S5 Chemistry Practice Paper

S5 | Chemistry | Time: 75 minutes | Total: 100 marks | 24 questions

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Part A: Acid-Base Titration and pH (17 marks)

Answer all 4 questions. Volumes are in cm3; show mole calculations.

1. 25.0 cm3 of 0.125 M sodium hydroxide is completely neutralised by 0.1 M hydrochloric acid. Find the moles of NaOH and the volume of acid required.

Answer: n(NaOH) = 0.125 x 25.0/1000 = 0.003125 mol. The ratio is 1:1, so n(HCl) = 0.003125 mol and V(HCl) = 0.003125 / 0.1 = 31.2 cm3.

2. A 0.1 M ethanoic acid solution has Ka = 1.8e-05. Find the hydrogen ion concentration and pH, and explain why the pH is higher than that of hydrochloric acid of the same concentration.

Answer: Let [H+] = x, then Ka is about x^2/0.1, so x = sqrt(1.8e-05 x 0.1) = 1.342e-03 M and pH = 2.87. Ethanoic acid is a weak acid that ionises only partially, so [H+] is far below 0.1 M; hydrochloric acid ionises completely and gives pH 1.00.

3. 10.0 cm3 of 0.5 M solution is diluted with water to 250 cm3. Find the new concentration and state how many pH units a strong acid would rise by.

Answer: Dilution keeps the number of moles constant: c1V1 = c2V2, so c2 = 0.5 x 10.0/250 = 0.02 M. A 25-fold dilution lowers [H+] of a strong acid 25 times, so pH rises by about 1.40 units.

4. 0.1 M hydrochloric acid titrates 25.0 cm3 of sodium hydroxide of unknown concentration; the three titres are 22.4, 22.35 and 22.45 cm3. Find the mean titre, moles of NaOH and its concentration, and state the phenolphthalein end point colour change.

Answer: Mean = (22.4 + 22.35 + 22.45) / 3 = 22.40 cm3. n(HCl) = 0.1 x 22.40/1000 = 0.002240 mol = n(NaOH), so c(NaOH) = 0.002240 / 0.0250 = 0.0896 M. Phenolphthalein turns from pink in alkali to colourless at the end point; titres within 0.10 cm3 of each other show good precision.

Part B: Redox and Electrolysis (17 marks)

Answer all 4 questions. Charge in coulombs; Faraday constant 96500 C mol-1.

5. Acidified potassium permanganate titrates 25.0 cm3 of iron(II) solution, using 18.50 cm3 of 0.02 M KMnO4. Given MnO4- + 8H+ + 5e- -> Mn2+ + 4H2O, find the moles and concentration of Fe2+.

Answer: n(MnO4-) = 0.02 x 18.50/1000 = 3.700e-04 mol. Each mole of MnO4- takes 5 moles of electrons and oxidises 5 moles of Fe2+, so n(Fe2+) = 5 x 3.700e-04 = 1.850e-03 mol and c(Fe2+) = 1.850e-03 / 0.0250 = 0.0740 M.

6. Copper(II) sulphate solution is electrolysed at 2.0 A for 30 minutes. Find the charge passed, moles of electrons and mass of copper deposited at the cathode (Cu = 63.5).

Answer: Q = It = 2.0 x 30 x 60 = 3600 C, so n(e-) = 3600 / 96500 = 0.03731 mol. Since Cu2+ + 2e- -> Cu, n(Cu) = 0.03731 / 2 = 0.01865 mol and the mass is 0.01865 x 63.5 = 1.184 g.

7. A cell has a standard EMF of 1.1 V with 2 electrons transferred. Find the standard Gibbs free energy change in kJ mol-1 and explain the meaning of a negative value.

Answer: DG = -nFE = -2 x 96500 x 1.1 = -212,300 J mol-1 = -212.3 kJ mol-1. A negative value means the reaction is spontaneous under standard conditions and the cell can do electrical work; the more negative the value, the greater the driving force.

8. State the oxidation number of manganese in MnO4- and explain why KMnO4 is a stronger oxidising agent in acidic solution (hint: the half equation contains 8H+).

Answer: In MnO4-: x + 4(-2) = -1, so x = +7. In acid, MnO4- is reduced by 5 electrons to Mn2+ (E about +1.51 V), which releases more energy and gives a higher electrode potential than reduction to MnO2 in neutral or alkaline solution (3 electrons, E about +0.59 V). Adding dilute sulphuric acid supplies H+ and avoids MnO2 precipitate.

Part C: Reaction Rate and Catalysis (17 marks)

Answer all 4 questions. State units clearly.

9. A reaction has an initial rate of 0.02 mol dm-3 s-1 at 0 C and 0.06 mol dm-3 s-1 at 20 C. Find the factor by which the rate rises per 10 K and comment on its temperature sensitivity.

Answer: The rate rises 3.0 times over 20 K, so about sqrt(3.0) = 1.73 times per 10 K. A typical reaction roughly doubles every 10 K, so this one is more sensitive, consistent with a higher activation energy; temperature control matters in industry.

10. Carbon-14 has a half-life of 5730 years. Find the first-order decay constant in year-1 and the fraction remaining after 11460 years.

Answer: k = ln2 / t(half) = 0.693/5730 = 1.2097e-04 per year. 11460 years is 2 half-lives, so 25% remains. For a first-order reaction the half-life is independent of initial concentration, which is the basis of radiometric dating.

11. A reaction has an activation energy of 50 kJ mol-1 and its rate constant is measured at 300 K and 310 K. Use the Arrhenius equation to estimate the factor increase (R = 8.314 J K-1 mol-1).

Answer: ln(k2/k1) = (Ea/R)(1/T1 - 1/T2) = (50000/8.314)(1/300 - 1/310) = 0.647, so k2/k1 = about 1.91. The exponential dependence means reactions with high activation energy are very sensitive to temperature.

12. In an experiment, with [B] fixed, raising [A] from 0.10 to 0.20 M raises the initial rate from 0.005 to 0.01 mol dm-3 s-1; with [A] fixed, doubling [B] does not change the rate. Find the orders in A and B, the overall order and the rate equation.

Answer: Doubling [A] doubles the rate, so the order in A is 1; doubling [B] leaves the rate unchanged, so the order in B is 0. The overall order is 1 and the rate equation is rate = k[A], with k = 0.005/0.1 = 0.0500 s-1. Zero order in B means B acts after the rate-determining step or its surface or enzyme sites are saturated.

Part D: Chemical Equilibrium (17 marks)

Answer all 4 questions. State units for equilibrium constants where they apply.

13. For H2(g) + I2(g) <=> 2HI(g) with initial [H2] = [I2] = 1.00 M and equilibrium [HI] = 1.56 M, find the equilibrium concentrations of H2 and I2 and Kc.

Answer: Forming 1.56 M HI consumes 0.78 M each of H2 and I2, so both are 0.22 M at equilibrium. Kc = 1.56^2 / (0.22 x 0.22) = 50.3 and is dimensionless here because the number of gas moles is unchanged.

14. For N2(g) + 3H2(g) <=> 2NH3(g) with initial [NH3] = 0.500 M and equilibrium [N2] = 0.0200 M, find the equilibrium concentrations of NH3 and H2 and Kc, and explain why high pressure favours ammonia.

Answer: Forming 0.0200 M N2 decomposes 0.0400 M NH3, leaving 0.4600 M, and produces 0.0600 M H2. Kc = 0.4600^2 / (0.0200 x 0.0600^3) = 48,981 with units mol-2 dm6. Raising pressure shifts the equilibrium towards the side with fewer gas moles, 2 against 4, favouring ammonia.

15. A reaction has Kc = 4.0 at a given temperature and the reaction quotient is Q = 2.0 at one moment. Decide the direction of net change and state the rule comparing Q with Kc.

Answer: Q = 2.0 is less than Kc = 4.0, so the net change is forwards towards products until Q reaches Kc. The rule is: Q below Kc runs forwards, Q above Kc runs backwards, Q equal to Kc means equilibrium. A catalyst speeds up attainment but does not change Kc or the position of equilibrium.

16. A buffer contains equal moles of CH3COOH and CH3COO- with pKa = 4.76. Find the pH and explain why adding a little strong acid changes it only slightly.

Answer: pH = pKa + log([A-]/[HA]) = 4.76 + 0 = 4.76. Added H+ is consumed by CH3COO- to form CH3COOH, so the ratio [A-]/[HA] changes only slightly and the pH barely moves. Buffer capacity is limited; excess acid or heavy dilution breaks it.

Part E: Organic Chemistry and Polymers (16 marks)

Answer all 4 questions. Relative atomic masses: C = 12, H = 1, O = 16.

17. A hydrocarbon contains 85.7% carbon and 14.3% hydrogen. Find its empirical formula and, given a relative molecular mass of 42, its molecular formula.

Answer: Mole ratio C : H = 85.7/12 : 14.3/1 = 1 : 2.0, so the empirical formula is CH2 with Mr 14. n = 42/14 = 3, so the molecular formula is (CH2)3 = C3H6, propene.

18. An addition polymer is made from a monomer of relative molecular mass 42 with a number-average degree of polymerisation of 2,500. Find the polymer Mr and state two differences between addition and condensation polymerisation.

Answer: Mr = 42 x 2,500 = 105,000.0. Differences: addition polymerisation releases no small molecule and keeps all atoms, whereas condensation polymerisation eliminates water or HCl; addition monomers need a C=C bond such as ethene or styrene, while condensation monomers need two functional groups, as in a diol with a diacid.

19. 0.2 mol of a carboxylic acid is esterified with excess ethanol; the theoretical yield is 17.6 g and 12.3 g is obtained. Find the percentage yield and suggest two ways to raise it.

Answer: Yield = 12.3 / 17.6 x 100% = 69.9%. Improve it by using concentrated sulphuric acid as catalyst with heating, and by distilling off the ester or adding more alcohol or acid so the equilibrium shifts towards the ester; removing the water formed also helps.

20. State the number of structural isomers of C4H10 and explain why C4H10 has only 2 while C4H9OH has more.

Answer: C4H10 has 2 structural isomers: butane in a straight chain and 2-methylpropane, which is branched. C4H9OH has more because the OH group can sit on different carbons, the carbon skeleton can be branched, and some isomers such as butan-2-ol are chiral, so the combinations of functional group position and skeleton multiply.

Part F: Enthalpy Change and Combustion Energy (16 marks)

Answer all 4 questions. Specific heat capacity of water is 4.18 J g-1 K-1.

21. Burning 0.500 g of ethanol heats 200 g of water by 20.7 °C. Find the heat absorbed by the water and the enthalpy of combustion in kJ mol-1 (ethanol Mr = 46).

Answer: q = mcDT = 200 x 4.18 x 20.7 = 17,305.2 J. n(ethanol) = 0.500/46 = 0.0109 mol, so the measured enthalpy is about -1,592 kJ mol-1, less exothermic in magnitude than the literature value of -1368 kJ mol-1 because of heat loss, incomplete combustion and heating of the apparatus.

22. Given standard enthalpies of formation: CO2(g) = -393.5, H2O(l) = -285.8 and CH4(g) = -74.8 kJ mol-1, use Hess law to find the standard enthalpy of combustion of methane.

Answer: For CH4 + 2O2 -> CO2 + 2H2O, DH = sum of formation enthalpies of products minus reactants = [-393.5 + 2(-285.8)] - (-74.8) = -890.3 kJ mol-1, negative as expected for combustion.

23. Estimate the enthalpy of CH4 + 2O2 -> CO2 + 2H2O from bond enthalpies: C-H = 413, O=O = 498, C=O = 799 and O-H = 463 kJ mol-1. Find DH and explain the difference from the accepted value.

Answer: Bonds broken absorb 4(413) + 2(498) = 2648 kJ and bonds formed release 2(799) + 4(463) = 3450 kJ, giving about -802 kJ mol-1. The gap from -890 kJ mol-1 arises because bond enthalpies are average values for gaseous species and ignore condensation of water.

24. The molar enthalpies of combustion of hydrogen and methane are about -286 and -890 kJ mol-1. Compare them per gram (H2 Mr = 2, CH4 Mr = 16), say which is the better fuel and give one storage difficulty.

Answer: Hydrogen gives 143 kJ g-1 and methane 55.62 kJ g-1, so hydrogen has about 2.6 times more energy per gram and burns to water only. Storage is the difficulty: very low density means compression to about 700 bar or cooling to -253 C, with heavy tanks, leakage and safety concerns raising transport cost.