23. Chemical energetics

23.4 Gibbs free energy change, ΔG

Paper 4

Marking Scheme

Q1.

(a)	**M1** $\Delta S^{\ominus} = (213.8 + 2 \times 248.2) - (237.8 + 3 \times 205.2)$ $\Delta S^{\ominus} = -143.2$ (J K^{-1} mol^{-1}) **M2** $\Delta H^{\ominus} = (-393.5 + 2 \times -296.8) - (116.7)$ $\Delta H^{\ominus} = -1103.8$ (kJ mol^{-1}) **M3** $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ $\Delta G^{\ominus} = -1103.8 - (298 \times -0.1432) = -1061.1$ to -1061.4 (kJ mol^{-1}) ecf min 3sf	**3**
(b)	**M1** $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ **AND** $\Delta G^{\ominus} = 0$ **OR** $T = \Delta H^{\ominus} / \Delta S^{\ominus}$ [1] **M2** $T = 261.6 \div 0.3655 = 715.7 / 716 / 715$ K min 3sf	**2**

Q2.

(d)	$\Delta G = \Delta H - T\Delta S$ answer +10.5	[1] [1]	**2**
(e)(i)	No, ΔG is positive	[1]	**1**
(e)(ii)	Becomes more / soluble **because** ΔG becomes more negative / less positive / smaller / closer to zero	[1]	**1**

Q3.

(b)(i)	measure / degree of disorder / randomness of a system **OR** the number of possible arrangements of the particles and the energy in a system	**1**

(b)(ii)	**M1** $\Delta S^{\ominus} = (192.8) + 213.8 - 238.2 - 188.8$ $\Delta S^{\ominus} = -20.4$ (J K^{-1} mol^{-1}) **M2** $\Delta H^{\ominus} = (-45.9) + (-393.5) - (-101.7) - (-241.8)$ $\Delta H^{\ominus} = -95.9$ (kJ mol^{-1}) **M3** $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ **M4** $\Delta G^{\ominus} = -95.9 - (298 \times -0.0204) = -89.8$ (kJ mol^{-1})	**4**
(c)	$4(NH_2)_2CO + 6NO_2 \rightarrow 7N_2 + 8H_2O + 4CO_2$	**1**

Q4.

(f)	• feasibility / it increases as temperature increases **ORA** • ΔS is positive / ΔS is >0 / entropy **change** is positive (and ΔH is positive) **OR** $-T\Delta S$ becomes more negative / $T\Delta S$ becomes more positive • as ΔG becomes / is negative / $\Delta G < 0$ Any two [1], all three [2]	**2**

Q5.

(c)	$\Delta G = \Delta H - T\Delta S$ seen or used with correct signs[1] $-238 = -196 - 298\Delta S$ $\Delta S = 42 / 298$ ΔS = (+)0.141 / 0.1409 (kJ K–1 mol–1) OR (+)141 / 140.9 (J K–1 mol–1) [1] ecf from $\Delta G = \Delta H + T\Delta S$ 141 = (2 × 70) + S(O_2(g)) – (2 × 102) S, O_2(g) = 205 / 204.94 (J K^{-1} mol^{-1}) [1] ecf	**3**

Q6.

(f)(i)	$\Delta S = -179$ [1] $\Delta G = \Delta H - T\Delta S$ [1] –74.7 [1]	**3**
(f)(ii)	less **AND** ΔG becomes more positive [1]	**1**

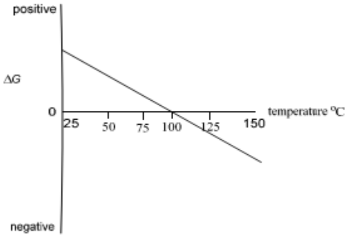
Q7.

(e)(i)	**M1** $\Delta G^\ominus = 0$ so $T = \Delta H_r^\ominus / \Delta S^\ominus$ **M2** T = 132 / 0.616 = 214.3 K T = –58.7 °C min 2sf	**2**
(e)(ii)	**M1** $\Delta S^\ominus = (203 + (70 \times 8) + (2 \times 192)) - (427 - (2 \times 95)) = +530\ J\ K^{-1}\ mol^{-1}$ **M2** $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ **M3** $\Delta G^\ominus = 133 - (298 \times 0.530) = -24.9\ kJ\ mol^{-1}$ ecf 1dp min	**3**

Q8.

(a)(i)	**M1** all five points plotted correctly **M2** best-fit straight line (ruler) with negative gradient drawn	**2**
(a)(ii)	**M1** gradient correctly calculated **OR** gradient working seen **M2** gradient = $-\Delta S^o$ ΔS^o evaluated correctly ecf ΔS^o = (+)160 ± 10 (J K^{-1} mol^{-1})	**2**

Q9.

(c)(iii)	 *two correct for 1 mark, three correct for two marks:* • starting at +8.6 kJ / in positive region close to the *y*-axis • line passes through *x*-axis around 100°C • negative gradient straight / curve line through the *x*-axis (no clear positive inflexions)	**2**
(d)	**M1:** ΔH negative / –, ΔS negative / – **M2:** as temperature increase, ΔG becomes (more) positive / less negative ora **OR** at low(er) T, (ΔH more negative than TΔS) so ΔG is negative **OR** at high(er) T, (ΔH less negative than TΔS) so ΔG is positive	**2**

Q10.

(e)(i)	ΔS = 262 + 205 – 140 = (+) **327** (J K^{-1} mol^{-1}) [1]	**1**
(e)(ii)	ΔG = ΔH – TΔS **OR** use of Gibbs equation [1] ΔG = 572 – (298 × 0.327) = (+)**474.6** (kJ mol^{-1}) [1] min 3sf ecf 1e(i)	**2**
(e)(iii)	becomes more feasible / spontaneous as TΔS is more positive / –TΔS becomes more negative • ✓	**1**

Q11.

(b)(i)	$K_{eq4} = K_{stab3}/K_{stab2}$	**1**
(b)(ii)	**M1** $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ $\Delta G^{\ominus}$ = 0.84 – (298*0.0809) **M2** $\Delta G^{\ominus}$ = **-23.3** (kJ mol^{-1}) **3sf min**	**2**
(b)(iii)	more negative as TΔS increases **OR** more negative as ΔS is positive	**1**

Q12.

(e)(i)	–20 [1]	**1**

(e)(ii)	states / uses correct Gibbs equation [1] answer = 190 / 191 / 190.0 [1]	**2**
(e)(iii)	Becomes less feasible / less spontaneous / **AND** because ΔS is negative / TΔS becomes more negative / –TΔS becomes more positive [1]	**1**

Q13.

(e)(i)	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ [1]	**1**
(e)(ii)	TΔS is more positive **OR** –TΔS becomes more negative [1]	**1**

Q14.

(c)(i)	(standard) Gibbs free energy <u>change</u>	**1**
(c)(ii)	**M1:** $(\Delta)G = \Delta H - T\Delta S$ **M2:** description of calculating the minimum value of T for which ΔG is zero / becomes negative **OR** $T = \Delta H / \Delta S$ [1]	**2**

Q15.

(b)	**M1:** States or uses correct form of Gibbs equation $\Delta G = \Delta H - T\Delta S$ **M2:** appreciates / includes $\Delta G = 0$ at temperature required **M3:** uses 1000 correctly and answer +624(.339) Award 3 marks for correct answer	**3**