S4 Chemistry Practice Paper (Set 2): Redox Reactions, Electrochemical Cells and Electrolysis, Reaction Rates, Chemical Equilibrium, Acid-Base Titration Calculations, Basic Organic Chemistry

S4 | Chemistry | Time: 75 minutes | Total: 100 marks | 24 questions

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Part 1 Redox Reactions

Show all working and state the oxidising and reducing agents.

1. Find the oxidation number of chromium in K2Cr2O7 and of manganese in KMnO4, and state which of the two oxyanions acts as the oxidising agent in acidic solution. [4]

Answer: In Cr2O7(2-): 2x + 7(-2) = -2, so 2x = 12 and x = +6. In MnO4(-): y + 4(-2) = -1, so y = +7. Both are in their highest oxidation state and can act as oxidising agents in acid; MnO4(-) is the stronger oxidising agent.

2. In acidic solution MnO4(-) oxidises Fe(2+) to Fe(3+) and is itself reduced to Mn(2+). Write the balanced ionic equation and find how many moles of Fe(2+) are oxidised by 0.0200 mol of MnO4(-). [4]

Answer: Half-equations: MnO4(-) + 8H(+) + 5e(-) -> Mn(2+) + 4H2O and Fe(2+) -> Fe(3+) + e(-). Balanced: MnO4(-) + 8H(+) + 5Fe(2+) -> Mn(2+) + 5Fe(3+) + 4H2O. The ratio is 1:5, so Fe(2+) = 0.0200 x 5 = 0.1000 mol.

3. When ClO3(-) is reduced to Cl(-), find the change in oxidation number of chlorine and the number of electrons transferred per ClO3(-) ion. [4]

Answer: In ClO3(-): z + 3(-2) = -1, so z = +5; in Cl(-) chlorine is -1. The oxidation number falls from +5 to -1, so each ion gains 6 electrons: this is reduction.

4. 0.850 mol of hydrogen peroxide decomposes into water and oxygen with a catalyst. Write the equation, find the moles of oxygen formed, and explain why H2O2 is both oxidised and reduced. [4]

Answer: Equation: 2H2O2 -> 2H2O + O2. O2 = 0.850 / 2 = 0.425 mol. Oxygen in H2O2 is -1: part falls to -2 (water, reduced) and part rises to 0 (oxygen, oxidised), transferring 0.850 mol of electrons in total. This is a disproportionation.

Part 2 Electrochemical Cells and Electrolysis

Use standard electrode potentials (Zn: -0.76 V, Cu: +0.34 V, Ag: +0.80 V).

5. A Daniell cell is made from zinc and copper electrodes in their own ion solutions. Find the cell emf, write both electrode reactions, and calculate the standard Gibbs energy change per mole of reaction (F = 96500 C/mol). [5]

Answer: Emf = cathode - anode = +0.34 - (-0.76) = 1.10 V. Anode (oxidation): Zn -> Zn(2+) + 2e(-); cathode (reduction): Cu(2+) + 2e(-) -> Cu. DG = -nFE = -2 x 96500 x 1.10 = -212,300 J = -212.3 kJ/mol; the negative value shows the reaction is spontaneous.

6. A current of 2.50 A passes through copper(II) sulphate solution for 30 minutes. Find the charge passed and the mass of copper deposited at the cathode (Cu = 63.5). [4]

Answer: Q = It = 2.50 x 1800 = 4,500 C. Moles of electrons = 4,500 / 96500 = 0.0466 mol. Since Cu(2+) + 2e(-) -> Cu, Cu = 0.0466 / 2 = 0.0233 mol and mass = 0.0233 x 63.5 = 1.48 g.

7. In a silver plating experiment the cathode gains 1.080 g (Ag = 108.0). Find the moles of electrons, the charge required, and the time in seconds at 1.50 A. [4]

Answer: Moles of Ag = 1.080 / 108.0 = 0.0100 mol. Since Ag(+) + e(-) -> Ag, electrons = 0.0100 mol and charge = 0.0100 x 96500 = 965 C. Time = 965 / 1.50 = 643.3 s (about 10.7 minutes).

8. Dilute sulphuric acid is electrolysed with platinum electrodes and 0.0200 mol of electrons passes. Write both electrode reactions and find the gas volumes at the anode and cathode (molar volume 24.0 dm3/mol). [4]

Answer: Cathode: 2H(+) + 2e(-) -> H2, so H2 = 0.0200 / 2 = 0.0100 mol and volume = 0.0100 x 24.0 = 0.24 dm3. Anode: 2H2O -> O2 + 4H(+) + 4e(-), so O2 = 0.0200 / 4 = 0.0050 mol and volume = 0.0050 x 24.0 = 0.12 dm3. The volume ratio of hydrogen to oxygen is 2:1.

Part 3 Reaction Rates

Give all rates in mol/s or mol dm-3 s-1 to three significant figures.

9. A reaction produces 0.500 mol of gas in 40 seconds. Find the average rate of formation and state how the rate usually changes when the temperature is raised by 10 degrees. [4]

Answer: Average rate = 0.500 / 40 = 0.0125 mol/s. Raising the temperature by 10 degrees increases the average kinetic energy, so many more collisions exceed the activation energy and the rate roughly doubles.

10. At 20 degrees a reaction has a rate of 0.0125 mol/s, and the rate doubles for every 10 degree rise. Find the rate at 50 degrees and explain why. [4]

Answer: The temperature rises 30 degrees from 20 to 50, that is three 10 degree steps, so rate = 0.0125 x 2^3 = 0.0125 x 8 = 0.1000 mol/s. More particles now have energy above the activation energy, so the frequency of effective collisions rises.

11. A reaction has the rate equation rate = k[A][B]^2 with k = 0.250. When [A] = 0.200 mol dm-3 and [B] = 0.100 mol dm-3, find the initial rate; if only [B] is doubled, by what factor does the rate change? [5]

Answer: Rate = 0.250 x 0.200 x (0.100)^2 = 0.250 x 0.200 x 0.0100 = 5.00e-04 mol dm-3 s-1. Since the rate is second order in B, doubling [B] multiplies the rate by 2^2 = 4, giving 2.00e-03 mol dm-3 s-1.

12. 50 cm3 of 0.200 M hydrochloric acid is added to excess magnesium ribbon and the reaction finishes in 25 seconds. Find the moles of acid, the average rate in mol/s, and how the rate changes with time. [4]

Answer: Moles = 0.200 x 0.0500 = 0.0100 mol. Average rate = 0.0100 / 25 = 4.00e-04 mol/s. As the acid is used up its concentration falls, so the rate decreases with time and the average rate is lower than the initial rate.

Part 4 Chemical Equilibrium

All volumes are 1.00 dm3 and the temperature is constant.

13. At equilibrium the reaction H2(g) + I2(g) -> 2HI(g) has 0.200 mol H2, 0.200 mol I2 and 1.600 mol HI in the vessel. Find Kc and write its expression. [4]

Answer: Kc = [HI]^2 / ([H2][I2]) = (1.600)^2 / (0.200 x 0.200) = 2.560 / 0.0400 = 64.0. Since Kc is greater than 1, the equilibrium lies towards the products.

14. At the same temperature Kc = 64.0. At one moment [H2] = 0.500 M, [I2] = 0.500 M and [HI] = 1.000 M. Find the reaction quotient Qc and state the direction of the net reaction. [5]

Answer: Qc = (1.000)^2 / (0.500 x 0.500) = 1.000 / 0.2500 = 4.0. Because Qc = 4.0 is less than Kc = 64.0, the net reaction goes to the right: HI rises while H2 and I2 fall.

15. For PCl5(g) -> PCl3(g) + Cl2(g) the value of Kc is 0.0400. Starting with 2.00 mol PCl5 and no products, find the moles of Cl2 at equilibrium to three significant figures. [4]

Answer: Let x mol of Cl2 form: Kc = x^2 / (2.00 - x) = 0.0400, that is x^2 + 0.0400x - 0.0800 = 0. Solving gives x = 0.264 mol, so Cl2 and PCl3 are each about 0.264 mol and 1.736 mol of PCl5 remains.

16. For 2SO2(g) + O2(g) -> 2SO3(g), Kc is 1600 at 700 K and 40 at 800 K. Deduce whether the forward reaction is exothermic, and state the effect of raising the pressure on the SO3 yield. [4]

Answer: Kc falls from 1600 at 700 K to 40 at 800 K, so the equilibrium shifts left on heating and the forward reaction is exothermic (DH negative). Raising the pressure shifts the equilibrium towards the side with fewer gas moles (2 against 3), increasing the SO3 yield.

Part 5 Acid-Base Titration Calculations

Assume strong acids and bases are fully ionised; give answers to three significant figures.

17. 25 cm3 of 0.100 M sodium hydroxide is neutralised by 0.125 M hydrochloric acid. Find the volume of acid needed in cm3. [4]

Answer: Moles of NaOH = 0.100 x 0.0250 = 0.00250 mol. The ratio is 1:1, so volume of HCl = 0.00250 / 0.125 = 0.0200 dm3 = 20.0 cm3.

18. Find the pH of 0.0100 M hydrochloric acid and 0.0100 M sulphuric acid (treat the acid as fully ionised) and explain the difference. [4]

Answer: HCl: pH = -log(0.0100) = 2.00. Each H2SO4 molecule gives 2 H(+), so [H(+)] = 0.0200 M and pH = 1.70. At the same concentration the diprotic acid supplies twice the hydrogen ions, so its pH is lower.

19. A weak monobasic acid HA of concentration 0.100 M has pH = 2.90. Find [H(+)], Ka and the percentage ionisation, and explain why it cannot be treated as a strong acid. [5]

Answer: [H(+)] = 10^(-2.90) = 1.259e-03 M. Ka = [H(+)]^2 / ([HA] - [H(+)]) = (1.259e-03)^2 / (0.100 - 1.259e-03) = 1.605e-05, about 1.61 x 10^-5. Percentage ionisation = 1.259e-03 / 0.100 x 100% = 1.26%. A weak acid is only partly ionised, so [H(+)] is far below the acid concentration and the pH is much higher than that of a strong acid of the same concentration.

20. 20 cm3 of 0.050 M oxalic acid (H2C2O4, a dibasic acid) is titrated with 0.100 M sodium hydroxide. Find the volume of alkali needed for complete neutralisation and write the equation. [4]

Answer: Equation: H2C2O4 + 2NaOH -> Na2C2O4 + 2H2O. Moles of oxalic acid = 0.050 x 0.0200 = 0.00100 mol; NaOH needed = 2 x 0.00100 = 0.00200 mol; volume = 0.00200 / 0.100 = 0.0200 dm3 = 20.0 cm3.

Part 6 Basic Organic Chemistry

Show all working and give answers to three significant figures.

21. An organic compound contains 40.0% carbon, 6.67% hydrogen and 53.33% oxygen by mass, and has a relative molecular mass of 180. Find its empirical and molecular formulae. [4]

Answer: Mole ratio C:H:O = 40.0/12 : 6.67/1 : 53.33/16 = 3.333 : 6.67 : 3.333 = 1 : 2 : 1, so the empirical formula is CH2O (formula mass 30). The molecular mass 180 / 30 = 6, so the molecular formula is C6H12O6.

22. 0.050 mol of propene (C3H6) is burned completely. Find the moles of carbon dioxide formed and its volume at room conditions (molar volume 24.0 dm3/mol). [4]

Answer: Equation: 2C3H6 + 9O2 -> 6CO2 + 6H2O, so each mole of C3H6 gives 3 mol CO2. CO2 = 0.050 x 3 = 0.150 mol and volume = 0.150 x 24.0 = 3.60 dm3.

23. 0.050 mol of an alkene decolourises bromine water completely. Find the moles and mass of bromine needed (Br = 80.0) and name the reaction type. [4]

Answer: The alkene adds Br2 in a 1:1 ratio, so Br2 = 0.050 mol. The relative molecular mass of Br2 = 2 x 80.0 = 160, so mass = 0.050 x 160.0 = 8.00 g. This is electrophilic addition across the C=C double bond.

24. 0.150 mol of ethanoic acid is esterified with excess ethanol; the relative molecular mass of ethyl ethanoate is 88.0. The experiment gives 9.68 g. Find the theoretical yield and the percentage yield. [4]

Answer: Theoretical yield = 0.150 x 88.0 = 13.20 g. Percentage yield = actual / theoretical x 100% = 9.68 / 13.20 x 100% = 73.3%. The loss comes mainly from the reversible reaction not going to completion and from purification steps.
