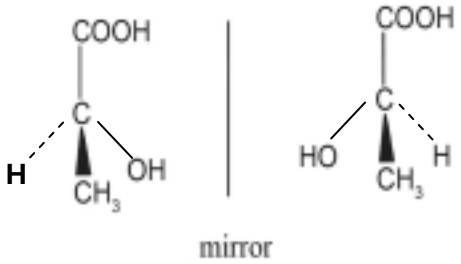
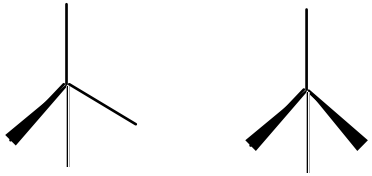
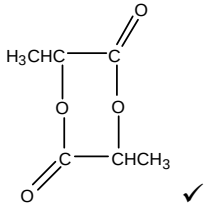
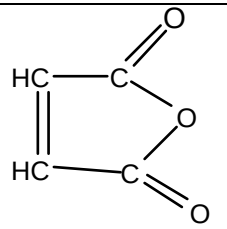
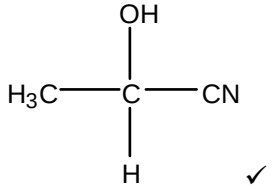
Question			Answer	Mark	Guidance
1	(a)	(i)	0 ✓, +2 ✓	2	**NOT** 2+
1	(a)	(ii)	nitrogen(IV) oxide ✓	1	**ACCEPT** nitrogen dioxide (or with no gap between words) or nitrogen(IV) dioxide (with or without gaps) **ALLOW** nitrogen (IV) oxide **ALLOW** without brackets round 'IV'
1	(b)		brown (gas) (formed) ✓	1	**IGNORE** 'colourless' as starting colour
1	(c)		*advantage*: nitrogen is fixed **OR** it (enters the soil and) benefits plants (*AW*) ✓ *disadvantage*: Acid rain **OR** an effect of acid rain eg buildings corroded / increasing acidity of soil / kills trees, increasing acidity of lakes (or rivers) / kills fish **OR** toxic **OR** causes respiratory problems **OR** (tropospheric) ozone formed **OR** contributes to photochemical smog ✓	2	idea of benefit to plants (eg: needed by plants / help plants grow / fertiliser / provides nutrients to soil, etc) needed for the 'or' version of the mark **IGNORE** 'harmful'/'polluting' for last two points must have idea of *giving rise to* ozone or photochemical smog **IGNORE** 'greenhouse gas'
1	(d)	(i)	0.2/24 ✓ **OR** $8.3 \times 10^{-3} \times 24 = 0.2$ **AND** comment that this is the fraction of oxygen in air 0.033(2) **or** 0.033333 (to 2 or more sf) ✓ [or standard form]	2	Numbers 0.2 (**or** 1/5) and divided by 24 must be there **OR** 1/120 **OR** 2/240 8.3×10^{-3} alone obviously does not score ie do not accept '0.03' Answer alone scores the mark. Working alone does not score **ALLOW** standard form eg 3.3×10^{-2} **ACCEPT** recurring decimal **NOT** rounding errors **watch out for 3.3×10^{-3} (incorrect)**
1	(d)	(ii)	$[NO_2]^2 / [N_2][O_2]^2$ ✓	1	**MUST** have square brackets **NOT** 'p' (even if with square brackets) **ALLOW** $[N_2] \times [O_2]^2$ or $[N_2].[O_2]^2$ **NOT** $[N_2] + [O_2]^2$ **ALLOW** '(g)' as state symbols. Others are CON

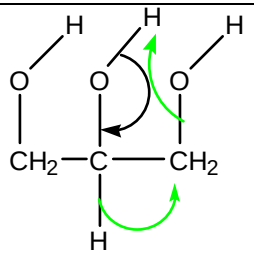
Question			Answer	Mark	Guidance
1	(d)	(iii)	$\sqrt{}$({ans for $[N_2]$ from d(i)} x $(8.3 \times 10^{-3})^2$ x 4×10^{-19}) ✓ **OR** $\sqrt{}([N_2] \times [O_2]^2 \times K_{(c)})$ **OR** part numbers part symbols evaluation (eg $[N_2] = 0.033$ gives $9.5(4) \times 10^{-13}$) ✓ (0.0332 gives $9.56/9.6 \times 10^{-13}$) one sig fig (eg 1×10^{-12}) ✓	3	correct evaluation of correct expression (even if expression is not written down) scores 2 No ecf from d(ii); no ecf for evaluating an incorrect expression, **except** that omission of the square root and then correctly evaluated (eg $9(.1) \times 10^{-25}$) **or** omission of square on O_2 (eg $1(.1) \times 10^{-11}$) score one mark. *A spreadsheet is available for other answers from (d)(i)* Mark sf separately, awarding the mark for *any* number to one sf. *So proceed as follows:* • *check for the three possible answers (with ecf if necessary using spreadsheet) One is worth two, others are worth one* • *If no matching answer is present, look for square root expression and award 1 if it is correct* • *Award sf mark if relevant*
1	(d)	(iv)	K_c larger ✓ (Forward) reaction endothermic **OR** right is endothermic direction ORA ✓ <u>Equilibrium</u> <u>position</u> moves to right/towards products ✓	3	Mark separately No ecf from second marking point incorrect **IGNORE** references to rates **must mention 'position' in connection with equilibrium**
1	(d)	(v)	Equilibrium (position) moves to right/products ✓ More <u>molecules/moles</u> on left-hand side/reactants ORA ✓	2	*Incorrect* effects on K_c are CON of first mark (**IGNORE** 'no effect') **ALLOW** 'it' for 'equilibrium position' **IGNORE** 'favours the right-hand side' **ALLOW** 'particles' instead of 'molecules' **IGNORE** 'more reactants than products' (ie without mention of moles etc) *Mark separately*
1	(e)	(i)	$HNO_3 \rightarrow H^+ + NO_3^-$ **or** $HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$ ✓ for correct species ✓ for correct species with arrow (not equm sign)	2	**IGNORE** state symbols **ALLOW** HNO_3 + aq $\rightarrow H^+ + NO_3^-$ $HNO_3 \rightarrow H_3O^+ + NO_3^-$ scores 1 overall Correct species in square brackets can just score the arrow mark

Question			Answer	Mark	Guidance
1	(e)	(ii)	– log(0.015) ✓ = 1.82(391) ✓	2	**ALLOW** 1.8 or more sf. **ALLOW** 'lg' Answer alone scores 2 marks No ecf from first mark
1	(f)	(i)	$H_2SO_4 + HNO_3 \rightarrow NO_2^+ + H_2O + HSO_4^-$ NO_2^+ ✓ rest correct ✓	2	**ALLOW** $2H_2SO_4 + HNO_3 \rightarrow NO_2^+ + H_3O^+ + 2HSO_4^-$ 'rest correct' means all other species correct with 'NO_2' (incorrect sign or no sign) **IGNORE** state symbols
1	(f)	(ii)	hydrogensulfate(VI) ✓	1	Mark separately from f(i) **IGNORE** formula **ALLOW** 'hydrogen sulfate' and 'hydrogensulfate' (i.e. no '(VI)') **ALLOW** 'sulphate' replacing 'sulfate'
1	(f)	(iii)	nitration **OR** nitrating (benzene/aromatics) **OR** making nitrobenzene ✓	1	**ALLOW** 'electrophilic substitution <u>of arene</u>'
			Total	25	

Question			Answer	Mark	Guidance
2	(a)	(i)	CO_2 / carbon dioxide ✓	1	
2	(a)	(ii)	2-hydroxypropanoic acid ✓	1	**ALLOW** errors in gaps, commas, dashes **ALLOW** '2-hydroxy**l**propanoic acid
2	(b)	(i)	 one correct 3d representation shown ✓ two correct mirror images of 3d structures and *either* line between them *or* the words 'mirror images' ✓	2	**ALLOW** groups on any carbons ambiguous attachments (eg COOH connected through O) structures drawn as  (but where two lines in the plane are shown (eg left-hand diagram here), they must **not** be at 90 or 180 degrees to each other) **ALLOW** for —— **ALLOW** skeletal (or mixed) formulae **ALLOW** structures breaking the 'two lines in the plane' rule above for *second* mark **NOT** flat structures
2	(b)	(ii)	1/ one ✓	1	
2	(c)	(i)	it has two: (carboxylic) acid / carboxyl groups / COOH groups ✓	1	**ALLOW** 'dicarboxylic' and **'**diprotic'
2	(c)	(ii)	lactic acid/it has a higher pK_a value / lower K_a / 3.86 is higher (ORA for malic acid) ✓ higher pH / lower concentration (or fewer) $\underline{H^{\pm}}$ ions / less dissociation into $\underline{H^{\pm}}$ ORA ✓	2	*Mark separately* **IGNORE** references to 5.13/larger value for malic acid **IGNORE** 'less acidic' (which is in the stem) *must refer to H^+ or pH*

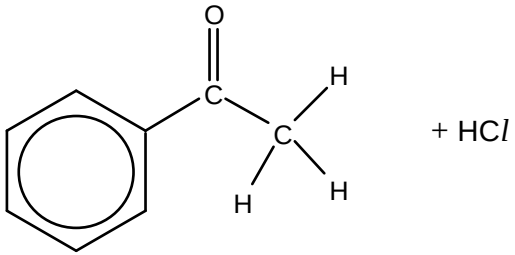
Question			Answer	Mark	Guidance
2	(d)	(i)	$C_3H_6O_3 \rightleftharpoons C_3H_5O_3^- + H^+$ ✓	1	**ALLOW** $C_3H_6O_3 + H_2O \rightleftharpoons C_3H_5O_3^- + H_3O^+$ **OR** $C_3H_6O_3$ + aq $\rightleftharpoons C_3H_5O_3^- + H^+$ **IGNORE** lactic acid shown as a structural formula **IGNORE** state symbols **watch out for incorrect anion formula**
2	(d)	(ii)	$K_a = 10^{-3.86}$/ $pK_a = -\log K_a$ **OR** $-\log 1.4 \times 10^{-4} = 3.86$ ✓	1	No marks obviously for 1.4×10^{-4} **ALLOW** 'inv(erse) log –3.86' or '$\log^{-1}(-3.86)$' **ALLOW** 'lg' for 'log'
2	(d)	(iii)	$[H^+] = \sqrt{(1.4 \times 10^{-4} \times 0.1)}$ $(= 3.74 \times 10^{-3})$ ✓ pH = 2.43 ✓	2	First mark is for working* or correct evaluation Allow ecf for second mark* (if $[H^+]$ is smaller than 1×10^{-2}) **ALLOW** 2.4 or more sf Correct pH value alone scores two marks * provided working shows 'H^+ =...' or '$[H^+]$ = ...'
2	(d)	(iv)	[salt]/[acid] = K_a / $[H^+]$ **OR** [salt]/[acid] = 1.4×10^{-4}/ (1 x) 10^{-3} ✓ $= 1.4 \times 10^{-4} / 1 \times 10^{-3} = 0.14$ ✓	2	Correct answer (to 2 or more sf) scores both marks without working. Allow ecf for second mark for inverse only (7.1429 [to 2 or more sf] or 50/7). This scores one mark even if no working. **ALLOW** 1/7.1 **OR** 7/50
2	(e)		C=O present <u>in ester</u> ✓ no OH/ alcohol (groups) / no alkene ✓  ✓	3	Both C=O and ester must be mentioned **IGNORE** references to other groups any unambiguous indication of the structure scores Any additional incorrect structures are CON **NOT** CH_2=CHCOOCH(CH_3)COOH since alkene C-H is 3000 up **NOT** ring with ether and anhydride as it is not an ester

Question			Answer	Mark	Guidance
2	(f)		 acid anhydride ✓ rest ✓	2	Any unambiguous indication of the structure scores marks Any additional incorrect structures are CON **ALLOW** any acid anhydride or just the anhydride group for the first mark **ALLOW** (-)CO-O-CO(-) for anhydride part of formula
2	(g)	(i)	ethanal ✓	1	
2	(g)	(ii)	 ✓	1	Any unambiguous representation of structure scores mark allow ambiguous attachment of any group **ALLOW** anion formed at OH group / O^- Na^+ (or any Group I cation)
2	(g)	(iii)	nucleophilic ✓ addition ✓	2	**ALLOW** any unambiguous indication of the words (eg circling) *Mark separately* Any extra words CON correct answers
2	(g)	(iv)	ammonium ion / NH_4^+ ✓✓	2	ammonia/ NH_3 scores one mark
2	(h)	(i)	orange/yellow to blue/green ✓ CH_3COOH ✓	2	**ALLOW** any combinations of these colours but no others should be mentioned **ALLOW** a more displayed or skeletal formula
2	(h)	(ii)	OH / (secondary) alcohol / hydroxyl (group) (in lactic acid) ✓ (lactic acid) reacts with reagent/acidified (potassium) dichromate gives same reaction / same colour change / same result / can be oxidised ✓	2	'primary/tertiary alcohol' is CON to first mark *mark separately* **ALLOW** 'both have a colour change'
			Total	29	

Question			Answer	Mark	Guidance
3	(a)		propane-1,2-diol ✓	1	**ALLOW** errors in dashes, gaps and commas **ACCEPT** propan-1,2-diol
3	(b)	(i)	co-product is formed in the <u>reaction</u> that produces the (main) product **OR** co-product is another substance (*AW*) that appears in the main <u>reaction/equation</u> ✓ by-product is formed by side/other/unwanted reactions ✓	2	must imply that co-product is *another* product of the *reaction* **IGNORE** 'process' (instead of 'reaction') **IGNORE** usefulness in either mark
3	(b)	(ii)	hydrolysis ✓	1	**ALLOW** 'saponification'
3	(c)		water is only (other) product / water and no other product **OR** glycerin is made from a renewable/carbon-neutral/ sustainable substance **OR** no toxic products ✓	1	must imply that it is only water **IGNORE** 'as a by-product' **ALLOW** **'**high atom economy' (but **IGNORE** 100%) **IGNORE** references to energy consumption **IGNORE** harmful/ 'no pollutants'
3	(d)		increases rate of reaction / faster reaction (*AW*) ✓ more frequent collisions (*AW*) ✓	2	**IGNORE** references to equilibrium **IGNORE** what is colliding **NOT** just 'more collisions' **IGNORE** 'chance of collisions'
3	(e)	(i)		1	Arrow must start and end on bonds (or do so if the lines are continued with the same curvature) Any other arrows *on the glycerin structure* are 'CON'

Question			Answer	Mark	Guidance
3	(e)	(ii)	elimination ✓	1	
3	(e)	(iii)	(primary) alcohol / hydroxyl ✓ ketone / carbonyl ✓	2	'secondary' or 'tertiary' CON the alcohol mark Any extra groups CON a correct answer
3	(e)	(iv)	**a** IR: acetol has peak at 1705 – 1725 ✓ **b** C=O / ketone ✓ **c** NMR: acetol has peaks of height/area/ratio 3:2:1 (any order) **OR** acetol has a peak at 2.0 – 2.7 **OR** ***two from the following:*** • acetol has 3 peaks • glycerin has 4 peaks • glycerin has a doublet or triplet at 3.3 – 4.8 ✓ **d** linking no. of peaks with <u>proton/hydrogen</u> <u>environments</u> in either compound ✓ **e** all singlets/single peaks/unsplit/splitting of 1 ✓ **f** the neighbouring <u>carbons</u> have no hydrogens/protons ✓	6	**Please place ticks where points scored** **check it is the correct numerical range** **IGNORE** references to other peaks **c** must mention peaks for this mark. **IGNORE** any extra material even if wrong **d** (**QWC** mark linking environments with no. of peaks) **ALLOW** if hydrogen environments described rather than number given (eg acetol has CH_3, CH_2 and OH) Number of peaks must be stated for either compound and be the same as the number of environments for this mark to be awarded **e** must imply all peaks are unsplit **f** must actually say 'no hydrogens' not just state the rule references to any split peaks loses **e** but **f** can be scored if it is made for any peak
3	(f)	(i)	+3 ✓	1	**NOT** 3+

Question			Answer	Mark	Guidance
3	(f)	(ii)	no effect ✓ catalyst affects the rate of/speeds up forward and back reactions (equally) **OR** affects/speeds up rate of attainment of equilibrium (*AW*) ✓	2	**ALLOW** 'only temperature affects K_c' **ALLOW** 'provides a route of lower activation enthalpy/energy' **IGNORE** 'affects rate' without qualification *mark separately*
3	(g)		calculation of both M_r values correctly ✓ (glycerin 92, prop glycol 76) % = (9/76) x (92/15) x 100 = 73% ✓	2	**ALLOW** 92.0 and 76.0 Answer on its own scores marks without reference to working **ALLOW** two or more sig figs allow any answer between 72 and 73 (intermediate rounding) **ALLOW** ecf from incorrect M_r values (if clearly indicated as such or by working)
			Total	22	

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Mark</th><th>Guidance</th></tr>
<tr><td>4</td><td>(a)</td><td>(i)</td><td> 

+ HCl
✓ ✓</td><td>2</td><td>ALLOW –CH_3
ALLOW H atoms on benzene carbons
IGNORE anything written over arrow</td></tr>
<tr><td>4</td><td>(a)</td><td>(ii)</td><td>ethanoyl chloride ✓</td><td>1</td><td>ALLOW without gap between words</td></tr>
<tr><td>4</td><td>(a)</td><td>(iii)</td><td>electrophilic ✓ substitution ✓</td><td>2</td><td>Mark separately
ALLOW mis-spellings that sound like ‘electrophilic’
IGNORE ‘acylation / acetylation / ethanoylation
Other words are CON to correct marks</td></tr>
<tr><td>4</td><td>(b)</td><td></td><td>Aluminium (compounds) are toxic OR HCl is a toxic/corrosive/acidic (gas) / lowers pH of rivers/lakes (etc) ✓</td><td>1</td><td>must name a product to score
ALLOW aluminium chloride giving HCl with consequences of this</td></tr>
<tr><td>4</td><td>(c)</td><td>(i)</td><td><table>
<tr><td>$(C_2H_5)_4N^+$</td><td>4</td><td>tetrahedral</td><td>107 – 110</td></tr>
<tr><td>PF_6^-</td><td>6</td><td>octahedral</td><td>90</td></tr>
</table>
✓✓ for each row; two if all correct, one if one error</td><td>4</td><td>No ecf
ALLOW ‘tetrahedron’ and/or ‘octahedron’</td></tr>
<tr><td>4</td><td>(c)</td><td>(ii)</td><td>small/weak (AW):
electrostatic attraction /
attraction between <u>ions</u> /
force between <u>ions</u> /
<u>ion-ion</u> bonds / <u>ionic</u> bonds ✓

small amount of <u>energy</u> required:
to separate (ions) /
break/overcome forces of attraction (or bonds) ✓</td><td>2</td><td>IGNORE ‘intermolecular’, named imb, ‘ion-dipole’ for first mark
IGNORE answers that discuss removing electrons from ions
first mark is for describing bonds between ions and implying they are weak

ALLOW breaking of any imb for second mark, provided energy is mentioned.
second mark is for saying that little energy is required to break attraction/bonds AW

mark separately</td></tr>
</table>

Question			Answer	Mark	Guidance
4	(d)	(i)	$CHCl_3$ or more displayed ✓	1	**ALLOW** $CHBr_3$ **ALLOW** triphenylmethane structure with one or two benzene rings replaced by Cl or Br (eg $CHCl(C_6H_5)_2$ or $C_{13}H_{11}Cl$ or $C_7H_6Cl_2$)
4	(d)	(ii)	**a** <u>electrons</u> excited/move up ✓ **b** to (higher) <u>energy level</u> ✓ *electron movement* **c** <u>difference</u> in levels related to frequency / ΔE = hv ✓ *relation between energy and frequency* **d** ΔE/energy gap **or** frequency is lower the greater the delocalisation / larger the chromophore ORA **OR** comparison of size of energy gap (eg 'bigger gap for benzene' or 'big gap for benzene and small gap for dye') ✓ *comparison of benzene and dyes in terms of ΔE* **e** more delocalisation/larger chromophore for dyes than benzene ORA ✓ *reason: difference in delocalisation* **f** uv has: high frequency/low wavelength/more energy (than visible) ORA **OR** benzene absorbs higher frequency than visible ORA ✓ *difference between uv and visible*	6	**Please place ticks where points scored** 'electrons move to higher energy levels' scores both **a** and **b** **QWC**: only award point **b** if marking point **a** has been scored **IGNORE** references to d-orbitals and ligands **c ALLOW** E = hv but only in context of energy <u>gaps</u> **ALLOW** 'f' for 'v' in E = hv **d ALLOW** in terms of excitation energies (eg 'it takes more energy to excite benzene's electrons') **ALLOW** 'conjugated system' for 'chromophore/delocalisation' in **d and e** **e ALLOW** comment just for benzene or dyes, provided it is a comparison (eg 'benzene has less delocalisation'). Award for eg 'dyes big delocalisation, benzene small' in different parts of answer If electrons dropping down **and** emission of light mentioned, max 2 out of 6 **Please place cross where 'emission' (AW) is mentioned**

Question			Answer	Mark	Guidance
4	(e)		**a** (Kekule structure would form) $C_6H_6Br_2$ or $C_6H_6Br_4$ or $C_6H_6Br_6$ or their structures ✓ **b** (Actual product is) C_6H_5Br or its structure ✓ **c** substitution **AND** addition mentioned correctly ✓ **d** benzene/delocalised structure is stable / addition removes stability ✓ **e** benzene has delocalisation/ has delocalised electrons ✓	**5**	**Please place ticks where points scored** **a** and **b ACCEPT** structures without specific reference to where they come from **ALLOW** skeletal structures **ALLOW** correct names (1,2-dibromocyclohexa-(3,5)-diene, (1,2,3,4,5,6-)hexabromocyclohexane; bromobenzene) but **IGNORE** names if structures given **ALLOW** full descriptions (eg 'one bromine added on each end of one double bond') **c IGNORE** type of addition/substitution **e** 'delocalisation'/'delocalised' must be spelled correctly at least once (**QWC**)
			Total	**24**	

Question			Answer	Mark	Guidance
5	(a)		$3d^{10}\ 4s^2$ ✓	1	**ALLOW** either order **ALLOW** upper case letters but numbers must be superscripts
5	(b)	(i)	$Zn^{2+}(g) \rightarrow Zn^{3+}(g) + e^{(-)}$ ✓	1	**IGNORE** any state symbol on the electron **ALLOW** $Zn^{2+}(g) - e^{(-)} \rightarrow Zn^{3+}(g)$ Zn symbol must be correct to score
5	(b)	(ii)	d^{10} / full (3)d ✓	1	'd' must be stated
5	(b)	(iii)	$ZnSO_4$ ✓	1	
5	(c)		$ZnCl_2 \cdot 2H_2O \rightarrow ZnCl(OH) + HCl + H_2O$ ✓	1	**IGNORE** state symbols **ALLOW** Zn(OH)Cl or either without brackets (but must be OH not HO) **ALLOW** the zinc salt product hydrated with one water (correctly represented as ' $\cdot H_2O$') eg '$ZnCl(OH) \cdot H_2O$' **ALLOW** $ZnCl^+ + OH^-$ for salt
5	(d)	(i)	lattice enthalpy/energy (of zinc chloride) ✓	1	**ALLOW** 'lattice formation energy/enthalpy' **ALLOW** 'enthalpy change of lattice (energy/enthalpy)', 'lattic' for 'lattice' **IGNORE** ΔH_{LE} etc **IGNORE** signs
5	(d)	(ii)	(Sum of enthalpy changes of hydration) = – 2772 ✓ Expression: (Sum of enthalpy changes of hydration) + 2734 ✓ evaluation of answer (–38) (with ecf) ✓	3	correctly evaluated *look to see if marked on diagram* expression or correct evaluation **ALLOW** –(–2734) –38 scores three overall*; (+)38 scores two overall* +325 scores two overall* –5506 scores two overall* +685 scores two overall* 325 or –325 score one overall* * whether any working shown or not

Question			Answer	Mark	Guidance
5	(d)	(iii)	broken: hydrogen bonds (in water) ✓ ionic bonds / electrostatic forces / ion-ion bonds (in lattice) ✓ made: ion-(permanent) dipole bonds/forces ✓	3	Extra wrong bonds mentioned are CON to correct bonds **IGNORE** the species linked by the bonds (eg 'Zn and Cl')
5	(e)		**a** Entropy is a measure of disorder **OR** entropy (implies) more ways of arrangement **OR** entropy measures number of ways of arrangement ✓ **b** (Particles in) solution (often) more disordered / have more ways of arrangement (than solids) ✓ **c** Ca ions: have large numbers of/more water molecules clustered round/ **OR** attract large numbers of/more water molecules **OR** are greatly/strongly hydrated **OR** have strong attraction to water molecules ✓ **d** Entropy loss of water / more order in water ✓	4	**Please place ticks where points scored** **a** If 'disorder' or 'ways of arrangement' are qualified it must be by plural 'particle**s**', 'ion**s**', 'molecule**s**', or '(quanta of) energy' **NOT** singular 'particle' etc, 'compound', 'atoms' or 'element' which CON correct words **IGNORE** 'substance' **b IGNORE** 'liquid' for 'solution'; must imply dissolving **ALLOW** 'molecules' or 'ions' or 'solute' for 'particles' **NOT** just 'higher entropy' **c** 'Ca' can be implied eg 'small highly charged ions' must say 'many' water molecules or 'strongly' hydrated **d** must refer to water
5	(f)		**a** (Solubility) increase ✓ **b** $\Delta S_{tot} = \Delta S_{sys} - \Delta H/T$ ✓ **c** $\Delta H/T$ gets smaller as T gets bigger (AW) ✓ **d** ΔS_{tot} gets more positive / less negative / increases ✓	4	**Please place ticks where points scored** **b ALLOW** $\Delta S_{tot} = \Delta S_{sys} + \Delta S_{surr}$ **and** $\Delta S_{surr} = -\Delta H/T$ **look out for this in any part of the answer** **c ALLOW** '$-\Delta H/T/\Delta S_{surr}$ gets less negative'/ 'ΔS_{surr} increases'/ '$-\Delta S_{surr}$ decreases' **IGNORE** 'ΔS_{surr} decreases' '$-\Delta H/T$ decreases' **d ALLOW** '*total* entropy gets...' **IGNORE** just 'entropy gets...'
			Total	20	