S5 Chemistry Practice Paper: Enthalpy and Hess's Law, Bond Energy and Calorimetry, Rate Orders and the Arrhenius Equation, Chemical Equilibrium and Kc, Weak Acids and Buffers, Industrial Processes, Electrochemical Cells and Electrolysis (100 marks)

Level: S5 | Subject: Chemistry | 75 minutes | 100 marks | 24 questions | answer key

Section A - Thermochemistry and Energy Calculations (18 marks)

Show all working and give units in every answer.

#	Question	Answer	Marks
1	Given ΔHf[CH4(g)] = -74.8, ΔHf[CO2(g)] = -393.5 and ΔHf[H2O(l)] = -285.8 kJ/mol, calculate the standard enthalpy change of combustion of methane.	ΔH = [-393.5 + 2(-285.8)] - (-74.8) = -890.3 kJ/mol (exothermic)	5
2	(i) C(s) + O2(g) -> CO2(g), ΔH1 = -393.5 kJ/mol; (ii) CO(g) + 1/2 O2(g) -> CO2(g), ΔH2 = -283.0 kJ/mol. Use Hess law to find ΔH for C(s) + 1/2 O2(g) -> CO(g).	ΔH = ΔH1 - ΔH2 = -393.5 - (-283.0) = -110.5 kJ/mol	5
3	Bond energies in kJ/mol: H-H 436, Cl-Cl 243, H-Cl 431. Calculate ΔH for H2(g) + Cl2(g) -> 2HCl(g).	Bonds broken 436 + 243 = 679; bonds formed 2 x 431 = 862; ΔH = 679 - 862 = -183 kJ/mol	4
4	Burning 0.0200 mol of a fuel raises the temperature of 50.0 g of water from 25.00 °C to 31.40 °C. Given c = 4.18 J/(g K), find the molar enthalpy change of combustion.	q = 50.0 x 4.18 x 6.40 = 1337.6 J; ΔH = -1337.6 / 0.0200 = -66 880 J/mol = -66.9 kJ/mol	4

Section B - Reaction Rates and Activation Energy (17 marks)

R = 8.314 J/(mol K); ln 2 = 0.693.

#	Question	Answer	Marks
5	Initial rates for A + B -> C: run 1 [A] = 0.10 M, [B] = 0.10 M, rate = 1.2 x 10^-3 M/s; run 2 [A] = 0.20 M, [B] = 0.10 M, rate = 4.8 x 10^-3 M/s; run 3 [A] = 0.20 M, [B] = 0.20 M, rate = 9.6 x 10^-3 M/s. Find the orders, the rate equation and k.	Order in A = 2 (doubling [A] gives x4), order in B = 1 (doubling [B] gives x2); rate = k[A]^2[B]; k = 1.2 x 10^-3 / (0.10^2 x 0.10) = 1.2 dm6 mol-2 s-1	5
6	For a reaction k = 2.0 x 10^-3 s-1 at 300 K and 8.0 x 10^-3 s-1 at 310 K. Find the activation energy using the Arrhenius equation (R = 8.314 J/(mol K)).	ln 4 = 1.386 = (Ea/8.314)(1/300 - 1/310) = (Ea/8.314)(1.075 x 10^-4); Ea = 1.386 x 8.314 / 1.075 x 10^-4 = 1.07 x 10^5 J/mol = 107 kJ/mol	4
7	A first-order decay has a half-life of 30.0 min. Find the rate constant and the percentage of the sample remaining after 120 min.	k = ln 2 / 30.0 = 0.0231 min-1; 120 min = 4 half-lives; remaining = (1/2)^4 = 6.25%	4
8	A catalyst lowers the activation energy by 10.0 kJ/mol. Assuming the frequency factor is unchanged at 298 K, find the factor by which the rate constant increases (R = 8.314 J/(mol K)).	k2/k1 = exp(10 000 / (8.314 x 298)) = exp(4.04) = 57	4

Section C - Chemical Equilibrium and Equilibrium Constants (17 marks)

All concentrations are in mol/dm3.

#	Question	Answer	Marks
9	In a 2.0 dm3 vessel H2(g) + I2(g) <=> 2HI(g) reaches equilibrium with 0.20 mol H2, 0.20 mol I2 and 1.60 mol HI. Find Kc.	[H2] = [I2] = 0.10 M, [HI] = 0.80 M; Kc = 0.80^2 / (0.10 x 0.10) = 64 (no units)	5
10	At the same temperature, 0.50 mol H2 and 0.50 mol I2 are sealed in a 1.0 dm3 vessel. Find the equilibrium concentration of HI.	Let x react: (2x)^2 / (0.50 - x)^2 = 64, so 2x / (0.50 - x) = 8 and x = 0.40; [HI] = 0.80 M	4
11	Haber process: N2(g) + 3H2(g) <=> 2NH3(g), ΔH = -92 kJ/mol. State the effect on the equilibrium yield of (a) raising the temperature, (b) raising the pressure, (c) continuously removing NH3.	(a) shifts left, yield falls (exothermic); (b) shifts right, yield rises (fewer gas moles); (c) shifts right, yield rises (product removed)	4
12	At 500 K, Kc = 0.040 mol/dm3 for PCl5(g) <=> PCl3(g) + Cl2(g). Starting with 0.20 mol PCl5 in a 1.0 dm3 vessel, find the percentage decomposition of PCl5.	x^2 / (0.20 - x) = 0.040, so x^2 + 0.040x - 0.0080 = 0 and x = 0.0716; decomposition = 0.0716 / 0.20 x 100% = 35.8%	4

Section D - Weak Acids, pH and Buffers (16 marks)

Assume a fixed temperature of 298 K and Kw = 1.0 x 10^-14.

#	Question	Answer	Marks
13	Find the pH of 0.10 M ethanoic acid (Ka = 1.8 x 10^-5).	[H+] = sqrt(1.8 x 10^-5 x 0.10) = 1.34 x 10^-3 M; pH = -log(1.34 x 10^-3) = 2.87	4
14	A 0.050 M solution of a weak acid HA has pH 3.00. Find Ka.	[H+] = 1.0 x 10^-3 M; Ka = (1.0 x 10^-3)^2 / (0.050 - 0.001) = 2.04 x 10^-5	4
15	A buffer contains 0.10 M HA (Ka = 1.8 x 10^-5) and 0.20 M NaA. Find its pH.	pH = pKa + log([A-]/[HA]) = 4.74 + log 2.0 = 4.74 + 0.30 = 5.05	4
16	25.0 cm3 of 0.100 M hydrochloric acid is diluted to 250 cm3. Find the hydrogen ion concentration and the pH of the diluted solution.	C2 = 0.100 x 25.0 / 250 = 0.0100 M; pH = -log(0.0100) = 2.00	4

Section E - Industrial Processes and Stoichiometry (16 marks)

Atomic masses: N = 14.0, H = 1.0, S = 32.0, O = 16.0.

#	Question	Answer	Marks
17	Haber process: N2 + 3H2 -> 2NH3. From 1.00 mol N2 and 3.00 mol H2, 1.50 mol NH3 is obtained. Find the percentage yield and the mass of NH3 formed (N = 14.0, H = 1.0).	Theoretical yield 2.00 mol; yield = 1.50 / 2.00 x 100% = 75.0%; mass = 1.50 x 17.0 = 25.5 g	4
18	Contact process: 320 kg of sulfur (S = 32.0) is burned to SO2 and then oxidised to SO3. If the yield of SO3 is 96%, find the mass of SO3 obtained (O = 16.0).	n(S) = 320 000 / 32.0 = 10 000 mol; theoretical SO3 = 10 000 x 80.0 = 800 kg; actual = 800 x 0.96 = 768 kg	4

19	The Haber process runs at about 450 °C and 200 atm over an iron catalyst. Explain (a) the high pressure, (b) 450 °C rather than a lower temperature, (c) the catalyst.	(a) high pressure shifts the equilibrium right and raises the rate; (b) a lower temperature favours the equilibrium but is far too slow, so 450 °C is a compromise; (c) the catalyst shortens the time to reach equilibrium without changing the yield	4
20	For N2 + 3H2 -> 2NH3, calculate the atom economy (N = 14.0, H = 1.0).	Mass of product = 2 x 17.0 = 34.0; mass of reactants = 28.0 + 3 x 2.0 = 34.0; atom economy = 34.0 / 34.0 x 100% = 100%	4

Section F - Electrochemical Cells and Electrolysis (16 marks)

Faraday constant = 96 500 C/mol.

#	Question	Answer	Marks
21	A cell is made from a zinc electrode in 1.0 M ZnSO4 and a copper electrode in 1.0 M CuSO4. Given E(Zn2+/Zn) = -0.76 V and E(Cu2+/Cu) = +0.34 V, find the emf and identify the anode and the cathode.	emf = 0.34 - (-0.76) = 1.10 V; zinc is the anode (oxidation), copper the cathode (reduction)	4
22	A current of 2.00 A is passed through copper(II) sulphate solution for 30.0 min. Find the mass of copper deposited at the cathode (Cu = 63.5, F = 96 500 C/mol).	Q = 2.00 x 1800 = 3600 C; n(e-) = 3600 / 96 500 = 0.0373 mol; n(Cu) = 0.01865 mol; mass = 0.01865 x 63.5 = 1.18 g	4
23	How long must a current of 0.500 A flow to deposit 1.00 g of silver from silver nitrate solution (Ag = 108, F = 96 500 C/mol)?	n(Ag) = 1.00 / 108 = 9.26 x 10^-3 mol; Q = 9.26 x 10^-3 x 96 500 = 894 C; t = 894 / 0.500 = 1.79 x 10^3 s (about 29.8 min)	4
24	During discharge of the Zn-Cu cell, (a) write the half-equation at each electrode, (b) state and explain how the emf changes if the concentration of Cu2+ is lowered.	(a) anode: Zn -> Zn2+ + 2e-; cathode: Cu2+ + 2e- -> Cu; (b) the emf falls because the cathode reduction potential decreases as [Cu2+] falls (Nernst equation)	4