Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
TOTAL	

General Certificate of Education
Advanced Level Examination
January 2011

Applied Science SC11

Unit 11 Controlling Chemical Processes

Wednesday 26 January 2011 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 Chemical engineers use many industrial processes. These industrial processes are classified as either batch or continuous.

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

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(2 marks)

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

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(2 marks)

1 (c) For many industrial processes, a chemical engineer would consider a continuous process to be more cost effective than a batch process.

Give **two** other advantages of a continuous process compared to a batch process.

Advantage 1 .....

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Advantage 2 .....

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(2 marks)

1 (d) Many industrial processes are continuous.
The manufacture of sulphuric acid involves the reversible process

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

1 (d) (i) State what condition is required for a dynamic equilibrium to be established.

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(1 mark)

1 (d) (ii) An expression for the equilibrium constant, K_c for this reaction is:

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

Calculate a value for the equilibrium constant when the equilibrium concentrations are

O_2 = 1.5 mol dm^{-3}
SO_2 = 0.7 mol dm^{-3}
SO_3 = 2.4 mol dm^{-3}

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(2 marks)

1 (d) (iii) What are the units of this equilibrium constant?

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(1 mark)

10

Turn over for the next question

2 Conservation chemists carry out investigations into the deterioration and conservation of archaeological objects.
Many cathedrals were constructed from limestone, which is mainly calcium carbonate ($CaCO_3$).
Acid rain can cause serious erosion of delicate limestone carvings on cathedrals.

Acid rain is usually a mixture of dilute sulphuric and dilute nitric acid. Carbon dioxide gas is a product of the reaction between calcium carbonate and an acid.

2 (a) (i) What type of reaction is the reaction between calcium carbonate and an acid?

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(1 mark)

2 (a) (ii) Balance the equation for the reaction between calcium carbonate ($CaCO_3$) and nitric acid (HNO_3).

$$CaCO_3(s) + HNO_3(aq) \rightarrow CO_2(g) + H_2O(l) + Ca(NO_3)_2(aq)$$

(1 mark)

2 (a) (iii) What word describes a reaction in which the reactants and products are not all in the same state?

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(1 mark)

2 (b) (i) Conservation chemists study the rate of erosion reactions such as these, and consider ways to slow them.

Explain what is meant by the term *rate of reaction*.

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(2 marks)

2 (b) (ii) A chemist decides to carry out an experiment to determine the rate of reaction between calcium carbonate pieces and nitric acid. During this reaction a gas is produced. List the apparatus that would be required to carry out this experiment.

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(3 marks)

2 (b) (iii) Describe how the experiment to determine the rate of reaction between calcium carbonate pieces and nitric acid would be carried out.

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

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(5 marks)

Question 2 continues on the next page

2 (b) (iv) State what precautions need to be taken to ensure that the results of this experiment are reliable if it is repeated.

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(2 marks)

2 (c) The delicate limestone carvings on the outside of a cathedral are often eroded so much that they fall from the cathedral walls and smash into many small pieces.
Why does the limestone react much faster once it is smashed into small pieces than it did when it was part of a large carving?

Use the collision theory in your answer.

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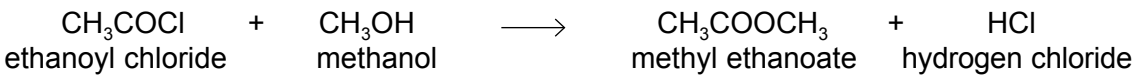
(3 marks)

18

3 Research chemists use reactive substances known as acyl chlorides to produce new, useful substances.

For example, ethanoyl chloride reacts very readily with methanol to produce methyl ethanoate. Methyl ethanoate is an ester. Esters are used as solvents and plasticisers.



3 (a) (i) Calculate the relative molecular masses of ethanoyl chloride and methyl ethanoate. (Relative atomic masses: C=12, O=16, H=1, Cl=35.5)

M_r ethanoyl chloride.....

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M_r methyl ethanoate .....

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(2 marks)

3 (a) (ii) What mass of methyl ethanoate would you expect to be produced if 10 g of ethanoyl chloride were used?

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(3 marks)

3 (a) (iii) The actual yield of methyl ethanoate achieved will be less than your answer to part (a)(ii).

Suggest why.

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(1 mark)

Question 3 continues on the next page

3 (b) The enthalpy change in this reaction can be determined using enthalpies of formation or using mean bond enthalpies.

Calculate the enthalpy change when one mole of methyl ethanoate is formed from ethanoyl chloride and methanol.

$$CH_3COCl + CH_3OH \longrightarrow CH_3COOCH_3 + HCl$$

Use the enthalpy of formation data in the table.

	CH_3COCl	CH_3OH	CH_3COOCH_3	HCl
Enthalpy of formation/ kJ mol^{-1}	–272.9	–239.1	–445.8	–92.3

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(4 marks)

3 (c) Explain the meaning of the term *mean bond enthalpy*.

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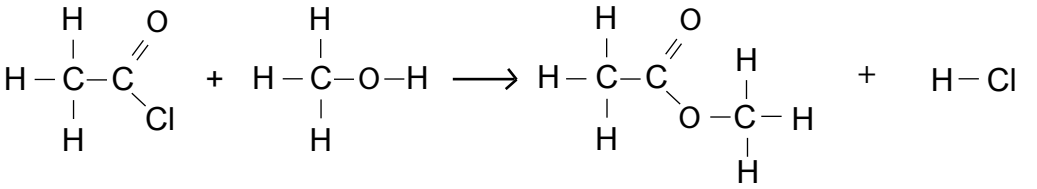
(2 marks)

3 (d) Calculate the enthalpy change when one mole of methyl ethanoate is formed from ethanoyl chloride and methanol.



ethanoyl chloride + methanol ⟶ methyl ethanoate + hydrogen chloride

Use the following mean bond enthalpy values.

	C−C	C−H	C−Cl	C=O	C−O	O−H	H−Cl
Mean bond enthalpy/ kJmol^{-1}	347	413	346	887	336	464	432

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(4 marks)

3 (e) Suggest why the values calculated in part (b) and part (d) are different.

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(1 mark)

17

4 The Haber process is used industrially to produce ammonia, NH_3. The following dynamic equilibrium is established.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -93.2\,kJmol^{-1}$$

4 (a) (i) Define a *dynamic equilibrium*.

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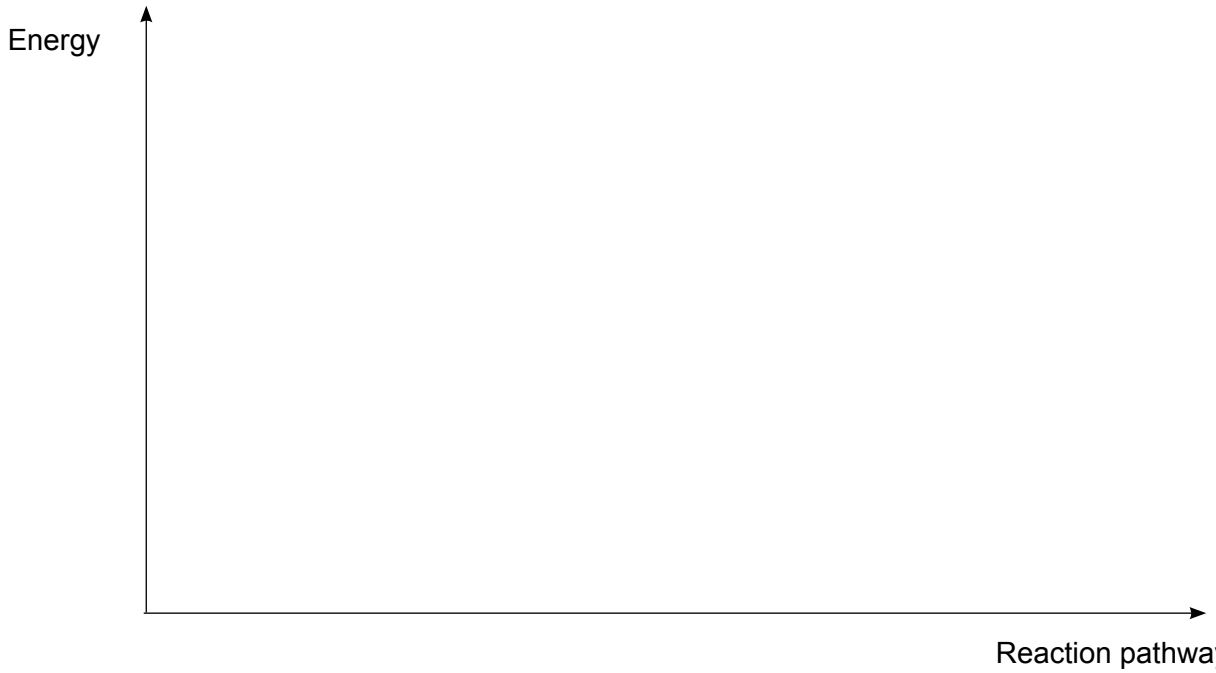
(2 marks)

4 (a) (ii) Sketch the reaction profile you would expect for the Haber process on the axes provided. Make sure that you label 'reactants' and 'products' on your sketch.



(2 marks)

4 (b) State Le Chatelier's principle.

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(2 marks)

4 (c) Discuss how an increase in pressure affects the rate of reaction and the equilibrium yield of ammonia in the Haber process.

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

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(5 marks)

Question 4 continues on the next page

4 (d) (i) What effect will increasing the temperature have on the equilibrium yield of ammonia, NH_3?

Effect.....

Explanation .....

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(3 marks)

4 (d) (ii) Explain why a temperature of 450°C is used as a compromise temperature.

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(1 mark)

15

5 Industrial chemical reactions should produce a satisfactory yield in a short time. Chemical engineers often use catalysts to achieve a faster rate of reaction.

5 (a) State the meaning of the term *catalyst.*

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(1 mark)

5 (b) (i) Define the term *activation energy*.

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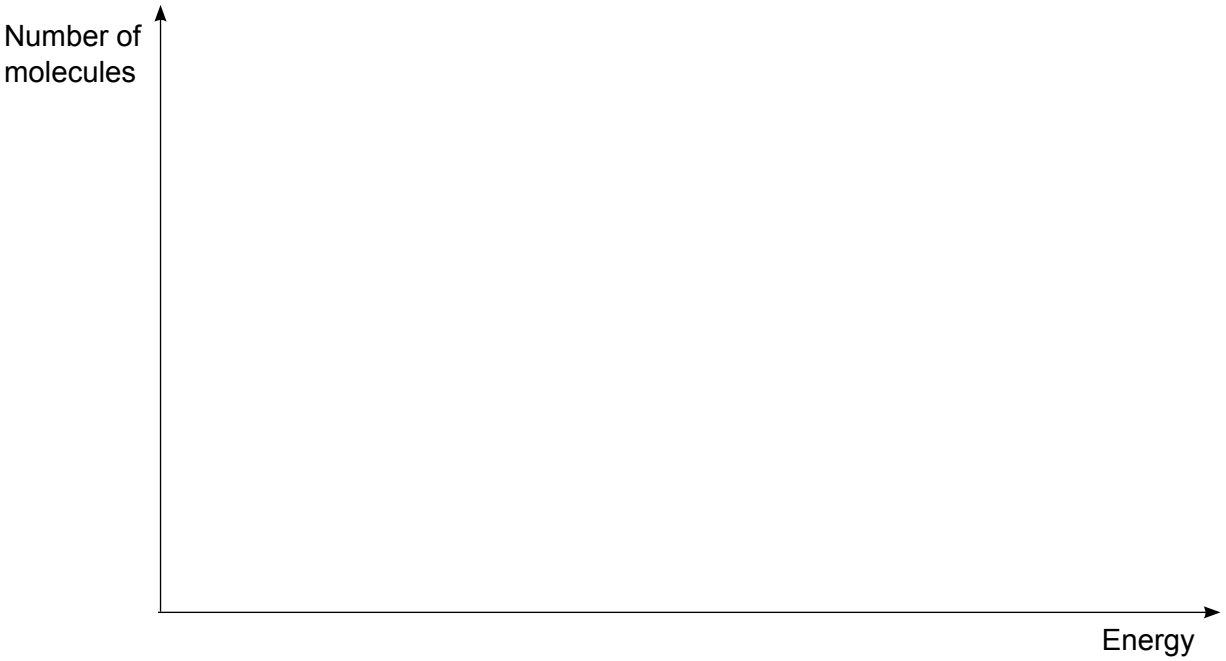
(2 marks)

Question 5 continues on the next page

5 (b) (ii) On the axes provided, sketch a Maxwell–Boltzmann curve to show the distribution of energies for the molecules in a gas at temperature *T*.



(2 marks)

5 (b) (iii) On the energy axis, indicate

- the activation energy without a catalyst. Label this E_a
- the activation energy with a catalyst. Label this E_a(cat). *(2 marks)*

5 (b) (iv) Use your Maxwell–Boltzmann curve to explain how the use of a catalyst can increase the rate of a reaction.

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(3 marks)

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6 Development chemists often investigate the rate of a reaction when they are considering how a laboratory experiment might be scaled up for industrial production. It is important that they find the best conditions to use in the industrial production.

6 (a) Two reactants **A** and **B** have been investigated. Both **A** and **B** are used in solution.

The results of the investigation are shown in the table below.

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	2.30×10^{-3}
2	0.30	0.10	6.90×10^{-3}
3	0.10	0.40	3.68×10^{-2}

6 (a) (i) Use the results shown above to determine the order of reaction with respect to each of the reactants **A** and **B**. Explain your reasoning.

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

Explanation .....

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

Explanation .....

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(4 marks)

6 (a) (ii) Suggest **one** variable that must be kept constant during this investigation.

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(1 mark)

6 (b) Another reaction, between reactants **X**, **Y**, and **Z**, was studied. It was found to be first order with respect to **Z**, zero order with respect to **Y**, and second order with respect to **X.**

6 (b) (i) Explain what *zero order with respect to **Y*** means.

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(1 mark)

Question 6 continues on the next page

6 (b) (ii) What is the overall order of the reaction between **X**,**Y** and **Z**?

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(1 mark)

6 (b) (iii) Write the rate equation for this reaction.

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(3 marks)

10

END OF QUESTIONS