S4 Chemistry Practice Paper 2 | Mole, titration, enthalpy, equilibrium and electrolysis calculations (with answers and marking scheme)

S4 chemistry paper: moles and gas volume, titration, enthalpy, equilibrium and Kc, electrolysis with Faraday calculations and rate graphs; full answers and marks included.

1. Mole and molar gas volume (16 marks)

A student obtains a bottle of carbon dioxide in the laboratory. Relative atomic masses: C = 12.0, O = 16.0; Avogadro constant = 6.02 x 10^23 mol^-1; molar volume at room temperature and pressure = 24.0 dm3 mol^-1; at standard conditions = 22.4 dm3 mol^-1. The mass of the sample is 8.8 g.

#	Question	Answer and marking notes
1	(a) Calculate the number of moles of carbon dioxide in the sample.	Answer: moles = mass / molar mass = 8.8 / 44.0 = 0.20 mol.
2	(b) Calculate the number of carbon dioxide molecules in the sample.	Answer: number of molecules = 0.20 x 6.02 x 10^23 = 1.20 x 10^23.
3	(c) Calculate the volume of the sample at room temperature and pressure.	Answer: volume = 0.20 x 24.0 = 4.8 dm3 (4800 cm3).
4	(d) If measured at standard conditions instead, what is the volume of the same number of moles?	Answer: volume = 0.20 x 22.4 = 4.48 dm3, i.e. 0.32 dm3 less than at room conditions.
5	(e) Calculate the number of moles of oxygen atoms and their total mass in 8.8 g of carbon dioxide.	Answer: each molecule has 2 oxygen atoms, so moles of O atoms = 0.20 x 2 = 0.40 mol; mass = 0.40 x 16.0 = 6.4 g.

2. Dilution and acid-base titration (18 marks)

25.0 cm3 of sodium hydroxide solution is titrated with 0.100 M hydrochloric acid; the indicator changes from pink to colourless and the mean titre of three runs is 22.40 cm3. The reaction is HCl + NaOH -> NaCl + H2O.

#	Question	Answer and marking notes
6	(a) Calculate the number of moles of hydrochloric acid used.	Answer: moles = 0.100 x 22.40 / 1000 = 2.24 x 10^-3 mol.
7	(b) Deduce the number of moles of sodium hydroxide from the equation.	Answer: the mole ratio of HCl to NaOH is 1 : 1, so NaOH = 2.24 x 10^-3 mol.
8	(c) Calculate the concentration of the sodium hydroxide solution in mol dm^-3.	Answer: concentration = 2.24 x 10^-3 / 0.0250 = 0.0896 M.
9	(d) If 25.0 cm3 of the sodium hydroxide solution is diluted with water to 250.0 cm3, find the new concentration.	Answer: the number of moles is unchanged, so concentration = 0.0896 x 25.0 / 250.0 = 0.00896 M (a tenfold dilution).
10	(e) 25.0 cm3 of the diluted solution is titrated with the same acid; find the volume of acid required.	Answer: moles of NaOH = 0.00896 x 0.0250 = 2.24 x 10^-4 mol; volume of acid = 2.24 x 10^-4 / 0.100 = 2.24 x 10^-3 dm3 = 2.24 cm3.

3. Enthalpy of combustion and heat calculation (16 marks)

Burning 0.500 g of ethanol (C2H5OH, molar mass 46.0 g mol^-1) raises the temperature of 100 g of water from 22.0 C to 40.0 C. Specific heat capacity of water = 4.2 J g^-1 K^-1; assume all heat is transferred to the water.

#	Question	Answer and marking notes
11	(a) Calculate the number of moles of ethanol burnt.	Answer: moles = 0.500 / 46.0 = 0.0109 mol (1.09 x 10^-2 mol).
12	(b) Calculate the heat absorbed by the water in kJ.	Answer: temperature rise = 18.0 K; heat = 100 x 4.2 x 18.0 = 7560 J = 7.56 kJ.
13	(c) Hence estimate the enthalpy of combustion of ethanol in kJ mol^-1.	Answer: heat per mole = 7.56 / 0.0109 = 695 kJ mol^-1, so the enthalpy of combustion is about -695 kJ mol^-1.
14	(d) The literature value is -1367 kJ mol^-1. Give two reasons why the calculated value is much smaller.	Answer: (1) heat is lost to the air and apparatus, so not all of it heats the water; (2) some ethanol evaporates or burns incompletely; (3) heat capacity of the container and thermometer error are ignored.
15	(e) Using the value in (c), what mass of ethanol must be burnt to heat 500 g of water from 20 C to 50 C?	Answer: heat needed = 500 x 4.2 x 30 = 63000 J = 63.0 kJ; moles = 63.0 / 695 = 0.0906 mol; mass = 0.0906 x 46.0 = 4.17 g.

4. Chemical equilibrium and the equilibrium constant (16 marks)

At a fixed temperature, 0.100 mol each of hydrogen and iodine vapour are sealed in a 1.00 dm3 vessel: H2(g) + I2(g) in a reversible reaction giving 2HI(g). At equilibrium the concentration of hydrogen iodide is 0.120 M.

#	Question	Answer and marking notes
16	(a) Find the change in concentration of hydrogen.	Answer: forming 0.120 M HI uses 0.060 M H2 (1 : 2 ratio), so hydrogen falls by 0.060 M.
17	(b) Find the equilibrium concentrations of hydrogen and iodine vapour.	Answer: both are 0.100 - 0.060 = 0.040 M.
18	(c) Calculate the equilibrium constant Kc at this temperature.	Answer: Kc = [HI]^2 / ([H2][I2]) = (0.120)^2 / (0.040 x 0.040) = 0.0144 / 0.0016 = 9.0.
19	(d) If a further 0.020 mol of hydrogen is added at constant volume, how do the position of equilibrium and Kc change?	Answer: the hydrogen concentration rises, so equilibrium shifts to the right, increasing HI and decreasing I2; Kc depends only on temperature, so Kc is unchanged.
20	(e) If the vessel is compressed to 0.50 dm3 at constant temperature, does Kc change? Explain.	Answer: Kc does not change because Kc depends only on temperature; all concentrations double and the reaction quotient keeps the same value, so the system stays at equilibrium.

5. Electrolysis and Faraday calculations (18 marks)

Copper(II) sulphate solution is electrolysed with a steady current of 2.00 A for 30.0 minutes using copper electrodes. Faraday constant = 96 500 C mol^-1; relative atomic mass of Cu = 64.0.

#	Question	Answer and marking notes
21	(a) Calculate the quantity of charge passed.	Answer: time = 30.0 x 60 = 1800 s; charge = 2.00 x 1800 = 3600 C.
22	(b) Calculate the number of moles of electrons passed.	Answer: moles of electrons = 3600 / 96500 = 0.0373 mol.
23	(c) From the half equation Cu^2+ + 2e^- -> Cu, find the moles of copper deposited at the cathode.	Answer: 2 mol of electrons give 1 mol of Cu, so copper = 0.0373 / 2 = 0.0187 mol.
24	(d) Calculate the increase in mass of the cathode.	Answer: mass = 0.0187 x 64.0 = 1.19 g.
25	(e) If the current efficiency is only 90%, what mass is actually deposited, and what happens at the anode?	Answer: actual mass = 1.19 x 0.90 = 1.07 g; the anode dissolves and loses about 1.07 g, so the Cu^2+ concentration stays roughly constant.

6. Reaction rate and gas volume graph (16 marks)

A strip of magnesium is added to excess 1.0 M hydrochloric acid and the volume of hydrogen is measured with a gas syringe: time s / volume cm3 = 0 / 0, 20 / 28, 40 / 46, 60 / 58, 80 / 64; the volume no longer changes after 80 s.

#	Question	Answer and marking notes
26	(a) Calculate the average rate over the first 20 s in cm3 s^-1.	Answer: rate = (28 - 0) / 20 = 1.4 cm3 s^-1.
27	(b) Calculate the average rate between 20 s and 40 s.	Answer: rate = (46 - 28) / 20 = 0.90 cm3 s^-1.
28	(c) Explain why the rate decreases with time.	Answer: the acid concentration and the surface area of magnesium fall as the reaction proceeds, so collisions are less frequent and the rate decreases.
29	(d) Calculate the percentage of the reaction completed at 40 s.	Answer: final volume is 64 cm3; percentage = 46 / 64 x 100% = 71.9%.
30	(e) If 0.50 M acid is used instead with magnesium still in excess, how do the initial slope and final volume differ?	Answer: the lower concentration gives a smaller initial slope and a flatter curve; with magnesium in excess the limiting reagent changes, so the final volume is smaller.
31	(f) If the same mass of magnesium is used as a powder instead of a strip, how does the curve change? Explain.	Answer: the much larger surface area makes the initial rate higher and the curve steeper, but the same amount of magnesium gives the same final volume.