# Section A

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| **A1.** | (a) | M1: q = mcΔT = 140 x 4.18 x (28.5 – 21.0) = 4390 J or 4.39 kJM2: moles of methanol = 0.352/32 = 0.011M3: ΔH = M1/M2 and -ve = -399 kJmol-1 |
|  | (b) | M4: moles of methanol = 3.13M5: q = ΔH x n = 1250 kJ[5] |
| **A2.** | (a) | M1: bonds broken: 5 x C-H + 1 x C-C + 1 x C-O (+1 x O-H) + 3 x O=O = 4256 or 4719M2: bonds formed: 4 x C=O + 5/6 x O-H = 5535 (if 4256 for M1) or 5998 (if 4719 for M1)M3: M1 - M2 = -1279 |
|  | (b) | M4: Bond enthalpies are mean valuesM5: the bond energies in the reactants and products may differ from mean values[5] |
| **A3.** | (a) | M1: ΔH = Σ(ΔHf(p)) - Σ(ΔHf(r)) or suitable cycleM2: (4 x -394) + (5 x -286) – (-327)M3: -2679 |
|  | (b) | M4: Moles of CO2 = 100/44 = 2.27 so moles of butan-1-ol = 2.27/4 = 0.568M5: q = 0.568 x 2679 = 1520 kJ[5] |
| **A4.** |  | (a)M1: all species correct with max two errorsM2: all species correct with no errorsM3: all lines connected with arrows | (b)-859 = 180 + 2(122) + 503 + 965 + 2x – 20562x = -859 – 180 – 2(122) – 503 – 965 + 2056 = -695x = - 348 M4: attempt at cycle with enthalpy of formation = sum of processesM5: atomization energy of Cl x 2 and 2x used for electron affinityM6 correct rearrangement to x = -348[max 5] |
| **A5.** | (a) | M1: particles are moving faster/have more energyM2: so the collisions are more energetic/collision energy is greaterM3: so collisions are more likely to be successful/higher fraction of successful collisions |
|  | (b) | M1: more particles per unit volume (or higher concentration)M2: so more frequent collisions[5] |

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| **A6.** | (a) | M1: When [NO] x 2 and [H2] stays the same, rate x 4 so order of reaction wrt NO is 2M2: When [NO] stays the same and [H2] x 2, rate stays the same order of reaction wrt H2 is 0 M3: rate = k[NO]2 |
|  | (b) | M4: k = rate/[NO]2 = 0.003/0.62 = 8.3 x 10-3 M5: mol-1dm3s-1[5] |
| **A7.** | M1: lnk = lnA - $\frac{E\_{a}}{RT}$ (takes logs anywhere in equation)M2: lnk2 – lnk1 = ln($\frac{k\_{2}}{k\_{1}}$) (idea that difference in lnk values leads to relative rate)M3: lnk2 – lnk1 = $\frac{E\_{a}}{RT\_{1}}$ - $\frac{E\_{a}}{RT\_{2}}$ (idea that relative rate is linked to difference in $\frac{E\_{a}}{RT}$ values)M4: $\frac{E\_{a}}{RT\_{2}}$ - $\frac{E\_{a}}{RT\_{1}}$ = (50000/8.31/298) - (50000/8.31/308) = 0.656 (calculates difference in $\frac{E\_{a}}{RT}$ values)M5: lnk2 – lnk1 = ln($\frac{k\_{2}}{k\_{1}}$) = 0.656 so $\frac{k\_{2}}{k\_{1}}$ = 1.93 (idea of reverse exponential to get relative rate)M6: so the reaction is 1.93 times faster at 308 K (understands significance of numerical answer)[max 5] |
| **A8.** | (a) | M1: V3+, V2+|Pt (species in any order)M2: Zn|Zn2+ (species in any order)M3: Zn|Zn2+|| V3+, V2+|Pt (all correct including order) |
|  | (b) | M4: Zn + 2V3+ 🡪 Zn2+ + 2V2+M5: -0.26 – (-0.76) = 0.50 V[5] |
| **A9.** | (a) | M1: Emf = Erhs - Elhs so 0.60 = 0.77 - ElhsM2: Elhs = 0.77 – 0.60 = +0.17 V |
|  | (b) | M3: H2SO3 on LHS, electrons and SO42- on RHSM4: H2SO3 + H2O 🡪 SO42- + 2e + 4H+ (fully balanced half-equation) |
|  | (c) | M5: H2SO3 + H2O + 2Fe3+ 🡪 SO42- + 2Fe2+ + 4H+[5] |
| **A10.** | (a) | M1: Zn |
|  | (b) | M2: Cl2 |
|  | (c) | M3: Fe3+ |
|  | (d) | M4: Cl2 and VO2+ on LHS, Cl- and VO2+ on RHSM5: Cl2 + 2VO2+ + 2H2O 🡪 2Cl- + 2VO2+ + 4H+ [5] |

# Section B

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| **B1.** | (a) | (i) | M1: ΔH = M1: ΔH = Σ(ΔHf(p)) - Σ(ΔHf(r)) or suitable cycle = (3 x -393.5) – 3 x (-110.5) – (-824.2)M2: = -24.8M3: ΔS = Σ(S(p)) - Σ(S(r)) = (3 x 213.6) + (2 x 27.3) – 87.4 – 3(197.6)M4: = +15.2 |
|  |  | (ii) | M5: ΔH is -ve and ΔS is +veM6: ΔG is always -ve |
|  |  | (iii) | M7: ΔH = M1: ΔH = Σ(ΔHf(p)) - Σ(ΔHf(r)) or suitable cycle = (3 x -110.5) – (-824.2)M8: = +492.7M9: ΔS = Σ(S(p)) - Σ(S(r)) = (3 x 197.6) + (2 x 27.3) – 87.4 – 3(5.7)M10: = +542.9 |
|  |  | (iv) | M11: critical T occurs when ΔG = 0M12: ΔH = TΔS so T = ΔH/ΔSM13: 492700/542.9 = 908 KM14: ΔH is +ve and ΔS is +ve or reaction is feasible when ΔG < 0M15: reaction is feasible above 908 K(15) |
|  | (b) | (i) | M1: energy is required to break bondsM2: intermolecular forces or hydrogen bonds |
|  |  | (ii) | M3: gas more disordered than liquidM4: so increase in disorder |
|  |  | (iii) | M5: 188.7 – 69.9 = +119 |
|  |  | (iv) | M6: critical T occurs when ΔG = 0 so ΔH = TΔS so T = ΔH/ΔSM7: T = 44000/118M8: = 370 KM9: this is close to the known boiling point of water (373 K)M10: slight difference must be due to data inaccuracies (10)Total 25 marks |
| **B2.** | (a) | M1: Ca(OH)2(s)M2: Ca2+(aq) + 2OH-(aq)M3: Ca2+(g) + 2OH-(g)M4: linking arrowsM5: ΔH = Σ(ΔHhyd) – ΔHlatt (can be awarded from a clear cycle)M6: = -1576 + 2(-460) – (-2637)M7 = +141 (max 6) |
|  | (b) | M1: aqueous more disordered than solidM2: so disorder increases(2) |
|  | (c) | M1: ΔG = ΔH – TΔSM2: = 141 – 298(0.374) = +29.5(2) |

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|  | (d) | M1: ΔG is +veM2: so reaction not feasibleM3: so calcium hydroxide not expected to dissolve significantly in water(3) |
|  | (e) | EitherM1: ΔS is +veM2: so increase in T makes ΔG more -veM3 so solubility should increase with T | OrM1: reaction is endothermicM2: so high temp favours forward reactionM3: to reduce the T/according to Le Chatelier(3) |
|  | (f) | M1: -RTlnKsp = +29500M2: lnKsp = -29500/(8.31 x 298) = -11.9M3: Ksp = 6.57 x 10-6(3) |
|  | (g) | M1: Ksp = [Ca2+][OH-]2M2: If [Ca2+] = x, Ksp = x(2x)2 = 4x3M3: x = $\sqrt[3]{\frac{K\_{sp}}{4}}$ = 0.0118 moldm-3(3) |
|  | (h) | M1: ΔH, ΔS not effective predictors of reaction feasibility alone or ΔH, ΔS can be effective binary predictor of reaction feasibility if considered together or any sensible point regarding limitations of ΔH and ΔSM2: ΔG an effective predictor of reaction feasibility (or feasible if ΔG = -ve)M3: Kc also effective predictor of reaction feasibility (or feasible if K > 1)M4: Kc also able to predict how far a reaction will go so more useful than ΔG(max 3)max 25 marks |

# Section C

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| **C1.** | (a) |  | M1: time on x-axis, linear scale, labelled with unitsM2: [NO2] on y-axis, linear scale, labelled with unitsM3: scale chosen ensures that points plotted cover more than half of the paper in both dimensionsM4: at least points plotted correctly to nearest small squareM5: all eight points plotted correctly to nearest small squareM6: smooth curve of best fit with sharp trace |
|  | (b) | M1: Evidence on graph of attempt to read time at [NO2] = 0.005 (160 – 190 s)M2: First half-life 160 – 190 sM3: Evidence on graph of attempt to read time at [NO2] = 0.0025 (530 – 570 s)M4: second half-life = 340 – 410 s(4) |
|  | (c) | M1: Half-life increases as concentration decreases so second orderM2: Rate = k[N2O5]2(2) |

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|  | (d) | M1: evidence of tangent to curve at t = 0M2: gradient = 4 x 10-5 – 8 x 10-5 = rate of reactionM3: k = rate/[N2O5]2 = M2/0.012 = 0.4 – 0.8M4: mol-1dm3s-1(4) |
|  | (e) | M1: any step involving 2 NO2 molecules, eg 2NO2 🡪 N2O4 or 2NO2 🡪 NO3 + NOM2: second order means rate determine step involves two NO2 molecules(2) |
|  | (f) | M1: order wrt [B] = 1M2: order wrt [A] = 2M3: order wrt [C] = 0M4: reasonable logic used to deduce orders, egExp 1 to 2: [B] x 4, [A] and [C] unchanged, rate x 4Exp 3 to 2: [C] unchanged, [B] / 2 so rate due to B alone would be 0.8 x 10-3, but [A] x 2 and rate 3.2 x 10-3, which is x 4Exp 4 to 3, [A] unchanged [B] x 8/3 so rate should increase by 8/3 to 1.6 x 10-3, [C] x 2 but rate is still 1.6 x 10-3 so unchangedM5: Rate = k[A]2[B]M6: k = rate/([A]2[B]) = (eg) 0.8 x 10-3/(0.22 x 0.1) = 0.2M7: mol-2dm6s-1 (7)Total 25 marks |

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| **C2.** | (a) |  | M1: Axes labelled: energy on x axis, number of molecules or probability on y axisM2: both curves start at origin, reach peak and falls again without rising againM3: neither curve touches x-axis except at originM4: T2 peak lower and further to the right than T1M5: T1 and T2 curves only cross once(5) |
|  | (b) | (i) | M1: ln both sides: lnk = lnA – Ea/RTM2: can be expressed as y = mx + c if y = ln(k), m = Ea/R and x = 1/T |
|  |  | (ii) | M3: rate is change in concentration /time or rate inversely proportional to time taken |
|  |  | (iii) |

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| T/C | T/K | 1/T | time | 1/t | ln(1/t) |
| 16 | 289 | 0.00346 | 149 | 0.00671 | -5.00 |
| 23 | 296 | 0.00338 | 101 | 0.00990 | -4.62 |
| 30 | 303 | 0.00330 | 54 | 0.01852 | -3.99 |
| 36 | 309 | 0.00324 | 38 | 0.02632 | -3.64 |

 | M4: 1/T on x-axis, linear scale, labelled with unitsM5: ln(1/t) on y-axis, linear scale, labelledM6: scale chosen ensures that points plotted cover more than half of the paper in both dimensionsM7: all four 1/T correct to 3sfM8: all four ln(1/t) correct to 3sfM9: all four points plotted correctly to nearest small squareM10: appropriate straight line of best fit |
|  |  | (iv) | M11: Gradient = - and between 5000 – 8000M12: grad = -Ea/R so Ea = grad x R (41600 – 66500)M13: expressed in kJmol-1 (41.6 – 66.5) (max 12) |
|  | (c) | (i) | M1: k = rate/([P]2[Q]) = 0.0018/(0.22 x 0.3) M2: =0.15M3: mol-2dm6s-1 |
|  |  | (ii) | M4: 0.15 x 0.42 x 0.6 = 0.0144 |
|  |  | (iii) | M5: [Q] = rate/(k[P]2)M6 = 0.1 |
|  |  | (iv) | M7: [P] = √(rate/(k[Q]))M8: = 0.3 (8)Total 25 marks |

# Section D

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| **D1.** | (a) | (i) | M1: copper electrode on right and hydrogen electrode on leftM2: copper electrode made of copperM3: copper electrode dipped into solution of Cu2+ ions or suitable salt (eg CuSO4)M4: hydrogen electrode made of platinumM5: platinum electrode dipped into solution of H+ ions or suitable acidM6: H2 bubbled through solution and in contact with platinum electrodeM7: voltmeter connected to both electrodesM8: salt bridge connected to both solutionsM9: Cu2+ and H+ both 1 moldm-3M10: temperature 298 K and pressure 100 kPa(max 8) |
|  |  | (ii) | M9: H2 🡪 2H+ + 2e and Cu2+ + 2e 🡪 CuM10: Cu2+ + H2 🡪 Cu + 2H+ |
|  |  | (iii) | M11: electrons move from hydrogen electrode to copper electrodeM12: through wire/voltmeterM13: anions move from copper electrode to hydrogen electrodeM14: through salt bridge(max 3) |
|  |  | (iv) | M15: Concentrations change over timeM16: Copper electrode potential gets more negative over timeM17: Hydrogen electrode potential gets more positive over time(max 2)(max 15) |
|  | (b) | (i) | Cu|Cu2+||Fe3+, Fe2+|PtM1: all speciesM2: correct order |
|  |  | (ii) | M3: 0.77 – 0.34 = 0.43 V |
|  |  | (iii) | M4: reduction direction favoured in Fe3+, Fe2+M5: to replace Fe2+M6: so Fe3+, Fe2+ electrode potential becomes more +ve(max 2)M6: so emf of cell increases(6) |
|  | (c) | (i) | M1: n = number of electrons gained or lost in the half equation  |
|  |  | (ii) | Calculate the electrode potential of the Cu2+/Cu electrode when [Cu2+] = 0.1 moldm-3M2: Q = 1/0.1 = 10 so lnQ = 2.30M3: E = 0.34 - (8.31 x 298 / (2 x 96500) x 1n QM4: = 0.31 V(4)Total 25 marks |
| **D2.** | (a) | (i) | M1: nothing will happenM2: Cl- oxidized to Cl2 or Eo = +1.36 VM3: Fe3+ reduced to Fe2+ or Er = +0.77 VM4: Er – Eo = 0.77 – 1.36 = -0.59 V or negative |
|  |  | (ii) | M5: Fe3+ reduced to Fe2+M6: H2SO3 oxidised to SO42-M7: Er – Eo = 0.77 – 0.17 = +0.60 V or positive |
|  |  | (iii) | M8: Ce4+M9: 5Ce4+ + Mn2+ + 4H2O 🡪 5Ce3+ + MnO4- + 8H+(9) |
|  | (b) | (i) | M1: 2Cu+ 🡪 Cu + Cu2+ |
|  |  | (ii) | M2: Er = Cu+ 🡪 Cu or +0.52 V and Eo = Cu2+ 🡪 Cu+ or 0.15 VM3: Er – Eo = 0.52 – 0.15 = +0.37 V or positiveM4: so disproportionation should take place |
|  |  | (iii) | M5: -nFE = -2 x 96500 x 0.37M6: = -71400 Jmol-1 or -71.4 kJmol-1(6) |
|  | (c) | (i) | M1: Mg + 2H2O 🡪 Mg2+ + 2OH- + H2 (allow Mg(OH)2)M2: Eo = -2.37 V or Mg oxidized and Er = -0.44 V or H2O reduced M3: Er – Eo = +1.93 V or positive  |
|  |  | (ii) | M4: activation energy highM5: so reaction slow |
|  |  | (iii) | M6: stability means no reactionM7: because activation energy is too high (kinetic stability)M8: because products have a higher free energy than reactants or ΔG is +ve or equilibrium constant less than 1 or Ecell is negativeM9: Mg and H2O are not thermodynamically stableM10: Mg and H2O are kinetically stable(10)Total 25 marks) |