M1.(a) The <u>enthalpy change / heat energy change / *ΔH*</u> for the formation of <u>one mole</u> of (chloride) ions from (chlorine) atoms

Allow enthalpy change for $Cl + e^- \rightarrow Cl^-$

Do not allow energy change

ionisation energy description is CE=0

Allow enthalpy change for the addition of 1 mol of electrons to Chlorine atoms

penalise Cl_2 and chlorine molecules CE = 0

allow chlorine ions

1

Atoms and ions in the gaseous state

Or state symbols in equation

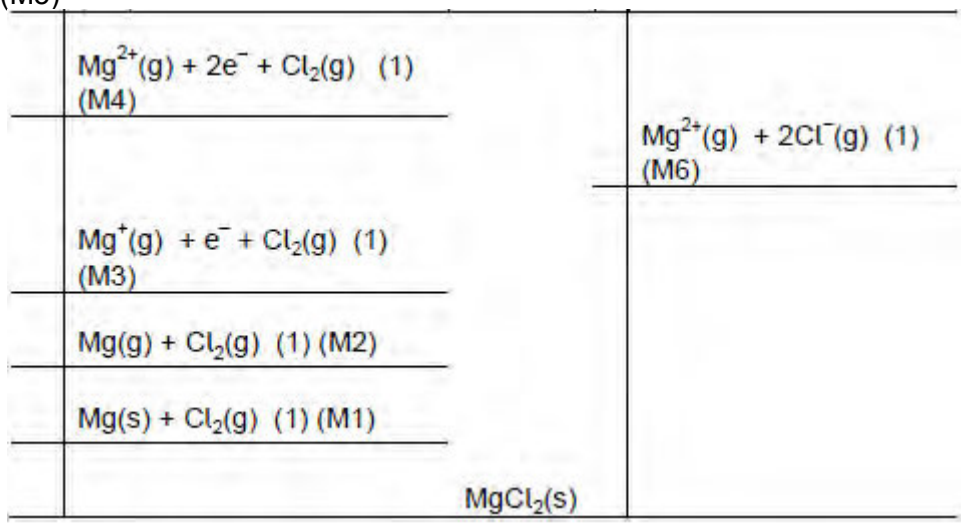
Cannot score M2 unless M1 scored

except allow M2 if energy change rather than enthalpy change

ignore standard conditions

1

(b) $Mg^{2+}(g) + 2e^- + 2Cl(g)$ (1) (M5)



Allow e for electrons (i.e. no charge)

State symbols essential

If no electrons allow M5 but not M3,M4

If incorrect 1 / 2 Cl_2 used allow M3 and M4 for correct electrons (scores 2 / 6)

6

(c) $-\Delta H_f(MgCl_2) + \Delta H_a(Mg) + 1^{st}$ IE(Mg) + 2^{nd} IE(Mg) $+2\Delta H_a(Cl) = -2EA(Cl) -$

LE($MgCl_2$)

Allow Enthalpy of Formation = sum of other enthalpy changes (incl lattice formation)

1

−2EA(Cl) = 642 + 150 + 736 + 1450 + 242 − 2493 = 727

1

EA(Cl) = −364 (kJ mol^{-1})

Allow −363 to −364
Allow M1 and M2 for −727
Allow 1 (1 out of 3) for +364 or +363 but award 2 if due to arithmetic error after correct M2
Also allow 1 for −303
Units not essential but penalise incorrect units
Look for a transcription error and mark as AE−1

1

(d) (i) Magnesium (ion) is smaller **and** more charged (than the sodium ion)
OR
magnesium (ion) has higher charge to size ratio / charge density

Do not allow wrong charge on ion if given

Do not allow similar size for M1

Do not allow mass / charge ratio

1

(magnesium ion) attracts water more strongly

Mark independently

Mention of intermolecular forces, (magnesium) atoms or atomic radius CE = 0

1

(ii) Enthalpy change = −LE($MgCl_2$) + Σ(ΔH_{hyd}ions)

= 2493 + (−1920 + 2 × −364)

1

= −155 (kJ mol^{-1})

Units not essential but penalise incorrect units

1

[15]

M2.(a) Start a clock when KCl is added to water

1

Record the temperature every subsequent minute for about 5 minutes

Allow record the temperature at regular time intervals untilsome time after all the solid has dissolved for M2

1

Plot a graph of temperature vs time

1

Extrapolate back to time of mixing = 0 and determine the temperature

1

(b) Heat taken in = $m \times c \times \Delta T = 50 \times 4.18 \times 5.4 = 1128.6$ J

Max 2 if 14.6 °C used as ΔT

1

Moles of KCl = 5.00 / 74.6 = 0.0670

1

Enthalpy change per mole = +1128.6 / 0.0670 = 16 839 J mol^{-1}

1

= +16.8 (kJ mol^{-1})

Answer must be given to this precision

1

(c) $\Delta H_{solution} = \Delta H_{lattice} + \Delta H$(hydration of calcium ions) + 2 × ΔH(hydration of chloride ions)

$\Delta H_{lattice} = \Delta H_{solution} - \Delta H$(hydration of calcium ions) –2 ×ΔH(hydration of chloride ions)

1

$\Delta H_{lattice} = -82-9 - (-1650 + 2 \times -364) = +2295$ (kJ mol^{-1})

1

(d) Magnesium ion is smaller than the calcium ion

1

Therefore, it attracts the chloride ion more strongly / stronger ionic bonding

1

[12]

M3.(a) $Cl(g) + e^- \rightarrow Cl^-(g)$

State symbols essential
Allow e with no charge
This and all subsequent equations must be balanced

1

(b) There is an attraction between the nucleus / protons and (the added) electron(s)

1

Energy is released (when the electron is gained)

Allow product more stable / product has lower energy
Allow reaction exothermic / heat released
Allow reference to chlorine rather than fluorine
Wrong process eg ionisation, boiling CE = 0

1

(c) (i) Top line: $+ e^- + F(g)$

Penalise missing / wrong state symbols one mark only
Penalise Fl or Cl one mark only

1

Second line from top : $+ e^- + \frac{1}{2}F_2(g)$

Mark independently
Allow e with no charge

1

Bottom two lines: $+\frac{1}{2}F_2(g)$

Penalise each lack of an electron in M1 and M2 each time

1

(ii) $\frac{1}{2}E(F–F) + 732 + 289 + +203 = 348 + 955$

$\frac{1}{2}E(F–F) = 79$

1

$E(F–F) = 158$ (kJ mol^{-1})

Award one mark (M2) if M1 wrong but answer = M1 × 2

Ignore no units, penalise wrong units but allow kJ mol^{-}

Any negative answer, CE = 0

1

(d) (i) Experimental lattice enthalpy value allows for / includes covalent interaction / non–spherical ions / distorted ions / polarisation

OR AgF has covalent character

Allow discussion of AgCl instead of AgF

CE = 0 for mention of molecules, atoms, macromolecular, mean bond enthalpy, intermolecular forces (imf), electronegativity

1

Theoretical lattice enthalpy value assumes only ionic interaction / point charges / no covalent / perfect spheres / perfectly ionic

OR AgF is not perfectly ionic

1

(ii) Chloride ion larger (than fluoride ion) / fluoride ion smaller (than chloride ion)

Penalise chlorine ion once only

Allow Cl^- and F^- instead of names of ions

Allow chloride ion has smaller charge density / smaller charge to size ratio but penalise mass to charge ratio

1

Attraction between Ag^+ and Cl^- weaker / attraction between Ag^+ and F^- stronger

For M2 Cl^- and F^- can be implied from an answer to M1
Mark M1 and M2 independently provided no contradiction
CE = 0 for mention of chlorine not chloride ion, molecules, atoms, macromolecular, mean bond enthalpy, intermolecular forces (imf), electronegativity

1

[12]

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 <u>attraction</u> 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) $\Delta G = \Delta H - T\Delta S$

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

($\Delta G = 0$ so) $T = \Delta H / \Delta S$

1

$T = 77 \times 1000 / 33 = 2333$ <u>K</u> (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

$= ((-15 + 9) \times 1000) / 298$ 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, <u>units must be correct</u>

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]

M1.(a) Enthalpy change (to separate) 1 mol of an (ionic) substance into its ions

If ionisation or hydration / solution, CE = 0
If atoms / molecules / elements mentioned, CE = 0
Allow heat energy change but not energy change alone.
If forms 1 mol ions, lose M1

1

Forms ions in the gaseous state

If lattice formation not dissociation, allow M2 only.
Ignore conditions.
Allow enthalpy change for
$MX(s) \rightarrow M^+(g) + X^-(g)$ (or similar) for M1 and M2

1

(b) Any **one** of:

- Ions are point charges
- Ions are perfect spheres
- Only electrostatic attraction / bonds (between ions)
- No covalent interaction / character
- Only ionic bonding / no polarisation of ions

If atoms / molecules mentioned, CE = 0

1 max

(c) (Ionic) radius / distance between ions / size

Allow in any order.
Do not allow charge / mass or mass / charge.

1

(Ionic) charge / charge density

Do not allow 'atomic radius'.

1

(d) $\Delta H_L = \Delta H_a$ (chlorine) + ΔH_a (Ag) + I.E(Ag) +EA(Cl) − $\Delta H_f^{\ominus}$

Or cycle
If $AgCl_2$, CE=0 / 3

1

= 121 + 289 + 732 − 364 + 127

1

= (+) 905 (kJ mol^{-1})

Allow 1 for −905

Allow 1 for (+)844.5 (use of 121 / 2)

Ignore units even if incorrect.

1

(e) M1 Greater

Do not penalise $AgCl_2$

1

M2 (Born-Haber cycle method allows for additional) covalent interaction

Allow AgCl has covalent character.

Only score M2 if M1 is correct

OR

M1 Equal

M2 AgCl is perfectly ionic / no covalent character

1

[10]

M2.(a) Chlor<u>ide</u> (ions) are smaller (than brom<u>ide</u> ions)

Must state or imply ions.

Allow chlor<u>ide</u> has greater charge density (than bromide).

Penalise <u>chlorine ions</u> once only (max 2 / 3).

1

So the force of attraction between chloride ions and water is stronger

This can be implied from M1 and M3 but do not allow intermolecular forces.

1

Chloride ions attract the δ+ on H of water / electron deficient H on water

Allow attraction between ions and polar / dipole water.
*Penalise H^+ (ions) and mention of hydrogen bonding for **M3***
Ignore any reference to electronegativity.
Note: If water not mentioned can score M1 only.

1

(b) $\Delta H_{solution} = \Delta H_L + \Delta H_{hyd}\ K^+$ ions + $\Delta H_{hyd}\ Br^-$ ions / = 670 − 322 − 335

Allow $\Delta H_{solution} = \Delta H_L + \Sigma \Delta H_{hyd}$

1

= (+)13 (kJ mol^{-1})

Ignore units even if incorrect.
+13 scores M1 and M2
−13 scores 0
−16 scores M2 only (transcription error).

1

(c) (i) The entropy change is positive / entropy increases

ΔS is negative loses M1 and M3

1

Because 1 mol (solid) → 2 mol (aqueous ions) / no of particles increases

Allow the aqueous ions are more disordered (than the solid).
Mention of atoms / molecules loses M2

1

Therefore $\underline{T\Delta S > \Delta H}$

1

(ii) Amount of KCl = $5/M_r = 5/74.6 = \underline{0.067(0)\ mol}$

If moles of KCl not worked out can score M3, M4 only (answer to M4 likely to be 205.7 K)

1

Heat absorbed = 17.2 × 0.0670 = 1.153 kJ

Process mark for M1 × 17.2

1

Heat absorbed = mass × sp ht × Δ*T*

(1.153 × 1000) = 20 × 4.18 × Δ*T*

If calculation uses 25 g not 20, lose M3 only (M4 = 11.04, M5 = 287)

1

Δ*T* = 1.153 × 1000 / (20 × 4.18) = 13.8 K

If 1000 not used, can only score M1, M2, M3

M4 is for a correct ΔT

Note that 311.8 K scores 4 (M1, M2, M3, M4).

1

T = 298 − 13.8 = 284(.2) K

If final temperature is negative, M5 = 0

Allow no units for final temp, penalise wrong units.

1

[13]

M3.(a) $MgCl_2(s) \rightarrow Mg^{2+}(g) + 2Cl^-(g)$

1

(b) The magnesium <u>ion</u> is smaller / has a smaller radius / greater charge density (than the calcium ion)

If not ionic or if molecules / IMF / metallic / covalent / bond pair / electronegativity mentioned, CE = 0

1

Attraction between ions / to the chloride ion stronger

Allow ionic bonds stronger

Do not allow any reference to polarisation or covalent character

Mark independently

1

(c) The oxide ion has a greater charge / charge density than the chloride ion

If not ionic or if molecules / IMF / metallic / covalent / bond pair mentioned, CE = 0

Allow oxide ion smaller than chloride ion

1

So it attracts the magnesium ion more strongly

Allow ionic bonds stronger

Mark independently

1

(d) $\Delta H_{solution} = \Delta H_{L} + \Sigma\Delta H_{hyd}$ Mg^{2+} ions + $\Sigma\Delta H_{hyd}$ Cl^{-} ions

Allow correct cycle

1

$-155 = 2493 + \Delta H_{hyd}$ Mg^{2+} ions $- 2 \times 364$

ΔH_{hyd} Mg^{2+} ions $= -155 - 2493 + 728$

1

$= -1920$ (kJ mol^{-1})

Ignore units

Allow max 1 for +1920

Answer of + or −1610, CE = 0

Answer of −2284, CE = 0

1

(e) Water is polar / O on water has a delta negative charge

Allow <u>O</u> (not water) has lone pairs (can score on diagram)

1

Mg^{2+} ion / $^{+}$ve ion / + charge attracts (negative) O on a water molecule

Allow Mg^{2+} attracts lone pair(s)

M2 must be stated in words (QoL)

Ignore mention of co-ordinate bonds
CE = 0 if O^{2-} or water ionic or H bonding

1

(f) Magnesium oxide reacts with water / forms $Mg(OH)_2$

Allow MgO does not dissolve in water / sparingly soluble / insoluble

1

[11]

M4.(a) Standard pressure (100 kPa) (and a stated temperature)

Allow standard conditions. Do not allow standard states
Allow any temperature
Allow 1 bar but not 1atm
Apply list principle if extra wrong conditions given
Penalise reference to concentrations

1

(b) Hydrogen bonds between water molecules

1

Energy must be supplied in order to break (or loosen) them

Allow M2 if intermolecular forces mentioned
Otherwise cannot score M2
CE = 0/2 if covalent or ionic bonds broken

1

(c) $T = \Delta H/\Delta S$

1

$= (6.03 \times 1000)/22.1$

1

= 273 K

Allow 272 to 273; units K must be given

Allow 0°C if units given
0.273 (with or without units) scores 1/3 only
Must score M2 in order to score M3
Negative temperature can score M1 only

1

(d) The heat given out escapes

1

(e) (Red end of white) light (in visible spectrum) absorbed by ice
Allow complementary colour to blue absorbed

1

Blue light / observed light is reflected / transmitted / left
Penalise emission of blue light

1

[9]

M5.(a) Enthalpy change/heat energy change when one mole of gaseous atoms
Allow explanation with an equation that includes state symbols

1

Form (one mole of) gaseous negative ions (with a single charge)
If ionisation/ionisation energy implied, CE=0 for both marks
Ignore conditions

1

(b) Fluorine (atom) is smaller than chlorine/shielding is less/ outer electrons closer to nucleus
Fluorine molecules/ions/charge density CE=0 for both marks

1

(Bond pair of) electrons attracted more strongly <u>to the nucleus/protons</u>

1

(c) Fluor<u>ide</u> (ions) smaller (than chloride) / have larger charge density

Any reference to electronegativity CE=0

1

So (negative charge) attracts (δ+ hydrogen on) water more strongly

Allow H on water, do not allow O on water

Allow F^- hydrogen bonds to water, chloride ion does not

Mark independently

1

(d) (i) ΔH(solution) = LE + Σ(hydration enthalpies) / correct cycle

AgF_2 or other wrong formula CE = 0

Ignore state symbols in cycle

1

LE = -20 -(-464 + -506)

1

= (+) 950 kJ mol^{-1}

Ignore no units, penalise M3 for wrong units

-950 scores max 1 mark out of 3

990 loses M3 but M1 and M2 may be correct

808 is transfer error (AE) scores 2 marks

848 max 1 if M1 correct

1456 CE=0 (results from AgF_2)

1

(ii) There is an increase in the number of particles / more disorder / less order

Allow incorrect formulae and numbers provided number increases

Do not penalise reference to atoms/molecules

Ignore incorrect reference to liquid rather than solution

1

(iii) Entropy change is positive/entropy increases and enthalpy change negative/exothermic

1

So ΔG is (always) negative

1

[12]

M1.(a) Enthalpy change when 1 mol of an (ionic) compound/lattice (under standard conditions)

Allow heat energy change

1

Is dissociated/broken/separated into its (component) ions

1

The ions being in the gaseous state (at infinite separation)

Mark independently. Ignore any conditions.

1

(b) There is an attractive force between the nucleus of an O atom and an external electron.

Allow any statement that implies attraction between the nucleus and an electron

1

(c) $Mg^{2+}(g) + O(g) + 2e^-$

Ignore lack of state symbols

Penalise incorrect state symbols

1

$Mg^{2+}(g) + O^-(g) + e^-$

1

$Mg^{2+}(g) + O^{2-}(g)$

1

First new level for Mg^{2+} and O above last on L

If levels are not correct allow if steps are in correct order with arrows in the correct direction and correct ΔH values

1

Next level for Mg^{2+} and O^{-} below that

Next level for Mg^{2+} and O^{2-} above that and also above that for Mg^{2+} and O

Allow +124

Allow M4 with incorrect number of electrons

(d) LE MgO = 602 + 150 + 736 + 1450 + 248 – 142 + 844

Note use of 124 instead of 248 CE=0

1

= +3888 kJ mol^{-1}

Allow 1 for –3888

Allow no units

Penalise wrong units

1

(e) Forms a protective layer/barrier of MgO / MgO prevents oxygen attacking Mg

Allow activation energy is (very) high

Allow reaction (very) slow

1

(f) $\Delta G = \Delta H - T\Delta S$

$\Delta S = \underline{(\Delta H - \Delta G)} \qquad T$

1

$\Delta S = (-602 - (-570)) \times 1000/ 298$

1

= –107 J K^{-1} mol^{-1} / –0.107 kJ K^{-1} mol^{-1}

If units not correct or missing, lose mark

Allow –107 to –108

+107 with correct units scores max 1/3

1

(g) 1 mol of solid and 0.5 mol of gas reactants form 1 mol solid products

Decrease in number of moles (of gas/species)

Allow gas converted into solid

Numbers of moles/species, if given, must be correct

1

System becomes more ordered

Allow consequential provided ∆S is –ve in 1(f)
If ∆S is +ve in 1(f) can only score M1

1

[16]

M2. (a) (i) (Enthalpy change for formation of) 1 mol (of CaF_2) from its ions

allow heat energy change
do not allow energy or wrong formula for CaF_2
penalise 1 mol of ions
CE=0 if atoms or elements or molecules mentioned
ignore conditions

1

ions in the gaseous state

ions can be mentioned in M1 to score in M2
allow fluorine ions
$Ca^{2+}(g) + 2F^-(g) \rightarrow CaF_2$ scores M1 and M2

1

(ii) (enthalpy change when) 1 mol of gaseous (fluoride) ions (is converted) into aqueous ions / an aqueous solution

allow $F^-(g) \rightarrow F^-(aq)$ (ignore + aq)
do not penalise energy instead of enthalpy
allow fluorine ions
do not allow F^- ions surrounded by water

1

(b) water is polar / H on water is $\delta+$ / is electron deficient / is unshielded

1

penalise H^+ on water 1 mark

(F^- ions) attract water / $\delta+$ on H / hydrogen

allow H on water forms H-bonds with F^-
allow fluorine ions

penalise co-ordinate bonds for M2
penalise attraction to O for M2

1

(c) $\Delta H = -(-2611) - 1650 + 2x - 506$

ignore cycles
M1 is for numbers and signs correct in expression

1

$= -51$ (kJ mol^{-1})

correct answer scores 2
ignore units even if incorrect

1

[7]

M3. (a) Enthalpy change for the formation of 1 mol of gaseous atoms

allow heat energy change for enthalpy change

1

From the element (in its standard state)

ignore reference to conditions

1

Enthalpy change to separate 1 mol of an ionic lattice/solid/compound

enthalpy change not required but penalise energy

1

Into (its component) gaseous ions

mark all points independently

1

(b) $\Delta H_L = {}^{-}\Delta H_f + \Delta H_a + \text{I.E.} + 1/2\text{E(Cl-Cl)} + \text{EA}$

Or correct Born-Haber cycle drawn out

1

$= +411 + 109 + 494 + 121 - 364$

1

$= +771$ (kJ mol^{-1})

–771 scores 2/3
+892 scores 1/3

–51 scores 1/3
–892 scores zero
+51 scores zero *ignore units*

1

(c) (i) Ions are perfect spheres (or point charges)

1

Only electrostatic attraction/no covalent interaction
mention of molecules/intermolecular forces/covalent bonds CE = 0
allow ionic bonding only
If mention of atoms CE = 0 for M2

1

(ii) Ionic
Allow no covalent character/bonding

1

(iii) Ionic with additional covalent bonding
Or has covalent character/partially covalent
Allow mention of polarisation of ions or description of polarisation

1

[11]

M4. (a) $CaF_2(s) \rightarrow Ca^{2+}(g) + 2F^-(g)$

1

(b) (i) Enthalpy change for formation of 1 mol of substance
Allow heat energy change, NOT energy

1

From its elements

1

Reactants and products/all substances in their standard states
Or normal states at 298 K, 1 bar (100 kPa)

1

(ii) $Ca(s) + F_2(g) \rightarrow CaF_2(s)$

1

(iii) $\Delta H_f(CaF_2) = \Delta H_a(Ca) + 1st\ IE(Ca) + 2^{nd}\ IE(Ca) + BE(F_2) + 2 \times EA(F) - \Delta H_L(CaF_2)$

Or labelled diagram

1

$= 193 + 590 + 1150 + 158 + (2 \times -348) - 2602$

1

$= -1207\ kJ\ mol^{-1}$

Correct answer scores 3
–842 scores 2 (transfer error)
–859 scores 1 only (using one E.A.)
Units not required, wrong units lose 1 mark

1

(c) Electrostatic attraction stronger/ionic bonding stronger/attraction between ions stronger/more energy to separate ions

Molecular attraction/atoms/intermolecular forces CE=0

1

Because fluoride (ion) smaller than chloride

Do not allow F or fluorine

1

(d) (i) $\Delta H = \Delta H_L + \Sigma \Delta H_{hyd} = 2237 - 1650 + (2 \times -364)$

Can be on cycle/diagram

1

$= -141\ kJ\ mol^{-1}$

Correct answer scores 2
Units not required, wrong units lose 1 mark

1

(ii) Decreases

If ans to (d)(i) positive allow increases

1

Reaction exothermic/ΔH –ve

If (d)(i) +ve allow endothermic/ΔH + ve

1

(Equilibrium) shifts to left/backwards
(as temperature rises)/equilibrium

opposes the change

If (d) (i) +ve allow shifts to right/forwards/equilibrium opposes the change

If no answer to (d) (i) assume –ve ΔH used
If effect deduced incorrectly from any ΔH CE = 0 for these 3 marks

1

(e) u.v. absorbed: electrons/they move to higher energy (levels)/electrons excited

1

visible light given out: electrons/they fall back down/move to lower energy (levels)

Must refer to absorbing u.v. NOT visible light or this must be implied.

1

[17]

M1. (a) 242

Units not essential

1

(b) Bond is shorter or bonding pair closer to nucleus

Allow Cl is a smaller atom
Allow fewer electron shells
do not allow smaller molecules

1

So attraction (between nucleus and) (to) bond pair is stronger

Allow shared pair (or bonding electrons) held more tightly
Mention of Cl^- loses M2

1

(c) Net attraction between the chlorine nucleus and the extra electron

Allow Cl^- ion more stable than Cl

1

(d) (i) step 1 $Ag(s) \rightarrow Ag(g)$ only change

1

step 2 $Ag(s) \rightarrow Ag^+(g) + e^-$ only change

1

step 3 $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$ only change

This step can be first, second or third

1

(ii) 127 + 289 + 732 + 121 – 364

1

= 905 kJ mol^{-1}

–905 scores 1 mark only

1

(e) (i) Ions can be regarded as point charges (or perfect spheres)

Allow no polarisation
OR *only bonding is ionic*
OR *no covalent character*

1

(ii) Greater

Electronegativity argument or mention of intermolecular, CE =0

1

Chloride ions are smaller than bromide

Mark independently but see above

1

They are attracted more strongly to the silver ions

Mark independently

1

(iii) AgCl has covalent character

Ignore reference to molecules

1

Forces in the lattice are stronger than pure ionic attractions

Allow stronger bonding OR additional/extra bonding

1

[15]

M2. (a) (i) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

1

(ii) The negative S^- ion

1

repels the added electron

1

(iii) Step B is the atomisation enthalpy of sulphur

1

Step D is the second ionisation enthalpy of calcium

1

(iv) Electrons nearer to the nucleus

1

Electrons removed from a positive species or more strongly attracted

1

(v) +178 +279 +590 +1145 -200 + 539 + G + 482 = 0

1

G + 3013 = 0 hence G = –3013

1

(b) The model used assumes the ions are spherical and in a lattice

1

The calculated value is smaller than the cycle value or stronger attraction

1

Indicating some covalent character or ions are polarised

1

(c) (i) For a reaction to occur $\Delta G < 0$

1

ΔS is positive and large as a gas is evolved

1

$T\Delta S$ is larger than ΔH and ΔG is negative

1

(ii) ΔS is negative

1

Four moles gaseous reactant forming or more moles of gaseous product

1

At high temperature $T\Delta S$ is larger than ΔH and ΔG is positive

1

[18]

M3. (a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ **1**

(b) $S^-(g)$ **1**

(c) The negative S^- ion **1**

repels the electron being added **1**

(d) (i) Enthalpy of atomisation of sulphur **1**

(ii) Second ionisation enthalpy of calcium **1**

(iii) Second electron affinity of sulphur **1**

(e) Electron more strongly attracted **1**

nearer to the nucleus or attracted by Ca^+ ion **1**

(f) Correct cycle

e.g. + 178 + 279 + 590 +1145 – 200 + E – 3013 + 482 = 0 **1**

= 539 **1**

Allow one mark for – 539

[11]

M4. (a) (i) ΔH atomisation/sublimation of magnesium

1

(ii) Bond/dissociation enthalpy of Cl-Cl

OR 2 × H atomisation of chlorine

1

(iii) Second ionisation enthalpy of magnesium

1

(iv) 2 × electron affinity of chlorine

1

(v) Lattice formation enthalpy of $MgCl_2$

1

(b) Equation $2MgCl(s) \rightarrow MgCl_2(s) + Mg(s)$

State symbols not required but penalise if incorrect

1

Calculation ΔH reaction = $\Sigma\Delta H_f$ products – $\Sigma\Delta H_f$ reactants

1

= – 653 – (2 × –133)

1

= – 427 ($kJmol^{-1}$)

Allow +427 to score (1) mark

Other answers; award (1) for a correct ΔH reaction expression

1

(c) ΔH soln $MgCl_2$ = – ΔH Lat.form. + ΔH hyd.Mg^{2+} + 2ΔH hyd.Cl^-

1

or cycle

= 2502 – 1920 – (2 × 364)

1

= – 146 ($kJmol^{-1}$)

Allow + 146 to score (1) mark

Other answers; award (1) for a correct ΔH soln $MgCl_2$ expression/cycle

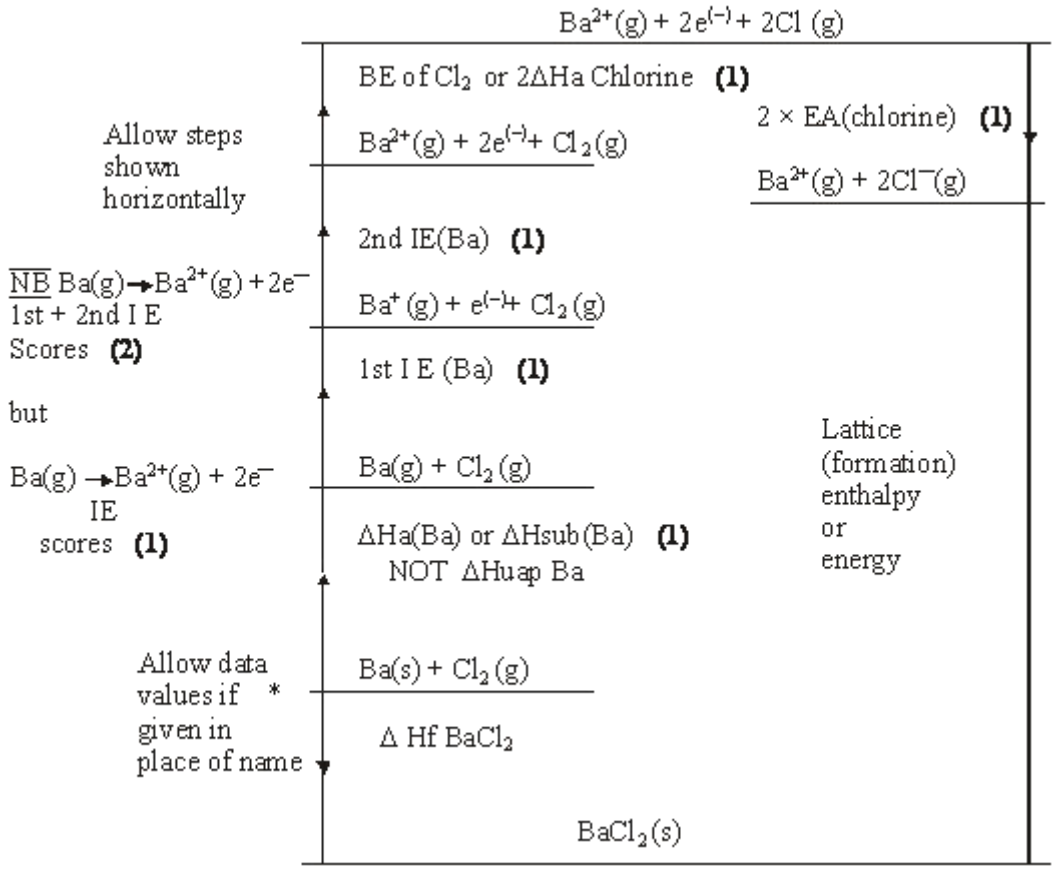
1

[12]

M5.A

[1]

M1. (a) (i)



ONLY consider species involved in the step marked

(ii) Cycling clockwise about (*)

CE if step missing

$\Delta H_a Ba + 1^{st}$ IEBa + 2^{nd} IE Ba + $2\Delta H_a Cl$ + 2EACl + LE – $\Delta H_f BaCl_2$ = 0 **(1)**
+180 + 503 + 965 + 2 × 122 + 2EA –2056 + 859 = 0 **(1)**
EA = –695/2 = – (347 to 348) **(1)**

Ignore units

Calculation –1 for each error

Mark conseq.

*Notes: –695 scores **(2)***
*+(347 to 348) scores **(2)***
*–(286 to 287) scores **(2)***
*+(286 to 287) scores **(1)***
*–573 scores **(1)***
*+573 scores **(0)***

9

(b) $\Delta S = \Sigma S$ products – ΣS reactants
= (63 +223) – 124 = 162 **(1)**

$\Delta G = \Delta H - T\Delta S$ or $\Delta H = T\Delta S$ or $T = \Delta H/\Delta S$ **(1)**
or used correctly

$\Delta H = 859 \times 10^3$ **(1)** $= T \times 162$
T = (5 300 to 5304) K **(1)**
Penalise if units °C
–1 for each error + mark conseq.

4

[13]

M2.D

[1]

M3.D

[1]

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 kJ K^{-1} mol^{-1}

Units not essential but penalise incorrect units

1

(b) When ΔG = 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 K

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 ΔG = −41 × 1000 − (1300 × −42) (M1)

1

= +13.6 $\underline{\text{kJ mol}^{-1}}$

=13600 $\underline{J\ mol^{-1}}$ (M2)

Units essential

1

Δ*G* must be negative for the reaction to be feasible.

OR Δ*G* is positive so reaction is not feasible

1

Method 2

For reaction to be feasible Δ*G* must be negative or zero

1

T when Δ*G* = 0 = Δ*H* / Δ*S* = 976*K*

1

Δ*S* is −ve so Δ*G* 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

Δ*G* will become (more) $\underline{\text{negative}}$ because

$\underline{\text{the } -T\Delta S \text{ term will be less positive}}$ / $\underline{T\Delta S > \Delta H}$

At this temperature (the reaction becomes feasible because)

ΔG < = 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**

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

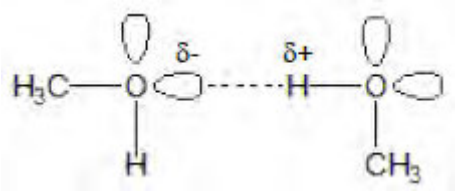


Diagram of a molecule showing O–H bond and two lone pairs on each oxygen **1**

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) + $\sum(\Delta H$hydration)

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 <u>attraction</u> 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) $\Delta G = \Delta H - T\Delta S$

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

($\Delta G = 0$ so) $T = \Delta H / \Delta S$

1

T = 77 × 1000 / 33 = 2333 <u>K</u> (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

$= ((-15 + 9) \times 1000) / 298$ 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, <u>units must be correct</u>

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]

M1.(a) (i) (At 0 K) particles are stationary / not moving / not vibrating

Allow have zero energy.

Ignore atoms / ions.

1

No disorder / perfect order / maximum order

Mark independently.

1

(ii) As *T* increases, particles start to move / vibrate

Ignore atoms / ions.

Allow have more energy.

If change in state, CE = 0

1

Disorder / randomness increases / order decreases

1

(iii) Mark on temperature axis vertically below second 'step'

Must be marked as a line, an 'x' , T_b or 'boiling point' on the temperature axis.

1

(iv) L_2 corresponds to boiling / evaporating / condensing / l → g / g → l

And L1 corresponds to melting / freezing / s → l / l → s

There must be a clear link between L_1, L_2 and the change in state.

1

Bigger change in disorder for L_2 / boiling compared with L_1 / melting

M2 answer must be in terms of changes in state and not absolute states eg must refer to change from liquid to gas not just gas.

Ignore reference to atoms even if incorrect.

1

(b) (i) $\Delta G = \Delta H - T\Delta S$

1

$\Delta H = c$ and $(-)\Delta S = m / \Delta H$ and ΔS are constants (approx)

Allow ΔH is the intercept, and (−)ΔS is the slope / gradient.

Can only score M2 if M1 is correct.

1

(ii) Because the entropy change / ΔS is positive / $T\Delta S$ gets bigger

Allow -TΔS gets more negative

1

(iii) Not feasible / unfeasible / not spontaneous

1

(c) (i) + 44.5 J K^{-1} mol^{-1}

Allow answer without units but if units given they must be correct (including mol^{-1})

1

(c) (ii) At 5440 $\Delta H = T\Delta S$

= 5440 × 44.5 = 242 080

1

(***OR*** using given value = 5440 × 98 = 533 120)

Mark is for answer to (c)(i) × 5440

1

ΔH = 242 kJ mol^{-1}

(***OR*** using given value ΔH = 533 kJ mol^{-1})

Mark is for correct answer to M2 with correct units (J mol^{-1} or kJ mol^{-1}) linked to answer.

If answer consequentially correct based on (c)(i) except for incorrect sign (eg −242), max 1 / 3 provided units are correct.

1

[15]

M2.(a) $\Delta G = \Delta H - T\Delta S$

Or expression $\Delta H - T\Delta S$ must be evaluated

1

If ΔG / expression <=0 reaction is feasible

Or any explanation that this expression <=0
Do not allow just $\Delta G = 0$

1

(b) The molecules become more disordered / random when water changes from a liquid to a gas / evaporates

For M1 must refer to change in state AND increase in disorder

1

Therefore the entropy change is positive / Entropy increases

Only score M2 if M1 awarded

1

$T\Delta S > \Delta H$

Allow M3 for T is large / high (provided M2 is scored)

1

ΔG<0

Mark M3, M4 independently

1

(c) (i) Condition is $T = \Delta H / \Delta S$

1

$\Delta S = 189 - 205 / 2 - 131 = -44.5$;

1

ΔH = −242 therefore T = (−242 × 1000) / −44.5)

1

= 5438 K (allow 5400 − 5500 K)

Units essential (so 5438 alone scores 3 out of 4)
2719 K allow score of 2
5.4 (K) scores 2 for M1 and M2 only
1646 (K) scores 1 for M1 only

1

(ii) It would decompose into hydrogen and oxygen / its elements

Can score this mark if mentioned in M2

1

Because ΔG for this reaction would be <= 0

Allow the reverse reaction / decomposition is feasible
Only score M2 if M1 awarded

1

(d) $\Delta H = T\Delta S$

Allow correct substituted values instead of symbols

1

ΔS = 70−189 = −119 JK^{-1} mol^{-1}

1

ΔH = (−119 × 373) / 1000 = −44.4 kJ (mol^{-1}) (allow −44 to −45)

Allow −44000 to −45000 J (mol^{-1})
Answer must have correct units of kJ or J

1

[15]

M3.(a) Standard pressure (100 kPa) (and a stated temperature)

Allow standard conditions. Do not allow standard states
Allow any temperature
Allow 1 bar but not 1atm
Apply list principle if extra wrong conditions given
Penalise reference to concentrations

1

(b) Hydrogen bonds between water molecules

1

Energy must be supplied in order to break (or loosen) them

Allow M2 if intermolecular forces mentioned
Otherwise cannot score M2
CE = 0/2 if covalent or ionic bonds broken

1

(c) $T = \Delta H/\Delta S$

1

$= (6.03 \times 1000)/22.1$

1

= 273 K

Allow 272 to 273; units K must be given
Allow 0°C if units given
0.273 (with or without units) scores 1/3 only
Must score M2 in order to score M3
Negative temperature can score M1 only

1

(d) The heat given out escapes

1

(e) (Red end of white) light (in visible spectrum) absorbed by ice

Allow complementary colour to blue absorbed

1

Blue light / observed light is reflected / transmitted / left

Penalise emission of blue light

1

[9]

M4.(a) $\Delta G = \Delta H - T\Delta S$

Ignore ⊖

1

(b) 0.098 or 98

Allow 0.097 to 0.099/97 to 99

Allow 0.1 only if 0.098 shown in working

1

kJ K^{-1} mol^{-1} J K^{-1} mol^{-1}

Allow in any order

Unless slope is approx. 100(90-110) accept only kJ K^{-1} mol^{-1}. If no slope value given, allow either units

1

$-\Delta S/\Delta S$

1

(c) ΔG becomes negative

Mark independently unless ΔG +ve then CE = 0

1

So reaction becomes spontaneous/feasible

Or reaction can occur below this temperature

Or reaction is not feasible above this temperature

1

(d) Ammonia liquefies (so entropy data wrong/different)

Allow any mention of change in state or implied change in state even if incorrect

eg freezing/boiling

1

[7]

M5.(a) $\Delta H = \Sigma(\Delta H_f$ products) - $\Sigma(\Delta H_f$ reactants)

Allow correct cycle

1

/= +34 - +90
= -56 kJ mol^{-1}

Ignore no units, penalise incorrect units

1

(b) $\Delta S = \Sigma(S$ products) - $\Sigma(S$ reactants)

1

/= 240 - (205 +211/2)
= -70.5 J K^{-1} mol^{-1} / -0.0705 kJ K^{-1} mol^{-1}

Ignore no units, penalise incorrect units

Allow -70 to -71/-.070 to -.071

1

(c) $T = \Delta H/\Delta S$ / T = (Ans to part(a) ×1000)/ans to part(b)

Mark consequentially on answers to parts (a) and (b)

1

/= -56/(-70.5 ÷ 1000)
= 794 K (789 to 800 K)

Must have correct units

Ignore signs; allow + or – and –ve temps

1

(d) Temperatures exceed this value

1

(e) $N_2 + O_2 \rightarrow 2NO$

Allow multiples

1

(f) there is no change in the number of moles (of gases)

Can only score these marks if the equation in (e) has equal number of moles on each side

Numbers, if stated must match equation

1

So entropy/disorder stays (approximately) constant / entropy/disorder change is very small / $\Delta S=0$ / $T\Delta S=0$

1

[10]

M1.(a) Enthalpy change when 1 mol of an (ionic) compound/lattice (under standard conditions)

Allow heat energy change

1

Is dissociated/broken/separated into its (component) ions

1

The ions being in the gaseous state (at infinite separation)

Mark independently. Ignore any conditions.

1

(b) There is an attractive force between the nucleus of an O atom and an external electron.

Allow any statement that implies attraction between the nucleus and an electron

1

(c) $Mg^{2+}(g) + O(g) + 2e^-$

Ignore lack of state symbols

Penalise incorrect state symbols

1

$Mg^{2+}(g) + O^-(g) + e^-$

1

$Mg^{2+}(g) + O^{2-}(g)$

1

First new level for Mg^{2+} and O above last on L

If levels are not correct allow if steps are in correct order with arrows in the correct direction and correct ΔH values

1

Next level for Mg^{2+} and O^{-} below that

Next level for Mg^{2+} and O^{2-} above that and also above that for Mg^{2+} and O

Allow +124

Allow M4 with incorrect number of electrons

(d) LE MgO = 602 + 150 + 736 + 1450 + 248 – 142 + 844

Note use of 124 instead of 248 CE=0

1

= +3888 kJ mol^{-1}

Allow 1 for –3888

Allow no units

Penalise wrong units

1

(e) Forms a protective layer/barrier of MgO / MgO prevents oxygen attacking Mg

Allow activation energy is (very) high

Allow reaction (very) slow

1

(f) $\Delta G = \Delta H - T\Delta S$

$\Delta S = \underline{(\Delta H - \Delta G)} \qquad T$

1

$\Delta S = (-602 - (-570)) \times 1000/ 298$

1

= –107 J K^{-1} mol^{-1} / –0.107 kJ K^{-1} mol^{-1}

If units not correct or missing, lose mark

Allow –107 to –108

+107 with correct units scores max 1/3

1

(g) 1 mol of solid and 0.5 mol of gas reactants form 1 mol solid products

Decrease in number of moles (of gas/species)

Allow gas converted into solid

Numbers of moles/species, if given, must be correct

1

System becomes more ordered

Allow consequential provided ∆S is –ve in 1(f)
If ∆S is +ve in 1(f) can only score M1

1

[16]

M2. (a) $KNO_3(s) \rightarrow K^+(aq) + NO_3^-(aq)$

do not allow equations with H_2O
allow aq and the word 'water' in equation

1

(b) increase in disorder because solid → solution / increase in number of particles / 1 mol (solid) gives 2 mol (ions/particles) / particles are more mobile

allow random or chaos instead of disorder
penalise if molecules/atoms stated instead of ions
allow any reference to increase in number of particles even if number of particles wrong

1

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

1

$T = \Delta H/\Delta S = (34.9 \times 1000)/117$

also scores M1

1

= 298 K

correct answer scores 3, units essential
0.298 scores M1 only

1

(d) (i) positive / increases / $\Delta G > 0$

Allow more positive

1

(ii) if ans to (d) (i) positive, dissolving is no longer spontaneous / no longer feasible / potassium nitrate does not dissolve / less soluble

if ans to (d) (i) negative, dissolving is spontaneous / feasible / potassium nitrate dissolves / more soluble

If no mention of change to ΔG in (d)(i),
Mark = 0 for (d)(ii)

1

[7]

M3. (a) (i) $\Delta H = \Sigma$ bonds broken $-\Sigma$ bonds formed

1

= 944/2 + 3/2 × 436 –3 × 388

1

= –38 (kJ mol^{-1})

ignore units even if incorrect
correct answer scores 3
–76 scores 2/3
+38 scores 1/3

1

(ii) mean / average bond enthalpies are from a range of compounds
or
mean / average bond enthalpies differ from those in a single compound / ammonia

1

(b) $\Delta S = \Sigma S$ products $-\Sigma S$ reactants

1

= 193 – (192/2 + 131 × 3/2)

1

= –99.5 J K^{-1} mol^{-1}

units essential for M3
correct answer with units scores 3
–199 J K^{-1} mol^{-1} & –99.5 score 2/3

–199 and + 99.5 J K^{-1} mol^{-1} score 1/3

1

(c) (i) $\Delta G = \Delta H - T\Delta S = -46 + 800 \times 99.5/1000$

mark is for putting in numbers with 1000

if factor of 1000 used incorrectly CE = 0

1

= 33.6 or 33600

allow 33 to 34 (or 33000 to 34000)

1

kJ mol^{-1} with J mol^{-1}

correct units for answer essential

if answer to part (b) is wrong or if -112 used, mark consequentially e.g.

- *–199 gives 113 to 114 kJ mol^{-1} (scores 3/3)*
- *–112 gives 43 to 44 kJ mol^{-1} (scores 3/3)*

1

(ii) If answer to (c) (i) is positive: not feasible / not spontaneous

If answer to (c) (i) is negative: feasible / spontaneous

if no answer to (c) (i) award zero marks

1

[11]

M4. (a) Particles are in maximum state of order

(or perfect order or completely ordered or perfect crystal or minimum disorder or no disorder)

(entropy is zero at 0 k by definition)

1

(b) (Ice) melts

(or freezes or changes from solid to liquid or from liquid to solid)

1

(c) Increase in disorder

1

Bigger (at T_2)

1

Second mark only given if first mark has been awarded

(d) (i) Moles of water = 1.53/18 (= 0.085)

1

Heat change per mole = 3.49/0.085 = 41.1 (kJ mol^{-1})

(allow 41 to 41.1, two sig. figs.)

(penalise –41 (negative value), also penalise wrong units but allow kJ only)

1

(ii) $\Delta G = \Delta H - T\Delta S$

1

(iii) $\Delta H = T\Delta S$ or $\Delta S = \Delta H/T$

(penalise if contradiction)

1

ΔS = 41.1/373 = 0.110 kJ K^{-1} (mol^{-1}) (or 110 (J K^{-1} (mol^{-1}))

(allow 2 sig. figs.)

(if use value given of 45, answer is 0.12 (or 120 to 121)

(if ΔH is negative in (d) (i), allow negative answer)

(if ΔH is negative in (d) (i), allow positive answer)

(if ΔH is positive in (d) (i), penalise negative answer)

1

Correct units as above (mol^{-1} not essential)

1

[10]

M5. (a) Because it is a <u>gas</u> compared with <u>solid</u> carbon

Mark independently

1

Nitrogen is more disordered/random/chaotic/free to move

1

(b) 0 K/–273 C/absolute zero

1

(c) $\Delta G = \Delta H - T\Delta S$

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

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

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

Ignore ~~o~~ in ΔG°

1

(d) ΔG is less than or equal to zero ($\Delta G \leq 0$)

Allow ΔG is less than zero ($\Delta G < 0$)

Allow ΔG is equal to zero ($\Delta G = 0$)

Allow ΔG is negative

1

(e) When $\Delta G = 0$ $T = \underline{\Delta H/\Delta S}$

1

$\Delta H = +90.4$

Allow $\Delta H = +90$

1

$\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$

1

$\Delta S = 211.1 - 205.3/2 - 192.2/2 = \underline{12.35}$

1

$T = (90.4 \times 1000)/12.35 = 7320$ K/7319.8 <u>K</u>

Allow 7230 to 7350 <u>K</u> (Note 7.32 K scores 4 marks)

Units of temperature essential to score the mark

1

(f) Activation energy is high

Allow chemical explanation of activation energy

Allow needs route with lower activation energy

Allow catalyst lowers activation energy

1

(g) $\Delta H = 1.9$ (kJ mol^{-1})

1

$\Delta S = 2.4 - 5.7 = -3.3$ (J K^{-1} mol^{-1})

for M1 and M2 allow no units, penalise wrong units

1

ΔG is always positive

This mark can only be scored if ΔH is +ve and ΔS is –ve

1

[14]

M1.B

[1]

M2.C

[1]

M3.B

[1]

M4. (a) $\Delta H = \Sigma\Delta H_f(\text{products}) - \Sigma\Delta H_f(\text{reactants})$

1

$= -201 - 242 - (-394)$

1

$= -49 \text{ kJ mol}^{-1}$

+49 kJ mol^{-1} = 1 mark
units not required, wrong units lose 1 mark

1

(b) $\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$

1

$= 238 + 189 - (214 + 3 \times 131)$

1

$= -180 \text{ J K}^{-1} \text{ mol}^{-1}$

+180 = 1 mark
units not required, wrong units lose 1 mark

1

(c) $\Delta G = \Delta H - T\Delta S$

If use G not ΔG penalise M1 but not M2 and M3

1

(ΔS is negative so) at high temp $-T\Delta S$ (is positive and) greater than ΔH/large

Do not award M2 or M3 if positive ΔS value used

1

So Δ*G* > 0

Independent mark unless positive ΔS value used

1

(Limiting condition Δ*G* = 0 so) *T* = Δ*H*/Δ*S*

1

= 272 K

Allow 297-298 if used given values.
Do not award M5 if T –ve or if M4 should give T –ve

1

Reaction is too slow at this temperature/to speed up the reaction

1

(d) $CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O$

Allow multiples.
Ignore state symbols.
Do not allow equation for wrong compound but mark on provided number of moles increases or stays the same.
If no equation or equation that gives a decrease in the number of moles,
CE = 0

1

2.5 mol give 3 mol (gases)

Allow statement 'increase in number of moles/molecules'
If numerical values given, they must match the equation in M1
Ignore the effect of incorrect state symbols on the number of moles of particles unless used correctly

1

Therefore Δ*S* is positive/entropy increases

If correct deduction from wrong equation is ΔS = 0 or ΔS very small must say H –ve

1

(combustion exothermic so Δ*H* –ve so Δ*H* – *T*Δ*S*) and hence Δ*G* always negative (less than zero)

1

Allow G instead of ΔG
Can score 3 out of 4 marks if equation wrong but leads to increase or no change in number of moles
M4 dependent on M3

Note, if equation wrong AND there is an incorrect deduction about the change in number of moles, CE = 0

(e) CO_2/CO/CH_4 may be produced during H_2 manufacture/building the plant/transport/operating the plant

1

[17]

M5. (a) *Standard enthalpy change, $\Delta H^{\ominus}$*: $\Delta H_R = \Sigma\Delta H_{f\text{products}} - \Sigma\Delta H_{f\text{reactants}}$ **(1)**
or cycle

ΔH_R = (0 + [2 × –242]) – (4 × –92) **(1)**
= -484 + 368
= –116 (kJ mol^{-1})
Allow max 1 for +116

Standard entropy change, $\Delta S^{\ominus}$: $\Delta S = \Sigma\Delta H_{f\text{ products}} - \Sigma\Delta H_{f\text{ reactants}}$

ΔS = ([2 × 223] + [2 × 189]) - (205 + [4 × 187]) **(1)**

= 824 – 953

= –129 (J K^{-1} mol^{-1})
allow max one for +129

6

(b) (i) *Effect*: Equilibrium displaced to right / to products **(1)**
Explanation: Reaction is endothermic **(1)**
Constraint reduced **(1)**
mark separately

(ii) Feasible when $\Delta G \leq 0$ **(1)**

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

T = $\Delta H/\Delta S$ = 208 × 1000 **(1)** / 253

= 822 K **(1)**

7

[13]

M6.A

[1]

M7. (a) (i) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

1

(ii) The negative S^- ion

1

repels the added electron

1

(iii) Step B is the atomisation enthalpy of sulphur

1

Step D is the second ionisation enthalpy of calcium

1

(iv) Electrons nearer to the nucleus

1

Electrons removed from a positive species or more strongly attracted

1

(v) +178 +279 +590 +1145 -200 + 539 + G + 482 = 0

1

G + 3013 = 0 hence G = –3013

1

(b) The model used assumes the ions are spherical and in a lattice

1

The calculated value is smaller than the cycle value or stronger attraction

1

Indicating some covalent character or ions are polarised

1

(c) (i) For a reaction to occur ΔG < 0

1

ΔS is positive and large as a gas is evolved

1

TΔS is larger than ΔH and ΔG is negative

1

(ii) ΔS is negative

1

Four moles gaseous reactant forming or more moles of gaseous product

1

At high temperature TΔS is larger than ΔH and ΔG is positive

1

[18]

M8.C

[1]

M9.C

[1]

M1. (a) *M1* $K_p = (_pY)^3 . (_pZ)^2 / (_pW)^2 . (_pX)$ *NB [ ] wrong*

1

M2 temperature

1

M3 increase

1

M4 particles have more energy or greater velocity/speed

1

M5 more collisions with $E > E_a$ or more successful collisions

1

M6 Reaction exothermic or converse

1

M7 Equilibrium moves in the left

1

Marks for other answers

Increase in pressure or concentration	*allow M1, M5, M6*	*Max 3*
Addition of a catalyst;	*allow M1, M5, M6*	*Max 3*
Decrease in temperature;	*allow M1, M2, M6*	*Max 3*
Two or more changes made;	*allow M1, M6*	*Max 2*

(b) (i) Advantage; reaction goes to completion, not reversible or faster

1

Disadvantage; reaction vigorous/dangerous

(exothermic must be qualified)

or HCl(g) evolved/toxic
or CH_3COCl expensive

NB Allow converse answers
Do not allow reactions with other reagents e.g. water or ease of separation

1

(ii) $\Delta S = \Sigma S$ products $- \Sigma S$ reactants

1

□□□□□□□□ $\Delta S = (259 + 187) - (201 + 161)$

1

□□□□□□□□ ΔS = 84 (JK^{-1} mol^{-1}) *(Ignore units)*

*Allow – 84 to score **(1)** mark*

1

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

1

$= -21.6 - 298 \times 84/1000$

$= -46.6$ kJ mol^{-1} or – 46 600 J mol^{-1}

1

*Allow **(2)** for – 46.6 without units*

(Mark ΔG consequentially to incorrect ΔS)

(e.g. ΔS = –84 gives ΔG = +3.4 kJ mol^{-1})

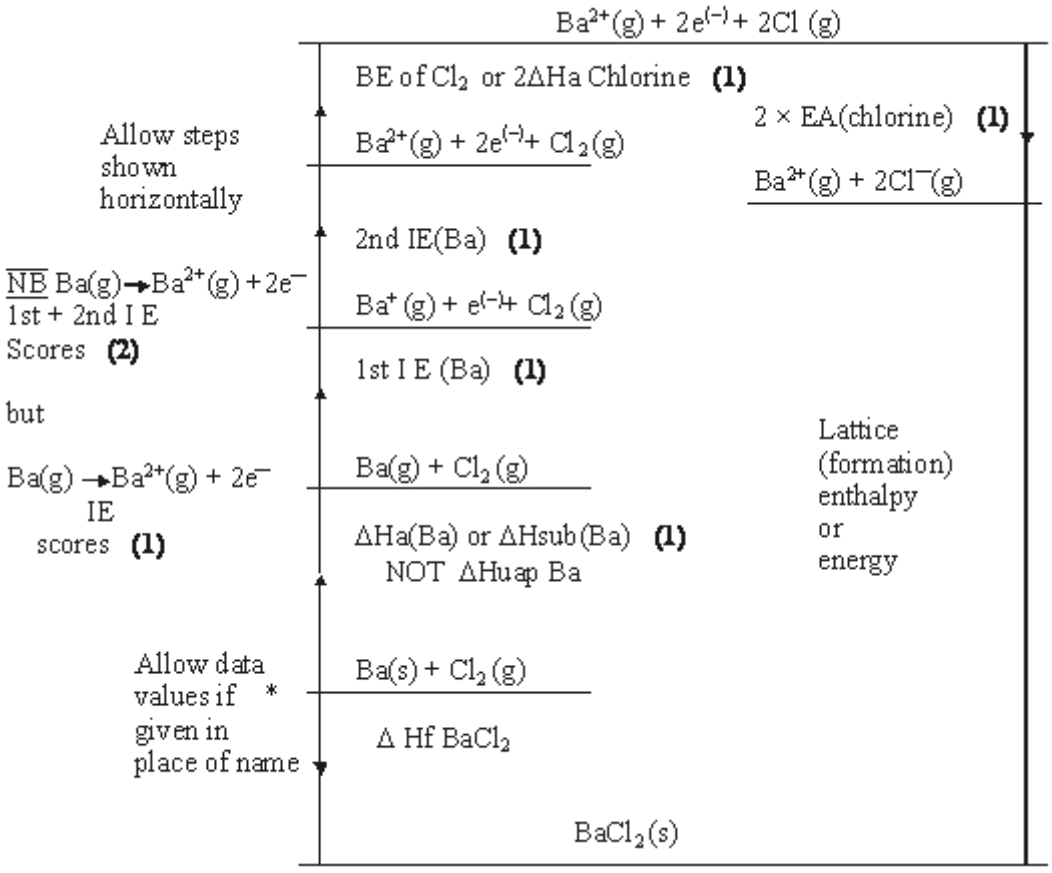
1

[15]

M2.B

[1]

M3. (a) (i)



ONLY consider species involved in the step marked

(ii) Cycling clockwise about (*)

CE if step missing

$\Delta H_a Ba + 1^{st}$ IEBa + 2^{nd} IE Ba + $2\Delta H_a Cl + 2EACl + LE - \Delta H_f BaCl_2 = 0$ **(1)**
$+180 + 503 + 965 + 2 \times 122 + 2EA - 2056 + 859 = 0$ **(1)**
$EA = -695/2 = -$ (347 to 348) **(1)**

Ignore units

Calculation –1 for each error

Mark conseq.

*Notes: –695 scores **(2)***
*+(347 to 348) scores **(2)***
*–(286 to 287) scores **(2)***
*+(286 to 287) scores **(1)***
*–573 scores **(1)***
*+573 scores **(0)***

9

(b) $\Delta S = \Sigma S$ products – ΣS reactants
$= (63 + 223) - 124 = 162$ **(1)**

$\Delta G = \Delta H - T\Delta S$ or $\Delta H = T\Delta S$ or $T = \Delta H/\Delta S$ **(1)**

or used correctly

$\Delta H = 859 \times 10^3$ **(1)** $= T \times 162$

T = (5 300 to 5304) K **(1)**

Penalise if units °C

–1 for each error + mark conseq.

4

[13]

M4. A

[1]

M5. (a) (i) *Standard enthalpy change*:

$\Delta H_R = \Sigma\Delta H_f$(products) - $\Sigma\Delta H_f$(reactants) **(1)**

or cycle

$\Delta H_R = ([2 \times 0] + [3 \times -393.5])$ - $(-824.2 + [3 \times -110.5])$ **(1)**

$= -24.8$ (kJ mol^{-1}) **(1)**

Allow + 24.8 max one

Standard entropy change: $\Delta S = \Sigma S$(products) - ΣS(reactants) **(1)**

$\Delta S = ([2 \times 27.3] + [3 \times 213.6])$ - $(87.4 + [3 \times 197.6])$ **(1)**

$= (54.6 + 640.8)$ - $(87.4 + 592.8)$ **(1)**

$= 15.2$ ($JK^{-1}mol^{-1}$) **(1)**

Allow -15.2 max one

(ii) $\Delta G = \Delta H$ - $T\Delta S$ **(1)**

ΔH negative and - $T\Delta S$ is negative **(or ΔS positive or or correct calc) (1)**

Hence ΔG is always negative

(or feasible when $\Delta G \leq 0$) (1)

9

(b) $\Delta G = O = \Delta H$ - $T\Delta S$ Hence $\Delta H = T\Delta S$ **(1)**

T **=** ΔH / ΔS = 492.7 × 1000 / 542.6 **(1)**
= 908 K **(1)**
penalise missing 1000 by one mark

3

(c) ΔG (b) = ΔG (a)
(492.7 × 10^3 - T × 542.6) = (-24.8 × 10^3 - T × 15.2) **(1)**
517.5 × 10^3 = 527.4 T **(1)**
T = 981.2 K**(1)**
Allow 980 - 982
Penalise missing 1000 by one mark

3

[15]

M6.C

[1]

M1.C

[1]

M2.C

[1]

M3.A

[1]

M4.B

[1]

M5.A

[1]

M6.B

[1]

M7.C

[1]

M8.C

[1]

M9.D

[1]

M10.D

[1]

M11.A

[1]

M12.B

[1]

M13.D

[1]