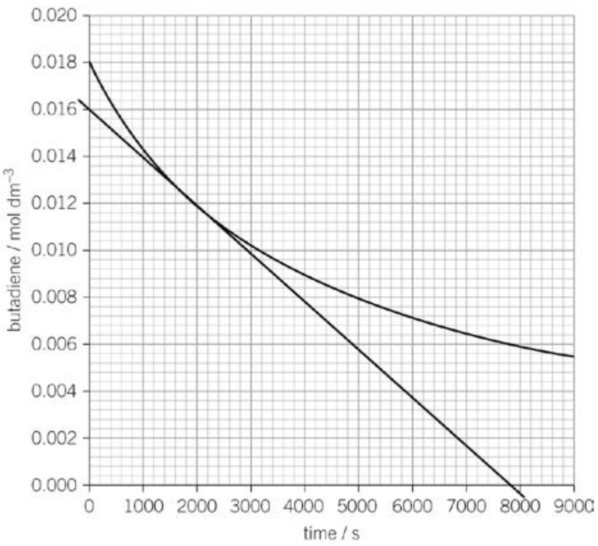
Question number	Answer	Marks	Guidance
1 (a)	$\Delta H = \Sigma(\Delta H_f \text{ products}) - \Sigma(\Delta H_f \text{ reactants})$ /= +34 − +90 = -56 kJ mol^{-1}	1 1	Allow correct cycle Ignore no units, penalise incorrect units
1 (b)	$\Delta S = \Sigma(S \text{ products}) - \Sigma(S \text{ reactants})$ /= 240 − (205 +211/2) = −70.5 J K^{-1} mol^{-1} / −0.0705 kJ K^{-1} mol^{-1}	1 1	Ignore no units, penalise incorrect units Allow -70 to -71/-.070 to -.071
1 (c)	$T = \Delta H / \Delta S$ T = (Answer to part (a) ×1000) / answer to part(b) /= −56 / (−70.5 ÷ 1000) = 794 K (789 to 800 K)	1 1	Mark consequentially on answers to parts (a) and (b) Must have correct units Ignore signs; allow + or – and negative temps
1 (d)	Temperatures exceed this value	1	
1 (e)	$N_2 + O_2 \rightarrow 2NO$	1	Allow multiples
1 (f)	There is no change in the number of moles (of gases) So entropy/disorder stays (approximately) constant / entropy/disorder change is very small / ΔS=0 / $T\Delta S$=0	1 1	Can only score these marks if the equation in (e) has equal number of moles on each side Numbers, if stated must match equation
2 (a)	Because it is a <u>gas</u> compared with <u>solid</u> carbon Nitrogen is more disordered/random/chaotic/free to move	1 1	Mark independently
2 (b)	0 K / –273 °C / absolute zero	1	
2 (c)	$\Delta G = \Delta H - T\Delta S$	1	Allow $\Delta H = \Delta G - T\Delta S$ $T\Delta S = \Delta H - \Delta G$ $\Delta S = (\Delta H - \Delta G)/T$ Ignore $\ominus$ in G
2 (d)	ΔG is less than or equal to zero ($\Delta G \leq 0$)	1	Allow ΔG is less than zero (ΔG < 0) Allow ΔG is equal to zero (ΔG = 0) Allow ΔG is negative

2 (e)	When $\Delta G = 0$, $T = \underline{\Delta H\ /\ \Delta S}$ $\Delta H = +90.4$ $\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$ $\Delta S = 211.1 - 205.3/2 - 192.2/2 = 12.35$ $T = (90.4 \times 1000) / 12.35 = 7320$ K (7319.8 K)	1 1 1 1 1	Allow $\Delta H = +90$ Allow 7230 to 7350 $\underline{\text{K}}$ (Note 7.32 K scores 4 marks) Units of temperature essential to score the mark
2 (f)	Activation energy is high	1	Allow chemical explanation of activation energy Allow needs route with lower activation energy Allow catalyst lowers activation energy
2 (g)	$\Delta H = 1.9\ \text{kJ mol}^{-1}$ $\Delta S = 2.4 - 5.7 = -3.3\ \text{J K}^{-1}\ \text{mol}^{-1}$ ΔG is always positive	1 1 1	for M1 and M2 allow no units, penalise wrong units This mark can only be scored if ΔH is positive and ΔS is negative
3 (a)	$1.00\ \text{mol dm}^{-3}$; 100 kPa	2	This is part of the definition, so learn these conditions.
3 (b) (i)	0.43 V	1	Remember that: $E_{cell} = E_{right} - E_{left}$
3 (b) (ii)	$2Br^- \rightarrow Br_2 + 2e^-$ $2BrO_3^- + 10Br^- + 12H^+ \rightarrow 6Br_2 + 6H_2O$	3	Remember oxidation is at the left-hand half-cell, which is the half cell with the lower E value. One mark is given for all the correct species and one mark for balancing the equation. Accept: $BrO_3^- + 5Br^- + 6H^+ \rightarrow 3Br_2 + 3H_2O$ which is half of the other equation.
4 (a) (i)	$[H^+][OH^-]$ OR $[H3O^+][OH^-]$	1	Must have [ ] not ( ) Ignore (aq)
4 (a) (ii)	$\sqrt{}(3.46 \times 10^{-14}) = 1.86 \times 10^{-7}$ pH = 6.73	1 1	If no square root, CE=0 **Must be 2 d.p.**

4 (a) (iii)	$[H^+] = 10^{-11.36}$ (= 4.365×10^{-12} OR 4.37×10^{-12}) K_w = [4.365×10^{-12} OR 4.37×10^{-12} × 0.047] = 2.05×10^{-13}	1 1	Mark for working Mark for answer Ignore units Allow 2.05×10^{-13} – 2.1×10^{-13}
4 (b) (i)	$HCOOH \rightleftharpoons HCOO^- + H^+$ OR $HCOOH + H_2O \rightleftharpoons HCOO^- + H_3O^+$	1	Must have ⇌ but ignore brackets. Allow HCO_2^- or $CHOO^-$, i.e., minus must be on oxygen, so penalise $COOH^-$
4 (b) (ii)	$K_a = [H^+][HCOO^-] / [HCOOH]$ OR $[H3O^+][HCOO^-] / [HCOOH]$	1	Must have all brackets but allow ( ) Must be HCOOH etc. Allow ecf in formulae from 2(b)(i)
4 (b) (iii)	$K_a = [H^+]^2 / [HCOOH]$ ($[H^+]^2 = 1.78 \times 10^{-4} \times 0.056 = 9.97 \times 10^{-6}$) $[H^+] = 3.16 \times 10^{-3}$ pH = 2.50	1 1 1	Allow HA or HX etc. Allow $[H^+] = \sqrt{}(k_a \times [HA])$ for M1 Mark for answer allow more than 2 d.p. but not fewer Allow correct pH from their wrong $[H^+]$ here only If square root shown but not taken, pH = 5.00 can score max 2 for M1 and M3
4 (b) (iv)	Decrease Equm <u>shifts/moves</u> to RHS **OR** more H^+ **OR** K_a increases **OR** more dissociation To reduce temperature or oppose increase/change in temperature	1 1 1	Mark M1 independently Only award M3 following correct M2
4 (c) (i)	$[H^+] = K_a \times [HX] / [X^-]$ **OR** $pH = pK_a - \log([HX]/[X^-])$ $1.78 \times 10^{-4} \times 2.35 \times 10^{-2} / 1.84 \times 10^{-2}$ **OR** $pH = 3.75 - \log(2.35 \times 10^{-2} / (1.84 \times 10^{-2}))$ = 2.27×10^{-4} pH = 3.64	1 1 1	If $[HX] / [X^-]$ upside down, no marks allow more than 2 d.p. but not fewer pH calc NOT allowed from their wrong $[H^+]$ here

4 (c) (ii)	Mol H^+ added = 5.00×10^{-4} Mol HCOOH = 2.40×10^{-2} **and** Mol $HCOO^-$ = 1.79×10^{-2} $[H^+] = K_a \times [HX] / [X^-]$ $= 1.78 \times 10^{-4} \times 2.40 \times 10^{-2} / (1.79 \times 10^{-2})$ $= 2.39 \times 10^{-4}$ **OR** pH = 3.75 – log $(2.40 \times 10^{-2} / (1.79 \times 10^{-2}))$ pH = 3.62	1 1 1 1	Mark on from AE in moles of HCl (e.g., 5×10^{-3} gives pH = 3.42 scores 3) If either wrong no further marks except AE (−1) OR if ECF in mol acid and/or mol salt from (c)(i), can score all 4 If $[HX] / [X^-]$ upside down here after correct expression in (c)(i), no further marks If $[HX] / [X^-]$ upside down here and is repeat error from (c)(i), max 3 (pH = 3.88 after 3.86 in 2(c)(i)) allow more than 2 dp but not fewer **pH calc NOT allowed from their wrong $[H^+]$ here**
5 (a)	methanoic acid	1	
5 (b)	An acid that is only partially dissociated in solution	1	
5 (c)	Oxygen is significantly more electronegative than hydrogen, so the O—H bond is polarised $O^{\delta-}$—$H^{\delta+}$ so the H is already in the process of becoming a H^+ ion.	1	
5 (d)	$K_a = \dfrac{[H^+(aq)]_{eqm} \times [A^-(aq)]_{eqm}}{[HA(aq)]_{eqm}}$	2	
5 (e)	Sulfamic acid as it has the lowest value of pK_a	2	
5 (f)	$pK_a = -\log_{10} K_a$, so $K_a = 1.58 \times 10^{-4}$ mol dm^{-3} $1.58 \times 10^{-4} = \dfrac{[H^+(aq)]_{eqm} \times [A^-(aq)]_{eqm}}{[HA(aq)]_{eqm}}$ $[H^+(aq)]_{eqm} = [A^-(aq)]_{eqm}$ and, as it is a weak acid, $[HA(aq)]_{eqm} \approx 1$ mol dm^{-3} So $1.58 \times 10^{-4} = \dfrac{[H^+(aq)]_{eqm}{}^2}{1}$ $[H^+(aq)]_{eqm} = 0.01261$ mol dm^{-3} pH = $-\log_{10} [H^+]$ = 1.90	1 1 1 1	
5 (g)	$CaCO_3(s) + 2HCOOH(aq) \rightarrow Ca(HCOO)_2 + H_2O(l) + CO_2(g)$	2	1 mark for formulae, 1 mark for balancing

5 (h)	M_r formic acid is 46.0 and M_r of calcium carbonate is 100.1 so 100.1 g $CaCO_3$ reacts with 92.0 g HCOOH, so 4.5 g HCOOH reacts with 4.89 g $CaCO_3$	1 1	
5 (i)	The formic acid would react with the OH^- ions so moving the equilibrium to the left. The chlorine gas formed is toxic	3	
6 (a)	The number of protons increases (across the period) / nuclear charge increases Therefore, the attraction between the nucleus and electrons increases	1 1	Can only score M2 if M1 is correct
6 (b)	S_8 molecules are bigger than P_4 molecules Therefore, van der Waals / dispersion / London forces between molecules are stronger in sulfur	1 1	Allow sulfur molecules have bigger surface area and sulfur molecules have bigger M_r
6 (c)	Sodium oxide contains O^{2-} ions These O^{2-} ions react with water forming OH^- ions	1 1	$O^{2-} + H_2O\ 2OH^-$ scores M1 and M2
6 (d)	$P_4O_{10} + 12OH^- \rightarrow 4PO_4^{3-} + 6H_2O$	1	
7 (a)	Gradiant drawn on graph  	1	Line must touch the curve at 0.012 but must not cross the curve.

7 (b)	Stage 1: Rate of reaction when concentration = 0.0120 mol dm^{-3} From the tangent Change in [butadiene] = –0.0160 – 0 and change in time = 7800 – 0 Gradient = –(0.0160 – 0) / (7800 – 0) = -2.05×10^{-6} Rate = 2.05×10^{-6} (mol dm^{-3} s^{-1}) Stage 2: Comparison of rates and concentrations Initial rate / rate at 0.0120 = (4.57×10^{-6}) / (2.05×10^{-6}) = 2.23 Initial concentration / concentration at point where tangent drawn =0.018 / 0.012 = 1.5 Stage 3: Deduction of order If order is 2, rate should increase by factor of $(1.5)^2$ = 2.25 this is approximately equal to 2.23 therefore order is 2nd with respect to butadiene	1 1 1 1 1	Extended response Marking points in stage 2 can be in either order
8 (a)	An acid that is fully dissociated into H^+ ions in solution.	1	
8 (b)	$HCl(g) + aq \rightarrow H^+(aq) + Cl^-(aq)$	1	
8 (c) (i)	0.01 mol	1	
8 (c) (ii)	pH = $-\log_{10}[H^+]$, so pH =2.00	1	
8 (d) (i)	$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + CO_2(g) + H_2O(l)$	2	1 mark for formulae, 1 mark for balancing
8 (d) (iii)	$CaCO_3(s) + 2HCl \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$	2	1 mark for formulae, 1 mark for balancing
8 (e) (i)	M_r $NaHCO_3$ is 84.0 so we have $\frac{0.267}{84.0}$ = 0.0032 mol 1 mol acid is neutralised by 1 mol $NaHCO_3$ so = 3.2×10^{-3} mol acid is neutralised by $NaHCO_3$	1	
8 (e) (ii)	M_r $CaCO_3$ is 100.1 so we have $\frac{0.160}{100.1}$ = 0.0016 mol 2 mol acid is neutralised by 1 mol $CaCO_3$ so = 3.2×10^{-3} mol acid is neutralised by $CaCO_3$	1 1	
8 (e) (iii)	1 mol $NaHCO_3$ neutralises 1 mol HCl 1 mol of $CaCO_3$ neutralises 2 mol HCl 3.2×10^{-3} mol + ($3.2 \times 10^{-3} \times 2$) = 9.6×10^{-3} mol	1	

8 (f) (i)	Total acid neutralised is 0.0064 mol leaving 0.01 − 0.0064 = 0.0036 mol HCl, dissolved in a volume of 1 dm^3	1	
8 (f) (ii)	pH = 2.44	1	