OCR
Oxford Cambridge and RSA

GCE

Chemistry A

Unit **F325:** Equilibria, Energetics and Elements

Advanced GCE

Mark Scheme for June 2016

1.   Annotations available in RM Assessor.
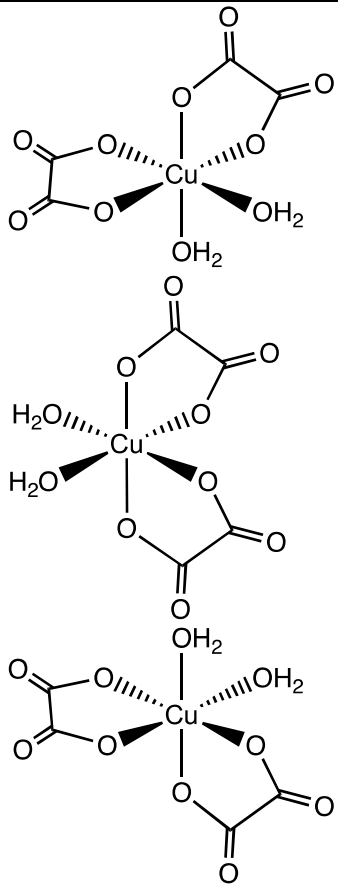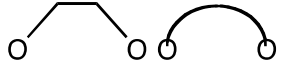
Annotation	Meaning
BOD	Benefit of doubt given
CON	Contradiction
✖	Incorrect response
ECF	Error carried forward
I	Ignore
NAQ	Not answered question
NBOD	Benefit of doubt not given
POT	Power of 10 error
∧	Omission mark
RE	Rounding error
SF	Error in number of significant figures
✔	Correct response

2.   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

3.   The following questions should be marked using **ALL** appropriate annotations to show where marks have been awarded in the body of the text:
2(a)
4(b)(ii)
4(c)
4(d)
5(c)(i)
5(c)(ii)
5(d)(iv)
6(c)
8(e)
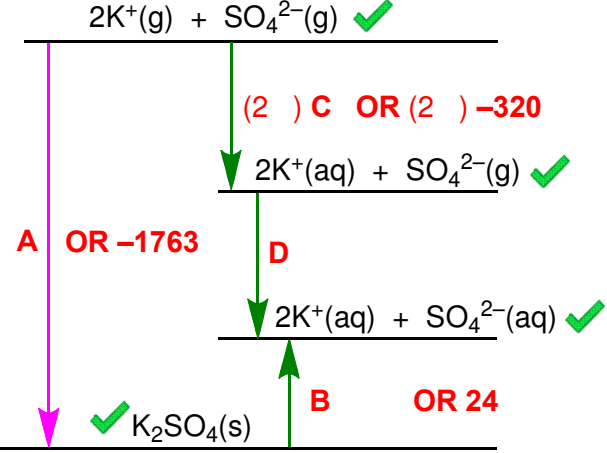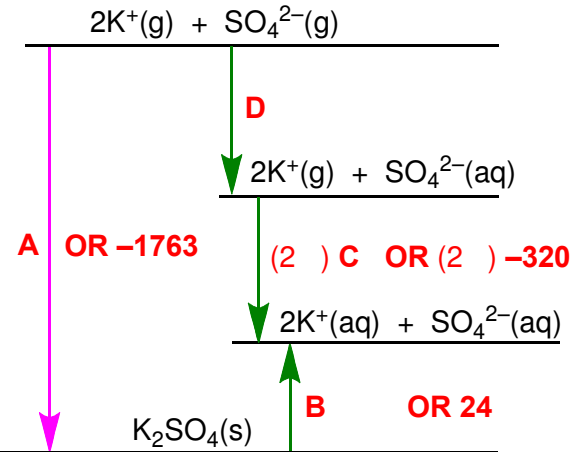
Question			Answer	Marks	Guidance

1	(a)		**IGNORE** any charges shown within complexes (treat as rough working)
			Formulae **2 marks**
			    $[Cu(NH_3)_4(H_2O)_2]^{2+}$ ✓
			
			    $[CuCl_4]^{2-}$ ✓
			
			Colours **1 mark**
			    blue **AND** yellow ✓
			Mark independently of formulae
				3	For charges, **ALLOW** +2 and –2
					
					Square brackets **required**, i.e.
					DO NOT ALLOW $Cu(NH_3)_4(H_2O)_2^{2+}$
					
					ALLOW Ligands in any order
					
					ALLOW $CuCl_4^{2-}$ i.e. no brackets **OR** $Cu(Cl)_4^{2-}$
					
					For $CuCl_4^{2-}$, **ALLOW** green–yellow **OR** yellow–green
					                DO NOT ALLOW green
					
					For $[Cu(NH_3)_4(H_2O)_2]^{2+}$ **DO NOT ALLOW** pale blue, light blue
					
					DO NOT ALLOW precipitate with blue **OR** yellow

1	(b)	(i)	**Donates two** electron **pairs** to a metal ion/metal/Cu^{2+}
			AND
			forms **two** coordinate **bonds** to a metal ion/metal/Cu^{2+} ✓
				1	**ALLOW** lone pairs for electron pairs
					ALLOW molecule/atom/ion/substance for 'ligand'
					ALLOW dative (covalent) bonds for coordinate bonds
					ALLOW transition element for metal
					
					Two is needed once only e.g.
					    Donates two electron **pairs** to form coordinate **bonds** to a metal ion/metal/Cu^{2+}
					    Donates electron **pairs** to form **two** coordinate **bonds** to a metal ion/metal/Cu^{2+}
					
					DO NOT ALLOW donates **two** electron pairs to form **one/a** coordinate bond

Question			Answer	Marks	Guidance
1	(b)	(ii)	*(structures of Cu oxalate complexes shown)*	3	***FULL ANNOTATIONS MUST BE USED*** --- **2 marks**: one for each correct isomer ✓✓ **TAKE CARE**: structures may be in different orientations and in different order **IF BOTH** isomers are 'correct', but O connectivity wrong, **AWARD** 1 mark for both structures **Check** H₂O ligands carefully for connectivity **ALLOW** H_2O reversed shown as $-O_2H$ **IGNORE** charges (**anywhere**) -- **NOTE**: For each structure, **ALL** O atoms must be shown **AND** For $(COO^-)_2$, **ALLOW** skeletal, structural or displayed formula **DO NOT ALLOW** structures such as those shown below

	cis	✓
	trans	
	optical	✓

	cis	
	trans	✓
	optical	

1 mark: for whole of 2nd row for whole of 'Type' row
i.e. (cis **AND** optical) **AND** trans only

Question			Answer	Marks	Guidance
1	(b)	(iii)	$CuC_4H_4O_{10}{}^{2-}$ Formula ✓ 2– charge ✓ **MARK formula and charge INDEPENDENTLY**	2	**Empirical** formula essential, e.g. **DO NOT ALLOW** $Cu(COO)_2(H_2O)_2$ for formula mark **ALLOW** any order of elements in formula **ALLOW** –2 for charge
			Total	9	

Question			Answer	Marks	Guidance

2	(a)		*initial rates data (3 marks)*
			NOTE: Each comparison **MUST** relate to the **actual** change in concentration/rate in the experiments
			                            EXPTS
			H_2O_2:$[H_2O_2] \times 2$ rate $\times 2$ (1 & 2)
			        AND
			        1st order ✓
			
			H^+: $[H^+] \times 2$ rate does not change (2 & 3)
			        AND
			        Zero order ✓
			
			I^-: $[I^-] \times 2$ **AND** $[H_2O_2] \times 2$ rate $\times 4$ (2 & 4)
			    OR $[I^-] \times 2$ **AND** $[H_2O_2] \times 4$ rate $\times 8$ (1 & 4)
			    OR $[I^-] \times 2$ **AND** $[H_2O_2] \times 2$ rate $\times 4$ (3 & 4)
			        AND
			        1st order ✓
				3	*FULL ANNOTATIONS MUST BE USED*
					--- 	
					
					THROUGHOUT,
					• Square brackets **NOT REQUIRED** around H_2O_2, H^+ and I^-
					• **ALLOW** 'doubles' for $\times 2$; quadruples for $\times 4$
					
					ALLOW direct comparison of concentrations and rate, e.g.
					$[H_2O_2]$ changes by $\frac{0.0020}{0.0010} = 2$, rate changes by $\frac{1.14 \times 10^{-5}}{5.70 \times 10^{-6}} = 2$
					AND 1st order (Expts 1 & 2)
					
					DO NOT ALLOW I_2 for I^-
					
					IGNORE $[H^+]$ for Expts 3 & 4

			Calculation of rate constant (3 marks), **EITHER** $k = \dfrac{5.70 \times 10^{-6}}{0.0010 \times 0.20}$ **OR** 2.85×10^{-2} **OR** 0.0285 **OR** 0.029 ✓ $k = 2.9 \times 10^{-2}$ ✓ (2 SF in standard form) *Subsumes previous mark if no working shown* $dm^3\ mol^{-1}\ s^{-1}$ ✓	3	**IGNORE working** **DO NOT ALLOW** 0.03 **ALLOW ECF** from error in powers of 10 **ONLY** e.g. 2.9×10^{-3} by use of 0.010 instead of 0.0010 **DO NOT ALLOW** 2.90×10^{-2} **(3 SF)** **OR** 29×10^{-3} (Not standard form) **ALLOW** mol^{-1}, dm^3 and s^{-1} in any order, e.g. $mol^{-1}\ dm^3\ s^{-1}$

Question			Answer	Marks	Guidance
2	**(b)**		H^+ ions are consumed/used up **OR** H^+ ions are in the (overall) equation ✓	1	**ALLOW** H^+ is **not** regenerated/reformed **ALLOW** H^+ is a reactant but not a product **ALLOW** 'it' for H^+ **IGNORE** H^+ is not in the rate equation/does not affect rate **IGNORE** does not take part in rate-determining step
2	**(c)**	**(i)**	The slowest/slow step ✓	1	**ALLOW** step that takes the longest time

2	**(c)**	**(ii)**	**NO ECF from incorrect rate equation** **Principles**
			 • H_2O_2 and I^- **must be** the reactants in **1st step**
			 • 2nd mark **only to be awarded** if 1st mark scored
			 • Step 4 is independent
			
			 Reactants of Step 1 as $H_2O_2 + I^-$ 1 mark
			      Step 1: $H_2O_2 + I^-$ ✓
			
			 Products of Step 1 AND all of Step 2 1 mark
			      Step 1 → $IO^- + H_2O$
			 AND Step 2: $H^+ + IO^- →$ HIO ✓
			
			 Step 4 (Independent mark) 1 mark
			      $H^+ + OH^- → H_2O$ ✓
				3	**IGNORE state symbols**
					
					 Elements can be in any order in formulae
					
					 Alternatives for 2nd mark
					      Step 1: → HIO + OH^-
					 AND Step 2: $H^+ + OH^-$ → H_2O ✓
					
					      Step 1: → $H_2O_2I^-$
					 AND Step 2: $H^+ + H_2O_2I^- →$ HIO + H_2O ✓
					
					 Other possibilities, contact TL
					
					 ALLOW $2H^+ + 2OH^- → 2H_2O$
					                   $H_3O^+ + OH^- → 2H_2O$

			Total	**11**	

Question			Answer	Marks	Guidance
3	**(a)**		(enthalpy change for) 1 mole of gaseous ions **OR** 1 mole of hydrated ions/aqueous ions ✓ gaseous ions forming aqueous/hydrated ions ✓	**2**	**one mole** can be stated just once **EITHER** with gaseous ions **OR** with aqueous ions, e.g. • 1 mole of gaseous ions **forms** hydrated ions/aqueous ions • Gaseous ions **form 1 mole of** hydrated ions/aqueous ions **ALLOW** 1 mol for 1 mole **IGNORE** 'energy released' **OR** 'energy required' For 2nd mark **IGNORE** gaseous ions are hydrated **IGNORE** gaseous ions dissolve in water ***Particles formed not stated*** **ALLOW** 1 mark for: 1 mole of gaseous <u>**IONS**</u> forms aqueous/hydrated **atoms/ particles/ molecules**

Question			Answer	Marks	Guidance
3	(b)	(i)	**4 marks** for species **AND** state symbols on all 4 energy levels (including added energy level) $2K^+(g) + SO_4^{2-}(g)$ ✔ $(2) \textbf{C}$ **OR** $(2) \textbf{–320}$ $2K^+(aq) + SO_4^{2-}(g)$ ✔ **A OR –1763** **D** $2K^+(aq) + SO_4^{2-}(aq)$ ✔ **B** **OR 24** ✔ $K_2SO_4(s)$ **1 mark** for **B**, **C AND D** labels **OR** enthalpy values **AND** arrow directions correct ✔ **ALLOW** $K_2SO_4(aq)$ for $2K^+(aq) + SO_4^{2-}(aq)$ **ALLOW** arrows not touching lines. **Direction** is important: • **FROM** $2K^+(g) + SO_4^{2-}(g)$ line • **FROM** $K_2SO_4(s)$ line **See APPENDIX** '2 ×' is **NOT** required – *part of calculation mark*	5	**IF** extra energy level is **above** top line **OR below** bottom line, **DO NOT ALLOW** mark for species on this line. **See APPENDIX** **ALLOW C** and **D** with associated labels, the other way round: $2K^+(g) + SO_4^{2-}(g)$ **D** $2K^+(g) + SO_4^{2-}(aq)$ **A OR –1763** $(2) \textbf{C}$ **OR** $(2) \textbf{–320}$ $2K^+(aq) + SO_4^{2-}(aq)$ **B** **OR 24** $K_2SO_4(s)$ State symbols are **essential** **IF** no extra energy level is shown with **C** and **D** combined forming $2K^+(aq) + SO_4^{2-}(aq)$, • No mark for the extra energy level with species • No mark for labels as **C** and **D** are combined Therefore 3 max for species on energy levels provided
3	(b)	(ii)	ΔH(hydration) SO_4^{2-} = **–1099** (kJ mol^{-1}) ✔	1	**ONLY** correct answer

	Question		Answer	Marks	Guidance
3	(c)	(i)	**Aqueous** particles are more disordered than **solid** (particles) **OR** **Solid** particles are more ordered than **aqueous** (particles) ✓	1	For particles, **ALLOW** ions **DO NOT ALLOW** molecules/atoms **ALLOW** 'When the state changes from solid to aqueous, disorder increases' For more disordered, **ALLOW l**ess ordered/ more freedom/ more ways of arranging energy/ more random For aqueous particles, **ALLOW particles in solution** **IGNORE** dissolved
3	(c)	(ii)	*Calculation (2 marks)* $\Delta G = 24 - (298 \times 0.225)$ **OR** $24 - 67.05$ *(in kJ)* **OR** $24000 - (298 \times 225)$ **OR** $24000 - 67050$ *(in J)* ✓ **Calculation of ΔG (IGNORE UNITS)** $\Delta G = -43$ (kJ mol^{-1}) **OR** -43000 (J mol^{-1}) ✓ *Subsumes 1st calculation mark* **Reason for solubility** Calculated value of ΔG that is **negative** **AND** Statement that: ΔG is negative **OR** $\Delta G < 0$ **OR** $-43 < 0$ **OR** $\Delta H - T\Delta S < 0$ **OR** $T\Delta S > \Delta H$ ✓	3	**Contact TL if solely entropy approach rather than ΔG** **ALLOW** -43.1 OR -43.05 (*calculator value*) **ALLOW 1 calculation mark (IGNORE units) for** $-67.(026)$ **OR** -67026 *ECF from 225 instead of 0.225* $18.(375)$ **OR** $+18.375$ *ECF from 25 instead of 298* **ALLOW other ECF** from **ONE** error in 1st step of calc, e.g. incorrect value for ΔH such as -1099 from 3bii $\rightarrow -1166.05$ **TAKE CARE** that same units used for ΔH and ΔS **NO reason mark from a +ve value of ΔG**
			Total	12	

Question			Answer	Marks	Guidance
4	(a)		Iodine is non-polar **OR** Iodine does not form H bonds **with water** ✓	1	**IGNORE** iodine is slightly polar **IGNORE** 'cannot bond to water' (too vague) **IGNORE** 'Lack of a lone pair' **IGNORE** 'inability to induce a dipole
4	(b)		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF K_c = 104 dm^3 mol^{-1} award 4 marks:** *3 for calculation of 104 from data, 1 for units* -- **Equilibrium concentrations (mol × 5) (1 mark)** I_2 = 4.00×10^{-5} × **5** = 2.00×10^{-4} (mol dm^{-3}) **AND** I^- = 9.404×10^{-2} × **5** = 0.4702 (mol dm^{-3}) ✓ **AND** I_3^- = 1.96×10^{-3} × **5** = 9.80×10^{-3} (mol dm^{-3}) **Calculation of K_c and units (3 marks)** $K_c = \dfrac{[\,I_3^-(aq)\,]}{[\,I_2(aq)\,] \times [\,I^-(aq)\,]}$ **OR** $\dfrac{9.80 \times 10^{-3}}{2.00 \times 10^{-4} \times 0.4702}$ ✓ = 104 ✓ **Must be 3 SF** dm^3 mol^{-1} **OR** mol^{-1} dm^3 ✓	4	***FULL ANNOTATIONS MUST BE USED*** -- Throughout, at least **3SF** but **ALLOW** absence of trailing zeroes e.g. for 9.80×10^{-3} **ALLOW** 9.8×10^{-3} **FOR** I^- 0.4702, **ALLOW** 0.47(0) (mol dm^{-3}) still →104 for calc State symbols **not** required in K_c expression **ALLOW ECF** from incorrect concentrations Any **ECF** value **MUST** be to **3 SF** for K_c value -- **COMMON ERRORS** **104.2 → 104.2109741 (calc)** *> 3 SF* **2 marks + units** **521** *no × 5 for concs* **2 marks + units** **521.1 → 521.0548703** as above and > 3SF **1 mark + units** **2610** *÷ 5 instead of × 5 for concs* **2 marks + units** **9.60×10^{-3}** K_c upside down, correct concs **2 marks + units** **1.92×10^{-3}** K_c upside down, no × *5 for concs* **1 mark + units** **NOTE**: With K_c upside down, units become mol dm^{-3} by **ECF**

Question			Answer	Marks	Guidance
4	(c)		Ag^+/silver nitrate reacts with I^- to form AgI/silver iodide **OR** $Ag^+ + I^- \rightarrow AgI$ ✓ yellow precipitate/solid forms ✓ **Equilibrium 2** shifts to the left ✓ **Equilibrium 1** shifts to left **AND** I_2 comes out of solution/less I_2 dissolves/ I_2 precipitates/black solid /grey solid /violet solid ✓	4	***FULL ANNOTATIONS MUST BE USED*** -- **DO NOT ALLOW** cream **OR** cream–yellow **ALLOW** just 'yellow' if supported by AgI(s) somewhere

4	(d)		**in all equations ALLOW equilibrium signs**
			                  IGNORE state symbols
			 -- 	
			 Reaction 1: 1 mark
			 $2I_2 + 5O_2 \rightarrow 2I_2O_5$ ✓
			 -- 	
			 Reaction 2: 2 marks
			 1st mark: ALL CORRECT species
			
			 e.g.: $I_2 + OH^- \rightarrow I^- + IO_3^- + H_2O$
			
			 2nd mark for **CORRECT balanced equation**
			     $3I_2 + 6OH^- \rightarrow 5I^- + IO_3^- + 3H_2O$
			 ✓✓
				3	***FULL ANNOTATIONS MUST BE USED***
					 -- 	
					
					 ALLOW correct multiples throughout, e.g. $I_2 + 2\frac{1}{2}O_2 \rightarrow I_2O_5$
					 -- 	
					 For 1st mark, IGNORE e^- present
					
					 ALLOW species/equation with NaOH or KOH,
					 e.g. $3I_2 + 6NaOH \rightarrow 5I^- + IO_3^- + 3H_2O + 6Na^+$
					        $3I_2 + 6NaOH \rightarrow 5NaI + NaIO_3 + 3H_2O$
					 ALLOW
					     Species: $I_2 + OH^- \rightarrow I^- + IO_2^+ + H_2O$ ✓
					 OR Equation: $3I_2 + 4OH^- \rightarrow 5I^- + IO_2^+ + 2H_2O$ ✓✓
					
					     Species: $I_2 + OH^- \rightarrow I^- + IO^{3+} + H_2O$ ✓
					 OR Equation: $3I_2 + 2OH^- \rightarrow 5I^- + IO^{3+} + H_2O$ ✓✓

			Total	12	

Question			Answer	Marks	Guidance
5	(a)		$(K_a =) \dfrac{[H^+]\,[NO_2^-]}{[HNO_2]}$ ✓ **IGNORE** state symbols	1	**IGNORE** $\dfrac{[H^+]^2}{[HNO_2]}$ **OR** $\dfrac{[H^+]\,[A^-]}{[A]}$ **ALLOW** H_3O^+ for H^+ Square brackets **required**
5	(b)		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 2.12 award **2 marks** --- $[H^+] = \sqrt{K_a\ [HNO_2]} = 7.502 \times 10^{-3}$ (mol dm^{-3}) ✓ pH = $-\log 7.502 \times 10^{-3} = 2.12$ ✓ **pH to 2 DP**	2	-- **ALLOW** intermediate value from 3 SF (7.50 up to calculator value of $7.501999733 \times 10^{-3}$ **ALLOW** 1 mark for 2.1 **OR** answer > 2 DP (i.e. not 2 DP) **ONLY ALLOW** pH mark by **ECF** if K_a **AND** 0.120 used and **AND** pH <7 --- **COMMON ERRORS (MUST be to 2 DP)** **pH = 4.25 No square root:1 mark** $[H^+] = (4.69 \times 10^{-4} \times 0.120) = 5.628 \times 10^{-5}$ (mol dm^{-3}) pH = $-\log 5.628 \times 10^{-5} = 4.25$ ✓ **pH = 0.92 no K_a used:** **zero marks** pH = $-\log 0.120 = 0.92$ **pH = 13.08 K_w/pOH used:** **zero marks** pH = $-\log \dfrac{1.00 \times 10^{-4}}{0.120}$ **OR** 14 $-$ log 0.120 = 13.08

Question			Answer	Marks	Guidance

5	**(c)**	**(i)**	**FIRST, CHECK THE ANSWER ON ANSWER LINE**
			IF answer = **3.43**, **AWARD 4 marks**
			--- 	
			Expression: $K_a \times$ acid/base ratio
			    Use of $K_a \times \dfrac{[HNO_2]}{[NO_2^-]}$ **OR** $4.69 \times 10^{-4} \times \dfrac{[HNO_2]}{[NO_2^-]}$ ✓
			
			Using correct concs/mol in expression
			    $[H^+] = 4.69 \times 10^{-4} \times \dfrac{0.0400}{0.0500}$ ✓ *Subsumes previous mark*
			
			Calculation of $[H^+]$
			    $[H^+] = 3.752 \times 10^{-4}$ (mol dm^{-3}) ✓
			
			pH to 2 DP (From 3.42573717)
			    pH = $-\log 3.752 \times 10^{-4}$ = 3.43 ✓
			
			NO marks are available using
			    K_a square root approach (weak acid pH)
			    $K_w /10^{-14}$ approach (strong base pH)
			--- 	
			ALLOW alternative approach based on Henderson–
			Hasselbalch equation (**ALLOW** $-\log K_a$ for pK_a)
			pH = pK_a + log $\dfrac{[NO_2^-]}{[HNO_2]}$ **OR** pK_a − log $\dfrac{[HNO_2]}{[NO_2^-]}$ ✓
			pH = pK_a + log $\dfrac{0.0500}{0.0400}$ **OR** pK_a − log $\dfrac{0.0400}{0.0500}$ ✓
			pH = pK_a + 0.097 ✓
			
			pH = 3.329 + 0.097 = 3.43 ✓
				4	***FULL ANNOTATIONS MUST BE USED***
					--- 	
					
					ALLOW just $K_a \times \dfrac{acid}{salt}$ *expression*
					
					Mark by **ECF** from $4.69 \times 10^{-4} \times \dfrac{[NO_2^-]}{[HNO_2]}$ *inverted expression*
					
					Mark by **ECF** from incorrect $[HNO_2]$ and $[NO_2^-]$
					ONLY award **marks** for a pH calculation via
					K_a **AND** using concentrations/mol derived from the question
					
					DO NOT ALLOW final pH mark by **ECF** if pH > 7
					--- 	
					COMMON ERRORS BUT CHECK WORKING
					pH = 2.82 **3 marks**
					    initial concs: 0.200 and 0.0625
					pH = 3.23 **3 marks**
					    0.0400 and 0.0500 acid/base ratio inverted
					pH = 3.83 **2 marks**
					    initial concs: 0.200 and 0.0625 and ratio inverted
					pH = 2.73 **3 marks**
					    Incorrect $[NO_2^-]$ = 0.01 and correct $[HNO_2]$ = 0.04
					pH = 4.03 **3 marks**
					correct $[NO_2^-]$ = 0.05 and incorrect $[HNO_2]$ = 0.01

Question			Answer	Marks	Guidance
5	(c)	(ii)	**Equilibrium: 1 mark** $HNO_2 \rightleftharpoons H^+ + NO_2^-$ ✓ (ignore state symbols) **Control of pH: 2 marks (QWC)** *Added HCl* NO_2^- reacts with added acid/HCl/H^+ **OR** $NO_2^- + H^+ \rightarrow$ **OR** more HNO_2 forms ✓ *Added NaOH* HNO_2 reacts with added alkali/NaOH/OH^- **OR** $HNO_2 + OH^- \rightarrow$ **OR** more NO_2^- forms **OR** H^+ reacts with added alkali/NaOH **OR** $H^+ + OH^- \rightarrow$ ✓ **Equilibrium shift:** **1 mark for shifts in $HNO_2 \rightleftharpoons H^+ + NO_2^-$ (See 1st mark)** Equilibrium for added **acid $\rightarrow$ left** **AND** Equilibrium for added **alkali $\rightarrow$ right** ✓ (**QWC**)	4	***FULL ANNOTATIONS MUST BE USED*** --- **IGNORE** $HA \rightleftharpoons H^+ + A^-$ Equilibrium sign **essential** **BUT ALLOW** small slips in its appearance if it is obviously an attempt to show an equilibrium sign rather than an arrow **QWC: Quality of written communication** **DO NOT ALLOW** HA and A^- for HNO_2 and NO_2^- **IGNORE just** acid reacts with added alkali **IGNORE just** conjugate base/salt/base reacts with added acid **DO NOT ALLOW** salt/base reacts with added acid **AWARD** 'shift mark' **ONLY** if correct equilibrium equation has been given **IGNORE** any other equilibria in response

Question			Answer	Marks	Guidance
5	(d)	(i)	Endothermic **AND** K_w increases with temperature **OR** Endothermic **AND** dissociation increases **with temperature** **OR** Endothermic **AND** (dissociation) involves breaking bonds ✓	1	Endothermic **and** reason required for the mark **ALLOW** Endothermic **AND** increasing temperature shifts equilibrium/reaction to the right/favours forward reaction **DO NOT ALLOW** breaking hydrogen bonds **OR** intermolecular bonds/forces
5	(d)	(ii)	***OH⁻ concentration*** $[OH^-] = \dfrac{9.311 \times 10^{-14}}{1.00 \times 10^{-7}} = 9.311 \times 10^{-7}$ (mol dm^{-3}) ✓ ***Explanation (dependent on 1st mark)*** $9.311 \times 10^{-7} > 1.(00) \times 10^{-7}$ **OR** $[OH^-] > [H^+]$ **OR** OH^- in excess **AND** Alkaline ✓	2	***H⁺ OR OH⁻ concentration (neutral pH)*** $[H^+] = [OH^-] = \sqrt{(9.311 \times 10^{-14})} = 3.05 \times 10^{-7}$ (mol dm^{-3}) ✓ ***Explanation (dependent on 1st mark)*** pH = $-\log (3.05 \times 10^{-7}) = 6.5 \rightarrow 6.515501837$ (calc) **AND** Alkaline ✓
5	(d)	(iii)	$pK_w = 13.03$ ✓	1	**ONLY** correct answer

Question			Answer	Marks	Guidance
5	**(d)**	**(iv)**	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = **10.76**, award **3 marks** -- *Dilution 1 mark* $[OH^-(aq)] = [NaOH(aq)] = \dfrac{0.0270}{5} = 0.00540$ (mol dm^{-3}) ✓ *[H⁺] 1 mark* $[H^+(aq)] = \dfrac{9.311 \times 10^{-14}}{0.00540} = 1.72 \times 10^{-11}$ (mol dm^{-3}) ✓ $\quad$ Calculator: $1.724259259 \times 10^{-11}$ *pH 1 mark* $pH = -\log 1.72 \times 10^{-11} = \mathbf{10.76}$ ✓ --- **ALLOW** pOH method for 2nd and 3rd mark: $pOH = -\log 0.00540 = 2.27$ ✓ (calculator 2.26760624) $pH = 13.03 - 2.27 = 10.76$ ✓	3	*FULL ANNOTATIONS MUST BE USED* -- **ALLOW** dilution **AFTER** calculation of $[H^+(aq)]$ i.e. original $[H^+] = \dfrac{9.311 \times 10^{-14}}{0.0270} = 3.45 \times 10^{-12}$ (mol dm^{-3}) ✓ After dilution, $[H^+] = 3.45 \times 10^{-12} \times 5 = 1.72 \times 10^{-11}$ (mol dm^{-3})✓ $pH = -\log 1.72 \times 10^{-11} = \mathbf{10.76}$ ✓ **ALLOW ECF** from incorrect $[H^+(aq)]$ provided that pH >7 --- **COMMON ERRORS (MUST be to 2 DP)** **pH = 11.73** At 25ºC (1.00×10^{-14}): **2 marks** $\quad pH = -\log 1.85 \times 10^{-12} = \mathbf{11.73}$ **pH = 11.46** No dilution at 60ºC (9.311×10^{-14}) **2 marks** $\quad pH = -\log(3.45 \times 10^{-12}) = \mathbf{11.46}$ **pH = 12.43** No dilution **AND** 25ºC (1.00×10^{-14}) **1 mark** $\quad pH = -\log(3.70 \times 10^{-13}) = \mathbf{12.43}$ **pH = 12.16** ×5 instead of ÷ 5 at 60ºC (9.311×10^{-14}) **2 marks** $\quad pH = -\log(6.879 \times 10^{-13}) = \mathbf{12.16}$ **pH = 13.13** ×5 instead of ÷ 5 at 25ºC (1.00×10^{-14}) **1 mark** $\quad pH = -\log(7.407 \times 10^{-14}) = \mathbf{13.13}$ **NOTE:** Attempts at dilution → 0.0270 with error in powers of 10 → 12.46 from 0.00270, etc may give 2 marks by **ECF**
			Total	**18**	

Question			Answer	Marks	Guidance
6	(a)		**Definition** The e.m.f. (of a half-cell) compared with/connected to a (standard**)** hydrogen half-cell/(standard**)** hydrogen electrode ✓ **Standard conditions** *Units essential* Temperature of 298 K / 25ºC **AND** (solution) concentrations of 1 mol dm^{-3} **AND** pressure of 100 kPa **OR** 10^5 Pa **OR** 1 bar ✓	2	For e.m.f., **ALLOW** voltage **OR** potential difference/p.d. **OR** electrode/reduction/redox potential **ALLOW** e.m.f. of a cell ….. **ALLOW** /(standard) hydrogen cell **IGNORE** S.H.E. (as abbreviation for standard hydrogen electrode) **DO NOT ALLOW** hydrogen fuel cell **ALLOW** 1M **OR** 1 mol/dm^3 **DO NOT ALLOW** 1 mol **OR** 1 mole **ALLOW** 1 atmosphere/1 atm **OR** 101 kPa **OR** 101325 Pa
6	(b)	(i)	**Complete** circuit with voltmeter **AND** labelled salt bridge linking two half-cells ✓ Cu electrode in Cu^{2+} ✓ Pt electrode in V^{2+} **AND** V^{3+} ✓ Cu shown as + **AND** Pt shown as – ✓ electrons in wire **AND** ions in salt bridge ✓ *On diagram or stated*	5	Half cells can be drawn in either order Half cells must show electrodes dipping into solutions **ALLOW** small gaps in circuit **DO NOT ALLOW** half-cell with H_2 added **IGNORE** any stated concentrations **IGNORE** 'anode' and 'cathode' In salt bridge, **ALLOW** any stated ion that may be present, e.g. K^+, NH_4^+, NO_3^-, Cu^{2+}, V^{2+}, V^{3+} **IGNORE** direction of travel of ions and electrons. **ALLOW** Cu half cell as + **AND** V half cell as –

Question	Answer	Marks	Guidance
6 (b) (ii)	0.60 **OR** 0.6 (V) ✓	1	**IGNORE** any sign
6 (c)	**Definitions:** *1 mark* Oxidising agent removes/accepts/gains electrons **OR** increases oxidation number (of another species) **AND** Reducing agent adds/donates/loses electrons **OR** decreases oxidation number (of another species) ✓ **Oxidising agent:** *2 marks* Cr^{3+} oxidises Al **OR** Cr^{3+} acts as oxidising agent **AND** $3Cr^{3+} + Al \rightarrow 3Cr^{2+} + Al^{3+}$ ✓ ***Explanation (dependent on Cr^{3+} oxidising Al above)*** E of redox system 2 (Cr^{3+}/Cr^{2+}) is **more** positive /**less** negative (than E of system 1 (Al^{3+}/Al)) **ORA**, i.e. in terms of 1 being more negative (than 2) ✓ **Reducing agent:** *3 marks* Cr^{3+} reduces FeO_4^{2-}(/H^+) ✓ $2Cr^{3+} + 2FeO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + 2Fe^{3+} + H_2O$ ✓ ***Explanation (dependent on Cr^{3+} reducing FeO_4^{2-} above)*** E of redox system 5 ($Cr_2O_7^{2-}/Cr^{3+}$) is **less** positive/ **more** negative (than E of system 6 (FeO_4^{2-}/Fe^{3+})) **ORA**, i.e. in terms of 6 being more positive (than 5) ✓	6	***FULL ANNOTATIONS MUST BE USED*** --- **ALLOW** oxidising agent decreases its oxidation number **AND** reducing agent increases its oxidation number **IGNORE** oxidising agent oxidises/is reduced **OR** reducing agent reduces/is oxidised **In equations,** • **IGNORE** state symbols (even if incorrect) • **ALLOW** ⇌ in equation **IF** more than one equation shown for **Cr^{3+} as oxidising agent**, **CON** and **zero marks** for 2 oxidising agent marks **IGNORE** equations with Cr^{2+} as reactant Explanations **MUST** be in terms of positive/negative: **IGNORE** 'higher' E **OR** 'greater' **ALLOW** E_{cell} = +1.25 V (+ sign required) **IF** more than one equation shown for **Cr^{3+} as a reducing agent**, **CON** and **zero marks** for 3 reducing agent marks **IGNORE** equations with Cr^{2+} as reactant Explanations **MUST** be in terms of positive/negative: **IGNORE** 'higher' E **OR** 'greater' **ALLOW** E_{cell} = +0.87 V (+ sign required)
	Total	14	

Question			Answer	Marks	Guidance
7	(a)	(i)	**IGNORE** any charges shown within complexes (treat as rough working) **Complex ion C**: $[Ni(H_2O)_6]^{2+}$ ✓ **Solid D**: $Ni(OH)_2$ ✓ **Complex ion E**: $[Ni(CN)_4]^{2-}$ ✓	3	**ALLOW** +2 and –2 for charges Square brackets required **ALLOW** $Ni(H_2O)_4(OH)_2$ $(H_2O)_4$ and $(OH)_2$ in any order **IGNORE** any square brackets Square brackets required **TAKE CARE** for round brackets within complex ion, i.e. (H_2O), (OH) and (CN)

Question			Answer	Marks	Guidance
7	(a)	(ii)	**Mark independently of 7(a)(i)** **ALLOW** +2 and −2 for charges **IGNORE** any charges shown within complexes (treat as rough working) $Ni^{2+} + 2OH^- \rightarrow Ni(OH)_2$ ✓ Type of reaction: precipitation ✓ **INDEPENDENT of equation** $[Ni(H_2O)_6]^{2+} + 4CN^- \rightarrow [Ni(CN)_4]^{2-} + 6H_2O(l)$ ✓ Type of reaction: ligand substitution ✓ **INDEPENDENT of equation**	4	**For equations: IGNORE** state symbol (even if wrong) Square brackets **not** required for $Ni(OH)_2$ **ALLOW** $[Ni(H_2O)_6]^{2+} + 2OH^- \rightarrow [Ni(H_2O)_4(OH)_2] + 2H_2O$ **ALLOW** $[Ni(H_2O)_6]^{2+} + 2OH^- \rightarrow Ni(OH)_2 + 6H_2O$ **ALLOW** $NiSO_4(aq) + 2OH^-(aq) \rightarrow Ni(OH)_2(s) + SO_4^{2-}(aq)$ **ALLOW** $NiSO_4(aq) + 2KOH(aq) \rightarrow Ni(OH)_2(s) + K_2SO_4(aq)$ **ALLOW** acid/base **OR** neutralisation **OR** deprotonation **ONLY IF** $[Ni(H_2O)_6]^{2+}$ **AND** $[Ni(H_2O)_4(OH)_2]$ used **ALLOW** precipitate **ALLOW** $[Ni(H_2O)_6]^{2+} + 4KCN \rightarrow [Ni(CN)_4]^{2-} + 6H_2O + 4K^+$ **LOOK** at formulae for **E** from **7(a)(i)** (copied at bottom) **ALLOW ECF** in **7aii** Equation for no round brackets around CN, i.e. $[NiCN_4]^{2-}$ in **7a(i)** This is the only **ECF** allowed from **7ai** structures. **ALLOW** ligand exchange
7	(b)	(i)	linear ✓	1	**IGNORE** planar

Question			Answer	Marks	Guidance
7	(b)	(ii)	Au/Gold has been **oxidised** from 0 to +1 ✓ O/Oxygen/O_2 has been **reduced** from 0 to –2 ✓	2	**IF** Ag referred to, rather than Au, treat as a slip and apply **BOD** **ALLOW** 0 to 1 (i.e. no + sign for +1) **ALLOW** 1 mark for **ALL** oxidation numbers correct with no oxidised or reduced **OR** oxidation and reduction wrong way round, e.g. Au goes from 0 to +1 and O goes from 0 to –2 ✓ Au is reduced from 0 to +1 and O is oxidised from 0 to –2 ✓
7	(b)	(iii)	**IGNORE** any charges shown within complexes (treat as rough working) $4Au + 8CN^- + 2H_2O + O_2 \rightarrow 4[Au(CN)_2]^- + 4OH^-$ ✓✓ First mark for all 6 species Second mark for balancing	2	**IF** Ag referred to, rather than Au, treat as a slip and apply **BOD** **IGNORE** state symbols **CARE**: In $[Au(CN)_2]^-$, – sign is **OUTSIDE** square brackets **For 1st mark, IGNORE** e^- present **ALLOW** 1 mark for balanced equation with CN^- missing, i.e. $4Au + 2H_2O + O_2 \rightarrow 4Au^+ + 4OH^-$ **ALLOW** 1 mark rogue e^- on either side **ALLOW** multiples, e.g. $2Au + 4CN^- + H_2O + \frac{1}{2}O_2 \rightarrow 2[Au(CN)_2]^- + 2OH^-$ $Au + 2CN^- + \frac{1}{2}H_2O + \frac{1}{4}O_2 \rightarrow [Au(CN)_2]^- + OH^-$
7	(b)	(iv)	$ClO^- + 2H^+ + 2e^- \rightarrow Cl^- + H_2O$ ✓	1	**IGNORE** state symbols **ALLOW** e for electron **ALLOW** multiples
			Total	13	

Question			Answer	Marks	Guidance
8	(a)		Cu^{2+}: $(1s^2)\ 2s^22p^63s^23p^63d^9$ ✓ Cu^+: $(1s^2)\ 2s^22p^63s^23p^63d^{10}$ ✓	2	**IGNORE** repeated $1s^2$ after $1s^2$ prompt on answer line **ALLOW** $4s^0$, either before or after 3d **ALLOW** upper case D, etc and subscripts, e.g. ......$3S_23P^6$ **DO NOT ALLOW** [Ar] as shorthand for $1s^22s^22p^63s^23p^6$
8	(b)		**IGNORE** any charges shown within formulae (treat as rough working) $CuCO_3 + 2HCOOH \rightarrow Cu(HCOO)_2 + H_2O + CO_2$ **OR** $CuO + 2HCOOH \rightarrow Cu(HCOO)_2 + H_2O$ **OR** $Cu(OH)_2 + 2HCOOH \rightarrow Cu(HCOO)_2 + \mathbf{2}H_2O$ ✓	1	**IGNORE** state symbols In formula of HCOOH/HCOO, **ALLOW** H, C and O in **ANY** order **ALLOW** H_2CO_3 for H_2O and CO_2 in carbonate equation **ALLOW** $(HCOO)_2Cu$ for $Cu(HCOO)_2$ **DO NOT ALLOW** equation with $CuSO_4$
8	(c)		$2Cu^{2+} + 4I^- \rightarrow 2CuI\mathbf{(s)} + I_2$ ✓ State symbol for CuI(s) **ONLY** required	1	**ALLOW** multiples, e.g. $Cu^{2+} + 2I^- \rightarrow CuI\mathbf{(s)} + ½I_2$ **IGNORE** other state symbols, even if incorrect

8	(d)		Starch ✓
			
			 Blue/black to colourless/white ✓
			
			 MARK INDEPENDENTLY
				2	**IGNORE** 'brown' in composite colour with blue or black, i.e.
					      ALLOW blue/brown to colourless
					      ALLOW black/brown to colourless
					
					 DO NOT ALLOW just 'it turns colourless/is decoloured'
					      Initial colour required
					
					 IGNORE clear for colourless

Question			Answer	Marks	Guidance

8	**(e)**		**WORKING REQUIRED**
			Correct answer: x = 4 required evidence of working
			-- 	
			
			$n(S_2O_3{}^{2-})$ **OR** $n(Cu^{2+}) = \dfrac{0.0420 \times 23.5}{1000} = 9.87 \times 10^{-4}$ (mol) ✓
			
			In 250.0 cm³ solution, $n(Cu^{2+}) = 9.87 \times 10^{-3}$ (mol) ✓
			
			$M(Cu(HCOO)_2 \cdot 4H_2O) = \dfrac{2.226}{9.87 \times 10^{-3}} = 225.5$ (g mol⁻¹) ✓
			
			$x(H_2O)$ has mass of $225.5 - M(Cu(HCOO)_2)$
			                       = 225.5 − 153.5
			                       = 72(.0) ✓
			
			$x = \dfrac{72(.0)}{18(.0)} = \mathbf{4}$ **WHOLE NUMBER** needed
			AND
			evidence of working ✓
				5	***FULL ANNOTATIONS MUST BE USED***
					-- 	
					At least **3 SF** required throughout
					
					Alternative approach for final 3 marks based on mass:
					
					mass $Cu(HCOO)_2 = 9.87 \times 10^{-3} \times 153.5 = 1.515$ g ✓
					
					$n(H_2O) = \dfrac{2.226 - 1.515}{18(.0)} = \dfrac{0.711}{18(.0)} = 0.0395$ (mol) ✓
					
					$x = \dfrac{0.0395}{9.87 \times 10^{-3}} = 4$ ✓
					
					ALLOW $Cu(HCOO)_2 \cdot 4H_2O$
					
					--- 	
					COMMON ERRORS for 4 marks
					$x = 117$ (calc 116.78)
					     Use of 9.87 × 10⁻⁴ (no scaling × 10) → M = 2255.319
					
					$x = 17$ (calc 16.53) 4 marks
					     Use of 4.935 × 10⁻⁴ (Use of 0.5 × 9.87 × 10⁻³)
					
					Check $n(Cu^{2+})$ for other **ECF**s
					Check for **ECF**s from incorrect M(anhydr salt) Actual = 153.5

			Total	**11**	

APPENDIX Q3(b)

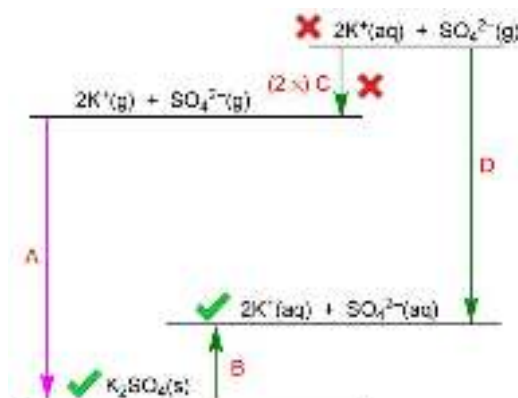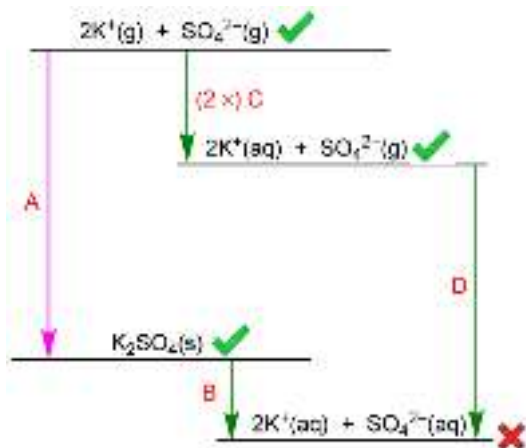|	
Extra energy line placed **ABOVE** top line 3 out of 4 marks awarded for energy lines and species. Top arrow is shown **FROM** $2K^+(g) + SO_4^{2-}(g)$ and arrow directions correct. Letter labels correct so last mark is awarded. **4/5 marks** 	Same as left-hand response **BUT** top arrow shown **TO** $2K^+(g) + SO_4^{2-}(g)$ so last mark not awarded **3/5 marks**
Extra energy line placed **BELOW** bottom line 3 out of 4 marks awarded for energy lines and species. Top arrow is shown **FROM** $K_2SO_4(s)$ and arrow directions correct. Letter labels correct so last mark is awarded. **4/5 marks** 	Same as left-hand response **BUT** bottom arrow shown **TO** $K_2SO_4(s)$ so last mark not awarded **3/5 marks**
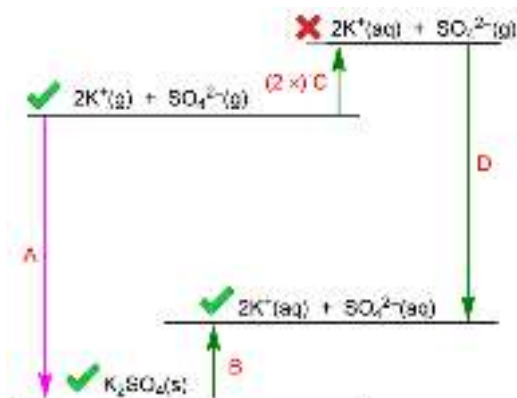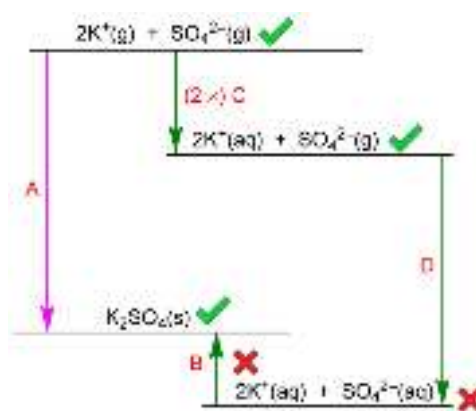
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