

IB Chemistry SL Paper 2 Mock Paper (third set, 10 questions, 50 marks, 75 minutes, calculator allowed)

IB DP 第一年 (Grade 11) Chemistry | 時限 : 75 分鐘 | 總分 : 50 分 | 共 10 題

Section A (Questions 1 to 5, 25 marks)

Answer ALL questions. A calculator may be used. Show your working in calculations, give numerical answers to three significant figures unless told otherwise, and state units in every final answer. All data are examples and this is not a past paper of any examination board.

1. At 298 K and 101.3 kPa a vessel contains 2.80 g of nitrogen (N_2 , molar mass 28.0 g mol⁻¹). (a) Calculate the amount, in moles, of nitrogen. (b) Use the ideal gas equation $PV = nRT$ to calculate the volume of this gas under these conditions, in dm³ ($R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$). (c) The temperature is raised to 350 K at constant pressure. Calculate the new volume in dm³. (d) At the same temperature and pressure, the 2.80 g of nitrogen is replaced by 2.80 g of helium (He, molar mass 4.00 g mol⁻¹). Calculate how many times larger the new volume is. (e) Explain why a real gas deviates noticeably from the ideal gas equation at very high pressure.

答案 : (a) $n = 2.80 / 28.0 = 0.100 \text{ mol}$. (b) $V = nRT / P = (0.100 \times 8.314 \times 298) / 101.3 = 2.445 \text{ dm}^3$, that is 2.45 dm³ to three significant figures. (c) At constant pressure the volume is proportional to the absolute temperature, so $V = 2.445 \times 350 / 298 = 2.872 \text{ dm}^3$, about 2.87 dm³. (d) $n(\text{He}) = 2.80 / 4.00 = 0.700 \text{ mol}$, which is 7.00 times the amount of nitrogen; at the same temperature and pressure the volume is proportional to the amount, so the volume is 7.00 times larger. (e) At high pressure the molecules are forced close together, so the volume occupied by the molecules themselves can no longer be ignored and the attractive forces between molecules become significant. The measured volume is therefore larger, and the pressure smaller, than the ideal values. Marking notes: 1 mark each for (a) to (e).

2. The Haber process for ammonia is $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$. 0.250 mol of nitrogen and 0.600 mol of hydrogen are placed in a reactor (molar masses: N_2 28.0, H_2 2.00, NH_3 17.0 g mol⁻¹). (a) Calculate the amount of hydrogen, in moles, needed to react completely with the nitrogen. (b) Identify the limiting reactant and justify your answer. (c) Calculate the theoretical amount of ammonia formed, in moles. (d) Calculate the theoretical mass of ammonia formed, in grams. (e) The actual yield is 80%. Calculate the mass of ammonia actually formed in grams and state how much nitrogen remains in the reactor.

答案 : (a) Hydrogen needed = $0.250 \times 3 = 0.750 \text{ mol}$. (b) Hydrogen is limiting: 0.600 mol of hydrogen can react with only 0.200 mol of nitrogen, which is less than the 0.250 mol supplied, so the hydrogen is used up first. (c) From the equation, $n(\text{NH}_3) = 2 \times 0.200 = 0.400 \text{ mol}$. (d) $m(\text{NH}_3) = 0.400 \times 17.0 = 6.81 \text{ g}$. (e) Actual $n(\text{NH}_3) = 0.400 \times 0.80 = 0.320 \text{ mol}$, giving $0.320 \times 17.0 = 5.45 \text{ g}$; nitrogen remaining = $0.250 - 0.200 = 0.050 \text{ mol}$. Marking notes: 1 mark each for (a) to (e).

3. First ionisation energies in kJ mol⁻¹: Na 496, Mg 738, Al 577, Si 786, P 1012, Cl 1251, Ne 2081. (a) Write the electron configurations of Na, Mg and Al in the form 1s² 2s² 2p⁶ ... (b) Explain why the first ionisation energy of Al is lower than that of Mg. (c) Explain why the first ionisation energy of P is higher than that of Si. (d) Describe the trend in atomic radius from Na to Cl and explain its cause. (e) Explain why Ne has the highest first ionisation energy in this period.

答案 : (a) Na: 1s² 2s² 2p⁶ 3s¹; Mg: 1s² 2s² 2p⁶ 3s²; Al: 1s² 2s² 2p⁶ 3s² 3p¹. (b) The outermost electron of Al is in a 3p orbital, which is higher in energy than the 3s electrons of Mg, and the 3s electrons shield the 3p electron effectively, so it is removed more easily. Mg also forms a stable 2p⁶ core after losing its 3s² electrons. (c) Si has a 3p² configuration whereas P has a half-filled 3p³ configuration, which is more stable and has less electron-pair repulsion; the greater effective nuclear charge in P also holds the electrons more tightly. (d) The radius decreases from Na to Cl: the nuclear charge rises from +11 to +17 while the extra electrons enter the same shell, so shielding increases only slightly and the greater effective nuclear charge pulls the shell closer to the nucleus. (e) Ne has a full second shell (1s² 2s² 2p⁶), so an electron is difficult to remove, and it also has the highest nuclear charge with the same number of shells in this period. Marking notes: 1 mark each for (a) to (e).

4. Consider the molecules CH₄, NH₃, H₂O, BF₃ and CO₂. (a) State the number of electron domains, the shape and the H-C-H bond angle of CH₄. (b) State the shape and the H-N-H bond angle of NH₃ and explain why it is smaller than in CH₄. (c) State the shape and the H-O-H bond angle of H₂O and explain the difference from NH₃. (d) Explain why BF₃ is trigonal planar rather than trigonal pyramidal. (e) Explain why CO₂ is linear and has no net dipole moment.

答案 : (a) CH₄ has four electron domains (four bonding pairs, no lone pairs), so it is tetrahedral with an H-C-H angle of 109.5 degrees. (b) NH₃ has three bonding pairs and one lone pair, giving a trigonal pyramidal shape with an H-N-H angle of 107 degrees; the lone pair repels more strongly than a bonding pair, compressing the angle below 109.5 degrees. (c) H₂O has two bonding pairs and two lone pairs, giving a bent shape with an H-O-H angle of 104.5 degrees; two lone pairs repel even more strongly, so the angle is smaller than in NH₃. (d) The boron atom in BF₃ has only three electron domains (three B-F bonds) and no lone pair; these domains spread as far apart as possible, giving a trigonal planar shape with 120 degree angles. A trigonal pyramidal shape would require four electron domains. (e) The carbon atom in CO₂ has two electron domains (two C=O double bonds) separated by 180 degrees, so the molecule is linear. The two bond dipoles are equal in size and opposite in direction, so they cancel and the net dipole moment is zero. Marking notes: 1 mark each for (a) to (e).

5. A current of 0.500 A is passed through copper(II) sulfate solution for 30.0 minutes, with inert electrodes. Copper (molar mass 63.55 g mol⁻¹) is deposited at the cathode. Faraday constant $F = 96500 \text{ C mol}^{-1}$, molar gas volume at room temperature 24.0 dm³. (a) Calculate the quantity of charge passed, in coulombs. (b) Calculate the amount of electrons passed, in moles. (c) Write the half-equation at the cathode and calculate the mass of copper deposited in grams. (d) Write the half-equation at the anode and calculate the volume of oxygen formed at room temperature, in cm³. (e) If the current efficiency is only 90%, state how the mass of copper deposited changes.

答案 : (a) $Q = I \times t = 0.500 \times 1800 = 900 \text{ C}$. (b) $n(e^-) = 900 / 96500 = 9.3264\text{e-}03 \text{ mol}$. (c) Cathode: $\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}$; $n(\text{Cu}) = 9.3264\text{e-}03 / 2 = 4.6632\text{e-}03 \text{ mol}$, so the mass is $4.6632\text{e-}03 \times 63.55 = 0.296 \text{ g}$. (d) Anode: $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4e^-$; $n(\text{O}_2) = 9.3264\text{e-}03 / 4 = 2.3316\text{e-}03 \text{ mol}$, so the volume is $2.3316\text{e-}03 \times 24.0 = 0.0560 \text{ dm}^3$, about 56.0 cm³. (e) With 90 per cent current efficiency only 90 per cent of the charge deposits copper, so both the amount and the mass fall to 0.90 of the values above, about 0.267 g. The remaining charge is used in other reduction reactions such as the reduction of water to hydrogen. Marking notes: 1 mark each for (a) to (e).

Section B (Questions 6 to 10, 25 marks)

Answer ALL questions. A calculator may be used. Show your working in calculations, give numerical answers to three significant figures unless told otherwise, and state units in every final answer. All data are examples and this is not a past paper of any examination board.

6. The initial rates for the reaction $\text{A} + \text{B} \rightarrow \text{C}$ at one temperature are: Experiment 1: $[\text{A}] = 0.10 \text{ mol dm}^{-3}$, $[\text{B}] = 0.10 \text{ mol dm}^{-3}$, rate = $2.0 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$ Experiment 2: $[\text{A}] = 0.20 \text{ mol dm}^{-3}$, $[\text{B}] = 0.10 \text{ mol dm}^{-3}$, rate = $4.0 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$ Experiment 3: $[\text{A}] = 0.20 \text{ mol dm}^{-3}$, $[\text{B}] = 0.20 \text{ mol dm}^{-3}$, rate = $1.6 \times 10^{-2} \text{ mol dm}^{-3} \text{ s}^{-1}$ (a) Deduce the order of reaction with respect to A. (b) Deduce the order of reaction with respect to B. (c) Write the rate equation and state the overall order. (d) Calculate the value and unit of the rate constant k . (e)

Calculate the initial rate when $[\text{A}] = 0.15 \text{ mol dm}^{-3}$ and $[\text{B}] = 0.25 \text{ mol dm}^{-3}$.

答案 : (a) Comparing experiments 1 and 2, $[\text{A}]$ doubles while $[\text{B}]$ is unchanged and the rate doubles from 2.0×10^{-3} to 4.0×10^{-3} , so the order with respect to A is one. (b) Comparing experiments 2 and 3, $[\text{A}]$ is unchanged and $[\text{B}]$ doubles from 0.10 to 0.20, while the rate rises from 4.0×10^{-3} to 1.6×10^{-2} , a factor of four, so the order with respect to B is two. (c) Rate = $k[\text{A}][\text{B}]^2$, so the overall order is $1 + 2 = 3$. (d) $k = \text{rate} / ([\text{A}][\text{B}]^2) = 2.0 \times 10^{-3} / (0.10 \times 0.10^2) = 2.0 \text{ mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$. (e) Rate = $2.0 \times 0.15 \times 0.25^2 = 0.01875$, about 0.0187 mol dm⁻³ s⁻¹, that is $1.9 \times 10^{-2} \text{ mol dm}^{-3} \text{ s}^{-1}$. Marking notes: 1 mark each for (a) to (e).

7. Industrial ammonia synthesis: $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$, enthalpy change of reaction -92 kJ mol^{-1} . (a) Explain the effect of increasing the total pressure on the equilibrium yield of ammonia. (b) Explain the effects of increasing the temperature on the equilibrium yield and on the rate. (c) Explain the effect of continuously condensing and removing ammonia. (d) Explain the effect of adding an iron catalyst on the position of equilibrium and on the time taken to reach equilibrium. (e) Explain why industry uses about 450 degrees C rather than a much lower temperature.

答案 : (a) Raising the pressure shifts the equilibrium towards the side with fewer moles of gas: four moles on the left against two on the right, so the equilibrium moves to the right and the yield of ammonia increases. (b) Raising the temperature shifts the equilibrium in the endothermic direction, which is to the left, so the equilibrium yield falls; however the average kinetic energy of the molecules rises, so more collisions are successful and both the forward and reverse rates increase. (c) Removing ammonia lowers the concentration of the product, so the equilibrium shifts to the right and more ammonia is formed. (d) A catalyst lowers the activation energy and speeds up the forward and reverse reactions equally, so equilibrium is reached sooner, but the position of equilibrium and the equilibrium yield are unchanged. (e) A much lower temperature favours the exothermic forward reaction but the rate becomes far too slow and equilibrium would take an impractical time. About 450 degrees C is a compromise between yield, rate and energy cost, and with high pressure and a catalyst it gives an acceptable overall yield. Marking notes: 1 mark each for (a) to (e).

8. 0.100 mol of ethanoic acid (CH_3COOH) is heated under reflux with excess ethanol and concentrated sulfuric acid to form ethyl ethanoate. (a) Write the equilibrium equation for this esterification and name the catalyst required. (b) Give the systematic name and molecular formula of the organic product. (c) The molar mass of the ester is 88.0 g mol^{-1} . Calculate the mass of ester formed in grams if the yield is 80 per cent. (d) Name two other esters that are isomers with the molecular formula $\text{C}_4\text{H}_8\text{O}_2$. (e) Explain why the reaction is heated under reflux and why the ester is separated by fractional distillation afterwards.

答案 : (a) $\text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \rightleftharpoons \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O}$; the catalyst is concentrated sulfuric acid, which also acts as a dehydrating agent. (b) Ethyl ethanoate, molecular formula $\text{C}_4\text{H}_8\text{O}_2$. (c) The theoretical amount of ester is 0.100 mol; the actual amount is $0.100 \times 0.80 = 0.080 \text{ mol}$, so the mass is $0.080 \times 88.0 = 7.05 \text{ g}$. (d) Two other ester isomers are propyl methanoate and 1-methylethyl methanoate; methyl propanoate is also acceptable. (e) Esterification is a slow reversible reaction; heating increases the rate, and reflux condenses the volatile ethanol and ethanoic acid and returns them to the flask, preventing loss of reactants and raising the yield. The components have different boiling points, so fractional distillation separates the more volatile ester. Marking notes: 1 mark each for (a) to (e).

9. Standard enthalpies of formation in kJ mol^{-1} : $\text{CH}_4(\text{g})$ -75, $\text{CO}_2(\text{g})$ -394, $\text{H}_2\text{O}(\text{l})$ -286. (a) Define the standard enthalpy of formation, including the standard conditions. (b) Write the balanced equation for the complete combustion of methane, showing all state symbols. (c) Write the expression, or an energy cycle, that gives the enthalpy of combustion from standard enthalpies of formation. (d) Calculate the standard enthalpy of combustion of methane in kJ mol^{-1} . (e) Explain why a calculation using average bond enthalpies gives a different value.

答案：(a) The standard enthalpy of formation is the enthalpy change when one mole of a compound is formed from its elements in their standard states at standard pressure (1 bar, about 100 kPa) and a stated temperature, usually 298 K. (b) $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$. (c) The enthalpy of combustion equals the sum of the formation enthalpies of the products minus that of the reactants: [enthalpy of formation of CO_2 + 2 x that of H_2O] - [that of CH_4 + 2 x that of O_2], and the formation enthalpy of an element is zero. (d) The value is $[(-394) + 2 \times (-286)] - [(-75) + 0] = -966 + 75 = -891 \text{ kJ mol}^{-1}$. (e) Bond enthalpies are average bond energies for gaseous species, so the value obtained refers to all substances in the gaseous state; in the standard enthalpy of combustion the water is liquid, and condensation releases extra energy. The averaging of bond enthalpies also introduces a difference. Marking notes: 1 mark each for (a) to (e).

10. Compound X contains only carbon, hydrogen and oxygen. Its mass spectrum shows a molecular ion peak at m/z 60 and prominent fragment peaks at m/z 43 and m/z 45. The infrared spectrum has a broad, strong absorption between 2500 and 3300 cm^{-1} and another strong absorption near 1700 cm^{-1} . (a) Use the mass spectrum to state the relative molecular mass of X. (b) Identify the functional groups responsible for the two infrared absorptions. (c) Given a molar mass of 60.0 g mol^{-1} , deduce the molecular formula of X (relative atomic masses: C 12.0, H 1.0, O 16.0). (d) Using all the evidence, name compound X. (e) Explain the origin of the fragment peak at m/z 45.

答案：(a) The molecular ion peak is at m/z 60, so the relative molecular mass of X is 60. (b) The broad absorption between 2500 and 3300 cm^{-1} is due to the O-H stretch of a hydrogen-bonded carboxylic acid, and the strong absorption near 1700 cm^{-1} is due to the C=O stretch. (c) If the formula is $\text{C}_x\text{H}_y\text{O}_z$ then $12x + y + 16z = 60$. A carboxylic acid contains two oxygen atoms, so $z = 2$ and $12x + y = 28$; with $x = 2$, $y = 4$, giving $\text{C}_2\text{H}_4\text{O}_2$ and a molar mass of $24 + 4 + 32 = 60$, which agrees with the data. (d) X contains both O-H and C=O groups of a dimeric carboxylic acid and has the formula $\text{C}_2\text{H}_4\text{O}_2$, so X is ethanoic acid, CH_3COOH . (e) The peak at m/z 45 arises from loss of a methyl group of mass 15, leaving the COOH^+ fragment, while m/z 43 arises from loss of the OH group of mass 17, leaving CH_3CO^+ . Both are consistent with the structure of ethanoic acid. Marking notes: 1 mark each for (a) to (e).