Chemistry

Higher Level

Paper 2 — Mock Examination

Mock Exam 1

Calculator required

Time allowed: **2 hours 30 minutes**

Maximum mark: **90 marks**

Candidate information

Candidate name: .....

Session number: .....

Date: .....

Topic emphasis: models of the particulate nature of matter, models of bonding and structure, what drives chemical reactions, how much / how fast / how far, what are the mechanisms of chemical change, and the tools of the chemist (spectroscopy and calorimetry).

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 $L = 6.02 \times 10^{23}\,\text{mol}^{-1}$, the Faraday constant to be $F = 9.65 \times 10^{4}\,\text{C}\,\text{mol}^{-1}$ 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	[19 marks]
Question 2	[18 marks]
Question 3	[26 marks]
Question 4	[12 marks]
Question 5	[15 marks]
Total	**[90 marks]**

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

1. Sulfur dioxide, SO_2, is formed when sulfur-containing fossil fuels are burned. It is also the starting material for the industrial manufacture of sulfuric acid by the Contact process.

(a) (i) Write an equation for the formation of sulfur dioxide from sulfur. **[1]**

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(ii) Outline **one** environmental consequence of sulfur dioxide emissions. **[1]**

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(b) (i) Draw the Lewis formula of SO_2 and state its molecular geometry and bond angle. **[2]**

Molecular geometry: . . . . . .

Bond angle: . . . . . .

(ii) Explain why SO_2 is a polar molecule whereas SO_3 is non-polar. **[2]**

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(This question continues on the following page)

(Question 1 continued)

(c) Sulfur dioxide is oxidized to sulfur trioxide in a reversible reaction.

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g) \qquad \Delta H^{\ominus} = -196\,kJ\,mol^{-1}$$

(i) Deduce the equilibrium constant expression, K_c, for this reaction. **[1]**

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(ii) At 700 K a 2.00 dm^3 vessel at equilibrium was found to contain 0.40 mol SO_2, 0.20 mol O_2 and 1.60 mol SO_3. Calculate the value of K_c at this temperature. **[2]**

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(iii) Predict, with a reason, the effect of increasing the temperature on the value of K_c. **[1]**

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(iv) State and explain the effect of increasing the pressure on the equilibrium yield of SO_3.**[2]**

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(v) Suggest why a temperature of approximately 700 K is used industrially, even though a lower temperature would give a greater equilibrium yield. **[1]**

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(vi) State the effect of the V_2O_5 catalyst on the value of K_c and on the time taken to reach equilibrium. **[1]**

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(This question continues on the following page)

(Question 1 continued)

(d) Sulfur trioxide is converted into sulfuric acid.

$$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$$

(i) Calculate the mass, in kg, of sulfuric acid produced from 1.00 kg of sulfur trioxide if the yield of the reaction is 95.0 %. Use sections 6 and 7 of the data booklet. **[2]**

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(ii) A 25.0 cm^3 sample of the sulfuric acid produced required 28.4 cm^3 of 0.150 mol dm^{-3} sodium hydroxide solution for complete neutralization. Calculate the concentration of the sulfuric acid, in mol dm^{-3}. **[2]**

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(e) Sulfuric acid contributes to acid deposition. Write an equation for the reaction of dilute sulfuric acid with calcium carbonate. **[1]**

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2. Magnesium is a group 2 metal that forms a range of ionic compounds.

(a) (i) State the full electron configuration of the Mg^{2+} ion. **[1]**

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(ii) Explain why the radius of Mg^{2+} is smaller than the radius of a magnesium atom. **[1]**

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(b) The first six successive ionization energies of magnesium, in kJ mol^{-1}, are given below.

738	1451	7733	10 540	13 630	18 020

(i) Explain the large increase between the second and third ionization energies. **[2]**

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(ii) Explain why the first ionization energy of magnesium is greater than that of aluminium. Use section 8 of the data booklet. **[2]**

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(This question continues on the following page)

(Question 2 continued)

(c) The following data refer to magnesium oxide.

Enthalpy of formation of MgO(s)	$-602\,\text{kJ mol}^{-1}$
Enthalpy of atomization of Mg(s)	$+148\,\text{kJ mol}^{-1}$
First ionization energy of Mg	$+738\,\text{kJ mol}^{-1}$
Second ionization energy of Mg	$+1451\,\text{kJ mol}^{-1}$
Bond enthalpy of O_2	$+498\,\text{kJ mol}^{-1}$
First electron affinity of O	$-141\,\text{kJ mol}^{-1}$
Second electron affinity of O	$+753\,\text{kJ mol}^{-1}$

(i) Determine the lattice enthalpy of magnesium oxide, in kJ mol^{-1}, defined as the enthalpy change for $\text{MgO(s)} \longrightarrow \text{Mg}^{2+}\text{(g)} + \text{O}^{2-}\text{(g)}$. **[3]**

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(ii) Explain why the lattice enthalpy of magnesium oxide is much greater than that of sodium fluoride. **[2]**

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(d) The lattice enthalpy of magnesium chloride is $+2493\,\text{kJ mol}^{-1}$, the enthalpy of hydration of Mg^{2+} is $-1963\,\text{kJ mol}^{-1}$ and the enthalpy of hydration of Cl^- is $-359\,\text{kJ mol}^{-1}$. Calculate the enthalpy of solution of magnesium chloride, in kJ mol^{-1}. **[2]**

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(This question continues on the following page)

(Question 2 continued)

(e) A student added 0.240 g of magnesium powder to 50.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid in a polystyrene cup. The temperature of the solution rose by 10.2 °C.

$$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$$

(i) Determine the enthalpy change of this reaction, in kJ mol^{-1} of magnesium. Assume the density of the solution is 1.00 g cm^{-3}. Use sections 1 and 2 of the data booklet. **[3]**

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(ii) State **two** assumptions made in this determination. **[2]**

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3. Propene, $CH_3CH=CH_2$, obtained from the cracking of long-chain alkanes, is the starting point for many industrial products.

(a) Propene reacts with hydrogen bromide.

(i) State the type of reaction, name the major organic product and explain why this product predominates. **[2]**

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(ii) Sketch the mechanism for the formation of the major product, using curly arrows to represent the movement of electron pairs. **[3]**

(This question continues on the following page)

(Question 3 continued)

(b) The product formed in (a) is warmed with dilute aqueous sodium hydroxide.

(i) Name the organic product and state the type of reaction. **[1]**

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(ii) Outline why this halogenoalkane may react by both the S_N1 and S_N2 mechanisms. **[1]**

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(iii) Predict, with a reason, how the rate would change if 2-iodopropane were used instead. Use section 12 of the data booklet. **[1]**

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(c) Propan-2-ol is heated with acidified potassium dichromate(VI).

(i) Name the organic product and state the colour change observed. **[2]**

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(ii) Write an equation for this oxidation, using [O] to represent the oxidizing agent. **[1]**

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(iii) Explain why the product of this reaction cannot be oxidized further, whereas the product obtained from propan-1-ol under reflux can. **[1]**

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(This question continues on the following page)

(Question 3 continued)

(d) Compound **X** gave the following data.

Mass spectrum	molecular ion peak at $m/z = 60$
Infrared spectrum	broad absorption at 3200–3600 cm^{-1}; no absorption near 1700 cm^{-1}
^1H NMR	doublet (6H) at 1.2 ppm; septet (1H) at 3.9 ppm; singlet (1H) at 2.2 ppm

(i) Deduce the structure of **X**, giving your reasoning. Use sections 20 and 21 of the data booklet. **[2]**

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(ii) Explain why the signal at 3.9 ppm is split into a septet. **[1]**

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(e) 2-hydroxypropanoic acid, $CH_3CH(OH)COOH$, exists as two optical isomers.

(i) Draw the structural formula of the molecule and mark the chiral carbon with an asterisk (*). **[1]**

(ii) State how the two optical isomers can be distinguished experimentally. **[1]**

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(This question continues on the following page)

(Question 3 continued)

(f) Propan-2-ol is heated under reflux with ethanoic acid and a few drops of concentrated sulfuric acid.

(i) Write an equation for the reaction and name the organic product. **[2]**

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(ii) State the role of the concentrated sulfuric acid. **[1]**

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(g) Propene can be polymerized.

(i) State the type of polymerization. **[1]**

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(ii) Draw one repeating unit of poly(propene). **[1]**

(h) Compare the atom economy of the addition of hydrogen bromide to propene with that of the substitution reaction in (b). Support your answer with a calculation for the addition reaction.**[2]**

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(This question continues on the following page)

(Question 3 continued)

(i) A hydrocarbon contains 85.7 % carbon and 14.3 % hydrogen by mass and has a molar mass of 42.08 g mol^{-1}. Determine its empirical formula and its molecular formula. **[2]**

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4. Dinitrogen pentoxide decomposes in the gas phase.

$$2\,N_2O_5(g) \longrightarrow 4\,NO_2(g) + O_2(g)$$

The following data were obtained at 320 K.

Experiment	$[N_2O_5]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.100	5.40×10^{-4}
2	0.200	1.08×10^{-3}
3	0.400	2.16×10^{-3}

(a) Deduce the order of reaction with respect to N_2O_5 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) Calculate the half-life of the reaction at 320 K. **[1]**

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(This question continues on the following page)

(Question 4 continued)

(d) The following mechanism has been proposed.

Step 1 $N_2O_5 \longrightarrow NO_2 + NO_3$
Step 2 $NO_2 + NO_3 \longrightarrow NO + O_2 + NO_2$
Step 3 $NO + N_2O_5 \longrightarrow 3\,NO_2$

(i) Deduce which step is the rate-determining step, explaining how this is consistent with the rate equation in (a). **[2]**

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(ii) Identify **one** reaction intermediate. **[1]**

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(iii) State the molecularity of step 1. **[1]**

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(e) The rate constant increases to $2.90 \times 10^{-2}\,s^{-1}$ at 340 K. Determine the activation energy of the reaction, in $kJ\,mol^{-1}$. Use sections 1 and 2 of the data booklet. **[3]**

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5. Electrochemical cells are used both to generate electricity and to bring about non-spontaneous reactions.

(a) A voltaic cell is made from a zinc half-cell and a copper half-cell under standard conditions.

(i) Determine the standard cell potential. Use section 19 of the data booklet. **[1]**

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(ii) Deduce the overall equation for the spontaneous cell reaction and state the direction of electron flow in the external circuit. **[2]**

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(iii) Calculate the standard Gibbs energy change, in $kJ\,mol^{-1}$, for the cell reaction. Use section 1 of the data booklet. **[2]**

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(This question continues on the following page)

(Question 5 continued)

(b) Concentrated aqueous sodium chloride is electrolysed using inert graphite electrodes.

(i) Deduce the half-equation for the reaction at each electrode and identify the product formed at each. **[2]**

Anode: .....

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Cathode: .....

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(ii) A current of 1.50 A was passed through aqueous copper(II) sulfate for 30.0 minutes. Calculate the mass of copper deposited at the cathode. **[2]**

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(c) Ethanoic acid is a weak acid with $K_a = 1.8 \times 10^{-5}$ at 298 K.

(i) Calculate the pH of 0.200 mol dm^{-3} ethanoic acid. Use section 1 of the data booklet. **[2]**

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(ii) Sodium ethanoate is dissolved in this solution to give a concentration of 0.150 mol dm^{-3}. Calculate the pH of the resulting buffer solution. **[2]**

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(iii) Explain, using equations, how this buffer resists a change in pH when a small amount of hydrochloric acid is added. **[2]**

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End of examination.

Total: 90 marks