Surname		Other Names	
Centre Number			Candidate Number	
Candidate Signature			

For Examiner's Use

General Certificate of Education
January 2010
Advanced Level Examination

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

Wednesday 27 January 2010 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. Use pencil only for drawing.
- Fill in the boxes at the top of this page.
- 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 that 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.

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 Research chemists study rates of reactions to give them information about how molecules interact.

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

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(2 marks)

1 (b) Bromoalkanes react with sodium hydroxide to produce alcohols.

The chemical equation for the reaction of 1-bromobutane with sodium hydroxide is

$$\underset{\text{1-bromobutane}}{CH_3CH_2CH_2CH_2Br} + \underset{\text{sodium hydroxide}}{NaOH} \rightarrow CH_3CH_2CH_2CH_2OH + NaBr$$

The rate equation for this reaction is

$$\text{Rate} = k[CH_3CH_2CH_2CH_2Br][NaOH]$$

1 (b) (i) What name is given to the term k in the rate equation.

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(1 mark)

1 (b) (ii) The table shows the results from a series of experiments carried out to study the effect of concentration on rate of reaction.
Use the rate equation to complete the table.

Experiment	**Initial concentration of 1-bromobutane (mol dm^{-3})**	**Initial concentration of sodium hydroxide (mol dm^{-3})**	**Initial rate of reaction (mol dm^{-3} s^{-1})**
1	0.25	2	3.2×10^{-2}
2	0.50	2	
3	0.50		1.6×10^{-2}

(2 marks)

1 (b) (iii) What is the overall order of this reaction?

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(1 mark)

1 (c) 2-bromo-2-methylpropane also produces an alcohol when it is reacted with sodium hydroxide.

$(CH_3)_3CBr$ + NaOH → $(CH_3)_3COH$ + NaBr

2-bromo-2-methylpropane — sodium hydroxide

The rate equation is, however, different from that in part (b). This indicates to research chemists that the reactions occur in different ways. The table shows the results from a series of experiments carried out to study the effect of concentration on rate of reaction.

Experiment	**Initial concentration of 2-bromo-2-methylpropane ($mol dm^{-3}$)**	**Initial concentration of sodium hydroxide ($mol dm^{-3}$)**	**Initial rate of reaction ($mol dm^{-3} s^{-1}$)**
1	0.2	2	1.1×10^{-2}
2	0.4	2	2.2×10^{-2}
3	0.2	4	1.1×10^{-2}

1 (c) (i) Use the information to determine the order of the reaction with respect to sodium hydroxide. Explain your answer.

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(2 marks)

1 (c) (ii) Write the rate equation for the reaction of 2-bromo-2-methylpropane and sodium hydroxide.

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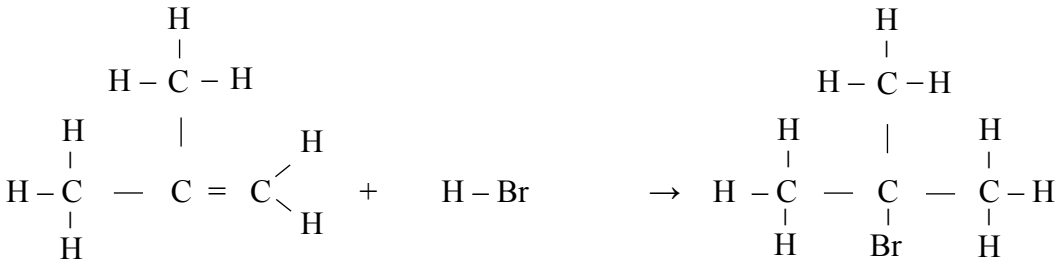
(2 marks)

Question 1 continues on the next page

1 (d) Bromoalkanes can be produced from alkenes. Alkenes are obtained from crude oil.

2-bromo-2-methylpropane is produced when methylpropene reacts with hydrogen bromide.



methylpropene + hydrogen bromide → 2-bromo-2-methylpropane

1 (d) (i) Use the following mean bond enthalpy data to calculate the enthalpy change when 1 mole of 2-bromo-2-methylpropane is produced in this reaction.

	C=C	C−H	C−Br	H−Br	C−C
Mean bond enthalpy/kJ mol^{-1}	612	413	290	366	347

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(4 marks)

1 (d) (ii) This reaction does not give 100% yield of 2-bromo-2-methylpropane. Suggest why.

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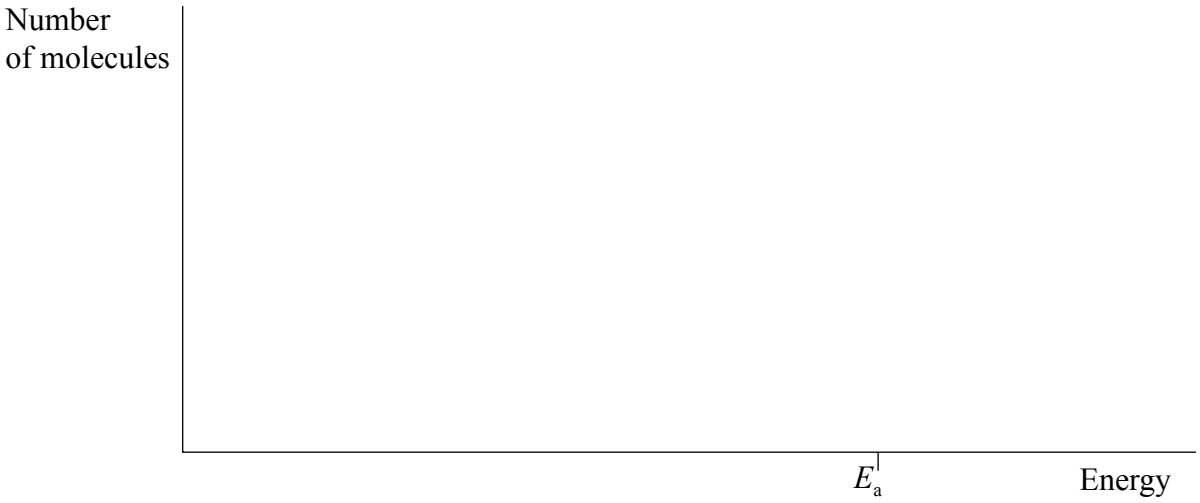
(1 mark)

15

2 Formulation chemists working for pharmaceutical companies must assess the shelf-life of their company's products. Temperature is one of the factors that will have a significant effect on the decomposition of pharmaceuticals.

2 (a) (i) On the axes provided, sketch a Maxwell–Boltzmann curve to show the distribution of energies for the molecules in a gas at temperature T. E_a is the activation energy for a reaction involving this gas.



(3 marks)

2 (a) (ii) Define the term *activation energy*.

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(2 marks)

2 (a) (iii) Shade on the curve the area that represents the number of molecules that can react at temperature T. *(1 mark)*

2 (b) Formulation chemists base their predictions of shelf-life on the assumption that the pharmaceuticals (e.g. aspirin) are stored at a low temperature.

2 (b) (i) State the effect on the activation energy for the decomposition of aspirin when the temperature is decreased.

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(1 mark)

Question 2 continues on the next page

2 (b) (ii) Use the idea of activation energy to explain why a decrease in temperature decreases the rate of the decomposition of aspirin.

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(3 marks)

2 (c) Aspirin breaks down by slowly reacting with water over a period of several years.

$$\underset{\text{aspirin}}{CH_3COOC_6H_4COOH} + H_2O \rightarrow C_6H_4(OH)COOH + \underset{\text{ethanoic acid}}{CH_3COOH}$$

2 (c) (i) Calculate the relative formula masses, M_r, of aspirin and ethanoic acid.
(Relative atomic masses, A_r, C = 12, O = 16, H = 1)

M_r aspirin .....

.....

M_r ethanoic acid .....

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(2 marks)

2 (c) (ii) The formulation chemists have ensured that the aspirin hardly breaks down at all during the first two years after manufacture. After three years, however, 24% of the aspirin decomposes to form ethanoic acid.
Use your answers in part (c)(i) to calculate the mass of ethanoic acid formed when 16 aspirin tablets have been stored for 3 years. Each tablet contains 300 mg aspirin.

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(4 marks)

2 (d) Suggest an analytical technique that formulation chemists could use to assess the extent of the decomposition of aspirin after a period of time.

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(1 mark)

17

Turn over for the next question

3 A chemical engineer at a fertiliser manufacturer has requested that you check the enthalpy change when nitric acid is neutralised with ammonia solution.

$$HNO_3(aq) + NH_3(aq) \rightarrow NH_4NO_3(aq)$$

3 (a) (i) Design an experiment to determine the enthalpy of neutralisation of nitric acid with ammonia solution.

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(3 marks)

3 (a) (ii) Describe how you would carry out the experiment.

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

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(5 marks)

3 (b) How would you ensure that your results were reliable?

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(1 mark)

3 (c) Write the mathematical equation you would use to calculate the heat energy released. Ensure that you state what each quantity represents in your mathematical equation.

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(2 marks)

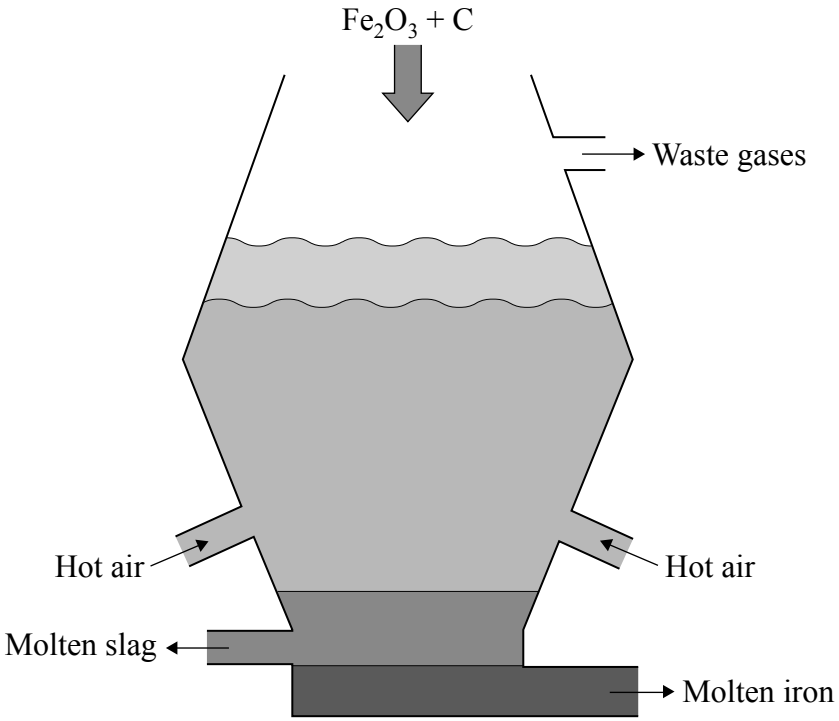
3 (d) Energy is released in this reaction. Sketch the reaction profile you would expect on the axes provided.

(3 marks)

14

4 Steel-making involves several processes. Steel is an alloy of iron. Iron is produced by reducing iron ore (mostly iron oxide, Fe_2O_3) with carbon in a blast furnace. Industrial chemists attempt to minimise costs while maintaining the purity of the product.

The raw materials used in the blast furnace are iron ore, coke (mostly carbon) and limestone.



4 (a) A blast furnace is operated as a continuous process.

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

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(2 marks)

4 (a) (ii) Some industrial processes are carried out as batch processes.

Give **one** advantage of using a continuous process rather than a batch process.

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(1 mark)

4 (a) (iii) Give **one** advantage of using a batch process rather than a continuous process.

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(1 mark)

4 (b) Costs, such as the cost of raw materials, must be carefully controlled to maintain the economy of all manufacturing processes. Costs can be classified as

Capital costs
Direct costs
Indirect costs

4 (b) (i) Explain what is meant by a *raw material.*

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(2 marks)

4 (b) (ii) Classify each of the following as **one** of the above costs.

Construction of the blast furnace .....

Cost of limestone .....

Maintenance of the blast furnace .....

Sales and advertising.....

(4 marks)

4 (c) Balance the equation for the reduction of iron oxide to iron in the blast furnace.

$$Fe_2O_3 + CO \rightarrow CO_2 + Fe$$

(2 marks)

4 (d) Oxidation numbers are used by chemists to decide whether a substance has been oxidised (the oxidation number increases) or reduced (the oxidation number decreases) in a chemical reaction. What is the oxidation number of iron in the following?

Fe_2O_3 .....

Fe .....

(2 marks)

14

Turn over ▶

5 A chemical manufacturing company uses phosphorus pentachloride, PCl_5, as a reagent in the production of several organic halogen compounds. For example

$$\underset{\text{ethanol}}{C_2H_5OH} + PCl_5 \rightarrow \underset{\text{chloroethane}}{C_2H_5Cl} + HCl + POCl_3$$

5 (a) Use the following enthalpy of formation data to calculate the enthalpy change when chloroethane is formed from ethanol.

	C_2H_5OH	$POCl_3$	HCl	C_2H_5Cl	PCl_5
Enthalpy of formation/ $kJ\,mol^{-1}$	–278	–597.1	–92.3	–136.8	–443.5

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(4 marks)

At high temperatures phosphorus pentachloride dissociates to form chlorine and phosphorus trichloride. This is a reversible reaction and so, after some time, a dynamic equilibrium is established.

$$PCl_5(g) \rightleftharpoons Cl_2(g) + PCl_3(g)$$

5 (b) State what condition is required for *dynamic equilibrium* to be established.

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(1 mark)

5 (c) Explain the meaning of *reversible*.

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(1 mark)

5 (d) Use le Chatelier's principle to explain the effect of increasing the pressure on the dissociation of phosphorus pentachloride to chlorine and phosphorus trichloride.

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

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(5 marks)

Question 5 continues on the next page

5 (e) (i) Write an expression for K_c for this equilibrium.

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(3 marks)

5 (e) (ii) The equilibrium mixture contains 1.20 moles of PCl_5, 0.10 moles of Cl_2 and 0.196 moles of PCl_3. The volume of the container is 2 dm^3. Calculate the value of the equilibrium constant.

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(3 marks)

5 (e) (iii) What are the units of this equilibrium constant?

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(1 mark)

5 (f) The dissociation of phosphorus pentachloride is a homogeneous equilibrium.
Not all reactions are homogeneous, some are heterogeneous.
A heterogeneous equilibrium can be established (under certain conditions) when calcium carbonate decomposes.

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$$

Explain what *heterogeneous* means.

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(2 marks)

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END OF QUESTIONS

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