

Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
TOTAL	



General Certificate of Education  
Advanced Level Examination  
June 2012

# Chemistry

# CHEM4

## Unit 4 Kinetics, Equilibria and Organic Chemistry

Wednesday 13 June 2012 9.00 am to 10.45 am

**For this paper you must have:**

- the Periodic Table/Data Sheet provided as an insert (enclosed)
- a calculator.

**Time allowed**

- 1 hour 45 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.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

**Information**

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator, where appropriate.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  - use good English
  - organise information clearly
  - use accurate scientific terminology.

**Advice**

- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.



J U N 1 2 C H E M 4 0 1

## Section A

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

- 1 (a)** A mixture of 1.50 mol of hydrogen and 1.20 mol of gaseous iodine was sealed in a container of volume  $V \text{ dm}^3$ . The mixture was left to reach equilibrium as shown by the following equation.



At a given temperature, the equilibrium mixture contained 2.06 mol of hydrogen iodide.

- 1 (a) (i)** Calculate the amounts, in moles, of hydrogen and of iodine in the equilibrium mixture.

Moles of hydrogen .....

Moles of iodine ..... (2 marks)

- 1 (a) (ii)** Write an expression for the equilibrium constant ( $K_c$ ) for this equilibrium.

.....  
 ..... (1 mark)

- 1 (a) (iii)**  $K_c$  for this equilibrium has no units.  
 State why the units cancel in the expression for  $K_c$

.....  
 ..... (1 mark)

- 1 (a) (iv)** A different mixture of hydrogen, iodine and hydrogen iodide was left to reach equilibrium at the same temperature in a container of the same volume.  
 This second equilibrium mixture contained 0.38 mol of hydrogen, 0.19 mol of iodine and 1.94 mol of hydrogen iodide.

Calculate a value for  $K_c$  for this equilibrium at this temperature.

.....  
 .....  
 .....  
 ..... (2 marks)

(Extra space) .....

.....



**1 (b)** This question concerns changes made to the four equilibria shown in parts **(b) (i)** to **(b) (iv)**.

In each case, use the information in the table to help you choose from the letters **A** to **E** the best description of what happens as a result of the change described. Write your answer in the box.

Each letter may be used once, more than once or not at all.

	Position of equilibrium	Value of equilibrium constant, $K_c$
<b>A</b>	remains the same	same
<b>B</b>	moves to the right	same
<b>C</b>	moves to the left	same
<b>D</b>	moves to the right	different
<b>E</b>	moves to the left	different

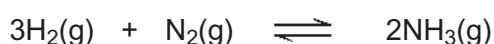
**1 (b) (i)** Change: increase the temperature of the equilibrium mixture at constant pressure.



$$\Delta H^\ominus = +52 \text{ kJ mol}^{-1}$$

(1 mark)

**1 (b) (ii)** Change: increase the total pressure of the equilibrium mixture at constant temperature.



$$\Delta H^\ominus = -92 \text{ kJ mol}^{-1}$$

(1 mark)

**1 (b) (iii)** Change: add a catalyst to the equilibrium mixture at constant temperature.



$$\Delta H^\ominus = -41 \text{ kJ mol}^{-1}$$

(1 mark)

**1 (b) (iv)** Change: add chlorine to the equilibrium mixture at constant temperature.

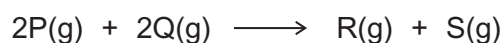


$$\Delta H^\ominus = +93 \text{ kJ mol}^{-1}$$

(1 mark)



2 Gases **P** and **Q** react as shown in the following equation.



The initial rate of the reaction was measured in a series of experiments at a constant temperature. The following rate equation was determined.

$$\text{rate} = k[\text{P}]^2[\text{Q}]$$

2 (a) Complete the table of data for the reaction between **P** and **Q**.

Experiment	Initial [P] / mol dm <sup>-3</sup>	Initial [Q] / mol dm <sup>-3</sup>	Initial rate / mol dm <sup>-3</sup> s <sup>-1</sup>
1	$2.5 \times 10^{-2}$	$1.8 \times 10^{-2}$	$5.0 \times 10^{-5}$
2	$7.5 \times 10^{-2}$	$1.8 \times 10^{-2}$	
3	$5.0 \times 10^{-2}$		$5.0 \times 10^{-5}$
4		$5.4 \times 10^{-2}$	$4.5 \times 10^{-4}$

(3 marks)

(Space for working) .....

.....

.....

.....

2 (b) Use the data from Experiment 1 to calculate a value for the rate constant ( $k$ ) at this temperature. Deduce the units of  $k$ .

Calculation .....

.....

.....

.....

Units .....

.....

(3 marks)



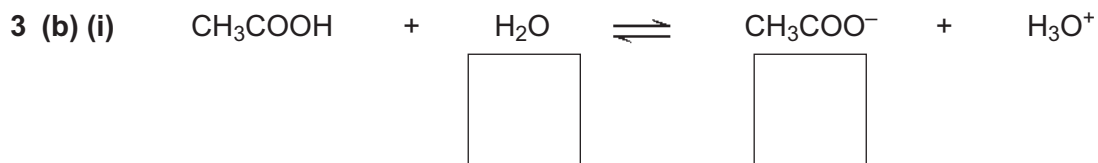
3 This question is about several Brønsted–Lowry acids and bases.

3 (a) Define the term *Brønsted–Lowry acid*.

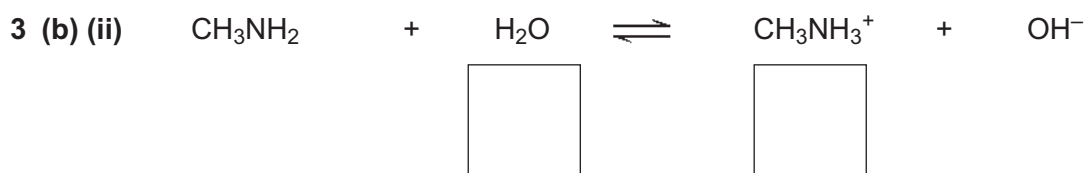
.....  
 .....

(1 mark)

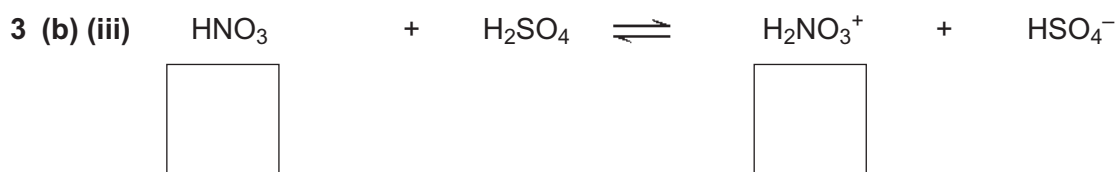
3 (b) Three equilibria are shown below. For each reaction, indicate whether the substance immediately **above** the box is acting as a Brønsted–Lowry acid (**A**) or a Brønsted–Lowry base (**B**) by writing **A** or **B** in each of the six boxes.



(1 mark)



(1 mark)



(1 mark)

3 (c) A 25.0 cm<sup>3</sup> sample of 0.0850 mol dm<sup>-3</sup> hydrochloric acid was placed in a beaker. Distilled water was added until the pH of the solution was 1.25. Calculate the total volume of the solution formed. State the units.

.....  
 .....  
 .....  
 .....  
 .....

(3 marks)

(Extra space) .....

.....  
 .....

Question 3 continues on the next page

Turn over ►



**3 (d)** At 298 K, the value of the acid dissociation constant ( $K_a$ ) for the weak acid HX in aqueous solution is  $3.01 \times 10^{-5} \text{ mol dm}^{-3}$ .

**3 (d) (i)** Calculate the value of  $\text{p}K_a$  for HX at this temperature.  
Give your answer to 2 decimal places.

.....  
.....  
(1 mark)

**3 (d) (ii)** Write an expression for the acid dissociation constant ( $K_a$ ) for the weak acid HX.

.....  
.....  
.....  
(1 mark)

**3 (d) (iii)** Calculate the pH of a  $0.174 \text{ mol dm}^{-3}$  solution of HX at this temperature.  
Give your answer to 2 decimal places.

.....  
.....  
.....  
.....  
.....  
.....  
(3 marks)

(Extra space) .....

.....

.....





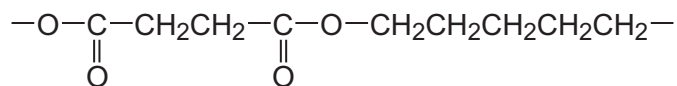
**4** Acyl chlorides and acid anhydrides are important compounds in organic synthesis.

**4 (a)** Outline a mechanism for the reaction of  $\text{CH}_3\text{CH}_2\text{COCl}$  with  $\text{CH}_3\text{OH}$  and name the organic product formed.

Mechanism

Name of organic product ..... (5 marks)

**4 (b)** A polyester was produced by reacting a diol with a diacyl chloride. The repeating unit of the polymer is shown below.



**4 (b) (i)** Name the diol used.

..... (1 mark)

**4 (b) (ii)** Draw the displayed formula of the diacyl chloride used.

(1 mark)





- 4 (b) (iii) A shirt was made from this polyester. A student wearing the shirt accidentally splashed aqueous sodium hydroxide on a sleeve. Holes later appeared in the sleeve where the sodium hydroxide had been.

Name the type of reaction that occurred between the polyester and the aqueous sodium hydroxide. Explain why the aqueous sodium hydroxide reacted with the polyester.

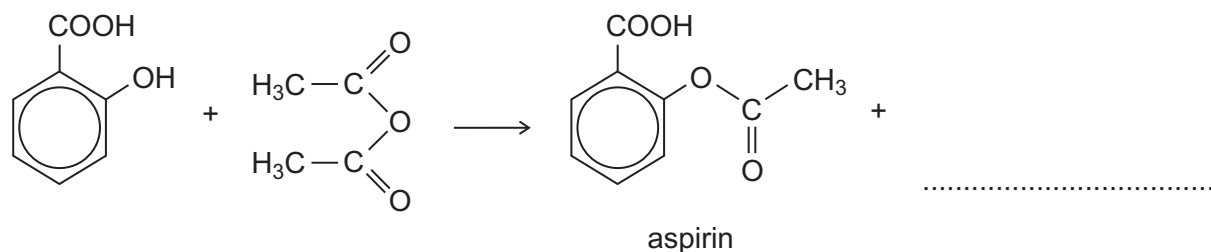
Type of reaction .....

Explanation .....

.....  
.....  
.....

(3 marks)

- 4 (c) (i) Complete the following equation for the preparation of aspirin using ethanoic anhydride by writing the structural formula of the missing product.



(1 mark)

- 4 (c) (ii) Suggest a name for the mechanism for the reaction in part (c) (i).

.....  
(1 mark)

- 4 (c) (iii) Give **two** industrial advantages, other than cost, of using ethanoic anhydride rather than ethanoyl chloride in the production of aspirin.

Advantage 1 .....

.....

.....

Advantage 2 .....

.....

.....

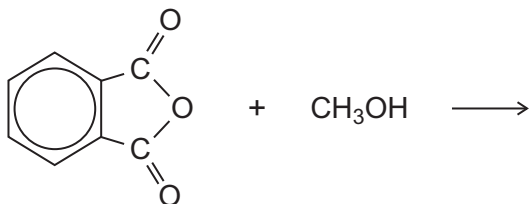
(2 marks)

Question 4 continues on the next page

Turn over ►

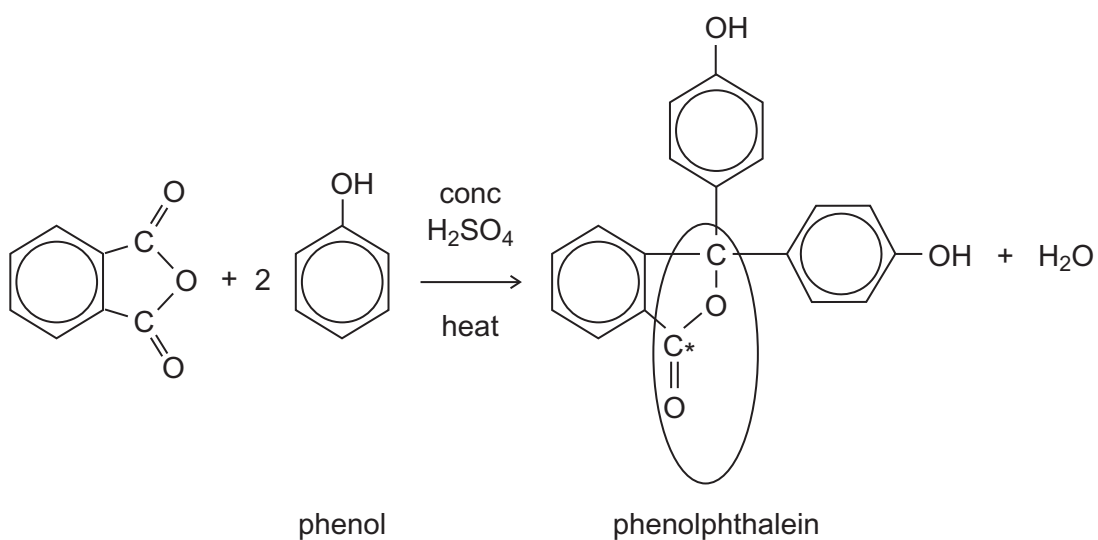


- 4 (d) Complete the following equation for the reaction of one molecule of benzene-1,2-dicarboxylic anhydride (phthalic anhydride) with one molecule of methanol by drawing the structural formula of the single product.



(1 mark)

- 4 (e) The indicator phenolphthalein is synthesised by reacting phthalic anhydride with phenol as shown in the following equation.



- 4 (e) (i) Name the functional group ringed in the structure of phenolphthalein.

.....  
(1 mark)

- 4 (e) (ii) Deduce the number of peaks in the  $^{13}\text{C}$  n.m.r. spectrum of phenolphthalein.

.....  
(1 mark)

- 4 (e) (iii) One of the carbon atoms in the structure of phenolphthalein shown above is labelled with an asterisk (\*).  
Use **Table 3** on the Data Sheet to suggest a range of  $\delta$  values for the peak due to this carbon atom in the  $^{13}\text{C}$  n.m.r. spectrum of phenolphthalein.

.....  
(1 mark)



- 4 (f) Phenolphthalein can be used as an indicator in some acid–alkali titrations. The pH range for phenolphthalein is 8.3 – 10.0

- 4 (f) (i) For **each** acid–alkali combination in the table below, put a tick (✓) in the box if phenolphthalein could be used as an indicator.

Acid	Alkali	Tick box (✓)
sulfuric acid	sodium hydroxide	
hydrochloric acid	ammonia	
ethanoic acid	potassium hydroxide	
nitric acid	methylamine	

(2 marks)

- 4 (f) (ii) In a titration, nitric acid is added from a burette to a solution of sodium hydroxide containing a few drops of phenolphthalein indicator. Give the colour **change** at the end-point.

.....

(1 mark)

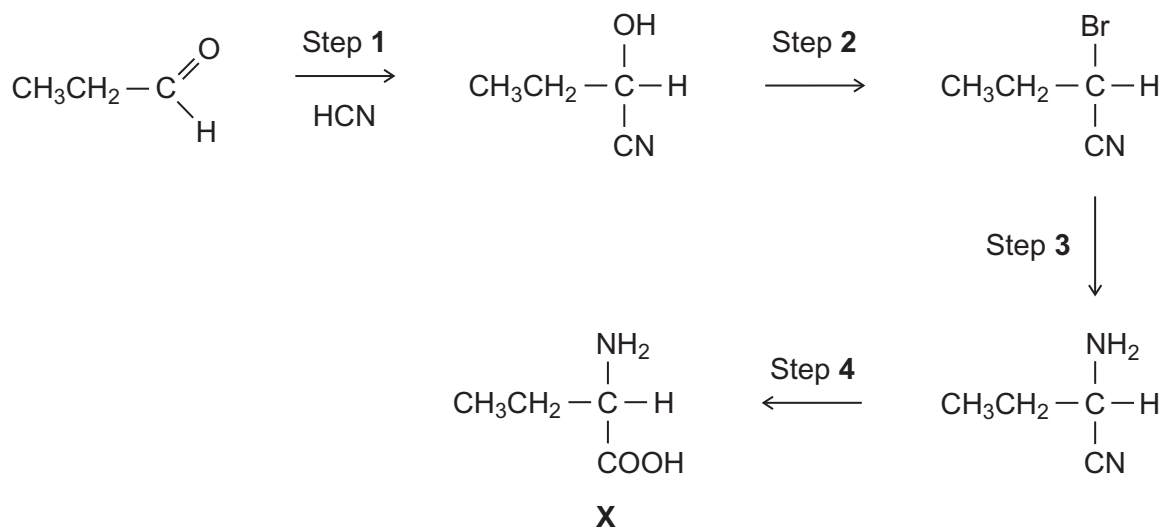
21
----

Turn over for the next question

Turn over ►



5 A possible synthesis of the amino acid **X** is shown below.



5 (a) Name and outline a mechanism for Step 1.

Name of mechanism .....

Mechanism

(5 marks)

5 (b) Give the IUPAC name of the product of Step 2.

.....

(1 mark)



**5 (c)** For Step 3, give the reagent, give a necessary condition and name the mechanism.

Reagent .....

Condition .....

Name of mechanism .....

(3 marks)

**5 (d)** At room temperature, the amino acid **X** exists as a solid.

**5 (d) (i)** Draw the structure of the species present in the solid amino acid.

(1 mark)

**5 (d) (ii)** With reference to your answer to part **(d) (i)**, explain why the melting point of the amino acid **X** is higher than the melting point of  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{COOH}$

.....  
.....  
.....  
.....  
.....  
.....

(2 marks)

(Extra space) .....

.....

**Question 5 continues on the next page**

**Turn over ►**



**5 (e)** There are many structural isomers of **X**,  $\text{CH}_3\text{CH}_2\text{CH}(\text{NH}_2)\text{COOH}$

**5 (e) (i)** Draw a structural isomer of **X** that is an ethyl ester.

(1 mark)

**5 (e) (ii)** Draw a structural isomer of **X** that is an amide and also a tertiary alcohol.

(1 mark)

**5 (e) (iii)** Draw a structural isomer of **X** that has an unbranched carbon chain and can be polymerised to form a polyamide.

(1 mark)

**5 (f)** Draw the structure of the tertiary amine formed when **X** reacts with bromomethane.

(1 mark)

16
----



**Turn over for the next question**

**DO NOT WRITE ON THIS PAGE  
ANSWER IN THE SPACES PROVIDED**

**Turn over ►**



**Section B**

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

**6** Benzene reacts with ethanoyl chloride in a substitution reaction to form  $C_6H_5COCH_3$ . This reaction is catalysed by aluminium chloride.

**6 (a)** Write equations to show the role of aluminium chloride as a catalyst in this reaction. Outline a mechanism for the reaction of benzene.

Name the product,  $C_6H_5COCH_3$

.....

.....

.....

(6 marks)





- 6 (b)** The product of the substitution reaction ( $\text{C}_6\text{H}_5\text{COCH}_3$ ) was analysed by mass spectrometry. The most abundant fragment ion gave a peak in the mass spectrum with  $m/z = 105$   
Draw the structure of this fragment ion.

(1 mark)

- 6 (c)** When methylbenzene reacts with ethanoyl chloride and aluminium chloride, a similar substitution reaction occurs but the reaction is faster than the reaction of benzene. Suggest why the reaction of methylbenzene is faster.

.....

.....

.....

.....

.....

.....

(2 marks)

9
---

Turn over for the next question

Turn over ►







**8** When the molecular formula of a compound is known, spectroscopic and other analytical techniques can be used to distinguish between possible structural isomers.

Draw **one** possible structure for each of the compounds described in parts **(a)** to **(d)**.

**8 (a)** Compounds **F** and **G** have the molecular formula  $C_6H_4N_2O_4$  and both are dinitrobenzenes.

**F** has two peaks in its  $^{13}C$  n.m.r. spectrum.

**G** has three peaks in its  $^{13}C$  n.m.r. spectrum.

**F**

**G**

*(Space for working)*

*(2 marks)*



- 8 (b)** Compounds **H** and **J** have the molecular formula  $C_6H_{12}$   
Both have only one peak in their  $^1H$  n.m.r. spectra.  
**H** reacts with aqueous bromine but **J** does not.

**H**

**J**

*(Space for working)*

*(2 marks)*

**Question 8 continues on the next page**

**Turn over ►**



- 8 (c)** **K** and **L** are cyclic compounds with the molecular formula  $C_6H_{10}O$   
Both have four peaks in their  $^{13}C$  n.m.r. spectra.  
**K** is a ketone and **L** is an aldehyde.

**K****L**

*(Space for working)*

*(2 marks)*



- 8 (d)** Compounds **M** and **N** have the molecular formula  $C_6H_{15}N$   
**M** is a tertiary amine with only two peaks in its  $^1H$  n.m.r. spectrum.  
**N** is a secondary amine with only three peaks in its  $^1H$  n.m.r. spectrum.

**M****N**

*(Space for working)*

*(2 marks)*

8
---

**END OF QUESTIONS**



**There are no questions printed on this page**

**DO NOT WRITE ON THIS PAGE  
ANSWER IN THE SPACES PROVIDED**

