Chemistry

Higher Level

Paper 2 — Mock Examination

Mock Exam 3

Calculator required

Time allowed: **2 hours 30 minutes**

Maximum mark: **90 marks**

Candidate information

Candidate name: .....

Session number: .....

Date: .....

Topic emphasis: models of bonding and structure, periodicity, what drives chemical reactions, how much / how fast / how far, proton transfer and electron transfer reactions, the mechanisms of chemical change, and the tools of the chemist (spectroscopic identification of organic compounds).

Instructions to candidates

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

The mark allocation is shown in square brackets at the end of each question or part question. Where a numerical answer is required, values of constants, molar masses and other data should be taken from the chemistry data booklet unless they are given in the question. Working must be shown for all calculations; marks are available for correct method even when the final answer is incorrect.

Take the ideal gas constant to be $R = 8.31\,\text{J}\,\text{K}^{-1}\,\text{mol}^{-1}$, Avogadro's constant to be $L = 6.02 \times 10^{23}\,\text{mol}^{-1}$ and the specific heat capacity of water to be $4.18\,\text{J}\,\text{g}^{-1}\,\text{K}^{-1}$. All questions refer to a temperature of 298 K unless otherwise stated.

Mark allocation	
Question 1	[20 marks]
Question 2	[16 marks]
Question 3	[24 marks]
Question 4	[16 marks]
Question 5	[14 marks]
Total	**[90 marks]**

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Octane, C_8H_{18}, is a component of petrol. Its combustion releases carbon dioxide into the atmosphere.

(a) Draw the Lewis formula of carbon dioxide, state its molecular geometry and explain why the molecule is non-polar although the bonds are polar. **[3]**

Molecular geometry: .....

Explanation: .....

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(b) Predict, with a reason, how the carbon–oxygen bond length in the carbonate ion, CO_3^{2-}, compares with that in carbon dioxide. Use section 11 of the data booklet. **[2]**

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(This question continues on the following page)

(Question 1 continued)

(c) Octane burns completely in oxygen.

(i) Write a balanced equation for the complete combustion of octane. **[1]**

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(ii) Calculate the mass of carbon dioxide, in kg, produced by the complete combustion of $1.00\,dm^3$ of octane. The density of octane is $0.703\,g\,cm^{-3}$. Use sections 6 and 7 of the data booklet. **[3]**

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(iii) Calculate the volume of this carbon dioxide, in dm^3, at $25\,°C$ and $1.00 \times 10^5\,Pa$. Use sections 1 and 2 of the data booklet. **[2]**

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(d) The enthalpy of combustion of octane is $-5470\,kJ\,mol^{-1}$.

(i) Distinguish between specific energy and energy density of a fuel. **[1]**

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(ii) Calculate the specific energy of octane, in kJ g^{-1}. **[1]**

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(This question continues on the following page)

(Question 1 continued)

(e) Explain why incomplete combustion of octane in an engine is hazardous to health. **[1]**

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(f) Bioethanol is a possible alternative to petrol. State **one** advantage and **one** disadvantage of using bioethanol as a fuel. **[2]**

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(g) A hydrogen fuel cell uses an acidic electrolyte. Deduce the half-equation at each electrode. **[2]**

Negative electrode: . . . . . .

Positive electrode: . . . . . .

(h) Explain why carbon dioxide absorbs infrared radiation whereas nitrogen, N_2, does not. **[1]**

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(i) Deduce the oxidation state of carbon in CO_2 and in CH_4. **[1]**

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2. The elements of period 3 show clear trends in their atomic properties and in the properties of their compounds.

(a) Explain the decrease in atomic radius from sodium to chlorine. Use section 9 of the data booklet. **[2]**

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(b) The first ionization energies of the period 3 elements do not increase uniformly. Explain the decrease from magnesium to aluminium and the decrease from phosphorus to sulfur. Use section 8 of the data booklet. **[3]**

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(c) Sodium oxide, aluminium oxide and sulfur trioxide were each added to separate samples of water. Classify each oxide as acidic, basic or amphoteric and write an equation for the reaction of sodium oxide and of sulfur trioxide with water. **[3]**

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(This question continues on the following page)

(Question 2 continued)

(d) Deduce, showing your working, the type of bonding present in magnesium chloride and in tetrachloromethane. Use section 9 of the data booklet. **[2]**

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(e) Sodium chloride, silicon dioxide and sulfur, S_8, are all solids at room temperature. Explain the difference in their melting points in terms of structure and bonding. **[3]**

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(f) Explain why magnesium has a higher melting point than sodium. **[2]**

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(g) Deduce the formula of the oxide formed by phosphorus in its highest oxidation state. **[1]**

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3. Compound **A** has the molecular formula C_4H_8O.

(a) Determine the index of hydrogen deficiency (degree of unsaturation) of **A** and state what this indicates about its structure. **[2]**

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(b) The infrared spectrum of **A** shows a strong absorption at 1715 cm^{-1} and no absorption in the range 3200–3600 cm^{-1}. Deduce the functional group present, giving your reasoning. Use section 20 of the data booklet. **[2]**

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(c) The ^1H NMR spectrum of **A** is summarized below.

Chemical shift / ppm	Relative area	Splitting pattern
1.05	3	triplet
2.15	3	singlet
2.45	2	quartet

Deduce the structure of **A** and explain how the splitting patterns support your answer. Use section 21 of the data booklet. **[3]**

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(This question continues on the following page)

(Question 3 continued)

(d) Compound **A** is reduced by sodium borohydride, $NaBH_4$, to compound **B**.

(i) Name compound **B** and state the type of reaction. **[2]**

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(ii) Explain why compound **B** is optically active. **[1]**

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(e) Compound **B** is heated with concentrated sulfuric acid at 170 °C.

(i) Name the two structural isomers that may be formed and identify the major product. **[2]**

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(ii) One of these products exists as cis and trans isomers. Draw the two isomers and state the feature of the molecule that gives rise to this type of isomerism. **[1]**

(This question continues on the following page)

(Question 3 continued)

(f) But-2-ene reacts with bromine in the dark.

(i) Sketch the mechanism of the reaction, using curly arrows to represent the movement of electron pairs. **[3]**

(ii) Name the organic product. **[1]**

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(This question continues on the following page)

(Question 3 continued)

(g) 2-bromobutane is converted into butan-2-ol.

(i) State the reagent and conditions required. **[1]**

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(ii) State the type and mechanism of this reaction, and deduce the overall order of reaction if the mechanism proceeds through a carbocation intermediate. **[2]**

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(h) 2-bromobutane reacts with an excess of ammonia in ethanol.

(i) Name the organic product and state the type of reaction. **[2]**

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(i) The mass spectrum of compound **A** shows a prominent peak at $m/z = 43$. Suggest the formula of the fragment responsible. **[1]**

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(j) Explain why compound **A** is more soluble in water than butane. **[1]**

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4. The reaction between compounds **X** and **Y** was studied at constant temperature.

$$X + Y \longrightarrow Z$$

Experiment	[X] / mol dm^{-3}	[Y] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.100	0.100	1.20×10^{-3}
2	0.200	0.100	4.80×10^{-3}
3	0.100	0.200	1.20×10^{-3}

(a) Deduce the order of reaction with respect to **X** and to **Y**, and state the rate equation. **[2]**

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(b) Calculate the value of the rate constant, k, and state its units. **[2]**

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(c) Suggest a two-step mechanism consistent with the rate equation, identifying the rate-determining step. **[2]**

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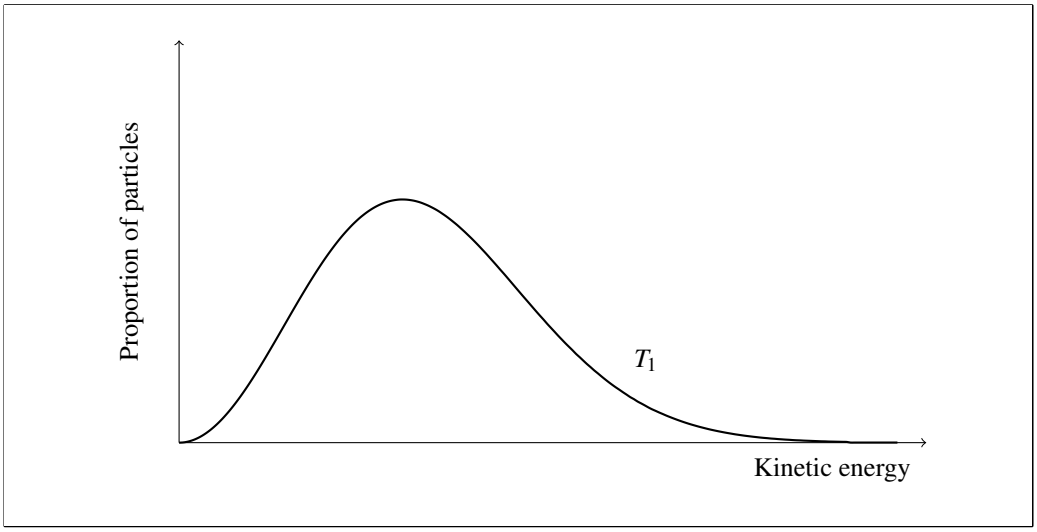
(This question continues on the following page)

(Question 4 continued)

(d) The graph below shows the Maxwell–Boltzmann distribution of molecular kinetic energies at temperature T_1.

(i) Sketch, on the same axes, the distribution at a higher temperature T_2 and label the activation energy, E_a. **[2]**



(ii) Explain, referring to your sketch, why an increase in temperature produces a large increase in the rate of reaction. **[2]**

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(e) State the effect of adding a catalyst on the activation energy and on the value of the rate constant. **[1]**

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(This question continues on the following page)

(Question 4 continued)

(f) Ethanoic acid and ethanol react in a reversible reaction.

$$CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$$

1.00 mol of ethanoic acid and 1.00 mol of ethanol were mixed and allowed to reach equilibrium in a flask of volume V. At equilibrium 0.667 mol of ester had formed.

(i) Calculate the value of K_c for this reaction. **[2]**

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(ii) State and explain the effect of adding more ethanol on the value of K_c and on the equilibrium yield of ester. **[2]**

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(g) Calculate the standard Gibbs energy change for the esterification reaction at 298 K, using your value of K_c and the relationship $\Delta G^{\ominus} = -RT \ln K$. Use section 1 of the data booklet. **[1]**

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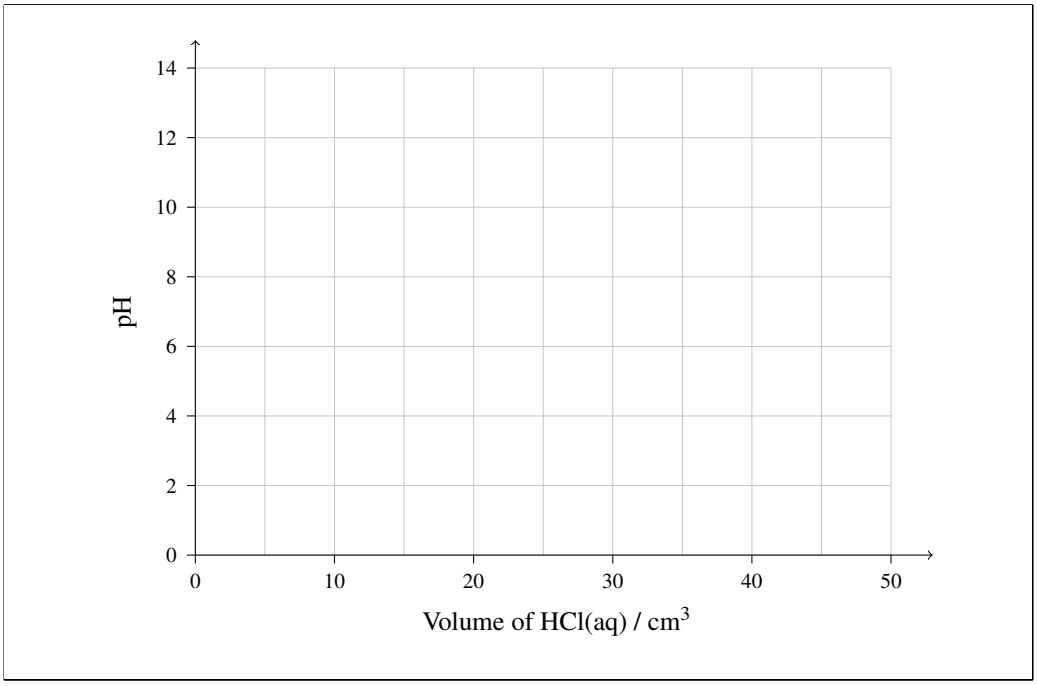
5. Aqueous solutions of acids, bases and oxidizing agents are widely used in analysis.

(a) $25.0\,cm^3$ of $0.100\,mol\,dm^{-3}$ aqueous ammonia was titrated with $0.100\,mol\,dm^{-3}$ hydrochloric acid.

(i) Sketch the pH curve obtained, marking the equivalence point. **[2]**



(ii) Suggest a suitable indicator for this titration, giving a reason. Use section 18 of the data booklet. **[1]**

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(This question continues on the following page)

(Question 5 continued)

(b) Calculate the pH of $0.0500\,\text{mol}\,\text{dm}^{-3}$ sulfuric acid, assuming complete dissociation of both protons. **[2]**

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(c) A $0.100\,\text{mol}\,\text{dm}^{-3}$ solution of a weak acid, HA, has a pH of 3.20 at 298 K. Calculate K_a for the acid. Use section 1 of the data booklet. **[2]**

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(d) Determine the mass of sodium ethanoate, CH_3COONa, that must be dissolved in $500\,\text{cm}^3$ of $0.100\,\text{mol}\,\text{dm}^{-3}$ ethanoic acid to give a buffer of pH 5.00. $pK_a(CH_3COOH) = 4.76$. Use sections 1 and 7 of the data booklet. **[3]**

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(e) Acidified potassium manganate(VII) was used to determine the concentration of an iron(II) solution.

$$MnO_4^-(aq) + 5\,Fe^{2+}(aq) + 8\,H^+(aq) \longrightarrow Mn^{2+}(aq) + 5\,Fe^{3+}(aq) + 4\,H_2O(l)$$

(i) A $25.0\,\text{cm}^3$ sample of the iron(II) solution required $21.5\,\text{cm}^3$ of $0.0200\,\text{mol}\,\text{dm}^{-3}$ potassium manganate(VII). Calculate the concentration of the iron(II) solution, in $\text{mol}\,\text{dm}^{-3}$. **[3]**

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(ii) State the colour change observed at the end point. **[1]**

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End of examination.

Total: 90 marks