

Markscheme

May 2019

Chemistry

Higher level

Paper 2

No part of this product may be reproduced in any form or by any electronic or mechanical means, including information storage and retrieval systems, without written permission from the IB.

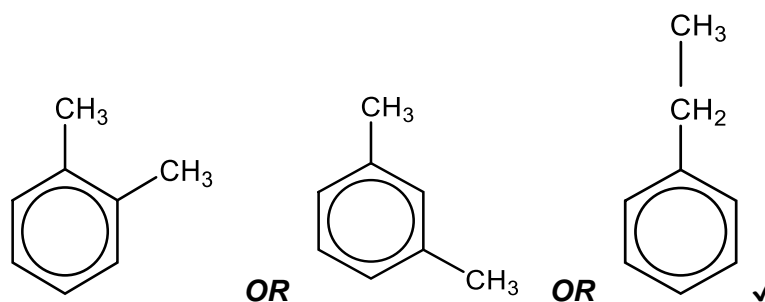
Additionally, the license tied with this product prohibits commercial use of any selected files or extracts from this product. Use by third parties, including but not limited to publishers, private teachers, tutoring or study services, preparatory schools, vendors operating curriculum mapping services or teacher resource digital platforms and app developers, is not permitted and is subject to the IB's prior written consent via a license. More information on how to request a license can be obtained from <http://www.ibo.org/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

Aucune partie de ce produit ne peut être reproduite sous quelque forme ni par quelque moyen que ce soit, électronique ou mécanique, y compris des systèmes de stockage et de récupération d'informations, sans l'autorisation écrite de l'IB.

De plus, la licence associée à ce produit interdit toute utilisation commerciale de tout fichier ou extrait sélectionné dans ce produit. L'utilisation par des tiers, y compris, sans toutefois s'y limiter, des éditeurs, des professeurs particuliers, des services de tutorat ou d'aide aux études, des établissements de préparation à l'enseignement supérieur, des fournisseurs de services de planification des programmes d'études, des gestionnaires de plateformes pédagogiques en ligne, et des développeurs d'applications, n'est pas autorisée et est soumise au consentement écrit préalable de l'IB par l'intermédiaire d'une licence. Pour plus d'informations sur la procédure à suivre pour demander une licence, rendez-vous à l'adresse <http://www.ibo.org/fr/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

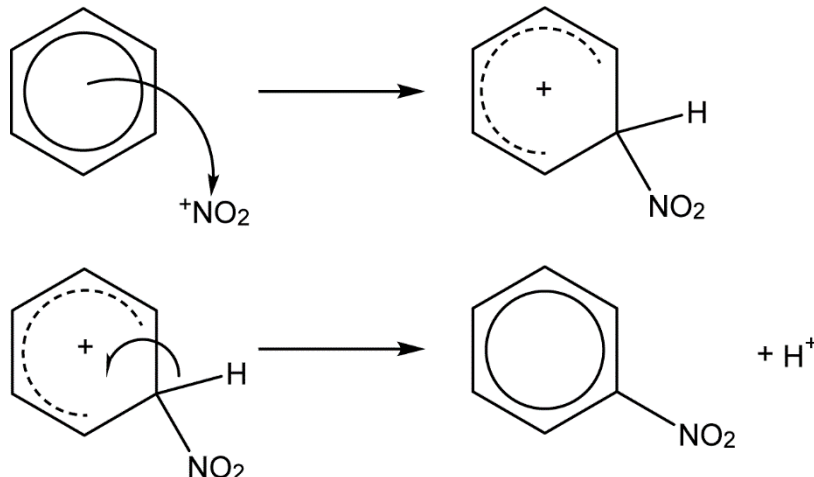
No se podrá reproducir ninguna parte de este producto de ninguna forma ni por ningún medio electrónico o mecánico, incluidos los sistemas de almacenamiento y recuperación de información, sin que medie la autorización escrita del IB.

Además, la licencia vinculada a este producto prohíbe el uso con fines comerciales de todo archivo o fragmento seleccionado de este producto. El uso por parte de terceros —lo que incluye, a título enunciativo, editoriales, profesores particulares, servicios de apoyo académico o ayuda para el estudio, colegios preparatorios, desarrolladores de aplicaciones y entidades que presten servicios de planificación curricular u ofrezcan recursos para docentes mediante plataformas digitales— no está permitido y estará sujeto al otorgamiento previo de una licencia escrita por parte del IB. En este enlace encontrará más información sobre cómo solicitar una licencia: <http://www.ibo.org/es/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

Question			Answers	Notes	Total
1.	a		<p>Number of signals: 2 ✓</p> <p>Ratio: 3:2 OR 6:4 ✓</p>	<p>Accept any correct integer or fractional ratio. Accept ratios in reverse order.</p>	2
1.	b				1
1.	c	i	$2\text{H}_2\text{SO}_4 + \text{HNO}_3 \rightleftharpoons \text{NO}_2^+ + 2\text{HSO}_4^- + \text{H}_3\text{O}^+ \checkmark$	<p>Accept a single arrow instead of an equilibrium sign.</p> <p>Accept "$\text{H}_2\text{SO}_4 + \text{HNO}_3 \rightleftharpoons \text{NO}_2^+ + \text{HSO}_4^- + \text{H}_2\text{O}$".</p> <p>Accept "$\text{H}_2\text{SO}_4 + \text{HNO}_3 \rightleftharpoons \text{H}_2\text{NO}_3^+ + \text{HSO}_4^-$".</p> <p>Accept equivalent two step reactions in which sulfuric acid first behaves as a strong acid and protonates the nitric acid, before behaving as a dehydrating agent removing water from it.</p>	1

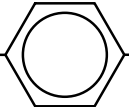
(continued...)

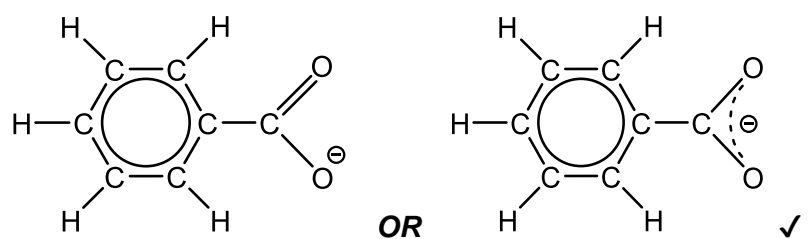
(Question 1 continued)

Question			Answers	Notes	Total
1.	c	ii	 <p>curly arrow going from benzene ring to N «of $^+\text{NO}_2/\text{NO}_2^+$» ✓ carbocation with correct formula and positive charge on ring ✓ curly arrow going from C–H bond to benzene ring of cation ✓ formation of organic product nitrobenzene AND H^+ ✓</p>	<p>Accept mechanism with corresponding Kekulé structures.</p> <p>Do not accept a circle in M2 or M3.</p> <p>Accept first arrow starting either inside the circle or on the circle.</p> <p>If Kekulé structure used, first arrow must start on the double bond.</p> <p>M2 may be awarded from correct diagram for M3.</p> <p>M4: Accept "$\text{C}_6\text{H}_5\text{NO}_2 + \text{H}_2\text{SO}_4$" if HSO_4^- used in M3.</p>	4

(continued...)

(Question 1 continued)

Question			Answers	Notes	Total
1.	d	i	$\text{Br}_2 \rightarrow 2\text{Br}\cdot \checkmark$ «sun»light/UV/hv OR high temperature \checkmark	Do not penalize missing radical symbol on Br. Accept "homolytic fission of bromine" for M1.	2
1.	d	ii	H_3C —  — CH_2Br \checkmark HBr \checkmark	Accept condensed formulae, such as $\text{CH}_3\text{C}_6\text{H}_4\text{CH}_2\text{Br}$.	2
1.	e		no AND there is no chiral carbon OR no AND there is no carbon with four different substituents/groups \checkmark	Accept "no AND no asymmetric carbon atom".	1

Question		Answers	Notes	Total
2.	a	<p>Any wavenumber in the following ranges:</p> <p>2500–3000 «cm⁻¹» ✓</p> <p>1700–1750 «cm⁻¹» ✓</p> <p>2850–3090 «cm⁻¹» ✓</p>		1
2.	b	X-ray «crystallography/spectroscopy» ✓		1
2.	c	<p>Any one of:</p> <p>«regular» hexagon</p> <p>OR</p> <p>all «H–C–C/C–C–C» angles equal/120° ✓</p> <p>all C–C bond lengths equal/intermediate between double and single</p> <p>OR</p> <p>bond order 1.5 ✓</p>		1
2.	d		<p>Accept Kekulé structures.</p> <p>Negative sign must be shown in correct position.</p>	1

(continued...)

(Question 2 continued)

Question		Answers	Notes	Total	
2.	e	electrons delocalized «across the O–C–O system» OR resonance occurs ✓ 122 «pm» < C–O < 143 «pm» ✓	Accept “delocalized π -bond”. Accept “bond intermediate between single and double bond” or “bond order 1.5” for M1. Accept any answer in range 123 to 142 pm.	2	
2.	f	i	ALTERNATIVE 1: $[H^+] \llcorner = 10^{-2.95} \llcorner = 1.122 \times 10^{-3} \llcorner \llcorner \text{mol dm}^{-3} \llcorner \llcorner \checkmark$ $\llcorner [OH^-] = \frac{1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}}{1.22 \times 10^{-3} \text{ mol dm}^{-3}} \llcorner = 8.91 \times 10^{-12} \llcorner \llcorner \text{mol dm}^{-3} \llcorner \llcorner \checkmark$ ALTERNATIVE 2: pOH = «14 – 2.95 =» 11.05 ✓ $\llcorner [OH^-] = 10^{-11.05} \llcorner = 8.91 \times 10^{-12} \llcorner \llcorner \text{mol dm}^{-3} \llcorner \llcorner \checkmark$	Award [2] for correct final answer. Accept other methods.	2
2.	f	ii	$2C_6H_5COOH(s) + 15O_2(g) \rightarrow 14CO_2(g) + 6H_2O(l)$ correct products ✓ correct balancing ✓		2
2.	g		Oxidized: C/carbon «in C ₆ H ₅ COOH» AND Reduced: O/oxygen «in O ₂ » ✓		1
2.	h		«intermolecular» hydrogen bonding ✓	Accept diagram showing hydrogen bonding.	1
2.	i		lithium aluminium hydride/LiAlH ₄ ✓		1

Question		Answers	Notes	Total
3.	a	<p style="text-align: center;">✓</p>	<p><i>Accept curve showing general trend.</i></p> <p><i>Award mark only if the energy difference between the first two points is larger than that between points 2/3 and 3/4.</i></p>	1
3.	b	<p>same number of electrons in outer shell</p> <p>OR</p> <p>all are s¹ ✓</p>		1
3.	c	<p>«3-D/giant» regularly repeating arrangement «of ions»</p> <p>OR</p> <p>lattice «of ions» ✓</p> <p>electrostatic attraction between oppositely charged ions</p> <p>OR</p> <p>electrostatic attraction between Na⁺ and O²⁻ ions ✓</p>	<p><i>Do not accept “ionic” without description.</i></p>	2

(continued...)

(Question 3 continued)

Question			Answers	Notes	Total
3.	d	i	$\frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{O}^{2-}(\text{g})$ <p>«$\Delta H_{\text{atomisation}}(\text{O}) + 1\text{st EA} + 2\text{nd EA} = 249 \text{ kJ mol}^{-1} - 141 \text{ kJ mol}^{-1} + 753 \text{ kJ mol}^{-1}$ \Rightarrow «+»861 «kJ mol⁻¹» ✓</p> <p>$\text{Na}(\text{s}) \rightarrow \text{Na}^+(\text{g})$ $\Delta H_{\text{atomisation}}(\text{Na}) + 1\text{st IE} = 107 \text{ kJ mol}^{-1} + 496 \text{ kJ mol}^{-1} \Rightarrow$ «+»603 «kJ mol⁻¹» ✓</p>		2
3.	d	ii	<p>lattice enthalpy = $861 \text{ «kJ mol}^{-1}\text{»} + 2 \times 603 \text{ «kJ mol}^{-1}\text{»} - (-414 \text{ «kJ mol}^{-1}\text{») ✓$</p> <p>«= +» 2481 «kJ mol⁻¹» ✓</p>	<p>Award [2] for correct final answer.</p> <p>If given values are used: M1: lattice enthalpy = $850 \text{ «kJ mol}^{-1}\text{»} + 2 \times 600 \text{ «kJ mol}^{-1}\text{»} - (-414 \text{ «kJ mol}^{-1}\text{») ✓$ M2: «= +» 2464 «kJ mol⁻¹»</p>	2
3.	d	iii	<p>K^+ ion is larger than Na^+ OR smaller attractive force because of greater distance between ion «centres» ✓</p>		1

(continued...)

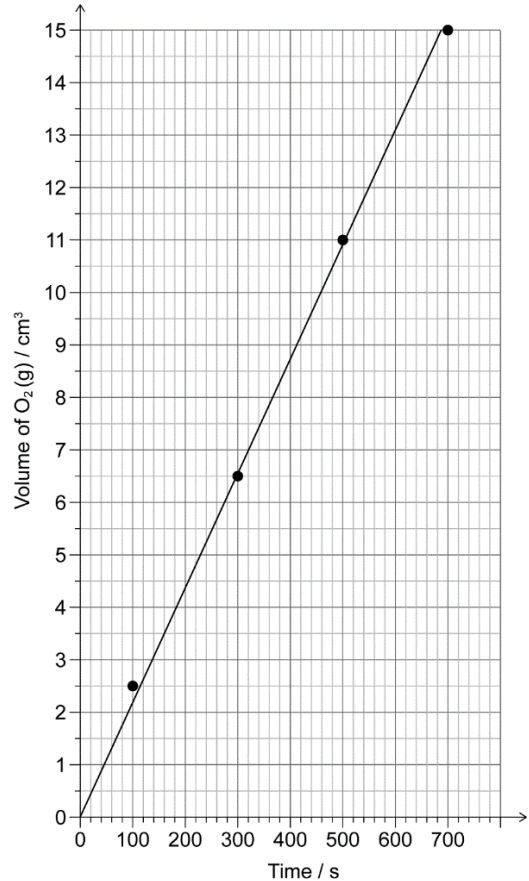
(Question 3 continued)

Question		Answers	Notes	Total
3.	e	<p><i>Sodium oxide:</i> $\text{Na}_2\text{O} (\text{s}) + \text{H}_2\text{O} (\text{l}) \rightarrow 2\text{NaOH} (\text{aq}) \checkmark$</p> <p><i>Phosphorus(V) oxide:</i> $\text{P}_4\text{O}_{10} (\text{s}) + 6\text{H}_2\text{O} (\text{l}) \rightarrow 4\text{H}_3\text{PO}_4 (\text{aq}) \checkmark$</p> <p><i>Differentiation:</i> NaOH/product of Na_2O is alkaline/basic/pH > 7 AND H_3PO_4/product of P_4O_{10} is acidic/pH < 7 \checkmark</p>		3
3.	f	<p>$n(\text{Na}_2\text{O}_2)$ theoretical yield «= $\frac{5.00 \text{ g}}{61.98 \text{ g mol}^{-1}}$ » = $0.0807/8.07 \times 10^{-2}$ «mol»</p> <p>OR</p> <p>mass of Na_2O_2 theoretical yield «= $\frac{5.00 \text{ g}}{61.98 \text{ g mol}^{-1}} \times 77.98 \text{ g mol}^{-1}$» = 6.291 «g» \checkmark</p> <p>% yield «= $\frac{5.50 \text{ g}}{6.291 \text{ g}} \times 100$» OR « $\frac{0.0705}{0.0807} \times 100$ » = 87.4 «%» \checkmark</p>	Award [2] for correct final answer.	2

(continued...)

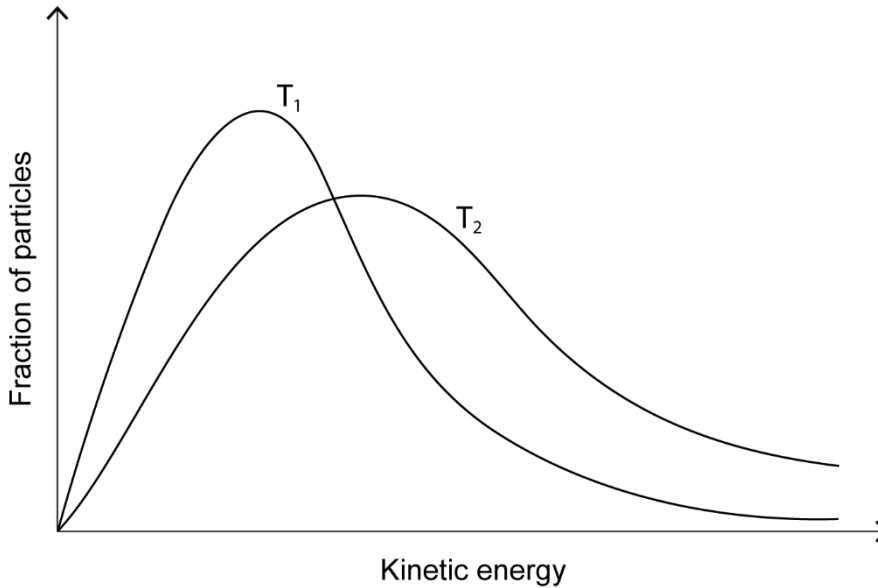
(Question 3 continued)

Question			Answers	Notes	Total
3.	g	i	$\Sigma\Delta H_f \text{ products} = 2 \times (-1130.7) / -2261.4 \text{ «kJ» } \checkmark$ $\Sigma\Delta H_f \text{ reactants} = 2 \times (-510.9) + 2 \times (-393.5) / -1808.8 \text{ «kJ» } \checkmark$ $\Delta H = \text{«}\Sigma\Delta H_f \text{ products} - \Sigma\Delta H_f \text{ reactants} = -2261.4 - (-1808.8) = \text{» } -452.6 \text{ «kJ» } \checkmark$	Award [3] for correct final answer. Award [2 max] for “+ 452.6 «kJ»”.	3
3.	g	ii	only valid for covalent bonds OR only valid in gaseous state \checkmark		1
3.	h		bond in O ₃ has lower enthalpy AND bond order is 1.5 «not 2» \checkmark	Accept “bond in ozone is longer”.	1
3.	i		Any one of: finite volume of particles «requires adjustment to volume of gas» \checkmark short-range attractive forces «overcomes low kinetic energy» \checkmark		1 max
3.	j		NaOH \checkmark		1
3.	k		IV \checkmark		1

Question			Answers	Notes	Total
4.	a		decomposes in light ✓	Accept "sensitive to light".	1
4.	b	i	 <p>points correctly plotted ✓ best fit line AND extended through (to) the origin ✓</p> <p>Average rate of reaction: «slope (gradient) of line => 0.022 «cm³ O₂ (g) s⁻¹» ✓</p>	Accept range 0.020–0.024 cm ³ O ₂ (g) s ⁻¹ .	3

(continued...)

(Question 4 continued)

Question			Answers	Notes	Total
4.	b	ii	<p>Rate equation: $\text{Rate} = k[\text{H}_2\text{O}_2] \times [\text{KI}] \checkmark$</p> <p>Overall order: 2 \checkmark</p>	Rate constant must be included.	2
4.	b	iii	 <p>peak of T_2 to right of AND lower than $T_1 \checkmark$ lines begin at origin AND T_2 must finish above $T_1 \checkmark$</p>		2

(continued...)

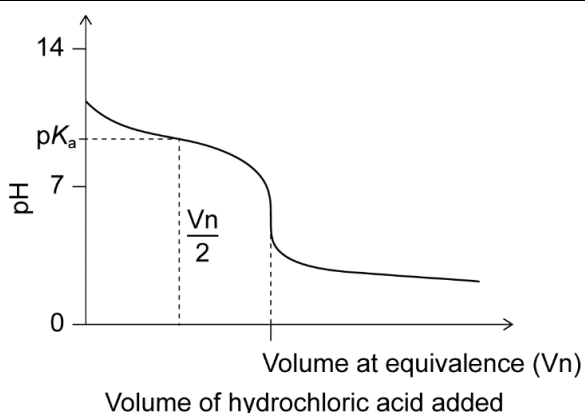
(Question 4 continued)

Question			Answers	Notes	Total
4.	b	iv	E_a marked on graph ✓ explanation in terms of more “particles” with $E \geq E_a$ OR greater area under curve to the right of E_a in T_2 ✓		2
4.	b	v	manganese(IV) oxide OR manganese dioxide ✓	Accept “manganese(IV) dioxide”.	1
4.	c		moves «position of» equilibrium to right/products ✓	Accept “reactants are always present as the reaction is in equilibrium”.	1
4.	d		$M(\text{H}_2\text{O}_2) \llcorner = 2 \times 1.01 + 2 \times 16.00 \llcorner = 34.02 \llcorner \text{g} \llcorner \checkmark$ $\llcorner \% \text{H}_2\text{O}_2 = 3 \times \frac{34.02}{314.04} \times 100 \llcorner = \llcorner 32.50 \llcorner \% \llcorner \checkmark$	Award [2] for correct final answer.	2

Question			Answers	Notes	Total
5.	a		partial dissociation «in aqueous solution» ✓		1
5.	b		ethanoic acid/vinegar reacts with NaOH ✓ moves equilibrium to left/reactant side ✓ releases Cl ₂ (g)/chlorine <u>gas</u> OR Cl ₂ (g)/chlorine <u>gas</u> is toxic ✓	Accept "ethanoic acid produces H ⁺ ions" Accept "ethanoic acid/vinegar reacts with NaOCl". Do not accept "2CH ₃ COOH + NaOCl + NaCl → 2CH ₃ COONa + Cl ₂ + H ₂ O" as it does not refer to equilibrium. Accept suitable molecular or ionic equations for M1 and M3.	3
5.	c	i	$\begin{array}{c} \text{H} : \ddot{\text{N}} : \ddot{\text{Cl}} : \\ \quad \quad \quad \cdot \\ \text{H} \end{array}$ <p style="text-align: right;">✓</p>	Accept any combination of dots/crosses or lines to represent electron pairs.	1
5.	c	ii	sp ³ ✓		1
5.	c	iii	Molecular geometry: «trigonal» pyramidal ✓ H–N–H bond angle: 107° ✓	Accept angles in the range of 100–109.	2
5.	c	iv	covalent/dative/coordinate ✓		1

(continued...)

(Question 5 continued)

Question			Answers	Notes	Total
5.	d	i	 <p>correct shape of graph AND vertical drop at V_n ✓ $pK_a = pH$ at $\frac{V_n}{2}$ /half neutralization/half equivalence ✓</p>	<p>M1: must show buffer region at $pH > 7$ and equivalence point at $pH < 7$. Graph must start below $pH = 14$.</p>	2
5.	d	ii	<p>methyl orange OR bromophenol blue OR bromocresol green OR methyl red ✓</p>		1

(continued...)

(Question 5d continued)

Question			Answers	Notes	Total
5.	d	iii	$\text{NH}_3(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{NH}_4^+(\text{aq}) \checkmark$ $\text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \checkmark$	Accept reaction arrows or equilibrium signs in both equations. Award [1 max] , based on two correct reverse equations but not clearly showing reacting with acid or base but rather dissociation.	2

Question			Answers	Notes	Total
6.	a		$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 \checkmark$		1
6.	b		«frequency/wavelength of visible» light absorbed by electrons moving between d levels/orbitals \checkmark colour due to remaining frequencies OR complementary colour transmitted \checkmark		2
6.	c		${}_{26}^{54}\text{Fe} \checkmark$		1
6.	d		$\llcorner A_r \Rightarrow 54 \times 0.0584 + 56 \times 0.9168 + 57 \times 0.0217 + 58 \times 0.0031$ OR $\llcorner A_r \Rightarrow 55.9111 \checkmark$ $\llcorner A_r \Rightarrow 55.91 \checkmark$	Award [2] for correct final answer. Do not accept data booklet value (55.85).	2

(continued...)

(Question 6 continued)

Question		Answers	Notes	Total
6.	e	<p>lemon juice is the electrolyte OR lemon juice allows flow of ions OR each nail/metal forms a half-cell with the lemon juice ✓</p> <p><i>Any one of:</i> iron is higher than copper in the activity series OR each half-cell/metal has a different redox/electrode potential ✓</p> <p>iron is oxidized OR $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$ OR $\text{Fe} \rightarrow \text{Fe}^{3+} + 3\text{e}^-$ OR iron is anode/negative electrode of cell ✓</p> <p>copper is cathode/positive electrode of cell OR reduction occurs at the cathode OR $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$ ✓</p> <p>electrons flow from iron to copper ✓</p>		2

(continued...)

(Question 6 continued)

Question			Answers	Notes	Total
6.	f	i	$\ll E^\ominus = +0.34 \text{ V} - (-0.45 \text{ V}) = +\gg 0.79 \text{ «V» } \checkmark$		1
6.	f	ii	$\ll \Delta G^\ominus = -nFE^\ominus = -2 \text{ mol} \times 96\,500 \text{ C mol}^{-1} \times \frac{0.79 \text{ J C}^{-1}}{1000} \Rightarrow -152 \text{ «kJ» } \checkmark$	Accept range 150–153 kJ.	1
6.	f	iii	$\ll \ln K_c = -\frac{\Delta G^\ominus}{RT} = -\frac{-152 \times 10^3 \text{ J mol}^{-1}}{8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 298 \text{ K}} \Rightarrow 61.38 \checkmark$ $K = 4.5 \times 10^{26} \checkmark$	Accept answers in range 2.0×10^{26} to 5.5×10^{26} . Do not award M2 if answer not given to two significant figures. If -140 kJ mol^{-1} used, answer is 3.6×10^{24} .	2
7.			Cathode (negative electrode): $\text{Ag}^+ (\text{aq}) + \text{e}^- \rightarrow \text{Ag} (\text{s}) \checkmark$ Anode (positive electrode): $2\text{H}_2\text{O} (\text{l}) \rightarrow \text{O}_2 (\text{g}) + 4\text{H}^+ (\text{aq}) + 4\text{e}^- \checkmark$	Accept $4\text{OH}^- (\text{aq}) \rightarrow \text{O}_2 (\text{g}) + 2\text{H}_2\text{O} (\text{l}) + 4\text{e}^-$. Accept multiple or fractional coefficients in both half-equations.	2