has eliminated a. Second mark can be awarded for correct value of b. Third mark is for final answer.*	☑ ☑ ☑
(k)	$$\frac{Aq\chi}{\frac{A}{q\chi}} = (q\chi)^2$$ $$(q\chi)^2 = \frac{1.73 \times 10^9\ \text{K}^{-1}\ \text{s}^{-1}}{6.618 \times 10^{14}\ \text{K}^{-1}\ \text{s}^{-1}}$$ $$(q\chi)^2 = 2.6111 \times 10^{-6}$$ $$q^2 = \frac{2.6111 \times 10^{-6}}{\chi^2}$$ $$q = \sqrt{\frac{2.6111 \times 10^{-6}}{(9.01 \times 10^{-4})^2}}$$ $$q = 1.79$$ *If using given values:* $$(q\chi)^2 = \frac{2.00 \times 10^9\ \text{K}^{-1}\ \text{s}^{-1}}{6.618 \times 10^{14}\ \text{K}^{-1}\ \text{s}^{-1}}$$ $$(q\chi)^2 = 3.0221 \times 10^{-6}$$ $$q = \sqrt{\frac{3.0221 \times 10^{-6}}{(1.00 \times 10^{-3})^2}}$$ $$q = 1.73$$ *Final answer scores both marks. One mark can be awarded for correct numerical value of $(q\chi)^2$.*	☑ ☑
	Total out of 24	**24**

5.	**This question is about sulfur-containing molecules in the atmosphere**	**Mark**
(a)	**B** **C** **E** 0 −2 +2 *One mark each.*	☑ ☑ ☑
(b)	(i) $C_2H_6S + ½O_2 \rightarrow C_2H_6OS$ *State symbols not required. Accept any multiple with correct stoichiometry.*	☑
	(ii)  *Either of the two resonance structures is acceptable for full marks.*	☑
(c)	SO_3	☑
(d)	**G** is SO_3. One mole of SO_3 forms one mole of H_2SO_4, which forms two moles of H^+ ions. $$n_{SO_3} = \frac{pV}{RT} = \frac{100000\ \text{Pa} \times 13.4 \times 10^{-6}\ \text{m}^3}{8.314\ \text{J K}^{-1}\ \text{mol}^{-1} \times 323\ \text{K}} = 4.99 \times 10^{-4}\ \text{mol}$$ $$n_{H^+} = 9.98 \times 10^{-4}\ \text{mol}$$ As sample is dissolved in 1.000 dm^3 of water $$[H^+] = 9.98 \times 10^{-4}\ \text{mol dm}^{-3}$$ $$pH = -\log_{10}[H^+]$$ $$pH = -\log_{10}[9.98 \times 10^{-4}]$$ $$pH = 3.003 \approx 3$$ *Only numerical answer needed for mark. No reasoning is required. Mark can be awarded if they have not rounded to the nearest whole number. If the student has forgotten the factor of two for the diprotic acid do not award mark.*	☑

(e)

	Forming **J**•	Forming **N**•
Loss of a H^+		
Loss of a H•		✓
Loss of a H^-		
Reduction of sulfur		
Oxidation of sulfur	✓	
Atomisation		
Radical substitution		
Radical addition	✓	

One mark for each correct tick. Minus one mark for any incorrect tick. Total for this part cannot be less than zero. E.g., Three correct ticks and one incorrect tick scores total of two.

☑ ☑ ☑

(f) HO•

☑

(g) [**C**] is large and effectively constant over the experiments.

Rate of loss of **L**• in Experiment 1 decays with a half-life of 10 s, so reaction is first order in **L**•.

An effective first-order rate law (with constant [**C**]) is rate = k_{eff} [**L**•], where k_{eff} is a function of [**C**]

In Experiment 2, [**L**•] decreases more slowly, with a half-life of 20 s, so k_{eff} is halved. Since [**C**] is also half of that in Experiment 1, we conclude that k_{eff} is proportional to [**C**], *i.e.*, k_{eff} = k[**C**], making:

rate = k[**C**]^1[**L**•]^1

So a =1 and b = 1

No reasoning is needed. One mark for correct value of a and one mark for correct value of b.

☑ ☑

(h)

$$k_{2eff} = k_3[X] = 5.7 \times 10^{-12}\ \mathrm{cm^3\ molecules^{-1}\ s^{-1}}$$

At 298 K, 100 kPa, the volume of 1 mol of an ideal gas is given by:

$$V = \frac{nRT}{P} = \frac{1 \times 8.314\ \mathrm{J\ K^{-1}\ mol^{-1}} \times 298\ \mathrm{K}}{100000\ \mathrm{Pa}} = 0.02478\ \mathrm{m^3} = 24.78\ \mathrm{dm^3}$$

$$[X] = \frac{1\ mol \times 6.02\ \ 10^{23}\ \mathrm{(molecules)\ mol^{-1}}}{24.78\ \mathrm{dm^3}} = 2.4293 \times 10^{22}\ \mathrm{molecules\ dm^{-3}}$$

$$[X] = 2.4293 \times 10^{19}\ \mathrm{molecules\ cm^{-3}}$$

$$k_3 = \frac{5.7 \times 10^{-12}\ \mathrm{cm^3\ molecules^{-1}\ s^{-1}}}{2.4293 \times 10^{19}\ \mathrm{molecules\ cm^{-3}}}$$

$$k_3 = 2.3 \times 10^{-31}\ \mathrm{cm^6\ molecules^{-2}}\ s^{-1}$$

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

☑ ☑

Total out of 15 **15**