For Examiner's Use

General Certificate of Education
June 2009
Advanced Level Examination

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

Wednesday 10 June 2009   9.00 am to 10.30 am

AQA

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.
- 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.

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

1   The chlor-alkali industry manufactures three main products – chlorine, hydrogen and sodium hydroxide. These substances are formed by the electrolysis of sodium chloride solution (brine). This is a continuous process.

1   (a)   Explain what is meant by a *continuous process*.

....

....

(2 marks)

1   (b)   Costs involved in manufacturing processes can be classified as

direct costs
capital costs
indirect costs

Classify each of the following costs involved in the electrolysis of sodium chloride solution.

1   (b)   (i)   Construction of the electrolysis cell ....

1   (b)   (ii)   Maintenance of the electrolysis cell ....

1   (b)   (iii)   Electricity used in the electrolysis cell ....

1   (b)   (iv)   Salaries of the workforce ....

(4 marks)

1   (c)   One type of electrolysis cell uses mercury. An analytical chemist working at a chlor-alkali plant must monitor the process carefully to ensure minimal leakage of mercury.

1   (c)   (i)   Suggest why it is important to minimise the leakage of mercury.

....

(1 mark)

1   (c)   (ii)   All three electrolysis products are hazardous. Hydrogen is flammable, for instance.

Suggest **one** safety precaution that workers at the plant should take when hydrogen is present.

....

(1 mark)

1 **(d)** Some of the sodium hydroxide produced by this process can be reacted with chlorine to form $NaClO_3$. This can be used as a weedkiller.

$$6NaOH + 3Cl_2 \longrightarrow 5NaCl + NaClO_3 + 3H_2O$$

1 **(d)** **(i)** What is the oxidation number of chlorine in

Cl_2 ....

$NaClO_3$? ....

(2 marks)

1 **(d)** **(ii)** Calculate the relative formula masses, M_r of NaOH and $NaClO_3$.
(Relative atomic masses, A_r, Na = 23, O = 16, H = 1, Cl = 35.5)

M_r NaOH ....

....

M_r $NaClO_3$ ....

....

(2 marks)

1 **(d)** **(iii)** Use the chemical equation to calculate the mass of $NaClO_3$ made when 100 kg of sodium hydroxide (NaOH) reacts with chlorine. Assume that the yield is 100%.

....

....

....

....

(3 marks)

1 **(d)** **(iv)** Very few reactions have a 100% yield. Suggest why the yield is often much less than 100%.

....

....

(1 mark)

16

2 Industrial chemists must consider rates of reaction. The rate of a reaction may be too rapid to allow a manufacturing process to be carried out safely.

2 (a) Explain what is meant by *rate of reaction*.

....

....

....

....

(2 marks)

2 (b) 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.

E_a
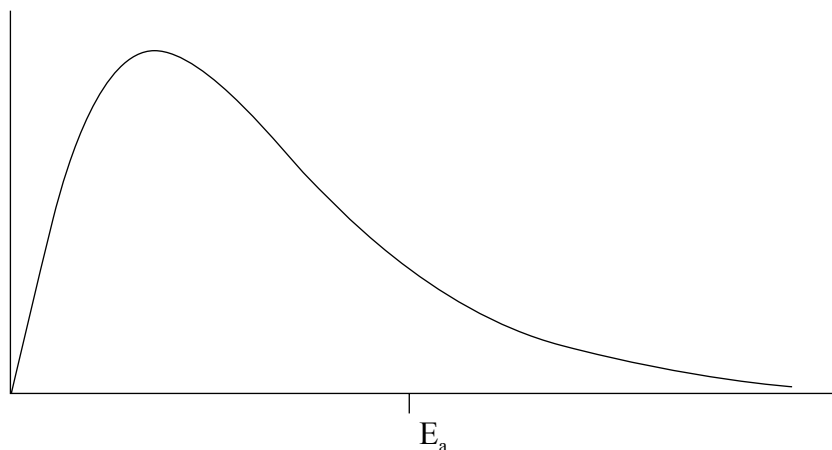
On the Maxwell–Boltzmann distribution

2 (b) (i) label the axes *(2 marks)*

2 (b) (ii) sketch the curve you would expect for the same particles at a lower temperature.

(2 marks)

2 (c) Define the term *activation energy*.

....

....

(2 marks)

2 **(d)** Use the idea of activation energy and the Maxwell–Boltzmann curves to explain why a decrease in temperature decreases the rate of a reaction.

....

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....

....

....

....
(3 marks)

2 **(e)** What is a catalyst?

....

....
(2 marks)

Question 2 continues on the next page

Turn over ▶

2 (f)   A typical reaction profile for a reaction is shown.

Energy

reactants

products

Reaction pathway
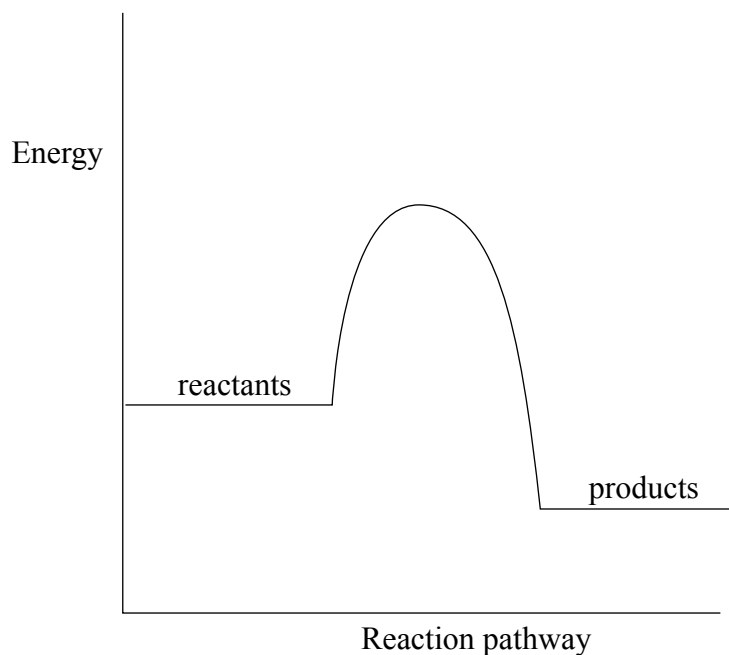
2 (f) (i)   Explain how you know that this reaction is exothermic.

....

....
(1 mark)

2 (f) (ii)   Some catalysts can be used to slow down a reaction. If used in this way, a catalyst is called an inhibitor.

On the reaction profile above, sketch the profile you would expect to see if the reaction was carried out with an inhibitor. *(2 marks)*

16

3 A chemist is studying the trend in enthalpies of combustion of the family of compounds known as the alcohols.

3 (a) Explain what is meant by the term *enthalpy of combustion*.

....

....

....

....

(2 marks)

3 (b) The chemist measured the enthalpy of combustion of ethanol (C_2H_5OH). It was $843\,kJ\,mol^{-1}$.

Would you expect the enthalpy of combustion of ethanol to have a positive or negative value?
Explain your answer.

....

....

(1 mark)

3 (c) The chemist wanted to measure the enthalpy of combustion of the alcohol with the next largest molecule, propan-1-ol.

3 (c) (i) Balance the equation for the complete combustion of propan-1-ol

$$2C_3H_7OH \quad + \quad O_2 \quad \longrightarrow \quad CO_2 \quad + \quad H_2O \qquad \textit{(2 marks)}$$

3 (c) (ii) List the apparatus that could be used to carry out this experiment.
Propan-1-ol is a liquid at room temperature.

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(3 marks)

Question 3 continues on the next page

Turn over ▶

3 (c) (iii) What measurements should be recorded during this experiment?

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(3 marks)

3 (c) (iv) Explain how the results from this experiment could be used to calculate the enthalpy of combustion for 1 mole of propan-1-ol.

....

....

....

(3 marks)

3 (c) (v) Suggest **three** ways in which the chemist could ensure the accuracy of the experimental results.

1 ....

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2 ....

....

3 ....

....

(3 marks)

17

4 A plastics manufacturing company uses tetrafluoroethene (C_2F_4) as a starting material for the reaction that produces PTFE, which is used in non-stick coatings.

Tetrafluoroethene is obtained from chlorodifluoromethane ($CHClF_2$) by the following reaction involving a homogeneous equilibrium.

$$2CHClF_2(g) \rightleftharpoons C_2F_4(g) + 2HCl(g) \qquad \Delta H = +128 \text{ kJ mol}^{-1}$$

4 (a) Explain the term *homogeneous*.

....

....
(2 marks)

4 (b) State the condition required for a dynamic equilibrium to be established.

....
(1 mark)

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

....

....

....
(2 marks)

4 (c) (ii) Calculate a value for the equilibrium constant when the equilibrium concentrations are

$CHClF_2 = 0.25$ mol dm^{-3}
$C_2F_4 \quad = 0.5$ mol dm^{-3}
$HCl \quad = 0.9$ mol dm^{-3}

....

....

....

....
(2 marks)

4 (c) (iii) What are the units of K_c for this reaction?

....

....
(1 mark)

Question 4 continues on the next page

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*Areas outside
the box will
not be scanned
for marking*

4 **(d)** What effect will increasing the temperature have on the yield of tetrafluoroethene? Use Le Chatelier's principle to explain your answer.
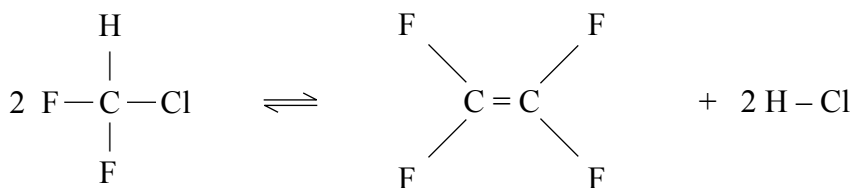
Effect ....

Explanation ....

....

....

....

(3 marks)

4 **(e)** What effect will increasing the pressure have on the yield of tetrafluoroethene?
Use Le Chatelier's principle to explain your answer.

Effect...

Explanation ....

....

....

....

(3 marks)

4 **(f)** **(i)** Use the following mean bond enthalpy data to calculate the enthalpy change when 1 mole of tetrafluoroethene (C_2F_4) is produced.

	C–F	C=C	C–H	C–Cl	H–Cl
Mean bond enthalpy/kJ mol^{-1}	467	612	413	346	432

....

....

....

....

(4 marks)

4 **(f)** **(ii)** Suggest why your answer to part (f)(i) differs from the actual enthalpy change ($+128 \, \text{kJ mol}^{-1}$) for this reaction.

....

....
(1 mark)

4 **(g)** A technician in the analytical laboratory of the plastics company placed 1.8 moles of $CHClF_2$ in a completely empty container, sealed it, and then heated it.
When equilibrium was reached the technician analysed the mixture and found that 0.4 moles of $CHClF_2$ remained.

$$2 \, CHClF_2(g) \rightleftharpoons C_2F_4(g) + 2HCl(g)$$
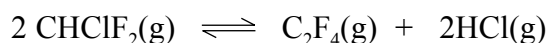
4 **(g)** **(i)** Calculate the number of moles of C_2F_4 formed.

....

....
(1 mark)

4 **(g)** **(ii)** Use your answer to part (g)(i) to calculate the volume of C_2F_4 produced at standard temperature and pressure.
(One mole of any gas occupies $22.4 \, \text{dm}^3$ under these conditions.)

....

.... dm^3
(1 mark)

21

Turn over for the next question

5 Chemical engineers decide on the most economical way to carry out industrial chemical reactions. Some reactions are carried out as a continuous process. Others are achieved using a batch process.

Batch processes are useful when reactions are being researched in laboratories. When these reactions are scaled up for commercial production, continuous processes are usually used.

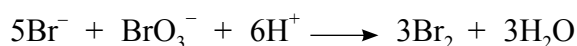**5** (a) (i) Explain what is meant by the term *batch process*.

....

....

(2 marks)

5 (a) (ii) Give **one** advantage of a continuous process compared to a batch process.

....

....

(1 mark)

5 (b) The chemical engineers at an industrial plant have asked a research chemist to investigate the rate of reaction between bromide ions (Br^-) and bromate(V) ions (BrO_3^-) in acid solution.

$$5Br^- + BrO_3^- + 6H^+ \longrightarrow 3Br_2 + 3H_2O$$

The chemist decided to measure pH to monitor the reaction.

Suggest another experimental method that could be used to monitor the rate of this reaction.

....

(1 mark)

5 (c) The rate equation for the reaction is

$$\text{rate} = k\,[Br^-][BrO_3^-][H^+]^2$$

5 (c) (i) What is the order with respect to bromide ions?

....

(1 mark)

5 (c) (ii) What is the overall order of the reaction?

....

(1 mark)

5 (c) (iii) What will be the effect of doubling the concentration of hydrogen ions (H$^+$) on the rate of this reaction? Explain your answer.

Effect ....

Explanation ....

....
(2 marks)

5 (c) (iv) Suggest a change in conditions that would increase the value of *k*.

....
(1 mark)

5 (c) (v) Concentrations are measured in mol dm^{-3}. Determine the units of the rate constant, *k*, for this reaction.

....
(1 mark)

END OF QUESTIONS

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15

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