GCE

Chemistry A

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

Advanced GCE

Mark Scheme for June 2016

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This mark scheme is published as an aid to teachers and students, to indicate the requirements of the examination. It shows the basis on which marks were awarded by examiners. It does not indicate the details of the discussions which took place at an examiners' meeting before marking commenced.

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.

OCR will not enter into any discussion or correspondence in connection with this mark scheme.

1. Annotations available in RM Assessor.

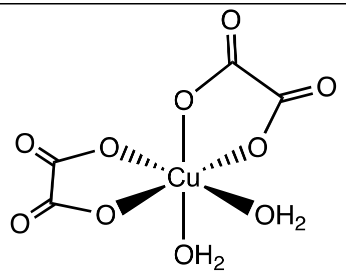
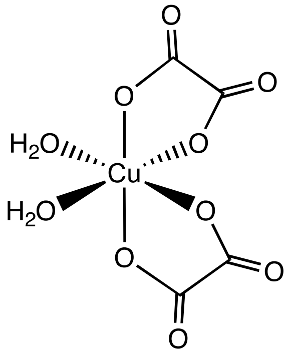
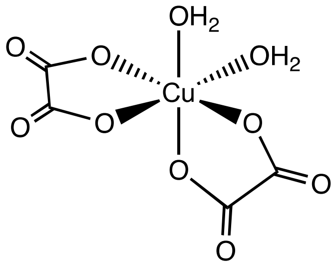
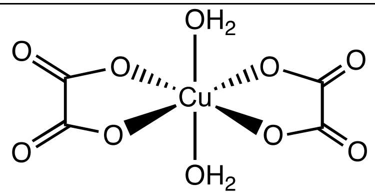
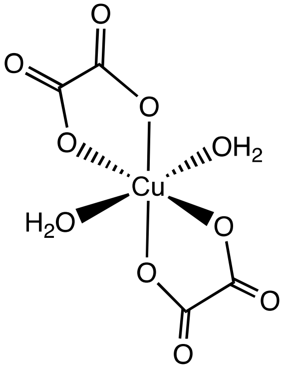
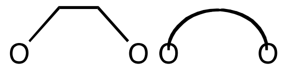
Annotation	Meaning
BOD	Benefit of doubt given
CON	Contradiction
✗	Incorrect response
ECF	Error carried forward
I	Ignore
NAQ	Not answered question
NBOD	Benefit of doubt not given
POT	Power of 10 error
^	Omission mark
RE	Rounding error
SF	Error in number of significant figures
✓	Correct response

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)	  	 	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** H_2O 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	

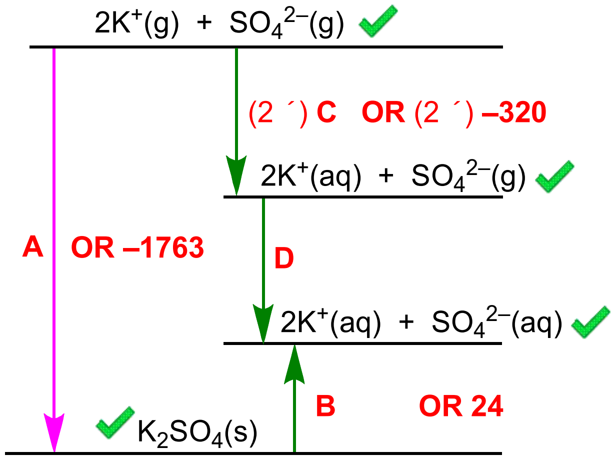
Question			Answer	Marks	Guidance
2	(a)		***initial rates data (3 marks)*** **NOTE**: Each comparison **MUST** relate to the **actual** change in concentration/rate in the experiments **EXPTS** $\mathbf{H_2O_2}$: $[H_2O_2] \times 2$ rate $\times$ 2 (1 & 2) **AND** 1st order ✓ $\mathbf{H^+}$: $[H^+] \times 2$ rate does not change (2 & 3) **AND** Zero order ✓ $\mathbf{I^-}$: $[I^-] \times 2$ **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 × 2; quadruples for × 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 1**st order (Expts 1 & 2) **DO NOT ALLOW** I_2 for I^- **IGNORE** $[H^+]$ for Expts 3 & 4
			Calculation of rate constant (3 marks), **EITHER** $k = \frac{5.70 \times 10^{-6}}{0.0010 \times 0.20}$ **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** $\times 10^{-2}$ **(3 SF)** **OR 29** $\times 10^{-3}$ (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** $\rightarrow$ $IO^- + H_2O$ **AND Step 2**: $H^+ + IO^- \rightarrow$ HIO ✓ **Step 4 (Independent mark)** **1 mark** $H^+ + OH^- \rightarrow H_2O$ ✓	3	**IGNORE state symbols** Elements can be in any order in formulae **Alternatives for 2nd mark** **Step 1:** $\rightarrow HIO + OH^-$ **AND Step 2**: $H^+ + OH^- \rightarrow H_2O$ ✓ **Step 1:** $\rightarrow H_2O_2I^-$ **AND Step 2**: $H^+ + H_2O_2I^- \rightarrow HIO + H_2O$ ✓ Other possibilities, contact TL **ALLOW** $2H^+ + 2OH^- \rightarrow 2H_2O$ $H_3O^+ + OH^- \rightarrow 2H_2O$
			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**

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Marks</th><th>Guidance</th></tr>
<tr><td>3</td><td>(b)</td><td>(i)</td><td>

4 marks for species **AND** state symbols on all 4 energy levels (including added energy level)



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

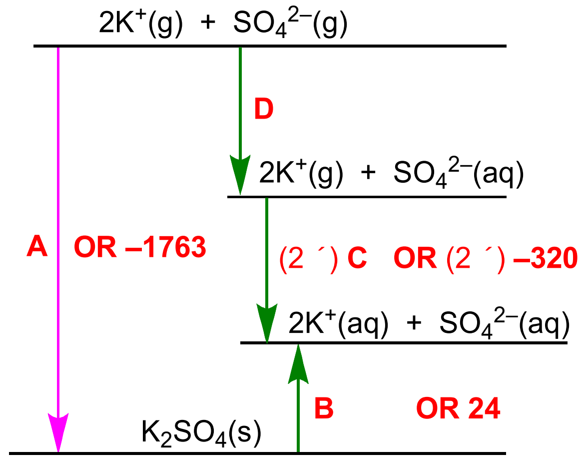
See APPENDIX

'2 ×' is **NOT** required – *part of calculation mark*

</td><td>5</td><td>

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:



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

</td></tr>
<tr><td>3</td><td>(b)</td><td>(ii)</td><td>ΔH(hydration) SO_4^{2-} = **–1099** (kJ mol^{-1}) ✓</td><td>1</td><td>ONLY correct answer</td></tr>
</table>

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)*** ΔG = 24 – (298 × 0.225) **OR** 24 – 67.05 *(in kJ)* **OR** 24000 – (298 × 225) **OR** 24000 – 67050 *(in J)* ✓ **Calculation of ΔG (IGNORE UNITS)** ΔG = –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** ΔG < 0 **OR** –43 < 0 **OR** $\Delta H - T\Delta S$ < 0 **OR** $T\Delta S$ > ΔH ✓	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 → –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)** $K_c = \frac{[I_3^-(aq)]}{[I_2(aq)] \times [I^-(aq)]}$ **OR** $\frac{9.80 \times 10^{-3}}{2.00 \times 10^{-4} \times 0.4702}$ ✓ = 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**	

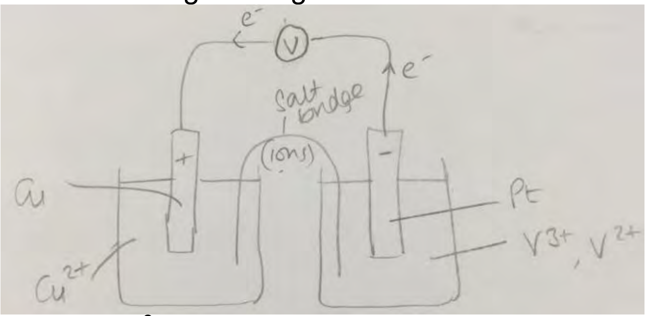
Question			Answer	Marks	Guidance
5	(a)		$(K_a =)\ \dfrac{[H^+]\,[NO_2^-]}{[HNO_2]}$ ✓ **IGNORE** state symbols	1	**IGNORE** $\dfrac{[H^+]^2}{[HNO_2]}$ **OR** $\dfrac{[H^+]\,[A^-]}{[A]}$ **ALLOW** H_3O^+ for H^+ Square brackets **required**
5	(b)		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 2.12 award **2 marks** --- $[H^+] = \sqrt{K_a \times [HNO_2]}$ = 7.502 × 10^{-3} (mol dm^{-3}) ✓ pH = –log 7.502 × 10^{-3} = 2.12 ✓ **pH to 2 DP**	2	--- **ALLOW** intermediate value from 3 SF (7.50 up to calculator value of 7.501999733 × 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 × 10^{-4} × 0.120) = 5.628 × 10^{-5} (mol dm^{-3}) pH = –log 5.628 × 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 × acid/base ratio* Use of $K_a \times \frac{[HNO_2]}{[NO_2^-]}$ **OR** $4.69 \times 10^{-4} \times \frac{[HNO_2]}{[NO_2^-]}$ ✓ *Using correct concs/mol in expression* $[H^+] = 4.69 \times 10^{-4} \times \frac{0.0400}{0.0500}$ ✓ *Subsumes previous mark* *Calculation of* $[H^+]$ $[H^+] = 3.752 \times 10^{-4}$ (mol dm^{-3}) ✓ *pH to 2 DP* **(***From 3.42573717)* pH = –log 3.752×10^{-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** –logK_a for pK_a) pH = pK_a + log $\frac{[NO_2^-]}{[HNO_2]}$ **OR** pK_a – log $\frac{[HNO_2]}{[NO_2^-]}$ ✓ pH = pK_a + log $\frac{0.0500}{0.0400}$ **OR** pK_a – log $\frac{0.0400}{0.0500}$ ✓ pH = pK_a + 0.097 ✓ pH = 3.329 + 0.097 = 3.43 ✓	4	***FULL ANNOTATIONS MUST BE USED*** -- **ALLOW** just $K_a \times \frac{\text{acid}}{\text{salt}}$ *expression* **Mark** by **ECF** from $4.69 \times 10^{-4} \times \frac{[NO_2^-]}{[HNO_2]}$ *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** → **left** **AND** Equilibrium for added **alkali** → **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*** $[OH^-] = \frac{9.311 \times 10^{-14}}{1.00 \times 10^{-7}} = 9.311 \times 10^{-7}$ (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*** $[OH^-(aq)] = [NaOH(aq)] = \frac{0.0270}{5} = 0.00540$ (mol dm^{-3}) ✓ ***[H⁺] 1 mark*** $[H^+(aq)] = \frac{9.311 \times 10^{-14}}{0.00540} = 1.72 \times 10^{-11}$ (mol dm^{-3}) ✓ Calculator: $1.724259259 \times 10^{-11}$ ***pH 1 mark*** pH = –log 1.72×10^{-11} = **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 $[H^+] = \frac{9.311 \times 10^{-14}}{0.0270} = 3.45 \times 10^{-12}$ (mol dm^{-3}) ✓ After dilution, $[H^+] = 3.45 \times 10^{-12} \times 5 = 1.72 \times 10^{-11}$ (mol dm^{-3})✓ pH = –log 1.72×10^{-11} = **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** pH = –log 1.85×10^{-12} = **11.73** **pH = 11.46** No dilution at 60ºC (9.311×10^{-14}) **2 marks** pH = –log(3.45×10^{-12}) = **11.46** **pH = 12.43** No dilution **AND** 25ºC (1.00×10^{-14}) **1 mark** pH = –log(3.70×10^{-13}) = **12.43** **pH = 12.16** ×5 instead of ÷ 5 at 60ºC (9.311×10^{-14}) **2 marks** pH = –log(6.879×10^{-13}) = **12.16** **pH = 13.13** ×5 instead of ÷ 5 at 25ºC (1.00×10^{-14}) **1 mark** pH = –log(7.407×10^{-14}) = **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. $2Au + 4CN^- + H_2O + ½O_2 \rightarrow 2[Au(CN)_2]^- + 2OH^-$ $Au + 2CN^- + ½ H_2O + ¼ O_2 \rightarrow [Au(CN)_2]^- + OH^-$
7	(b)	(iv)	$ClO^- + 2H^+ + 2e^- \rightarrow Cl^- + H_2O$ ✓	1	**IGNORE** state symbols **ALLOW** e for electron **ALLOW** multiples
			Total	**13**	

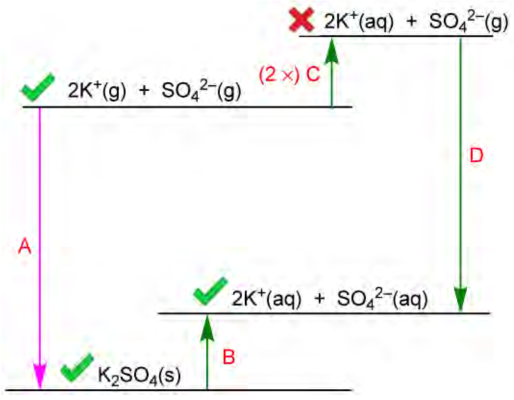
Question			Answer	Marks	Guidance
8	(a)		Cu^{2+}: $(1s^2)\,2s^2 2p^6 3s^2 3p^6 3d^9$ ✓ Cu^+: $(1s^2)\,2s^2 2p^6 3s^2 3p^6 3d^{10}$ ✓	2	**IGNORE** repeated $1s^2$ after $1s^2$ prompt on answer line **ALLOW** $4s^0$, either before or after 3d **ALLOW** upper case D, etc and subscripts, e.g. ……$3S_2 3P^6$ **DO NOT ALLOW** [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$
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** $n(Cu^{2+}) = \frac{0.0420 \times 23.5}{1000} = 9.87 \times 10^{-4}$ (mol) ✓ In 250.0 cm^3 solution, $n(Cu^{2+}) = 9.87 \times 10^{-3}$ (mol) ✓ $M(Cu(HCOO)_2{\bullet}4H_2O) = \frac{2.226}{9.87 \times 10^{-3}} = 225.5$ ($g\ mol^{-1}$) ✓ $\boldsymbol{x}(H_2O)$ has mass of $225.5 - M(Cu(HCOO)_2)$ $= 225.5 - 153.5$ $= 72(.0)$ ✓ $\boldsymbol{x} = \frac{72(.0)}{18(.0)} = \mathbf{4}$ **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 ✓ $n(H_2O) = \frac{2.226 - 1.515}{18(.0)} = \frac{0.711}{18(.0)} = 0.0395$ (mol) ✓ $\boldsymbol{x} = \frac{0.0395}{9.87 \times 10^{-3}} = 4$ ✓ **ALLOW** $Cu(HCOO)_2{\bullet}4H_2O$ -- **COMMON ERRORS for 4 marks** $\boldsymbol{x} = 117$ (calc 116.78) *Use of 9.87×10^{-4} (no scaling × 10)* $\rightarrow$ *M* = 2255.319 $\boldsymbol{x} = 17$ (calc 16.53) 4 marks *Use of 4.935×10^{-4} (Use of $0.5 \times 9.87 \times 10^{-3}$)* 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)

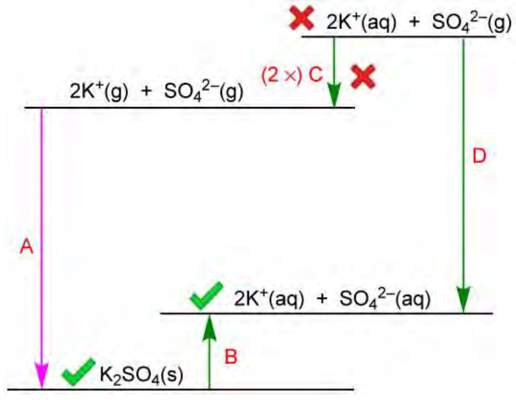
Extra energy line placed **ABOVE** top line
3 out of 4 marks awarded for energy lines and species.

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**



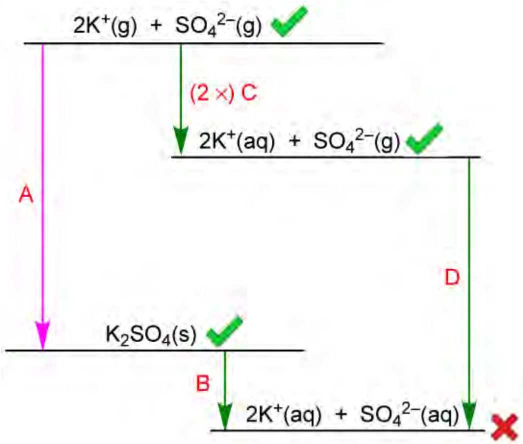
Same as left-hand response

BUT top arrow shown **TO** $2K^+(g) + SO_4^{2-}(g)$ so last mark not awarded
3/5 marks



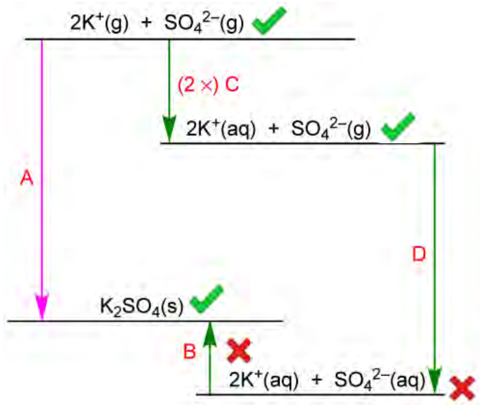
Extra energy line placed **BELOW** bottom line
3 out of 4 marks awarded for energy lines and species.

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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