Surname		Other Names	
Centre Number			Candidate Number				
Candidate Signature									

For Examiner's Use

General Certificate of Education
January 2009
Advanced Level Examination

APPLIED SCIENCE **SC11**
Unit 11 Controlling Chemical Processes

Tuesday 27 January 2009 9.00 am to 10.30 am

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

Time allowed: 1 hour 30 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- You must answer **all** questions.
- You must answer the questions in the spaces provided. Answers written in margins or on blank pages will not be marked.
- 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 maximum mark for this paper is 80.
- The marks for questions are shown in brackets.
- You are expected to use a calculator where appropriate.

For Examiner's Use			
Question	Mark	Question	Mark
1		5	
2			
3			
4			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

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

1 A chemical company manufactures ethyl ethanoate, $CH_3COOCH_2CH_3$, which is often used as a solvent. It is produced by the reaction of ethanol with ethanoic acid.

$$\underset{\text{ethanol}}{CH_3CH_2OH} + \underset{\text{ethanoic acid}}{CH_3COOH} \rightleftharpoons \underset{\text{ethyl ethanoate}}{CH_3COOCH_2CH_3} + H_2O$$

This is a reversible reaction and, after some time, a dynamic equilibrium is established.

1 (a) Explain what is meant by a *dynamic equilibrium*.

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(2 marks)

1 (b) (i) Write an expression for the equilibrium constant, K_c for the reaction above.

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(2 marks)

1 (b) (ii) Calculate a value for the equilibrium constant when the number of moles of each substance at equilibrium is:

	CH_3CH_2OH ethanol	CH_3COOH ethanoic acid	$CH_3COOCH_2CH_3$ ethyl ethanoate	H_2O water
Number of moles	0.5	0.6	0.9	1.2

The total volume of the equilibrium mixture is 1.5 dm^3.

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(3 marks)

1 (c) A technician in the solvent manufacturer's laboratory has been asked to analyse various equilibrium mixtures. The technician decides to investigate the effect of temperature on the equilibrium.
The mixtures all start with the same concentrations of ethanol and ethanoic acid and a small amount of hydrochloric acid catalyst. They are left at 20°C, 30°C, 40°C, 50°C and 60°C for some time until equilibrium is reached. Each mixture is then analysed by titration.

1 (c) (i) Suggest what type of container should be used for the reaction to ensure that dynamic equilibrium is established.

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(1 mark)

1 (c) (ii) How might the technician effectively stop a reaction to make sure no further reactions occur during the analysis?

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(1 mark)

1 (c) (iii) Describe how the technician would carry out a titration to analyse one of the mixtures.
Include a list of apparatus and procedures to ensure reliability.

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(6 marks)

Question 1 continues on the next page

1 (c) (iv) One of the equilibrium mixtures might have had different initial concentrations from the others. It is suspected that the volumes could have been measured inaccurately. State how the technician could ensure that the results were checked so that any such error could be identified.

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(1 mark)

1 (c) (v) The total number of moles of acid in each equilibrium mixture can be calculated from the titration results. The technician needs to subtract from each result the number of moles of hydrochloric acid originally added.
How does the technician know that this amount will remain unchanged?

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(1 mark)

1 (c) (vi) How will the hydrochloric acid affect the position of equilibrium?
Explain your answer.

Effect .....

Explanation .....

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(2 marks)

19

2 Industrial chemists often need to know enthalpy changes. The enthalpy of combustion of an alcohol can either be determined experimentally or can be calculated using enthalpies of formation.

Ethanol forms carbon dioxide and water on combustion.

$$\underset{\text{ethanol}}{C_2H_5OH} + 3O_2 \longrightarrow 2CO_2 + 3H_2O$$

2 (a) (i) Use the following enthalpy of formation data to calculate the enthalpy of combustion for ethanol.

	C_2H_5OH	O_2	CO_2	H_2O
Enthalpy of formation/ $kJmol^{-1}$	–278	0	–394	–286

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(3 marks)

2 (a) (ii) Explain why the enthalpy of formation for oxygen is zero.

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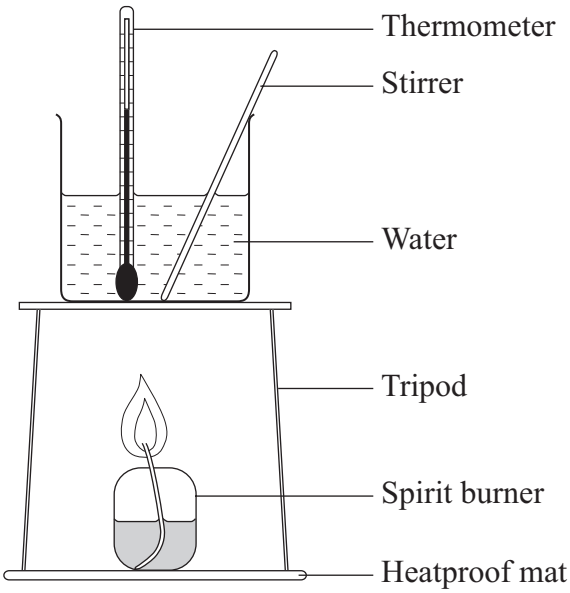
(1 mark)

Question 2 continues on the next page

2 (b) The enthalpy of combustion for ethanol can be determined using a spirit burner containing ethanol to heat a known mass of water.



The results for an experiment carried out as shown are given in the table.

Mass of water	150 g
Mass of spirit burner and ethanol before experiment	62.09 g
Mass of spirit burner and ethanol after experiment	61.26 g
Temperature of the water before experiment	22°C
Temperature of the water at the end of the experiment	43°C

2 (b) (i) What is the temperature rise of the water in this experiment?

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(1 mark)

2 (b) (ii) Calculate the heat energy released in this experiment.
(Specific heat capacity of water = 4.2 $J\,g^{-1}\,{}^{o}C^{-1}$)

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(4 marks)

2 (b) (iii) Calculate the number of moles of ethanol burned in this experiment.
The relative molecular mass, M_r, of ethanol is 46.

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(2 marks)

2 (b) (iv) Use your answers to part (b)(ii) and part (b)(iii) to calculate the experimentally determined enthalpy of combustion for ethanol.

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(2 marks)

2 (b) (v) Suggest **two** reasons why your answers to part (a)(i) and part (b)(iv) are so different.

Reason 1 .....

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Reason 2 .....

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(2 marks)

15

3 An example of a reaction in which the reactants and products are in the gaseous state is the reaction of hydrogen with iodine to form hydrogen iodide.

$$H_2(g) + I_2(g) \longrightarrow 2HI(g) \qquad \Delta H = -10\,kJ\,mol^{-1}$$

3 (a) What term is used for a reaction where all the reactants and products have the same state?

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(1 mark)

3 (b) The rate of this reaction is first order with respect to each of the reactants.

3 (b) (i) Write the rate equation for this reaction.

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(1 mark)

3 (b) (ii) What would be the effect on the initial rate of reaction if the concentration of iodine was doubled but the concentration of hydrogen was kept the same?

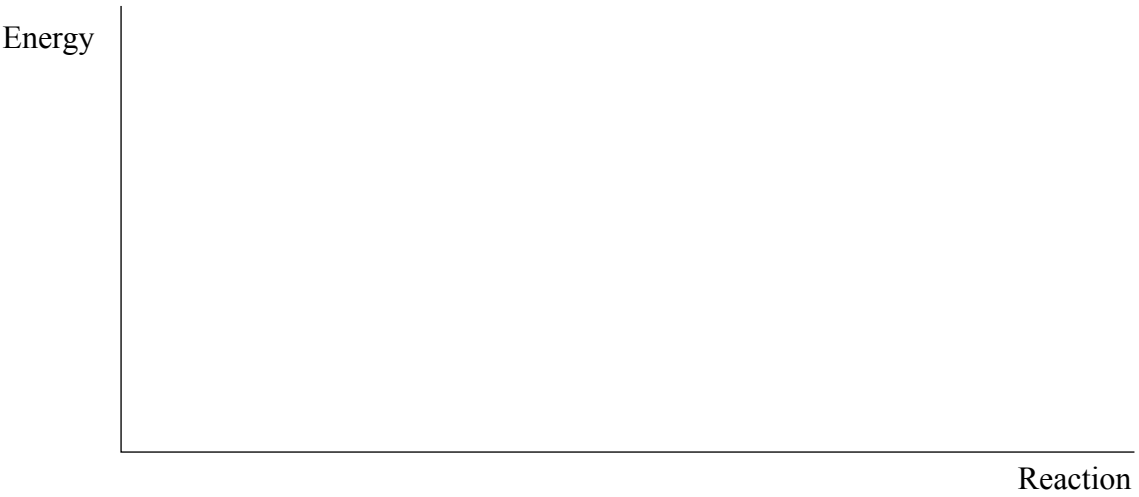
.....

(1 mark)

3 (c) (i) Sketch, on the axes provided, the reaction profile you would expect for the reaction between hydrogen and iodine.

(3 marks)

3 (c) (ii) Indicate the activation energy of the reaction on your sketch. *(1 mark)*



An industrial chemist investigated the rate of reaction between two compounds, **A** and **B**. A series of experiments was carried out and the following rate equation was deduced.

$$\text{rate} = k[\mathbf{A}]^2[\mathbf{B}]$$

3 (d) What is the overall order of this reaction?

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(1 mark)

3 (e) Use the rate equation to complete this table.

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	0.4	0.2	4×10^{-2}
2		0.2	1×10^{-2}
3	0.4		8×10^{-2}
4	1.2	0.1	

(3 marks)

3 (f) (i) What name is given to the term k in the rate equation?

.....

(1 mark)

3 (f) (ii) Calculate the units of k for this reaction.

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(1 mark)

3 (f) (iii) State **one** change in conditions that will increase the value of k.

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(1 mark)

14

4 Crude oil is the main source of hydrocarbons. As crude oil is a finite resource, development chemists have been investigating processes that synthesise a range of hydrocarbons from coal.
Coal reacts with steam to make carbon monoxide and hydrogen.
Methane, CH_4, can be formed in the equilibrium reaction between carbon monoxide and hydrogen using a nickel catalyst.

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g) \qquad \Delta H = -205 \text{ kJ mol}^{-1}$$

4 (a) The costs involved in this industrial process can be classified as:

capital costs, direct costs, indirect costs

Classify **each** of the following as **one** of the above costs.

4 (a) (i) Sales and advertising .....

(1 mark)

4 (a) (ii) Construction of the chemical plant .....

(1 mark)

4 (a) (iii) Cost of coal .....

(1 mark)

4 (a) (iv) Maintenance of the chemical plant .....

(1 mark)

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

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(2 marks)

4 (b) (ii) What effect will increasing the pressure have on the yield of methane in this process? Use Le Chatelier's principle to explain your answer.

Effect .....

Explanation .....

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(3 marks)

4 (b) (iii) What effect will increasing the temperature have on the yield of methane in this process? Use Le Chatelier's principle to explain your answer.

Effect .....

Explanation .....

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(3 marks)

4 (c) Define the term activation energy, E_a.

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(2 marks)

4 (d) (i) On the axes provided, sketch a Maxwell–Boltzmann distribution curve to show the distribution of energy among the molecules in a mixture of gases. Indicate the activation energy on your sketch.

(4 marks)

Question 4 continues on the next page

4 (d) (ii) Use the idea of activation energy to explain why an increase in temperature increases the rate of a reaction.

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(3 marks)

21

5 Nitrous oxide, N_2O, has been used for many years as an anaesthetic. It is manufactured by the thermal decomposition of ammonium nitrate in a continuous process.

$$NH_4NO_3 \longrightarrow N_2O + 2H_2O$$

5 (a) (i) Explain what is meant by the term *continuous process*.

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(2 marks)

5 (a) (ii) Give **two** ways in which a continuous process reduces costs compared to a batch process.

1 .....

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2 .....

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(2 marks)

5 (a) (iii) Suggest a situation where a batch process may be preferred to a continuous process.

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(1 mark)

5 (b) (i) Calculate the relative molecular masses of ammonium nitrate and nitrous oxide. (Relative atomic masses: N=14, O=16, H=1)

M_r ammonium nitrate, NH_4NO_3 .....

.....

M_r nitrous oxide, N_2O .....

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(2 marks)

Question 5 continues on the next page

5 (b) (ii) Calculate the mass of ammonium nitrate required to make 132 kg of nitrous oxide.

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(3 marks)

5 (b) (iii) Calculate the percentage yield of nitrous oxide achieved if only 103 kg of the product is formed instead of the expected 132 kg.

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(1 mark)

11

END OF QUESTIONS

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