



GCE

Chemistry A

H432/03: Unified chemistry

Advanced GCE

Mark Scheme for November 2020



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All examiners are instructed that alternative correct answers and unexpected approaches in candidates' scripts must be given marks that fairly reflect the relevant knowledge and skills demonstrated.

Mark schemes should be read in conjunction with the published question papers and the report on the examination.

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Annotations

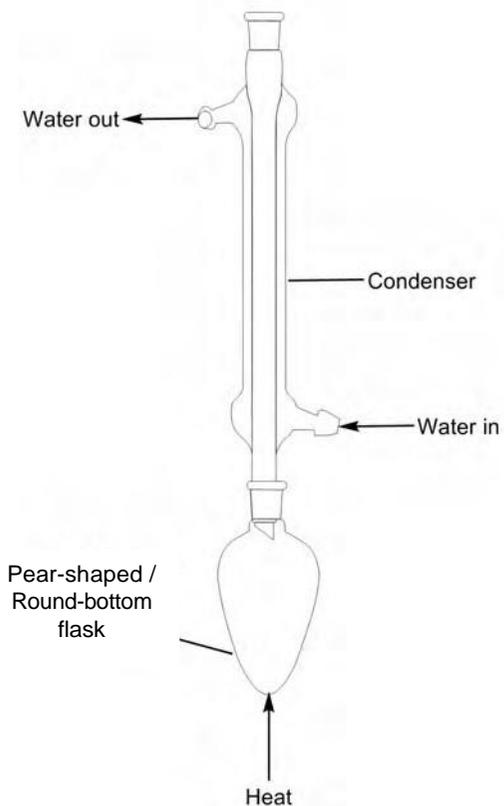
Annotation	Meaning
	Correct response
	Incorrect response
	Omission mark
	Benefit of doubt given
	Contradiction
	Rounding error
	Error in number of significant figures
	Error carried forward
	Level 1
	Level 2
	Level 3
	Benefit of doubt not given
	Noted but no credit given
	Ignore



Abbreviations, annotations and conventions used in the detailed Mark Scheme (to include abbreviations and subject-specific conventions).

Annotation	Meaning
DO NOT ALLOW	Answers which are not worthy of credit
IGNORE	Statements which are irrelevant
ALLOW	Answers that can be accepted
()	Words which are not essential to gain credit
—	Underlined words must be present in answer to score a mark
ECF	Error carried forward
AW	Alternative wording
ORA	Or reverse argument



Question			Answer	Marks	AO element	Guidance
1	(a)	(i)	 <p>Water flow AND condenser Water in at bottom and out at top AND condenser ✓</p> <p>Flask and technique Pear-shaped/round-bottom flask AND reflux ✓</p>	2	1.2 × 2	<p>DO NOT ALLOW conical flask, volumetric flask, beaker in place of round bottom/pear shaped flask</p>



Question		Answer	Marks	AO element	Guidance
(b)	(i)	<p>Comparison of branching and points of contact e.g. $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ has longer chain / straight chain / no branches AND e.g. $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ has more points of contact / more surface interaction (between molecules) ✓</p> <p>Relative strength of force e.g. $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ has stronger/more induced dipole(–dipole) interactions OR London forces ✓</p> <p>-----</p> <p>Hydrogen bonds $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ OR $(\text{CH}_3)_2\text{CHNH}_2$ have hydrogen/H bonds OR $(\text{CH}_3)_3\text{N}$ has no hydrogen/H bonds ✓</p> <p>Relative strength of force Hydrogen bonds are stronger than London forces /permanent dipole interactions ✓</p> <p>-----</p> <p>Comparison of energy required to break force e.g. More energy to break/overcome London forces/intermolecular forces in $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ OR More energy is needed to break H bonds (than London forces) ✓</p>	5 → 4 max		<p>ANNOTATE WITH TICKS AND CROSSES, etc.</p> <p>-----</p> <p>ALLOW ORA throughout ALLOW 'The straighter the chain, the more points of contact'</p> <p>1.2 IGNORE comparison using 'primary', 'secondary' and 'tertiary'. <i>Comparison of branching is required.</i></p> <p>For London forces, 2.1</p> <ul style="list-style-type: none"> • ALLOW induced dipole(–dipole) interactions • IGNORE IDID OR van der Waals' forces/VDW <p>DO NOT ALLOW $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ has more electrons <i>(number of electrons are the same)</i></p> <p>1.2</p> <p>DO NOT ALLOW 'more energy to break covalent bonds</p> <p>2.1 ALLOW little energy is required to break London forces (compared with H bonds)</p>



Question	Answer	Marks	AO element	Guidance
	<p>Structure of amine A from $C_5H_{13}N$ ✓</p>		3.2	<p>ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous</p> <p>ALLOW structures below from molecular formula = $C_3H_9N_3$</p> <p>ALLOW ECF but only if structure has calculated M_r AND has 3 peaks in ^{13}C NMR spectrum.</p>
<p>Use of 24000</p>	<p>3 marks max possible for use of 72.0 cm^3 OR 0.720 dm^3 by ECF</p> <p>Calculation</p> <p>e.g. $n = \frac{72.0}{24000} = 3.00 \times 10^{-3}$ No mark (calculation much simpler)</p> <p>$M = \frac{0.202}{3.00 \times 10^{-3}} = 67.3$ OR 67 ✓ ECF</p> <p>Molecular formula = C_4H_5N ✓ ECF</p> <p>Structure</p> <p>✓ ECF</p>			



Question	Answer	Marks	AO element	Guidance
(c)	<p style="text-align: center;"> </p> <p>Organic product and water marked independently.</p> <p><i>1st mark</i> correct organic product OR water IGNORE balancing numbers</p> <p><i>2nd mark</i> BOTH products AND correctly balanced.</p>	2	3.2	<p>ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous</p> <p>ALLOW</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> </div> <div style="text-align: center;"> </div> </div> <p>NOTE: For ECF, any structure must have correct number of bonds to C, H, O and N</p> <p>DO NOT ALLOW structure of dimer <i>Question states molecular formula = C₃H₃NO</i></p>
	Total	16		



Question	Answer	Marks	AO element	Guidance
2*	<p>Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.</p> <p>Level 3 (5-6 marks) Comprehensive explanation of the terms, ligand and coordination number and ligand substitution AND 3D diagrams of suitable examples of 6 AND 4 coordinate complex ions with different shapes AND Ligand substitution illustrated with a balanced equation</p> <p><i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i></p> <p>Level 2 (3-4 marks) Explanation of the terms, ligand and coordination number and ligand substitution with some errors or omissions AND: Diagrams of suitable examples of 6 AND 4 coordinate complex ions with different shapes OR A 3D wedged diagram of a suitable example of 6 OR 4 coordination OR A diagram of a suitable example of 6 OR 4 coordination AND ligand substitution illustrated with an equation OR Ligand substitution illustrated with a balanced equation</p> <p><i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence</i></p>	6	1.1×4 2.1×2	<p>Indicative scientific points may include:</p> <p>Terms</p> <ul style="list-style-type: none"> • Ligand: Donates a lone pair to metal ion Forms dative covalent (coordinate) bond with metal ion • Coordination number: Number of coordinate bonds to metal ion. Could be implicit in annotated diagrams NOTE: For monodentate ligands, 'number of ligands' is the same as the number of coordination number • Ligand substitution: One ligand replacing another <p>Suitable examples of complex ions with different shapes</p> <ul style="list-style-type: none"> • Coordination no 6 Octahedral e.g. $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$, $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ • Coordination no 4 Tetrahedral e.g. CuCl_4^{2-}, CoCl_4^{2-} OR Square planar Pt complexes, e.g. $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ <p>Diagrams and equations</p> <ul style="list-style-type: none"> • Diagrams of complex ions (may be 3D) • Equation for ligand substitution e.g. $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow \text{CuCl}_4^{2-} + 6\text{H}_2\text{O}$ $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$ <p>NOTE: A clear and logically structured response would link shapes with some of: coordination number, names of shapes, connectivity, involvement of lone pairs, bond angles, etc. (not inclusive)</p> <p>ALLOW minor slips</p> <p>NOTE: Levels and the mark within a level is a 'best-fit', not perfection</p>



Question			Answer	Marks	AO element	Guidance
			<p>Level 1 (1-2 marks) Explanation of some terms: ligand, coordination number and ligand substitution with some errors or omissions. AND A suitable example of a complex ion OR Ligand substitution illustrated with an equation with some errors</p> <p><i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i></p> <p>0 marks No response or no response worthy of credit.</p>			
			Total	6		



Question			Answer	Marks	AO element	Guidance
3	(a)	(i)	<p>FIRST, CHECK THE ANSWER ON ANSWER LINE IF $\Delta_c H = -1860$ OR -1850 (kJ mol⁻¹) with evidence of working, award 3 marks IF $\Delta_c H = -1862$, award 2 marks (not 3 SF)</p> <hr/> <p>Energy released in J OR kJ $= 100 \times 4.18 \times 24.5 = \pm 10241$ (J) OR ± 10.241 (kJ) ✓ 3 SF minimum required</p> <p>Calculates $n(\text{C}_3\text{H}_8)$ $= \frac{0.242}{44(.0)} = 0.0055(0)$ (mol) ✓</p> <p>Calculates $\Delta_c H$ with – sign AND 3 SF (appropriate) $\Delta_c H = \frac{10241}{0.0055 \times 1000} = -1862$ No mark</p> <p>$= -1860$ OR -1.86×10^3 (kJ mol⁻¹) ✓ – sign AND 3 SF required</p>	3		<p>FULL ANNOTATIONS MUST BE USED</p> <hr/> <p>ALLOW ECF throughout</p> <p>DO NOT ALLOW $c = 4.2 \rightarrow 10290$ Next 2 marks available by ECF $\rightarrow -1870$</p> <p>ALLOW 10240/10200 J OR 10.24/10.2 kJ IGNORE units</p> <p>ALLOW ECF from initial 3 SF rounding to 10.2 kJ: $\pm \frac{10200}{0.0055 \times 1000} \rightarrow \pm 1854.545455$ ✓ $\rightarrow 1850$ ✓</p> <hr/> <p>Common errors</p> <p>$\Delta H = -54.6$ OR -54.7 2 marks by ECF from $mc\Delta T$ m wrong as 0.242 and ΔT wrong as 297.5 K $\rightarrow mc\Delta T$ wrong as 300.9391 (J)</p> <p>$\Delta H = -4.51$ 2 marks by ECF from $mc\Delta T$ m wrong as 0.242 and ΔT correct as 24.5) $\rightarrow mc\Delta T$ wrong as 24.78322 (J)</p> <p>$\Delta H = -22600$ 2 marks by ECF from $mc\Delta T$ m correct as 100 and ΔT wrong as 297.5) $\rightarrow mc\Delta T$ wrong as 124355 (J)</p>
	(a)	(ii)	<p>Any two from: 1 MARK ONLY ✓</p> <ul style="list-style-type: none"> Heat loss/released to surroundings Incomplete combustion/reaction with oxygen or air <p>OR not everything burns</p> <ul style="list-style-type: none"> Evaporation of water 	1	1.2	<p>IGNORE incomplete ‘reaction’ Needs link to combustion/burning/reaction with air/O₂</p> <p>IGNORE evaporation of C₃H₈</p>



Question		Answer	Marks	AO element	Guidance
	(b)*	<p>Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.</p> <p>Level 3 (5-6 marks) Calculates $\Delta_r H$ for reaction 3.1 correctly with correct sign AND Calculates a value for $\Delta_c H^\ominus$ of propane using $\Delta_r H$ AND $\pm 4 \times \Delta_{\text{vap}} H$</p> <p><i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i></p> <p>Level 2 (3-4 marks) Calculates $\Delta_r H$ for reaction 3.1 correctly with correct sign OR Calculates bonds broken OR bonds made correctly to obtain a value of $\Delta_r H$ for reaction 3.1 AND attempts to link $\Delta_r H$ with $\Delta_{\text{vap}} H$ OR calculates $4 \times \Delta_{\text{vap}} H$</p> <p><i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i></p> <p>Level 1 (1-2 marks) Uses bond enthalpies for bonds broken and bonds made but may contain errors or omissions AND obtains a value for $\Delta_r H$. OR Calculates bonds broken OR bonds made correctly.</p> <p><i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i></p> <p>0 marks No response or no response worthy of credit.</p>	6	2.4×2 3.1×2 3.2×2	<p>Indicative scientific points may include:</p> <p>Bond enthalpy calculation of $\Delta_r H$</p> <p>Bonds broken</p> $= (2 \times 347) + (8 \times 413) + (5 \times 498)$ $= (694) + (3304) + (2490)$ $= \pm 6488 \text{ kJ mol}^{-1}$ <p>Bonds made</p> $= (6 \times 805) + (8 \times 464)$ $= (4830) + (3712) = \pm 8542 \text{ kJ mol}^{-1}$ $\Delta_r H = 6488 - 8542 = -2054 \text{ kJ mol}^{-1}$ <p>NOTE: 3 C–C → 6835 for bond broken: $\Delta H = -1707$ 2 C–C omitted from bonds broken gives: $\Delta H = -2748$</p> <p>-----</p> <p>Determination of $\Delta_c H(\text{C}_3\text{H}_8)$</p> <p>$\Delta_c H^\ominus$ of propane using $\Delta_r H$ AND $\pm 4 \times \Delta_{\text{vap}} H$</p> <p>Correct</p> $\Delta_c H(\text{C}_3\text{H}_8) = \Delta_r H - 4 \times \Delta_{\text{vap}} H$ $= -2054 - (4 \times 40.65)$ $= -2054 - 162.6$ $= -2216.6 / -2217 \text{ kJ mol}^{-1}$ <p>Incorrect</p> $\Delta_c H(\text{C}_3\text{H}_8) = -2054 + (4 \times 40.65)$ $= -2054 + 162.6$ $= -1891.4 / -1891 \text{ kJ mol}^{-1}$ <p>NOTE: A clear and logically structured response would include a correct energy cycle for $\Delta_c H(\text{C}_3\text{H}_8)$ using $\Delta_r H$ AND $4 \times \Delta_{\text{vap}} H$ in energy cycle or expression:</p> <p>ALLOW trailing zeroes OR minor slips</p>
			Total	10	



Question			Answer	Marks	AO element	Guidance
4	(a)	(i)	<p>Overall equation AND state symbols: $M(s) + 2HCl(aq) \rightarrow MCl_2(aq) + H_2(g)$ ✓</p> <p>STATE SYMBOLS required in overall equation ONLY</p> <p>Half equations: Oxidation $M \rightarrow M^{2+} + 2e^-$ ✓</p> <p>Reduction $2H^+ + 2e^- \rightarrow H_2$ OR $H^+ + e^- \rightarrow \frac{1}{2}H_2$ ✓</p>	3	2.6×3	<p>All 3 marks are independent.</p> <p>IGNORE charges/oxidation numbers shown around overall equation. <i>Treat as rough working</i></p> <p>ALLOW overall equation shown with some or all ions that are present e.g. (with state symbols) $M + 2H^+ \rightarrow M^{2+} + H_2$ $M + 2HCl \rightarrow M^{2+} + 2Cl^- + H_2$ $M + 2H^+ + 2Cl^- \rightarrow M^{2+} + 2Cl^- + H_2$</p> <p>In half equations, IGNORE state symbols even is wrong BUT half equations MUST only have species that change.</p> <p>For charges on half equations, ALLOW M^{+2} for M^{2+} OR H^{+1} for H^+ ALLOW $M - 2e^- \rightarrow M^{2+}$</p> <p>If BOTH half equations are correct but shown with oxidation and reduction the wrong way around, award 1 mark from the 2 marks for half equations</p>
	(a)	(ii)	<p>Bubbles/effervescence/fizzing stops ✓</p> <p>M/metal/solid has disappeared/dissolved ✓</p>	2	3.3×2	<p>Responses must imply that all fizzing has stopped and that all the solid has dissolved i.e. 'metal disappears' is not quite enough. 'All the metal disappears' is enough</p> <p>IGNORE constant mass IGNORE no increase in temperature</p>
	(a)	(iii)	<p>$H^+ + OH^- \rightarrow H_2O$ ✓</p>	1	2.5	<p>ALLOW multiples e.g. $2H^+ + 2OH^- \rightarrow 2H_2O$</p> <p>IGNORE state symbols, even if wrong</p>



Question		Answer	Marks	AO element	Guidance	
	(b)	(i)	$n(\text{CO}_2) = \frac{2.75}{44} = 0.0625 \text{ (mol)} \checkmark$	1	2.8	
	(b)	(ii)	$n(\text{X}_2\text{CO}_3) = 0.0625 \text{ (mol)}$ OR 0.0625 used in molar mass expression below \checkmark $\text{Molar mass of X}_2\text{CO}_3 = \frac{14.57}{0.0625} = 233.12 \text{ (g mol}^{-1}\text{)} \checkmark$ $\text{Metal X} = \text{Rubidium/Rb} \checkmark$	3	1.2 2.8 3.2	ALLOW ECF from 4b(i) ALLOW to nearest whole number DO NOT ALLOW strontium/Sr <i>wrong carbonate formula</i> <hr/> ALLOW ECF for X from calculated molar mass ONLY IF X is a Group 1 metal OR Ag Working: $\text{Mass of X in X}_2\text{CO}_3 = 233.14 - 60 = 173.12 \text{ OR } 173$ $A_r \text{ of X} = \frac{173.12}{2} \text{ OR } 86.56 \text{ OR } 85.6 \text{ OR } 87$
	(c)	(i)	Reweigh to constant mass \checkmark	1	3.4	ALLOW response implying leaving for longer and monitoring by reweighing to constant mass, e.g. Leave flask until the mass does not change IGNORE 'leave for longer' OR wait till fizzing stops <i>Needs link to constant mass</i> ALLOW Collect gas until gas volume is constant
	(c)	(ii)	Mass (CO ₂) OR $n(\text{CO}_2)$ loss would be smaller OR Mass X ₂ CO ₃ OR $n(\text{X}_2\text{CO}_3)$ reacted (seems to be) less \checkmark Molar mass would be greater \checkmark	2	3.1 3.2	
			Total	19		



Question		Answer					Marks	AO element	Guidance	
5	(a)	T/K	500	600	700	800		2	1.2×2	Mark by row ALLOW 2 SF or more for $1/T$ but ignore trailing zeroes ALLOW whole numbers (± 1) for $\ln K_p$ ALLOW 1 small slip in each row. e.g. 1.66 for 1.67; 71.7 for 71.8 <i>Check with calculator values below table</i> BUT DO NOT ALLOW whole number errors, e.g. 85 for 86 ☒
		K_p	5.86×10^{45}	1.83×10^{37}	1.46×10^{31}	1.14×10^{26}				
		$\frac{1}{T}$ /K ⁻¹	2.00×10^{-3}	1.67×10^{-3}	1.43×10^{-3}	1.25×10^{-3}	✓			
		$\ln K_p$	105	86	72	60	✓			
		<i>Calculator values</i>								
		$1/T/10^{-3}$	2.00	1.66 recurring	1.428571429	1.25				
		$\ln K_p$	105.3844788	85.79996441	71.75857432	59.99824068				
	(b)	Equilibrium (position) shifts to the left AND (forward) reaction is exothermic ✓					1	2.2	ALLOW 'favours reverse reaction' <i>Implies shift to left</i> ALLOW 'shifts in endothermic direction' BUT only if (forward) reaction stated as exothermic	



Question		Answer		Marks	AO element	Guidance					
6	(a)	<table border="1"> <tr> <td>Bond angle</td> <td>Name of shape</td> </tr> <tr> <td>120(°)</td> <td>Trigonal planar</td> </tr> <tr> <td>104–105(°)</td> <td>Non-linear</td> </tr> </table> <p>Mark by row OR by column to give higher mark</p> <p>i.e. 2 bond angles correct ✓ 2 shapes correct ✓</p> <p>OR</p> <p>i.e. bond angle AND shape correct in 1st row ✓ bond angle AND shape correct in 2nd row ✓</p>	Bond angle	Name of shape	120(°)	Trigonal planar	104–105(°)	Non-linear	2	1.2×2	For non-linear, ALLOW bent, v-shaped, angular IGNORE planar, 'not straight'
Bond angle	Name of shape										
120(°)	Trigonal planar										
104–105(°)	Non-linear										
	(b)	<p>$\text{CH}_3\text{SO}_2\text{OH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{SO}_2\text{O}^- + \text{H}_3\text{O}^+$ ✓</p> <p>A1 B2 B1 A2 ✓</p> <p>For an equilibrium shown using CH_3COOH instead of H_2O, mark acid–base pairs by ECF, i.e.</p> <p>$\text{CH}_3\text{SO}_2\text{OH} + \text{CH}_3\text{COOH} \rightleftharpoons \text{CH}_3\text{SO}_2\text{O}^- + \text{CH}_3\text{COOH}_2^+$ ☒</p> <p>A1 B2 B1 A2 ECF ✓</p> <p>$\text{CH}_3\text{SO}_2\text{OH}$ dissociates more (than CH_3COOH) OR $\text{CH}_3\text{SO}_2\text{OH}$ is a stronger acid ✓</p> <p>ORA in terms of CH_3COOH being a weaker acid</p> <p>Student is correct AND (sulfonic acid has) lower pK_a/higher K_a OR greater $[\text{H}^+]$ ORA ✓</p>	4	2.1×2	<p>ALLOW → for ⇌</p> <p>ALLOW acid–base pairs labelled other way round. i.e. $\text{CH}_3\text{SO}_2\text{OH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{SO}_2\text{O}^- + \text{H}_3\text{O}^+$</p> <p>A2 B1 B2 A1</p> <p>ALLOW small slip</p> <p>If ONE charge is missing from equilibrium. ALLOW ECF for acid–base pairs mark</p> <p>IGNORE 'more acidic' <i>Response needs strength/dissociation</i></p> <p>ALLOW maths explanation for final 2 marks, e.g.</p> <p>$K_a(\text{CH}_3\text{COOH}) = 10^{-(4.76)} = 1.74 \times 10^{-5}$ $[\text{H}^+] = \sqrt{(1.74 \times 10^{-5}) \times 1} = 4.17 \times 10^{-3}$ $\text{pH} = -\log 4.17 \times 10^{-3} = 2.38$ ✓</p> <p>3.1</p> <p>3.2</p> <p>$K_a(\text{CH}_3\text{SO}_2\text{OH}) = 10^{-(1.90)} = 79.4$ $[\text{H}^+] = \sqrt{(79.4) \times 1} = 8.91$ $\text{pH} = -\log 8.91 = -0.95$ ✓</p> <p>BOTH pH calcs subsumes 'Student is correct'</p>						



Question	Answer	Marks	AO element	Guidance
(c)	<p>6 curly arrows correct ✓✓✓✓ 5 curly arrows correct ✓✓✓ 4 curly arrows correct ✓✓ 3 curly arrows correct ✓</p>	4	3.1×4	<p>IGNORE any added charges OR dipoles. <i>Marks solely for curly arrows</i></p> <p>IGNORE any curly arrows on bottom structures (not in boxes):</p> <p>$\text{H}_3\text{C}-\text{S}(\text{O})_2-\text{O}^- + \text{HOCH}_3$</p>
	Total	10		

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