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

ΔS = 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]