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
January 2012

Applied Science SC11

Unit 11 Controlling Chemical Processes

Thursday 26 January 2012 9.00 am to 10.30 am

For this paper you must have:
- a pencil
- 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.
- 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 Many industrial processes are continuous. This is because continuous processes produce large amounts of substances cost effectively. A smaller number of processes are classified as batch processes.

1 (a) (i) What is meant by a *continuous process*?

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(2 marks)

1 (a) (ii) Apart from being cost effective, give **two other** advantages of a continuous process compared to a batch process.

1 .....

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2 .....

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(2 marks)

1 (b) Titanium is a very strong and corrosion resistant metal. Despite being expensive to produce, it is widely used in the aerospace industry.
It is extracted from its ore, which is mainly titanium dioxide, TiO_2.

The extraction of titanium is a two-stage process.

First the titanium dioxide, TiO_2, is converted to titanium chloride, $TiCl_4$, at a temperature of about 900°C.

1 (b) (i) Balance the equation for the first stage:

Equation 1: TiO_2 + ... Cl_2 + ... C $\rightarrow$ $TiCl_4$ + ... CO

(2 marks)

The second stage is a batch process. It uses sodium to convert the titanium chloride to titanium metal and sodium chloride:

Equation 2: $TiCl_4 + 4Na \rightarrow Ti + 4NaCl$

1 (b) (ii) What is meant by a *batch process?*

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(2 marks)

1 (b) (iii) Give the oxidation state of titanium in the following:

Titanium chloride, $TiCl_4$ .....

Titanium, Ti .....

(2 marks)

1 (b) (iv) What type of reaction happens in the second stage of this production process? Use your answer to part **(b)(iii)** to decide.

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(1 mark)

1 (c) Industrial chemists try to minimise costs in both stages. The costs involved in industrial processes can be classified as:

capital costs, direct costs and **indirect costs**

1 (c) (i) Define a *direct cost*.

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(2 marks)

1 (c) (ii) Classify each of the following as one of the above costs:

Cost of sodium.....

Sales and advertising .....

Construction of the chemical plant .....

(3 marks)

16

2 Crude oil provides many useful hydrocarbons, including butane and propane. Butane and propane are conveniently stored as liquids under pressure in canisters and are used in camping stoves.

The enthalpy change of combustion of a hydrocarbon must be considered by engineers when they are developing new designs of camping stoves.

2 (a) Explain what is meant by *enthalpy change of combustion*.

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(2 marks)

2 (b) A chemist working for a camping stove manufacturer has been asked to determine the enthalpy change of combustion of butane.

2 (b) (i) Suggest the apparatus that could be used to conduct such an experiment.

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(3 marks)

2 (b) (ii) Describe how the chemist would carry out the experiment and how the chemist would use the results to calculate the enthalpy change.

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

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(5 marks)

2 (b) (iii) Suggest **two** ways in which the chemist could ensure that the results of this experiment were valid.

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(2 marks)

Question 2 continues on the next page

2 (c) After a camping stove had been designed it was tested in a field trial.
Two campers carried out the field trial. They decided they would need to boil 3 litres of water if they camped for one night.

Calculate the number of moles of butane they must take with them if:

- the specific heat capacity, *c*, of water is $4.2\,J\,g^{-1}\,°C^{-1}$
- the enthalpy change of combustion of butane is $-2876.5\,kJ\,mol^{-1}$
- the water had a starting temperature of 5°C.

State what assumption you have made in doing this calculation.

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Assumption .....

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(4 marks)

2 (d) (i) In a different trial the campers calculated they would require 0.732 moles of propane. However, they did not take into account the fact that the camping stove was only 80% efficient.
Calculate the number of moles of propane the campers will really need.

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(1 mark)

2 (d) (ii) What volume would this number of moles of propane gas occupy at standard temperature and pressure?
(One mole of any gas occupies $22.4\,dm^3$ under these conditions)

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.....dm^3

(1 mark)

18

3 Car manufacturers try to reduce harmful exhaust emissions.
Research chemists at car manufacturers will consider several reactions that occur in car engines.
One such reaction is the formation of nitrogen(II) oxide, NO

$$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)} \quad \Delta H = +181\,kJ\,mol^{-1}$$

This is a homogeneous dynamic equilibrium.

3 (a) (i) Explain what is meant by *homogeneous*.

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(2 marks)

3 (a) (ii) If a dynamic equilibrium is to be established, a reversible reaction is required.

What is a *reversible* reaction?

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(1 mark)

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

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(2 marks)

Question 3 continues on the next page

3 (b) (ii) Use Le Chatelier's principle to decide what effect increasing the **temperature** will have on the amount of nitrogen(II) oxide in a car engine.
Explain your answer.

Effect.....

Explanation .....

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(3 marks)

3 (b) (iii) Use Le Chatelier's principle to decide what effect increasing the **pressure** will have on the amount of nitrogen(II) oxide in a car engine.
Explain your answer.

Effect.....

Explanation .....

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(3 marks)

3 (c) (i) The expression for the equilibrium constant, K_c, for this reaction is:

$$K_c = \frac{[NO]^2}{[N_2][O_2]}$$

Calculate the value of the equilibrium constant when the number of moles of each substance at equilibrium is:

$N_2 = 0.8$
$O_2 = 0.05$
NO = 0.12

The volume of the reaction vessel is 1.5 dm^3.

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(3 marks)

3 (c) (ii) Why are there no units for this equilibrium constant?

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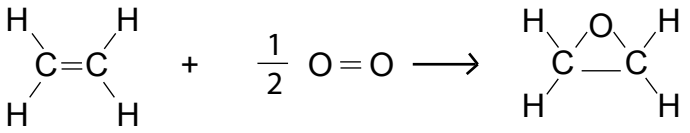
(1 mark)

15

Turn over for the next question

4 Epoxyethane is the starting material for a large range of substances including antifreeze, detergents and plastics.
Epoxyethane $(CH_2)_2O$ is made by reacting ethene, $CH_2{=}CH_2$, with oxygen gas in the presence of a silver catalyst.



4 (a) (i) An analytical chemist who works for the company that manufactures epoxyethane wants to determine the enthalpy change for this reaction.
Either mean bond enthalpies or enthalpy of formation data can be used to calculate this enthalpy change.

Use the following enthalpy of formation data to calculate the enthalpy change when one mole of epoxyethane is formed from ethene and oxygen.

	$CH_2{=}CH_2$	O_2	$(CH_2)_2O$
Enthalpy of formation/ kJ mol^{-1}	+52.3	0	–77.6

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(2 marks)

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

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(1 mark)

4 (a) (iii) Use the following mean bond enthalpy data and the chemical equation on page 10 to calculate the enthalpy change when one mole of epoxyethane is formed from ethene and oxygen.

	C–O	C=C	C-H	C–C	O=O
Mean bond enthalpy/ kJ mol^{-1}	360	612	413	348	496

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(3 marks)

4 (a) (iv) Explain why your answers to parts **(a)(i)** and **(a)(iii)** differ.

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(2 marks)

4 (b) The temperature of the production of epoxyethane must be controlled carefully. Not only is the reaction exothermic but the product, epoxyethane, is toxic, explosive and flammable.

Apart from controlling the temperature of the reaction vessel, suggest a safety precaution the epoxyethane manufacturer must take.

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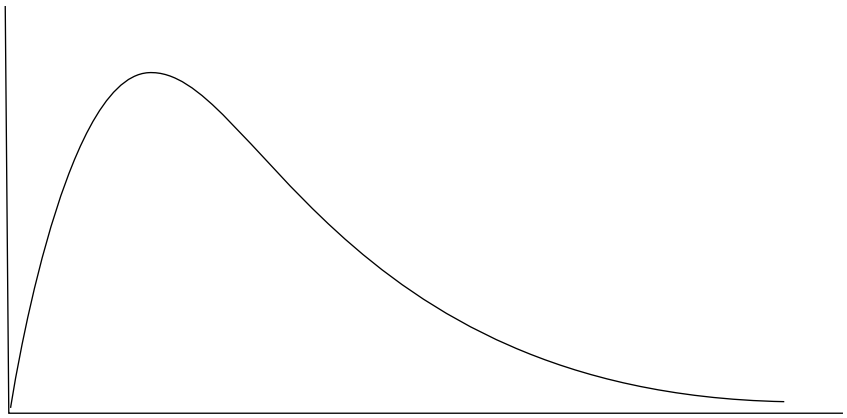
(1 mark)

Question 4 continues on the next page

4 (c) A Maxwell–Boltzmann curve showing the distribution of energies of particles can be used to explain why a decrease in temperature decreases the rate of a reaction. Such a curve is shown below.



4 (c) (i) Label the vertical and horizontal axes on the graph. *(2 marks)*

4 (c) (ii) On the graph, sketch the curve you would expect for the same particles at a lower temperature. *(2 marks)*

4 (c) (iii) Define and use the idea of activation energy to explain why a decrease in temperature decreases the rate of a reaction.

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

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(5 marks)

18

5 Research chemists often carry out investigations into the rate of a reaction when they want information about how molecules react. Three reactants, **A**, **B** and **C** were investigated. The three reactants were used as solutions in water.

The rate equation is found to be rate = $k[A]^2[B][C]$

5 (a) What is the overall order of the reaction?

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(1 mark)

5 (b) (i) The results of the investigation are shown in the table.

Use the rate equation to complete the table.

(2 marks)

Expt	Initial concentration of A ($mol\,dm^{-3}$)	Initial concentration of B ($mol\,dm^{-3}$)	Initial concentration of C ($mol\,dm^{-3}$)	Initial rate of reaction ($mol\,dm^{-3}\,s^{-1}$)
1	0.1	0.1	0.1	1.1×10^{-3}
2	0.2	0.1	0.1	
3	0.1		0.4	1.32×10^{-2}

5 (b) (ii) In the rate equation, what is *k* called?

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(1 mark)

5 (b) (iii) Calculate the value of *k*.

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(1 mark)

5 (b) (iv) What are the units of *k*?

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(1 mark)

Question 5 continues on the next page

Turn over ▶

5 (c) Industrial chemists often use catalysts to achieve the desired rate of an industrial process. They must consider many factors, including enthalpy change of reaction and activation energy, to get the best yield.

5 (c) (i) Define the term *catalyst*.

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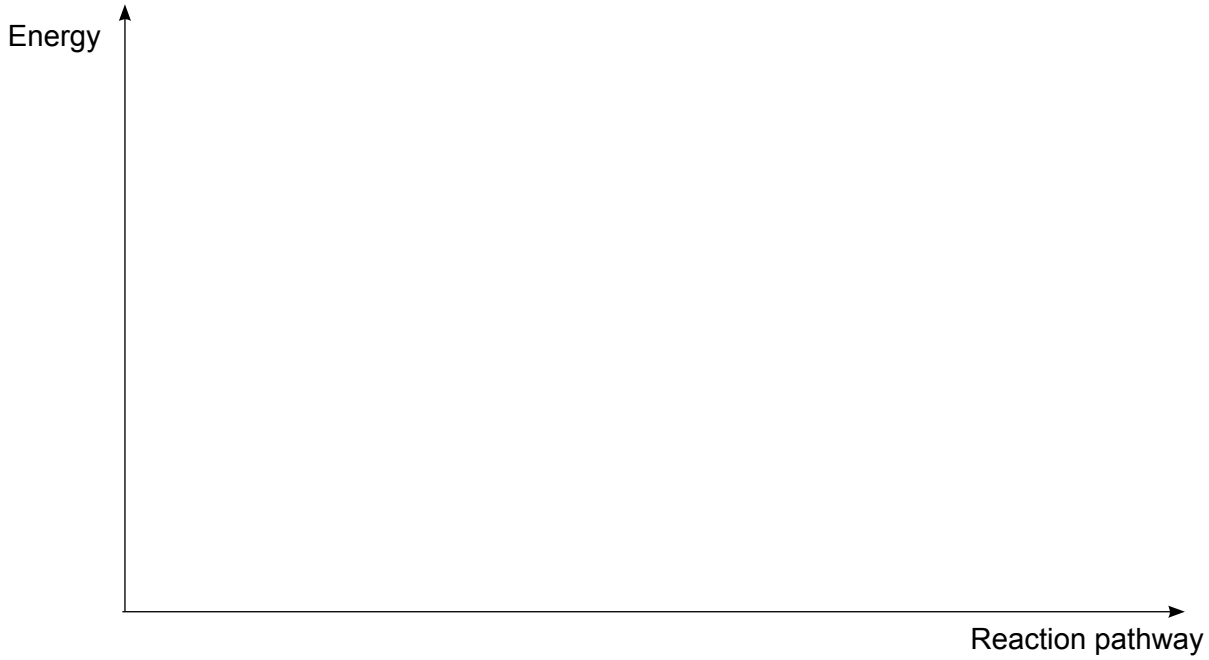
(2 marks)

5 (c) (ii) Using the axes given, sketch the reaction profile you would expect for an exothermic reaction. Label this reaction profile **1**.



(3 marks)

5 (c) (iii) On the same axes, draw the reaction profile you would expect if a catalyst were added. Label this reaction profile **2**. *(2 marks)*

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END OF QUESTIONS

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