# 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 kJ  M2: moles of methanol = 0.352/32 = 0.011  M3: ΔH = M1/M2 and -ve = -399 kJmol-1 | |
|  | (b) | M4: moles of methanol = 3.13  M5: 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 4719  M2: 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 values  M5: 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 cycle  M2: (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 = 0.568  M5: q = 0.568 x 2679 = 1520 kJ  [5] | |
| **A4.** |  | (a)    M1: all species correct with max two errors  M2: all species correct with no errors  M3: all lines connected with arrows | (b)  -859 = 180 + 2(122) + 503 + 965 + 2x – 2056  2x = -859 – 180 – 2(122) – 503 – 965 + 2056 = -695  x = - 348  M4: attempt at cycle with enthalpy of formation = sum of processes  M5: atomization energy of Cl x 2 and 2x used for electron affinity  M6 correct rearrangement to x = -348  [max 5] |
| **A5.** | (a) | M1: particles are moving faster/have more energy  M2: so the collisions are more energetic/collision energy is greater  M3: 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 2  M2: 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 - (takes logs anywhere in equation)  M2: lnk2 – lnk1 = ln() (idea that difference in lnk values leads to relative rate)  M3: lnk2 – lnk1 = - (idea that relative rate is linked to difference in values)  M4: - = (50000/8.31/298) - (50000/8.31/308) = 0.656 (calculates difference in values)  M5: lnk2 – lnk1 = ln() = 0.656 so = 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 - Elhs  M2: Elhs = 0.77 – 0.60 = +0.17 V |
|  | (b) | M3: H2SO3 on LHS, electrons and SO42- on RHS  M4: 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 RHS  M5: 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: = -24.8  M3: 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 +ve  M6: 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: = +492.7  M9: 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 = 0  M12: ΔH = TΔS so T = ΔH/ΔS  M13: 492700/542.9 = 908 K  M14: ΔH is +ve and ΔS is +ve or reaction is feasible when ΔG < 0  M15: reaction is feasible above 908 K  (15) |
|  | (b) | (i) | M1: energy is required to break bonds  M2: intermolecular forces or hydrogen bonds |
|  |  | (ii) | M3: gas more disordered than liquid  M4: 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/ΔS  M7: T = 44000/118  M8: = 370 K  M9: 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 arrows  M5: 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 solid  M2: so disorder increases  (2) | |
|  | (c) | M1: ΔG = ΔH – TΔS  M2: = 141 – 298(0.374) = +29.5  (2) | |

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|  | (d) | M1: ΔG is +ve  M2: so reaction not feasible  M3: so calcium hydroxide not expected to dissolve significantly in water  (3) | |
|  | (e) | Either  M1: ΔS is +ve  M2: so increase in T makes ΔG more -ve  M3 so solubility should increase with T | Or  M1: reaction is endothermic  M2: so high temp favours forward reaction  M3: to reduce the T/according to Le Chatelier  (3) |
|  | (f) | M1: -RTlnKsp = +29500  M2: lnKsp = -29500/(8.31 x 298) = -11.9  M3: Ksp = 6.57 x 10-6  (3) | |
|  | (g) | M1: Ksp = [Ca2+][OH-]2  M2: If [Ca2+] = x, Ksp = x(2x)2 = 4x3  M3: x = = 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 ΔS  M2: 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 units  M2: [NO2] on y-axis, linear scale, labelled with units  M3: scale chosen ensures that points plotted cover more than half of the paper in both dimensions  M4: at least points plotted correctly to nearest small square  M5: all eight points plotted correctly to nearest small square  M6: 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 s  M3: 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 order  M2: Rate = k[N2O5]2  (2) | |

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|  | (d) | M1: evidence of tangent to curve at t = 0  M2: gradient = 4 x 10-5 – 8 x 10-5 = rate of reaction  M3: k = rate/[N2O5]2 = M2/0.012 = 0.4 – 0.8  M4: mol-1dm3s-1  (4) |
|  | (e) | M1: any step involving 2 NO2 molecules, eg 2NO2 🡪 N2O4 or 2NO2 🡪 NO3 + NO  M2: second order means rate determine step involves two NO2 molecules  (2) |
|  | (f) | M1: order wrt [B] = 1  M2: order wrt [A] = 2  M3: order wrt [C] = 0  M4: reasonable logic used to deduce orders, eg  Exp 1 to 2: [B] x 4, [A] and [C] unchanged, rate x 4  Exp 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 4  Exp 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 unchanged  M5: Rate = k[A]2[B]  M6: k = rate/([A]2[B]) = (eg) 0.8 x 10-3/(0.22 x 0.1) = 0.2  M7: 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 axis  M2: both curves start at origin, reach peak and falls again without rising again  M3: neither curve touches x-axis except at origin  M4: T2 peak lower and further to the right than T1  M5: T1 and T2 curves only cross once  (5) | |
|  | (b) | (i) | M1: ln both sides: lnk = lnA – Ea/RT  M2: 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) | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | 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 units  M5: ln(1/t) on y-axis, linear scale, labelled  M6: scale chosen ensures that points plotted cover more than half of the paper in both dimensions  M7: all four 1/T correct to 3sf  M8: all four ln(1/t) correct to 3sf  M9: all four points plotted correctly to nearest small square  M10: appropriate straight line of best fit |
|  |  | (iv) | M11: Gradient = - and between 5000 – 8000  M12: 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: =0.15  M3: 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 left  M2: copper electrode made of copper  M3: copper electrode dipped into solution of Cu2+ ions or suitable salt (eg CuSO4)  M4: hydrogen electrode made of platinum  M5: platinum electrode dipped into solution of H+ ions or suitable acid  M6: H2 bubbled through solution and in contact with platinum electrode  M7: voltmeter connected to both electrodes  M8: salt bridge connected to both solutions  M9: Cu2+ and H+ both 1 moldm-3  M10: temperature 298 K and pressure 100 kPa  (max 8) |
|  | |  | | (ii) | | M9: H2 🡪 2H+ + 2e and Cu2+ + 2e 🡪 Cu  M10: Cu2+ + H2 🡪 Cu + 2H+ |
|  | |  | | (iii) | | M11: electrons move from hydrogen electrode to copper electrode  M12: through wire/voltmeter  M13: anions move from copper electrode to hydrogen electrode  M14: through salt bridge  (max 3) |
|  | |  | | (iv) | | M15: Concentrations change over time  M16: Copper electrode potential gets more negative over time  M17: Hydrogen electrode potential gets more positive over time  (max 2)  (max 15) |
|  | | (b) | | (i) | | Cu|Cu2+||Fe3+, Fe2+|Pt  M1: all species  M2: 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-3  M2: Q = 1/0.1 = 10 so lnQ = 2.30  M3: E = 0.34 - (8.31 x 298 / (2 x 96500) x 1n Q  M4: = 0.31 V  (4)  Total 25 marks |
| **D2.** | (a) | | (i) | | M1: nothing will happen  M2: Cl- oxidized to Cl2 or Eo = +1.36 V  M3: Fe3+ reduced to Fe2+ or Er = +0.77 V  M4: 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 V  M3: Er – Eo = 0.52 – 0.15 = +0.37 V or positive  M4: so disproportionation should take place | | |
|  |  | | (iii) | | M5: -nFE = -2 x 96500 x 0.37  M6: = -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 high  M5: so reaction slow | | |
|  |  | | (iii) | | M6: stability means no reaction  M7: 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 negative  M9: Mg and H2O are not thermodynamically stable  M10: Mg and H2O are kinetically stable  (10)  Total 25 marks) | | |