Centre Number						Candidate Number				
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Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
TOTAL	

General Certificate of Education
Advanced Level Examination
June 2015

Applied Science SC11

Unit 11 Controlling Chemical Processes

Monday 8 June 2015 1.30 pm to 3.00 pm

For this paper you must have:
- a pencil
- a ruler
- a calculator.

Time allowed
- 1 hour 30 minutes

A

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- Do all rough work in this book. Cross through any work you do not want to be marked.
- Show the working of your calculations.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 80.
- You will be marked on your ability to
  - use good English
  - organise information clearly
  - use specialist vocabulary where appropriate.
- You are expected to use a calculator where appropriate.

Answer **all** questions in the spaces provided.

1 Industrial chemists must consider the rate of reaction for each reaction they use. It is important to find the conditions that provide the required product in a reasonable time.

1 (a) Explain what is meant by the term **rate of reaction**.

[2 marks]

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1 (b) Two reactants, **A** and **B**, have been investigated by industrial research chemists. Both reactants are used in aqueous solution. The results of the investigation are shown in **Table 1**.

Table 1

Experiment	Initial concentration of A (mol dm^{-3})	Initial concentration of B (mol dm^{-3})	Initial rate of reaction (mol dm^{-3} s^{-1})
1	0.10	0.10	3.10×10^{-2}
2	0.10	0.20	1.24×10^{-1}
3	0.05	0.10	1.55×10^{-2}

Use the results in **Table 1** to determine the order of reaction with respect to the reactants **A** and **B**. Explain how you decided on your answers.

[4 marks]

Order with respect to **A**.....

Explanation .....

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Order with respect to **B** .....

Explanation .....

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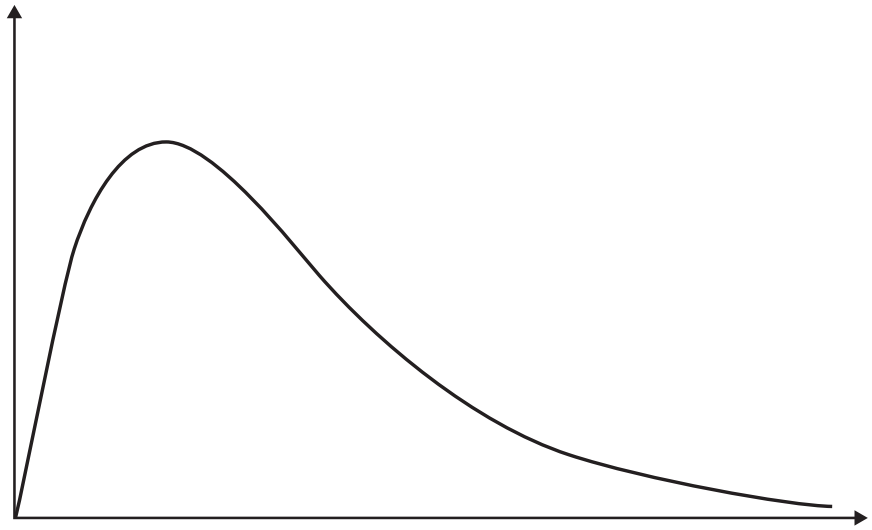
1 (c) Industrial chemists often need to control the rate of a reaction for the safety of the workforce. They may do this by considering the temperature at which the reaction takes place.

Figure 1 shows a Maxwell–Boltzmann curve showing the distribution of energies of particles. This curve can be used to explain why a decrease in temperature decreases the rate of a reaction.

Figure 1



1 (c) (i) Add the correct labels to the vertical and horizontal axes in **Figure 1**.

[2 marks]

1 (c) (ii) On **Figure 1**, sketch the curve you would expect for the same particles at a lower temperature.

[2 marks]

1 (c) (iii) Use the idea of activation energy to explain why a decrease in temperature decreases the rate of a chemical reaction.

[3 marks]

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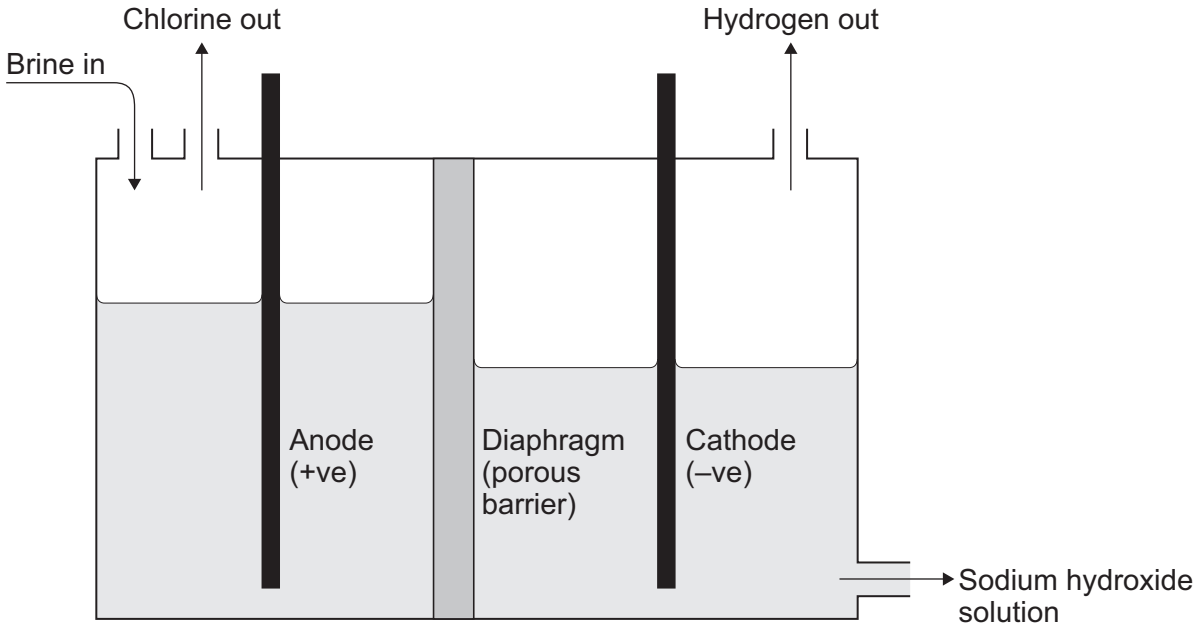
2 The chloralkali industry produces three useful substances from brine (sodium chloride solution). Two of the substances produced are chlorine gas and hydrogen gas.

Figure 2 shows one of the types of electrolysis cell that is used.

Figure 2



2 (a) (i) State **one** hazard of chlorine gas.

[1 mark]

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2 (a) (ii) Suggest **one** appropriate safety precaution to be taken by the workers exposed to chlorine in order to avoid this hazard.

[1 mark]

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2 (a) (iii) Give **one** use for chlorine.

[1 mark]

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2 (b) Sodium hydroxide solution is the other product made using the electrolysis cell.

Give **one** use for sodium hydroxide.

[1 mark]

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2 (c) Development chemists must consider the costs involved in industrial processes. Costs involved in industrial processes can be classified as:

capital costs, direct costs, indirect costs

2 (c) (i) Classify each of the following as **one** of the above costs:

[4 marks]

electricity for electrolysis .....

labour .....

construction of the chemical plant .....

research and development .....

2 (c) (ii) Define the term **indirect costs**.

[2 marks]

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Question 2 continues on the next page

2 (d) (i) The electrolysis process shown in **Figure 2** operates as a continuous process.

What is meant by a **continuous process**?

[2 marks]

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2 (d) (ii) Give **two** advantages of a continuous process compared with a batch process.

[2 marks]

Advantage 1 .....

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Advantage 2 .....

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2 (e) The balanced symbol equation for the electrolysis process in **Figure 2** is:

$$2NaCl + 2H_2O \rightarrow H_2 + Cl_2 + 2NaOH$$

2 (e) (i) Calculate the relative molecular mass, M_r, of sodium chloride, NaCl.

(Relative atomic masses: Na = 23, Cl = 35.5)

[1 mark]

M_r of sodium chloride = ...

2 (e) (ii) Use the balanced symbol equation to calculate the mass of chlorine, Cl_2, formed when 740 kg of sodium chloride is electrolysed.

[3 marks]

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Mass = ...kg

2 (e) (iii) Calculate the mass of sodium chloride that would be needed to form the same mass of chlorine as you calculated in part (e)(ii) if the electrolysis were only 85% efficient.

[1 mark]

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Mass = ...kg

19

Turn over for the next question

3 Analytical chemists use a variety of techniques, including titrimetric analysis.

Titrimetric analysis is suitable for studying the rate of reactions such as that between iodine and propanone. This reaction is catalysed by an acid.

$$CH_3COCH_3 + I_2 + H^+ \rightarrow CH_3COCH_2I + 2H^+ + I^-$$

propanone; iodine; hydrogen ions; hydrogen ions; iodide ions

3 (a) Small portions of the reaction mixture are removed at intervals and are quenched with an alkali.

Explain why the sample is quenched.

[1 mark]

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3 (b) Unreacted iodine is a red-brown colour.

The quenched mixture is analysed by titrating the unreacted iodine against a standard solution of sodium thiosulfate.

3 (b) (i) Balance the ionic equation for the reaction of iodine with sodium thiosulfate.

[2 marks]

$$I_2 + S_2O_3^{2-} \rightarrow I^- + S_4O_6^{2-}$$

3 (b) (ii) Calculate the oxidation state of sulfur in the thiosulfate, $S_2O_3^{2-}$ ion.

[1 mark]

Oxidation state of S = ...

3 (b) (iii) What is the type of reaction between iodine and sodium thiosulfate called?

[1 mark]

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3 (c) An analytical chemist wants to determine the rate of reaction between iodine and propanone. To do this, the analytical chemist mixes 50 cm^3 of 0.02 mol dm^{-3} iodine solution with 50 cm^3 of acidified 0.25 mol dm^{-3} propanone solution.

3 (c) (i) List the apparatus the analytical chemist would use.

[3 marks]

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Question 3 continues on the next page

3 (c) (ii) Describe how the analytical chemist would do the experiment to determine the rate of reaction between iodine and propanone.

You will be assessed on the quality of written communication in your answer to this question.

[5 marks]

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Extra space (if needed) .....

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3 (c) (iii) The analytical chemist would use a graph of the results to find the rate of reaction.

State the quantity that would be plotted on each axis.

[2 marks]

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3 (c) (iv) Describe how the analytical chemist would calculate the rate of reaction from the graph in part (c)(iii).

[1 mark]

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3 (d) Suggest another analytical method that could be used to study the rate of reaction between iodine and propanone.

[1 mark]

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17

Turn over for the next question

4 Many industrial processes involve reversible reactions. Chemical engineers need to think carefully about the conditions used to ensure a good yield.

4 (a) The manufacture of nitric acid involves three stages. The first stage is the catalytic oxidation of ammonia to nitrogen monoxide.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^{\ominus} = -950 \text{ kJ mol}^{-1}$$

Which of the following terms means that all the reactants and products in this reaction are in the same state? Circle the correct answer.

[1 mark]

heterogeneous homolytic heterolytic homogeneous

4 (b) This reaction is reversible and therefore, after some time, a dynamic equilibrium is established.

4 (b) (i) Write an expression for the equilibrium constant, K_c, for this reaction.

[2 marks]

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4 (b) (ii) Use your expression for K_c in part (b)(i) to determine the units of K_c.

[1 mark]

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4 (c) (i) State Le Chatelier's principle.

[2 marks]

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4 (c) (ii) Use Le Chatelier's principle to decide what effect increasing the temperature will have on the equilibrium yield of nitrogen monoxide. Explain your answer.

[3 marks]

Effect .....

Explanation .....

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Question 4 continues on the next page

4 (c) (iii) The equation for the oxidation of ammonia to nitrogen monoxide is:

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^{\ominus} = -950 \text{ kJ mol}^{-1}$$

Explain how an increase in pressure will affect the equilibrium yield of nitrogen monoxide and the rate at which nitrogen monoxide is produced.

You will be assessed on the quality of written communication in your answer to this question.

[5 marks]

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Extra space (if needed) .....

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4 (d) The expression for the equilibrium constant for a different reaction is:

$$K_c = \frac{[X]^2}{[Y][Z]^2}$$

For this reaction, assume the following experimental results:

[X] = 0.57 mol dm^{-3}

[Z] = 0.84 mol dm^{-3}

number of moles of Y = 3.74

volume of reaction vessel = 2.3 dm^3

Use these results to calculate the value of the equilibrium constant, K_c.

[3 marks]

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K_c = ...

17

Turn over for the next question

5 Alkenes, obtained from crude oil, are used to make polymers. Propenenitrile is a monomer required for the manufacture of several polymers. Propenenitrile can be formed from propene.

$$2C_3H_6 + 2NH_3 + 3O_2 \rightarrow 2C_2H_3CN + 6H_2O$$

propene ammonia oxygen propenenitrile water

Chemical engineers need to know the enthalpy changes of all the reactions in an industrial process. Both enthalpy of formation data and mean bond enthalpy data can be used to calculate an enthalpy change.

5 (a) Use the enthalpy of formation data shown in **Table 2** to calculate the enthalpy change when one mole of propenenitrile is made from propene.

Table 2

Substance	Water	Oxygen	Ammonia	Propene	Propenenitrile
Enthalpy of formation (kJ mol^{-1})	−241.8	0	−394.4	+20.2	+147.2

[4 marks]

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Enthalpy change = ...kJ mol^{-1}

5 (b) State the meaning of the term **mean bond enthalpy**.

[2 marks]

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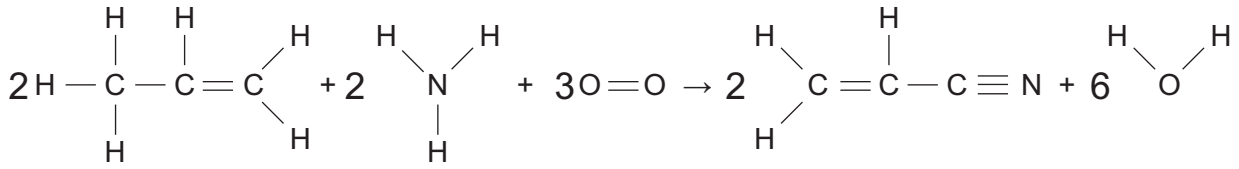
5 (c) Use the formula below and the mean bond enthalpy data in **Table 3** to calculate the enthalpy change when one mole of propenenitrile is made from propene.



propene ammonia oxygen propenenitrile water

Table 3

Bond	C−C	C=C	C−H	H−O	O=O	C≡N	N−H
Mean bond enthalpy (kJ mol^{-1})	346	610	413	463	497	887	390

[4 marks]

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Enthalpy change = ... kJ mol^{-1}

5 (d) The enthalpy changes calculated in parts (a) and (c) are significantly different.

Which answer do you think is closer to the true enthalpy change? Explain why.

[1 mark]

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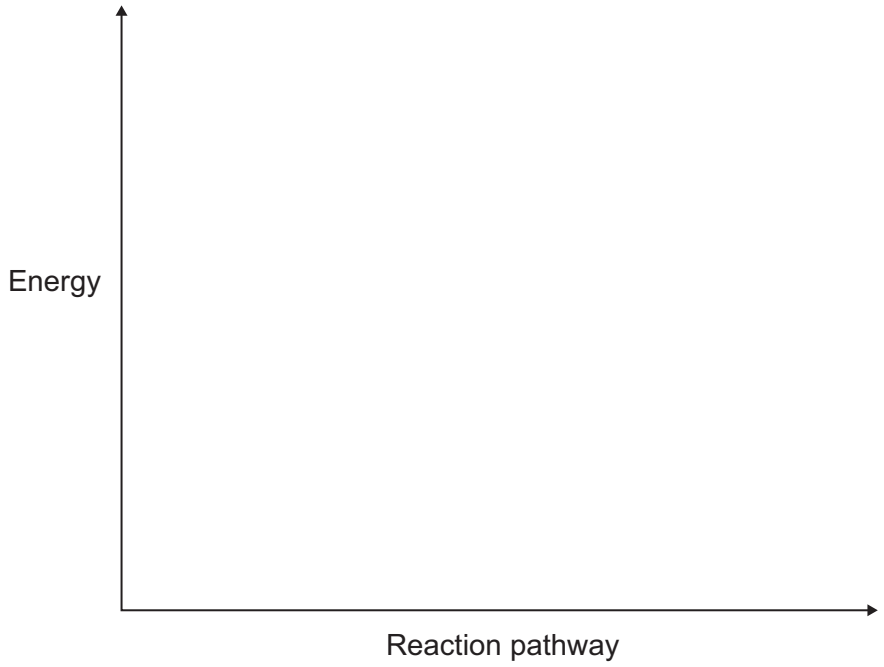
Question 5 continues on the next page

5 (e) On **Figure 3** sketch the reaction profile you would expect for the formation of propenenitrile from propene.

[3 marks]

Figure 3



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END OF QUESTIONS

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