M1.(a) (i) ΔH = Σ(enthalpies formation products) − Σ(enthalpies formation reactants)

Or correct cycle with enthalpy changes labelled

1

= −111 −(−75 − 242)

1

= (+)206 (kJ mol⁻1)

−206 scores 1 only

Units not essential if ans in kJ mol^{-1} but penalise incorrect units

1

(ii) ΔS = Σ(entropies of products) − Σ(entropies reactants)

= 198 + 3 × 131 − (186 + 189)

1

= (+) 216 (J K^{-1} mol^{-1})
OR
0.216 <u>kJ K^{-1}</u> <u>mol^{-1}</u>

Units not essential but penalise incorrect units

1

(b) When $\Delta G = 0$ OR $\Delta H = T\Delta S$

1

$T = \Delta H / \Delta S$

M2 also scores M1

1

= 206 × 1000 / 216

Allow error carried forward from (a)(i) and (a)(ii)

Ignore unexplained change of sign from − to +

1

= 954 <u>K</u>

Allow 953 − 955, Units of K essential, must be +ve

If values from (a)(i) and (a)(ii) lead to negative value in M3 allow M1 to M3 but do not allow negative temperature for M4

If negative value changed to positive for M4, allow M4

1

(c) To speed up the rate of reaction OR wtte

Allow so that more molecules have energy greater than the activation energy

IF T in (b) > 1300 allow answers such as;

to reduce energy cost

to slow down reaction

do NOT allow to increase rate

1

(d) (i) **Method 1**

$\Delta G = \Delta H - T\Delta S$

$\Delta G = -41 - (1300 \times -42 / 1000)$ (M1)

If 42 and not 42 / 1000 used can score M3 only

but allow $\Delta G = -41 \times 1000 - (1300 \times -42)$ (M1)

1

= +13.6 <u>kJ mol</u>$^{-1}$

=13600 <u>J mol</u>$^{-1}$ (M2)

Units essential

1

ΔG must be negative for the reaction to be feasible.

OR ΔG is positive so reaction is not feasible

1

Method 2

For reaction to be feasible ΔG must be negative or zero

1

T when $\Delta G = 0 = \Delta H / \Delta S = 976K$

1

ΔS is −ve so ΔG must be +ve at temperatures above 976K / at 1300 K

1

(ii) If the temperature is lowered

(Ignore reference to catalyst and / or pressure)

Alternative mark scheme (if T is calculated)

Allow T reduced to 976 K or lower M1

1

ΔG will become (more) <u>negative</u> because

<u>the $-T\Delta S$ term will be less positive / $T\Delta S > \Delta H$</u>

At this temperature (the reaction becomes feasible because) $\Delta G <= 0$ M2

1

[15]

M2.(a) $\Delta S = 238 + 189 - 214 - 3 \times 131 = -180$ J K^{-1} mol^{-1} **1**

$\Delta G = \Delta H - T\Delta S$ **1**

$= -49 - \dfrac{523 \times (-180)}{1000}$ **1**

$= +45.1$ kJ mol^{-1}

Units essential **1**

(b) When $\Delta G = 0$, $\Delta H = T\Delta S$ therefore $T = \Delta H / \Delta S$ **1**

$= -49 \times 1000 / -180 = 272$ (K)

Mark consequentially to ΔS in part (a) **1**

(c) Diagram marks

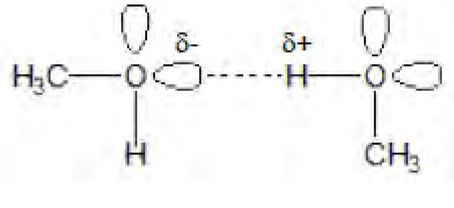

Diagram of a molecule showing O–H bond and two lone pairs on each oxygen **1**

Labels on diagram showing δ+ and δ- charges

Allow explanation of position of δ+ and δ- charges on H and O

1

Diagram showing δ+ hydrogen on one molecule attracted to lone pair on a second molecule

1

Explanation mark

Hydrogen bonding (the name mentioned) is a strong enough force (to hold methanol molecules together in a liquid)

1

[10]

M3.(a) An electron pair on the ligand

1

Is donated from the ligand to the central metal ion

1

(b) Blue precipitate

1

Dissolves to give a dark blue solution

1

$[Cu(H_2O)_6]^{2+} + 2NH_3 \longrightarrow Cu(H_2O)_4(OH)_2 + 2NH_4^+$

1

$Cu(H_2O)_4(OH)_2 + 4NH_3 \longrightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 2OH^- + 2H_2O$

1

(c) $[Cu(NH_3)_4(H_2O)_2]^{2+} + 2H_2NCH_2CH_2NH_2 \longrightarrow [Cu(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+} + 4NH_3$

1

(d) Cu–N bonds formed have similar enthalpy / energy to Cu–N bonds broken

1

And the same number of bonds broken and made

1

(e) 3 particles form 5 particles / disorder increases because more particles are formed / entropy change is positive

1

Therefore, the free-energy change is negative

M2 can only be awarded if M1 is correct

1

[11]

M4.(a) Enthalpy change / ΔH when 1 mol of a gaseous ion

Enthalpy change for $X^{+/-}(g) \rightarrow X^{+/-}(aq)$ scores M1 and M2

1

forms aqueous ions

Allow heat energy change instead of enthalpy change

Allow 1 mol applied to aqueous or gaseous ions

If substance / atoms in M1 CE = 0

If wrong process (eg boiling) CE = 0

1

(b) ΔH(solution) = ΔH(lattice) + $\underline{\Sigma}$(ΔHhydration)

OR +77 = +905 – 464 + ΔH(hydration, Cl^-)

OR ΔH(hydration, Cl^-) = +77 –905 + 464

Allow any one of these three for M1 even if one is incorrect

1

= –364 (kJ mol^{-1})

Allow no units, penalise incorrect units, allow kJ mol^{-}

Allow lower case j for J (Joules)

+364 does not score M2 but look back for correct M1

1

(c) Water is polar / water has Hδ+

1

(Chloride ion) attracts (the H in) water molecules

(note chloride ion can be implied from the question stem)

Idea that there is a force of attraction between the chloride ion and water

Do not allow H bonds / dipole–dipole / vdW / intermolecular but ignore loose mention of bonding

Do not allow just chlorine or chlorine atoms / ion

Mark independently

1

(d) *ΔG = ΔH – TΔS*

Look for this equation in part (d) and / or (e); equation can be stated or implied by correct use. Record the mark in part (d)

1

(ΔG = 0 so) T = ΔH / ΔS

1

T = 77 × 1000 / 33 = 2333 K (allow range 2300 to 2333.3)

Units essential, allow lower case k for K (Kelvin)

Correct answer with units scores M1, M2 and M3

2.3 (K) scores M1 and M2 but not M3

1

Above the boiling point of water (therefore too high to be sensible) / water would evaporate

Can only score this mark if M3 >373 K

1

(e) $\Delta S = (\Delta H - \Delta G) / T$ OR $\Delta S = (\Delta G - \Delta H) / -T$

1

= ((–15 + 9) × 1000) / 298 OR (–15 + 9) / 298

1

= –20 J K^{-1} mol^{-1} OR –0.020 kJ K^{-1} mol^{-1}

(allow –20 to –20.2) (allow –0.020 to –0.0202)

Answer with units must be linked to correct M2

For M3, units must be correct

Correct answer with appropriate units scores M1, M2 and M3 and possibly M1 in part (d) if not already given

Correct answer without units scores M1 and M2 and possibly M1 in part (d) if not already given

Answer of –240 / –0.24 means temperature of 25 used instead of 298 so scores M1 only

If ans = +20 / +0.020 assume AE and look back to see if M1 and possibly M2 are scored

1

[13]