Instructions

- Use black ink or ball-point pen.
- Fill in the boxes at the top of this page with your name, centre number and candidate number.
- Answer all questions.
- Answer the questions in the spaces provided – there may be more space than you need.

Information

- The total mark for this paper is 90.
- The marks for each question are shown in brackets – use this as a guide as to how much time to spend on each question.
- Questions labelled with an asterisk (*) are ones where the quality of your written communication will be assessed – you should take particular care with your spelling, punctuation and grammar, as well as the clarity of expression, on these questions.
- A Periodic Table is printed on the back cover of this paper.

Advice

- Read each question carefully before you start to answer it.
- Keep an eye on the time.
- Try to answer every question.
- Check your answers if you have time at the end.

Pearson Edexcel International Advanced Level

Chemistry Advanced
Unit 4: General Principles of Chemistry I – Rates, Equilibria and Further Organic Chemistry (including synoptic assessment)

Monday 13 January 2014 – Afternoon
Time: 1 hour 40 minutes

You must have: Data Booklet
Candidates may use a calculator.

Total Marks
SECTION A

Answer ALL the questions in this section. You should aim to spend no more than 20 minutes on this section. For each question, select one answer from A to D and put a cross in the box. If you change your mind, put a line through the box and then mark your new answer with a cross.

1. Select the correct states for the stationary and mobile phases in HPLC.

<table>
<thead>
<tr>
<th>Stationary phase</th>
<th>Mobile phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>A liquid</td>
<td>gas</td>
</tr>
<tr>
<td>B gas</td>
<td>liquid</td>
</tr>
<tr>
<td>C solid</td>
<td>liquid</td>
</tr>
<tr>
<td>D solid</td>
<td>gas</td>
</tr>
</tbody>
</table>

(Total for Question 1 = 1 mark)

2. This question is about low resolution proton nuclear magnetic resonance spectroscopy, NMR.

(a) NMR involves the interaction of hydrogen nuclei, \(^{1}\)H, in the presence of a powerful magnetic field with

- A microwaves.
- B radio waves.
- C ultraviolet radiation.
- D X-rays.

(b) Which of the following has two peaks in its low resolution NMR spectrum?

- A Dichloromethane, \(\text{CH}_2\text{Cl}_2\)
- B Ethane, \(\text{CH}_3\text{CH}_3\)
- C Methanal, \(\text{HCHO}\)
- D Methanol, \(\text{CH}_3\text{OH}\)
(c) NMR spectra depend on the number of different hydrogen environments in a molecule.

How many different hydrogen environments are there in a molecule of 2,3-dimethylpentane, the skeletal formula of which is shown below?

☐ A Seven
☐ B Six
☐ C Five
☐ D Four

(Total for Question 2 = 3 marks)

3 Energy is given out when one mole of gaseous strontium ions is hydrated.

\[ \text{Sr}^{2+}(g) + \text{aq} \rightarrow \text{Sr}^{2+}(\text{aq}) \]

This reaction is less exothermic than the corresponding reaction for magnesium ions, \( \text{Mg}^{2+}(g) \), because

☐ A the sum of the first two ionization energies of magnesium is more than that of strontium.

☐ B the lattice energies of magnesium compounds are more exothermic than the lattice energies of corresponding strontium compounds.

☐ C the solubility of magnesium hydroxide is less than the solubility of strontium hydroxide.

☐ D the ionic radius of Mg\(^{2+}\) is less than the ionic radius of Sr\(^{2+}\).

(Total for Question 3 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.
4 Use the data below to calculate the enthalpy change of solution of magnesium chloride.

<table>
<thead>
<tr>
<th>Lattice energy of magnesium chloride</th>
<th>−2526 kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enthalpy of hydration of Mg²⁺(g)</td>
<td>−2003 kJ mol⁻¹</td>
</tr>
<tr>
<td>Enthalpy of hydration of Cl⁻(g)</td>
<td>−340 kJ mol⁻¹</td>
</tr>
</tbody>
</table>

The enthalpy change of solution of magnesium chloride, in kJ mol⁻¹, is

- **A** +183
- **B** +157
- **C** −157
- **D** −183

(Total for Question 4 = 1 mark)

5 In kinetics, the progress of a reaction can be followed by

- **A** colorimetry.
- **B** measurement of optical activity.
- **C** measurement of change in mass.
- **D** quenching with ice-cold water followed by titration with acid.

Which method would be most suitable to investigate the rates of the following reactions?

(a) \( \text{CH}_3\text{CH}_2\text{Br}(l) + \text{OH}^-(aq) \rightarrow \text{CH}_3\text{CH}_2\text{OH}(l) + \text{Br}^-(aq) \)

- **A**
- **B**
- **C**
- **D**

(b) \( \text{I}_2(aq) + \text{CH}_3\text{COCH}_3(aq) \rightarrow \text{CH}_3\text{COCH}_2\text{I}(aq) + \text{HI}(aq) \)

- **A**
- **B**
- **C**
- **D**

(Total for Question 5 = 2 marks)
6 A halogenoalkane reacts with hydroxide ions to form an alcohol. Which of the following statements is true if the reaction is first order?

- A Increasing the concentration of hydroxide ions increases the rate of the reaction.
- B The rate equation for the reaction is rate = [halogenoalkane].
- C The reaction mechanism is $S_N^1$.
- D The reaction involves the formation of a transition state.

(Total for Question 6 = 1 mark)

7 The rate equation for the oxidation of bromide ions by bromate(V) ions in acid solution is shown below.

$$\text{Rate} = k[\text{BrO}_3^-(aq)][\text{Br}^-(aq)][\text{H}^+(aq)]^2$$

If the concentrations of all three reactants double, the rate will increase by a factor of

- A 2
- B 4
- C 8
- D 16

(Total for Question 7 = 1 mark)

8 The gaseous first order reaction, $A \rightarrow B + C$, was found to have a half-life of 20 s when the initial pressure of $A$ was 2 atm.

When the initial pressure of $A$ is increased to 4 atm, the half-life is

- A 10 s
- B 20 s
- C 40 s
- D 400 s

(Total for Question 8 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.
The equation for the equilibrium between nitrogen and oxygen may be written in two ways.

\[ \text{N}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}(g) \quad \text{Equilibrium constant } K_1 \]

\[ \frac{1}{2}\text{N}_2(g) + \frac{1}{2}\text{O}_2(g) \rightleftharpoons \text{NO}(g) \quad \text{Equilibrium constant } K_2 \]

The standard enthalpy change, \( \Delta H \), for the reaction as shown in the first equation is +180 kJ mol\(^{-1}\).

(a) What is the standard enthalpy change for the reaction as shown in the second equation?

\[ \square \text{ A} \quad +45 \text{ kJ mol}^{-1} \]
\[ \square \text{ B} \quad +90 \text{ kJ mol}^{-1} \]
\[ \square \text{ C} \quad +180 \text{ kJ mol}^{-1} \]
\[ \square \text{ D} \quad +360 \text{ kJ mol}^{-1} \]

(b) The equilibrium mole fraction of NO is increased by

\[ \square \text{ A} \quad \text{increasing the temperature.} \]
\[ \square \text{ B} \quad \text{decreasing the temperature.} \]
\[ \square \text{ C} \quad \text{increasing the total pressure.} \]
\[ \square \text{ D} \quad \text{decreasing the total pressure.} \]

(c) Which of the following expressions is correct?

\[ \square \text{ A} \quad K_1 = K_2 \]
\[ \square \text{ B} \quad K_1 = 2K_2 \]
\[ \square \text{ C} \quad K_1 = K_2^2 \]
\[ \square \text{ D} \quad K_1 = K_2^{1/2} \]

(Total for Question 9 = 3 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.
10 Which of the following solutions, when mixed, would make a buffer with pH greater than 7?

- A Ethanoic acid and sodium ethanoate.
- B Sodium hydroxide and sodium chloride.
- C Ammonia and sodium chloride.
- D Ammonia and ammonium chloride.

(Total for Question 10 = 1 mark)

11 In acid solution, methyl orange is red. When an alkali is added, the solution turns yellow because the indicator

- A gains OH⁻ ions to form cations.
- B loses H⁺ ions to form cations.
- C gains OH⁻ ions to form anions.
- D loses H⁺ ions to form anions.

(Total for Question 11 = 1 mark)

12 Which method may be used to make a carboxylic acid in a single reaction?

- A Hydrolysis of an ester with sodium hydroxide.
- B Hydrolysis of an ester with hydrochloric acid.
- C Reaction of acidified potassium manganate(VII) with an alkene.
- D Reaction of an acyl chloride with ammonia.

(Total for Question 12 = 1 mark)

13 Which of the following pairs of compounds would react to form a polyester?

- A Ethanol and benzoic acid.
- B Ethane-1,2-diol and benzoic acid.
- C Ethanol and benzene-1,4-dicarboxylic acid.
- D Ethane-1,2-diol and benzene-1,4-dicarboxylic acid.

(Total for Question 13 = 1 mark)
14 Which of the following compounds has both optical and E-Z isomers?

- A: CH₃CH−CHCH₂CH₃
- B: CH₃CHBrCH−C(CH₃)₂
- C: CHBr−CHCHBrCH₃
- D: CH₂=CHCHBrCH₃

(Total for Question 14 = 1 mark)

15 At which of the following \(m/e\) values would you not expect to find a peak in the mass spectrum of ethanoyl chloride?

- A: 35.5
- B: 37
- C: 43
- D: 78

(Total for Question 15 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS
SECTION B

Answer ALL the questions. Write your answers in the spaces provided.

16 This question is about the reaction scheme below which may be used to convert propanoic acid to ethyl butanoate in five steps.

\[
\begin{align*}
CH_3CH_2COOH & \quad \text{Step 1} \\
\rightarrow CH_3CH_2CH_2OH & \quad \text{Step 2} \\
\rightarrow CH_3CH_2CH_2Cl & \quad \text{Step 3} \\
\rightarrow \text{Butanenitrile} & \quad \text{Step 4} \\
\rightarrow CH_3CH_2CH_2COOH & \quad \text{Step 5} \\
\rightarrow CH_3CH_2CH_2COOCH_2CH_3
\end{align*}
\]

(a) Give the structural formula for butanenitrile, showing any multiple bonds.

(1)
(b) Give the formula of the reagent needed for each of the Steps 1, 2, 4 and 5. The reagent for Step 3 has been given.

Conditions and solvents are not required.

Step 1

Step 2

Step 3 KCN

Step 4

Step 5

(c) Write the equation for the neutralization of sodium carbonate by butanoic acid. State symbols are not required.

(d) State two differences between the low resolution proton nuclear magnetic resonance spectra of butan-1-ol and butanoic acid.

(e) Give two differences between the infrared spectra of butan-1-ol and butanoic acid, mentioning any bonds involved with their wavenumber ranges.
(f) Give the skeletal formula of ethyl butanoate, \( \text{CH}_3\text{CH}_2\text{CH}_2\text{COOCH}_2\text{CH}_3 \).

(1)

(g) Suggest the reagents required for a different, two-step method which could be used instead of the single step method you have given for Step 5 in part (b), to obtain ethyl butanoate from butanoic acid.

What is the advantage of using this alternative method?

(3)

Reagent for first step ................................................................. .................................................................

Reagent for second step ................................................................. .................................................................

Advantage ........................................................................................................................................................................

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(Total for Question 16 = 15 marks)
The decomposition of dinitrogen pentoxide in a suitable solvent produces nitrogen dioxide, which remains in solution, and oxygen gas which is given off.

The overall equation for the reaction is:

\[ \text{N}_2\text{O}_5 \rightarrow 2\text{NO}_2 + \frac{1}{2}\text{O}_2 \]

(a) Draw a diagram of the apparatus you would use to follow the rate of this reaction and give the measurements you would make.

(b) (i) The rate equation for this reaction is:

\[ \text{Rate} = k[N_2\text{O}_5] \]

What are the units of the rate constant, \( k \)?

(ii) A suggested mechanism for the reaction is:

1st Step \[ \text{N}_2\text{O}_5 \rightarrow \text{NO}_2 + \text{NO}_3 \]

2nd Step \[ \text{NO}_2 + \text{NO}_3 \rightarrow \text{NO} + \text{O}_2 + \text{NO}_2 \]

3rd Step \[ \text{NO} + \text{N}_2\text{O}_5 \rightarrow 3\text{NO}_2 \]

Label these reactions, fast or slow, and explain how your labelling is consistent with the rate equation for the reaction.
(c) The rate constant, $k$, was calculated at different temperatures.

(i) Suggest a practical method for keeping the temperature constant.

(ii) The table shows the measurements of the rate constant, $k$, at different temperatures. Some of the corresponding values for reciprocal of temperature and $\ln k$ are also shown.

Complete the table by calculating the missing values.

<table>
<thead>
<tr>
<th>T/K</th>
<th>$k$</th>
<th>$\frac{1}{T}$ / K$^{-1}$</th>
<th>$\ln k$</th>
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</thead>
<tbody>
<tr>
<td>280</td>
<td>$3.80 \times 10^{-6}$</td>
<td>$3.57 \times 10^{-3}$</td>
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<td>290</td>
<td>$1.65 \times 10^{-5}$</td>
<td>$3.45 \times 10^{-3}$</td>
<td>$-11.0$</td>
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<tr>
<td>300</td>
<td>$6.87 \times 10^{-5}$</td>
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<tr>
<td>310</td>
<td>$2.48 \times 10^{-4}$</td>
<td>$3.23 \times 10^{-3}$</td>
<td>$-8.3$</td>
</tr>
<tr>
<td>320</td>
<td>$8.65 \times 10^{-4}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*(iii) Plot a graph of $\ln k$ on the vertical axis against $1/T$ on the horizontal axis.

Calculate the gradient of your graph and use this to calculate the activation energy, $E_a$. Remember to include units with your answer, which should be given to three significant figures.

The Arrhenius equation can be expressed as

$$\ln k = \frac{-E_a}{R} \times \frac{1}{T} + \text{a constant}$$

[Gas constant, $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$]
18 (a) Ammonia is a weak alkali. Consider the following equilibrium that exists in an aqueous solution of ammonia.

\[
\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq}) \quad K_b = 1.8 \times 10^{-5} \text{ mol dm}^{-3}
\]

The base dissociation constant, \(K_b\), for this reaction is

\[
K_b = \frac{[\text{NH}_4^+(\text{aq})][\text{OH}^-(\text{aq})]}{[\text{NH}_3(\text{aq})]}
\]

(i) Calculate the concentration of hydroxide ions at equilibrium in a 4.0 mol dm\(^{-3}\) aqueous solution of ammonia.

Assume that the concentration of ammonia at equilibrium is 4.0 mol dm\(^{-3}\) and that the equilibrium concentration of hydroxide ions is equal to the equilibrium concentration of ammonium ions.

(ii) Calculate the pH of 4.0 mol dm\(^{-3}\) ammonia solution.

\([K_w = 1.0 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6} \text{ at } 298 \text{ K}]\)
(b) (i) Calculate the pH of 4.0 mol dm\(^{-3}\) hydrochloric acid, assuming it is fully ionized. 

(1)

(ii) Draw the titration curve, showing the change in pH when 4.0 mol dm\(^{-3}\) hydrochloric acid is added to 25 cm\(^3\) of 4.0 mol dm\(^{-3}\) ammonia solution, until 30 cm\(^3\) of the acid have been added. 

(4)
(iii) Select a suitable indicator for this titration, giving the colour change you would expect to see.

Justify your selection.

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(c) The titration above can be used to determine the concentration of ammonia solution when ammonia is distributed between the two immiscible solvents, trichloromethane and water.

An experiment is carried out to find the equilibrium constant for the reaction:

\[ \text{NH}_3(\text{CHCl}_3) \rightleftharpoons \text{NH}_3(\text{aq}) \]

75 cm\(^3\) of 4.0 mol dm\(^{-3}\) aqueous ammonia solution and 75 cm\(^3\) of the trichloromethane are shaken together. The two liquids are allowed to separate and 25.0 cm\(^3\) of the aqueous layer is taken and titrated with 4.0 mol dm\(^{-3}\) hydrochloric acid. The whole procedure is repeated.

The average titre is 24.0 cm\(^3\).

(i) Calculate the number of moles of ammonia, and hence the concentration of ammonia, in mol dm\(^{-3}\), in the aqueous layer.

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(ii) The initial volumes of the two solvents are the same. Hence deduce the concentration of ammonia in the trichloromethane layer in mol dm$^{-3}$.

(iii) Write the expression for the equilibrium constant, $K_c$, for this reaction and calculate its value.

(iv) Suggest why ammonia is much more soluble in water than in trichloromethane.

(Total for Question 18 = 18 marks)

TOTAL FOR SECTION B = 50 MARKS
SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

19 This question is about sucrose, the chemical commonly known as sugar. Some thermochemical data for sucrose and oxygen are given in the table below.

| Standard entropy of sucrose, $S^\circ [C_{12}H_{22}O_{11}(s)]$ | +392.4 J mol$^{-1}$ K$^{-1}$ |
| Standard enthalpy change of combustion of sucrose, $\Delta H^\circ$ | −5639.7 kJ mol$^{-1}$ |
| Standard entropy of oxygen, $S^\circ [\frac{1}{2}O_2(g)]$ | +102.5 J mol$^{-1}$ K$^{-1}$ |

The equation for the complete combustion of sucrose, $C_{12}H_{22}O_{11}$, is

$$C_{12}H_{22}O_{11}(s) + 12O_2(g) \rightarrow 12CO_2(g) + 11H_2O(l)$$

(a) (i) Calculate the standard entropy change of the system, $\Delta S^\circ_{system}$, for this combustion, using the data given in the table and your Data Booklet. Include a sign and units in your answer.

(3)

(ii) Calculate the standard entropy change of the surroundings, $\Delta S^\circ_{surroundings}$, for this combustion at 298 K. Include a sign and units in your answer.

(2)
(iii) Calculate the total standard entropy change for the combustion, $\Delta S_{\text{total}}$, at 298 K.

State the significance of your answer. (2)

(iv) State and explain the effect, if any, of increasing the temperature on $\Delta S_{\text{surroundings}}$, $\Delta S_{\text{total}}$, and the extent of the reaction. (3)

(v) Icing sugar can be hazardous when it is being finely powdered in a factory.

Explain why sucrose is stable at room temperature, in spite of your answer to part (iii), but its manufacture is hazardous. (2)

(vi) Suggest two risks associated with high levels of sucrose in the diet. (2)
(b) Sucrose can be hydrolysed by warming with dilute hydrochloric acid to form glucose and fructose.

In aqueous solution, a structure of glucose is

```
CHO
H-C-OH
HO-C-H
H-C-OH
H-C-OH
CH_2OH
```

(i) Circle or mark with an asterisk (*) all the chiral centres on the structure of glucose.

(ii) State the physical property associated with molecules which have chiral centres.

(iii) State what change you would expect to see when glucose is boiled with Benedict's or Fehling's solutions.

Explain the chemistry involved in this reaction.

(Total for Question 19 = 20 marks)
The Periodic Table of Elements

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<th>(1)</th>
<th>(2)</th>
<th>Key</th>
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<td>platinum</td>
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<td>Au</td>
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<td>204.4</td>
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<td>thallium</td>
</tr>
<tr>
<td>207.2</td>
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<td>lead</td>
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<tr>
<td>209.0</td>
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<td>bismuth</td>
</tr>
<tr>
<td>210.0</td>
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<td>polonium</td>
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<tr>
<td>212.2</td>
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</tr>
<tr>
<td>222</td>
<td>Rn</td>
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</tr>
</tbody>
</table>

Elements with atomic numbers 112-116 have been reported but not fully authenticated.

* Lanthanide series
* Actinide series