# Chemistry (Mock-Easy)

# Higher level

# Paper 2

17 March 2026

**Zone D** morning

Candidate session number

_____

2 hours 30 minutes

**Instructions to candidates**

- Write your session number in the boxes above
- Do not open this examination paper until instructed to do so.
- Answers all questions.
- Answers must be written within the answers boxes provided.
- A calculator is required for this paper.
- A clean copy of **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

*Question 1: Periodicity and d-d Transitions* [10 marks]

Part (a) [3 marks]

(i) State the electron configuration of $Cr^{3+}$ and $Mn^{2+}$ ions. [1 mark]

(ii) Explain why $Sc^{3+}$ and $Zn^{2+}$ compounds are generally colorless, while $Cr^{3+}$ compounds are typically colored. [2 marks]

Part (b) [4 marks]

Consider the octahedral complex ions $[Ti(H_2O)_6]^{3+}$ and $[TiCl_6]^{3-}$.
(i) Using the spectrochemical series, predict which complex will absorb light of higher energy. Justify your answer. [2 marks]

Ligands can be arranged in a spectrochemical series according to the energy difference they produce between the two sets of d-orbitals in an octahedral complex.

$$I^- < Br^- < S^{2-} < Cl^- < F^- < OH^- < H_2O < SCN^- < NH_3 < CN^- \approx CO$$

(ii) The $[Ti(H_2O)_6]^{3+}$ complex appears purple in aqueous solution. Using the color wheel concept, determine the approximate wavelength range and color of light being absorbed by this complex. [2 marks]

Part (c) [3 marks]

(i) Explain the trend in atomic radius across the first transition series from Sc to Zn. [2 marks]

(ii) Compare the effectiveness of d-electrons versus s-electrons in shielding the nuclear charge from outer electrons. [1 mark]

Question 2: Chemical Bonding and Molecular Properties [12 marks]

## Part (a) [4 marks]

Consider the following compounds: butanoic acid ($C_3H_7COOH$), butanol ($C_4H_9OH$), butanal ($C_3H_7CHO$), and butane ($C_4H_{10}$).
**(i)** Arrange these compounds in order of increasing boiling point. [1 mark]

**(ii)** Explain the trend in boiling points by identifying the dominant intermolecular forces present in each compound. [3 marks]

## Part (b) [3 marks]

For the sulfate ion ($SO_4^{2-}$):
**(i)** Draw the Lewis structure showing all resonance forms and use formal charges to identify the most stable structure. [2 marks]

**(ii)** Determine the electron domain geometry and molecular geometry around the sulfur atom. [1 mark]

## Part (c) [3 marks]

**(i)** Determine the hybridization of the central atom and predict the bond angle in $NH_3$ (ammonia). [2 marks]

**(ii)** Explain why the bond angle in $NH_3$ (107°) is smaller than the tetrahedral angle (109.5°). [1 mark]

## Part (d) [2 marks]

Consider the molecules $CCl_4$ and $CHCl_3$.
**(i)** Using electronegativity values, explain why $CCl_4$ is nonpolar while $CHCl_3$ is polar. [1 mark]

**(ii)** Predict which molecule will have the higher boiling point and justify your answer. [1 mark]

Question 3: Hydrogen Emission Spectrum and Energy Calculations [6 marks]

## Part (a) [2 marks]

**(i)** In the space below, sketch the hydrogen emission spectrum in the visible region (Balmer series), showing the relative positions and intensities of the spectral lines. Label the wavelengths approximately. [1 mark]

**(ii)** Explain why the hydrogen emission spectrum consists of discrete lines rather than a continuous spectrum. [1 mark]

## Part (b) [2 marks]

The Balmer series corresponds to electronic transitions from higher energy levels (n ≥ 3) to the second energy level (n = 2) in hydrogen atoms.
**(i)** Calculate the frequency of the photon emitted when an electron transitions from n = 3 to n = 2 in a hydrogen atom. The wavelength of this transition is 656 nm. [1 mark]

**(ii)** Using the equation $E = h\nu = \frac{hc}{\lambda}$, calculate the energy of this photon in joules.
**Given:** $h = 6.63 \times 10^{-34} J \cdot s, c = 3.00 \times 10^8 m \cdot s^{-1}$ [1 mark]

## Part (c) [2 marks]

**(i)** Define first ionization energy in terms of electron transitions in hydrogen. [1 mark]

**(ii)** The first ionization energy of hydrogen is 1312 kJ mol$^{-1}$. Calculate the wavelength of electromagnetic radiation that would just ionize a hydrogen atom from its ground state. Express your answer in nanometers. [1 mark]

Question 4: Thermodynamics, Born-Haber Cycles, and Calorimetry [15 marks]

Part (a) [4 marks]

Consider the formation of sodium chloride from its elements: $Na(s) + \frac{1}{2}Cl_2(g) \rightarrow NaCl(s)$

The following data is provided:

- Enthalpy of formation of NaCl(s): $\Delta H_f = -411 \; kJ \; mol^{-1}$
- Enthalpy of atomization of Na(s): $+107 \; kJ \; mol^{-1}$
- First ionization energy of Na(g): $+496 \; kJ \; mol^{-1}$
- Bond dissociation energy of $\frac{1}{2}Cl_2(g)$: $+122 \; kJ \; mol^{-1}$
- Electron affinity of Cl(g): $-349 \; kJ \; mol^{-1}$

**(i)** Construct a complete Born-Haber cycle for the formation of NaCl(s). [2 marks]

**(ii)** Calculate the lattice enthalpy of NaCl(s) using the Born-Haber cycle. [2 marks]

Part (b) [5 marks]

A student performed a calorimetry experiment to determine the enthalpy of neutralization between hydrochloric acid and sodium hydroxide:

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$
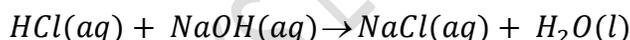
**Experimental data:**

- Volume of 1.0 M HCl used: 50.0 mL
- Volume of 1.0 M NaOH used: 50.0 mL
- Initial temperature of both solutions: 20.0°C
- Final temperature after mixing: 26.8°C
- Density of solution: 1.00 g mL⁻¹
- Specific heat capacity of solution: 4.18 J g⁻¹ K⁻¹

**(i)** Calculate the heat energy released in this reaction using $q = mc\Delta T$. [2 marks]

**(ii)** Calculate the number of moles of water formed in the reaction. [1 mark]

**(iii)** Determine the enthalpy of neutralization per mole of water formed. [1 mark]

**(iv)** Suggest two sources of experimental error that could affect the accuracy of this result. [1 mark]

Part (c) [6 marks]

For a hypothetical reaction: $A(s) + B(g) \rightarrow C(g) + D(l)$
The following thermodynamic data is given:
- $\Delta H° = +85 \ kJ \ mol^{-1}$
- $\Delta S° = +120 \ J \ mol^{-1}K^{-1}$

**(i)** State the relationship between Gibbs free energy ($\Delta G°$), enthalpy ($\Delta H°$), and entropy ($\Delta S°$). [1 mark]

**(ii)** Calculate $\Delta G°$ for this reaction at 298 K. [2 marks]

**(iii)** Determine whether this reaction is spontaneous at 298 K. Justify your answer. [1 mark]

**(iv)** Calculate the temperature at which this reaction becomes spontaneous ($\Delta G° = 0$). [1 mark]

**(v)** Explain how increasing temperature affects the spontaneity of this reaction, considering both the enthalpy and entropy terms. [1 mark]

Question 5: Chemical Kinetics and Reaction Mechanisms [15 marks]

Part (a) [4 marks]

The reaction between nitrogen monoxide and hydrogen was studied:

$$2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(g)$$
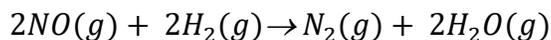
The following experimental data was obtained at 1000 K:

| Experiment | [NO] / mol dm$^{-3}$ | [H$_2$] / mol dm$^{-3}$ | Initial Rate / mol dm$^{-3}$ s$^{-1}$ |
|---|---|---|---|
| 1 | 0.10 | 0.10 | $2.0 \times 10^{-4}$ |
| 2 | 0.20 | 0.10 | $8.0 \times 10^{-4}$ |
| 3 | 0.10 | 0.20 | $4.0 \times 10^{-4}$ |

**(i)** Determine the order of reaction with respect to NO and H₂. Show your working. [2 marks]

**(ii)** Write the rate equation for this reaction. [1 mark]

**(iii)** Calculate the rate constant, k, including appropriate units. [1 mark]

Part (b) [3 marks]

The same reaction was studied at different temperatures, and the following rate constants were obtained:

| Temperature / K | Rate constant / dm$^9$ mol$^{-3}$ s$^{-1}$ |
|---|---|
| 900 | $1.5 \times 10^2$ |
| 1000 | $2.0 \times 10^3$ |

**(i)** Using the Arrhenius equation, calculate the activation energy for this reaction.
**Given:** R = 8.314 J mol$^{-1}$ K$^{-1}$ [2 marks]

**(ii)** State what happens to the rate constant when temperature increases, and explain this in terms of the Arrhenius equation. [1 mark]

Part (c) [4 marks]

Based on kinetic studies, the following two-step mechanism has been proposed for the reaction:

**Step 1:** $NO(g) + H_2(g) \rightarrow NOH_2(g)$ (fast equilibrium)

**Step 2:** $NOH_2(g) + NO(g) \rightarrow N_2(g) + H_2O(g) + H_2O(g)$ (slow)

**(i)** Identify the intermediate in this mechanism. [1 mark]

**(ii)** Determine which step is the rate-determining step and justify your answer. [1 mark]

**(iii)** In the space below, sketch an energy profile diagram for this two-step mechanism. Clearly label:

- Reactants and products
- Intermediate
- Transition states (TS1 and TS2)
- Activation energies (Ea1 and Ea2)
- Overall enthalpy change (ΔH) [2 marks]

Part (d) [4 marks]

**(i)** In the space below, sketch the Maxwell-Boltzmann distribution of molecular energies for a gas at temperature $T_1$. Label the axes and mark the activation energy (Ea) on your diagram. [1 mark]

**(ii)** On the same diagram, sketch the distribution curve for the same gas at a higher temperature $T_2$ (where $T_2 > T_1$). Explain how this affects the reaction rate. [1 mark]

**(iii)** On a separate diagram, sketch the Maxwell-Boltzmann distribution showing the effect of adding a catalyst. Label both curves (with and without catalyst) and explain how the catalyst affects the reaction rate. [2 marks]

Question 6: Acid-Base Equilibria and Titration Analysis [12 marks]

Part (a) [5 marks]

A student titrates 25.0 mL of 0.100 M ethanoic acid (CH₃COOH) with 0.100 M sodium hydroxide (NaOH).

**Given:** $K_a$ for ethanoic acid = $1.8 \times 10^{-5}$, $K_w = 1.0 \times 10^{-14}$ at 25°C

**(i)** Calculate the initial pH of the ethanoic acid solution before any NaOH is added. [2 marks]

**(ii)** Calculate the pH at the equivalence point of this titration. [2 marks]

**(iii)** In the space below, sketch the pH titration curve for this reaction. Clearly label:
- Initial pH
- pH at equivalence point
- End-point region
- Buffer region [1 mark]

Part (b) [2 marks]

**(i)** Choose a suitable indicator for the titration in part (a) from the following options. Justify your choice.

**Available indicators:**
- Methyl orange (pH range 3.1 - 4.4)
- Bromothymol blue (pH range 6.0 - 7.6)
- Phenolphthalein (pH range 8.3 - 10.0)
- Thymol blue (pH range 8.0 - 9.6) [1 mark]

**(ii)** Explain why methyl orange would be unsuitable for this titration. [1 mark]

Part (c) [3 marks]

An acid buffer solution is prepared by mixing 50.0 mL of 0.200 M ethanoic acid with 50.0 mL of 0.150 M sodium ethanoate (CH₃COONa).

**(i)** Calculate the pH of this buffer solution using the Henderson-Hasselbalch equation. **Given:** $pK_a$ for ethanoic acid = 4.74 [2 marks]

**(ii)** State what happens to the pH when a small amount of strong acid is added to this buffer, and briefly explain the mechanism involved. [1 mark]

Part (d) [2 marks]

**(i)** Calculate the pH of a $1.0 \times 10^{-8}$ M HCl solution at 25°C. Explain why the simple formula pH = -log[H⁺] cannot be used directly. [1 mark]
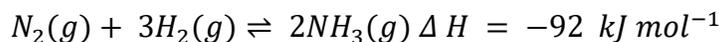
**(ii)** The dissociation constant of water ($K_w$) increases with temperature. Explain the effect this has on the pH of pure water at temperatures above 25°C, and state whether pure water remains neutral. [1 mark]

Question 7: Chemical Equilibrium and Le Chatelier's Principle [8 marks]

Part (a) [3 marks]

Consider the following equilibrium reaction:
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \, \Delta H = -92 \; kJ \; mol^{-1}$$
**(i)** Predict the effect of each of the following changes on the position of equilibrium. In each case, justify your answer using Le Chatelier's principle:
- **Increasing temperature** [1 mark]
- **Increasing pressure** [1 mark]
- **Adding a catalyst** [1 mark]

Part (b) [2 marks]

At 500°C, the equilibrium constant $K_c$ for the above reaction is $6.2 \times 10^{-3}$.
**(i)** Write the expression for $K_c$ for this reaction. [0.5 marks]

**(ii)** Comment on the significance of this $K_c$ value in terms of the position of equilibrium and the relative concentrations of reactants and products. [1 mark]

**(iii)** At a particular moment, the concentrations are: [$N_2$] = 0.50 M, [$H_2$] = 1.2 M, [$NH_3$] = 0.25 M. Calculate the reaction quotient $Q_c$ and predict the direction of the reaction. [0.5 marks]

Part (c) [2 marks]

The relationship between the equilibrium constant and Gibbs free energy is given by: $\Delta G° = -RT \ln K$
**(i)** Calculate $\Delta G°$ for the ammonia synthesis reaction at 500°C (773 K). **Given:** R = 8.314 J mol⁻¹ K⁻¹, $K_c = 6.2 \times 10^{-3}$ [1 mark]

**(ii)** State what the sign and magnitude of $\Delta G°$ indicate about the spontaneity of this reaction under standard conditions. [1 mark]

Part (d) [1 mark]

Explain why industrial ammonia production (Haber process) is typically carried out at high pressure and moderate temperature (around 450-500°C), despite the equilibrium considerations discussed above.

Question 8: Electrochemical Cells and Electrolysis [12 marks]

### Part (a) [4 marks]

Consider an electrochemical cell consisting of a zinc electrode in 1.0 M $Zn^{2+}$ solution connected to a copper electrode in 1.0 M $Cu^{2+}$ solution.

**Given standard reduction potentials:**
- $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ E° = +0.34 V
- $Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ E° = -0.76 V

**(i)** In the space below, draw a labeled diagram of this electrochemical cell. Include and clearly label:
- Anode and cathode electrodes
- Direction of electron flow
- Salt bridge
- Polarity of electrodes (+ and -)
- Ion movement in the salt bridge [2 marks]

**(ii)** Write the half-equations for the reactions occurring at:
- **Anode:** [0.5 marks]
- **Cathode:** [0.5 marks]

**(iii)** Calculate the standard cell potential (E°cell) for this electrochemical cell. [1 mark]

### Part (b) [3 marks]

**(i)** State the key differences between an electrochemical cell and an electrolytic cell in terms of:
- Energy conversion [0.5 marks]
- Spontaneity of reactions [0.5 marks]

**(ii)** In an electrolytic cell for the electrolysis of molten sodium chloride (NaCl):
Write the half-equations for the reactions at:
- **Anode:** [0.5 marks]
- **Cathode:** [0.5 marks]

**(iii)** Explain why the electrolysis of aqueous NaCl produces different products compared to molten NaCl. [1 mark]

## Part (c) [3 marks]

An electrolytic cell is used to electroplate a metal spoon with silver using a silver nitrate solution. A current of 0.50 A is passed through the cell for 45 minutes.

**Given:**

- Faraday constant (F) = 96,500 C mol⁻¹
- Molar mass of Ag = 107.9 g mol⁻¹
- $Ag^+(aq) + e^- \rightarrow Ag(s)$

**(i)** Calculate the quantity of electricity (charge) passed through the cell using Q = It. [1 mark]

**(ii)** Calculate the number of moles of electrons transferred. [1 mark]

**(iii)** Calculate the mass of silver deposited on the spoon. [1 mark]

## Part (d) [2 marks]

A hydrogen fuel cell operates using the following reactions:
**Anode:** $H_2(g) \rightarrow 2H^+(aq) + 2e^-$ **Cathode:** $O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$

**(i)** Write the overall equation for the reaction in the hydrogen fuel cell. [0.5 marks]

**(ii)** State two advantages of hydrogen fuel cells compared to conventional batteries. [1 mark]

**(iii)** Identify whether a hydrogen fuel cell is a primary cell or secondary cell, and justify your answer. [0.5 marks]

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