HODDER GIBSON

Model Paper
WITH ANSWERS

Advanced Higher Chemistry
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Chemistry
Section 1 — Questions

Duration — 2 hours 30 minutes

Instructions for the completion of Section 1 are given on Page two of your question and answer booklet.

Record your answers on the answer grid on Page three of your question and answer booklet.
Reference may be made to the Chemistry Higher and Advanced Higher Data Booklet.

Before leaving the examination room you must give your question and answer booklet to the Invigilator; if you do not you may lose all the marks for this paper.
1. The electronic configuration of Cu⁺(g) is
   A  4s¹3d⁹
   B  4s²3d⁸
   C  4s⁰3d¹⁰
   D  4s¹3d⁹.

The following two questions refer to the absorption spectrum of [Ti(H₂O)₆]³⁺ below.

2. The colour which would be observed is
   A  blue
   B  green
   C  purple
   D  yellow.

3. The colour is caused by
   A  electrons absorbing energy to jump from one d orbital to another d orbital
   B  excited electrons dropping to the ground state
   C  electrons absorbing energy to jump from the first to the second shell
   D  electrons absorbing energy to jump from the second to the third shell.

4. The correct formula for the tetraamminedichlorocopper(II) complex is
   A  [Cu(NH₃)₄Cl₂]²⁻
   B  [Cu(NH₃)₄Cl₄]
   C  [Cu(NH₃)₄Cl₂]²⁺
   D  [Cu(NH₃)₄Cl₂]⁴⁺.
5. When one mole of phosphorus pentachloride was heated to 523 K in a closed vessel, 50% dissociated as shown

\[ \text{PCl}_5(g) \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g) \]

How many moles of gas were present in the equilibrium mixture?

A 0.5
B 1.0
C 1.5
D 2.0

6. Which of the following would **not** be suitable to act as a buffer solution?

A Boric acid and sodium borate
B Nitric acid and sodium nitrate
C Benzoic acid and sodium benzoate
D Propanoic acid and sodium propanoate

7. Which of the following 0.01 mol·L\(^{-1}\) aqueous solutions has the highest pH value?

A Sodium fluoride
B Sodium benzoate
C Sodium propanoate
D Sodium methanoate

8. An acid is a substance which

A donates a proton leaving a conjugate acid
B donates a proton leaving a conjugate base
C accepts a proton leaving a conjugate acid
D accepts a proton leaving a conjugate base.
9. The pH ranges over which some indicators change colour are shown below.

Which line in the table shows the indicator most suitable for the titration of hydrochloric acid with ammonia solution?

<table>
<thead>
<tr>
<th>Indicator</th>
<th>pH range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Methyl orange</td>
<td>4.2–6.3</td>
</tr>
<tr>
<td>B Bromothymol blue</td>
<td>6.0–7.6</td>
</tr>
<tr>
<td>C Phenol red</td>
<td>6.8–8.4</td>
</tr>
<tr>
<td>D Phenolphthalein</td>
<td>8.3–10.0</td>
</tr>
</tbody>
</table>

10. Which of the following reactions would show the greatest decrease in entropy?

A \( \text{H}_2(\text{g}) + \text{F}_2(\text{g}) \rightarrow 2\text{HF}(\text{g}) \)

B \( \text{KNO}_3(\text{s}) \rightarrow \text{KNO}_2(\text{s}) + \frac{1}{2}\text{O}_2(\text{g}) \)

C \( \text{CO}_3^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g}) \)

D \( \text{CO}_3^{2-}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{HCO}_3^-(\text{aq}) \)

11. Which line in the table is correct for the enthalpy change and entropy change when steam condenses?

<table>
<thead>
<tr>
<th></th>
<th>( \Delta H )</th>
<th>( \Delta S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>+ve</td>
<td>+ve</td>
</tr>
<tr>
<td>B</td>
<td>+ve</td>
<td>-ve</td>
</tr>
<tr>
<td>C</td>
<td>-ve</td>
<td>-ve</td>
</tr>
<tr>
<td>D</td>
<td>-ve</td>
<td>+ve</td>
</tr>
</tbody>
</table>

12. Which of the following graphs shows the variation in \( \Delta G^0 \) with temperature for a reaction which is always feasible?
13. For the reaction
\[ 2\text{NO}(g) + \text{Cl}_2(g) \rightarrow 2\text{NOCl}(g) \]
the rate equation is
\[ \text{rate} = k[\text{NO}][\text{Cl}_2] \]
The overall order of this reaction is
A  1  
B  2  
C  3  
D  5.

14. What volume of water needs to be added to 25 cm\(^3\) of 0.2 mol l\(^{-1}\) calcium chloride solution to produce a solution with a chloride ion concentration of 0.1 mol l\(^{-1}\)?
A  25 cm\(^3\)  
B  50 cm\(^3\)  
C  75 cm\(^3\)  
D  100 cm\(^3\)

15. Which of the following best describes the bonding in ethane?
A  \(sp^2\) hybridisation of the carbon atoms giving sigma bonds only
B  \(sp^3\) hybridisation of the carbon atoms giving sigma and pi bonds
C  \(sp^3\) hybridisation of the carbon atoms giving sigma bonds only
D  \(sp^3\) hybridisation of the carbon atoms giving sigma and pi bonds

16. \[ \text{KI(aq)} + \text{Pb(NO}_3\text{)}_2(aq) \rightarrow \text{PbI}_2(\text{s}) + \text{KNO}_3(aq) \]
Which of the following would be the most appropriate technique for obtaining a dry sample of PbI\(_2\)?
A  evaporation of the product mixture
B  distillation of the product mixture
C  vacuum filtration of the product mixture
D  refluxing the product mixture
17. In the homologous series of alcohols, increase in chain length from \(\text{CH}_3\text{OH}\) to \(\text{C}_{10}\text{H}_{21}\text{OH}\) is accompanied by

A. increased volatility and increased solubility in water  
B. increased volatility and decreased solubility in water  
C. decreased volatility and decreased solubility in water  
D. decreased volatility and increased solubility in water.

18. Which of the following is not caused by hydrogen bonding?

A. The low density of ice compared to water  
B. The solubility of methoxymethane in water  
C. The higher boiling point of methanol compared to ethane  
D. The higher melting point of hydrogen compared to helium

19. Melting point determination and thin layer chromatography are useful techniques for assessing the purity of a compound. Which line in the table below shows the results expected from a pure compound, which is known to have a melting point of 128°C?

<table>
<thead>
<tr>
<th>Melting point range (°C)</th>
<th>Number of spots shown on a chromatography plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>92.1–101.7</td>
</tr>
<tr>
<td>B</td>
<td>120.2–128.0</td>
</tr>
<tr>
<td>C</td>
<td>127.5–127.9</td>
</tr>
<tr>
<td>D</td>
<td>127.8–130.1</td>
</tr>
</tbody>
</table>

20. Which of the following compounds would liberate one mole of hydrogen gas if one mole of it reacts with two moles of sodium?

A. \(\text{C}_2\text{H}_5\text{OH}\)  
B. \(\text{HOCH}_2\text{CH}_2\text{OH}\)  
C. \(\text{CH}_3\text{COOH}\)  
D. \(\text{CH}_3\text{CHO}\)
21. Mandelic acid has two optical isomers, X and Y. The table shows the rotation of plane polarised light caused by various solutions of X and Y.

<table>
<thead>
<tr>
<th>Volume of 0·1 mol l⁻¹ X/cm³</th>
<th>Volume of 0·1 mol l⁻¹ Y/cm³</th>
<th>Volume of water/cm³</th>
<th>Observed rotation/°</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>0</td>
<td>+158</td>
</tr>
<tr>
<td>50</td>
<td>0</td>
<td>50</td>
<td>+79</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>0</td>
<td>-158</td>
</tr>
</tbody>
</table>

What would be the observed rotation for a solution containing 25 cm³ of 0·1 mol l⁻¹ X and 75 cm³ of 0·1 mol l⁻¹ Y?

A  -79°
B  -39·5°
C  +39·5°
D  79°

22. Carbonyl groups in aldehydes and ketones react with HCN and the product can then be hydrolysed forming a 2-hydroxycarboxylic acid as shown in the equation below.

```
\begin{align*}
\text{HCN} \rightarrow \text{H} - \text{C} - \text{O} & \quad \text{methanal} \\
\text{H} - \text{C} - \text{O} \rightarrow \text{H} - \text{C} - \text{OH} & \quad \text{HCN} \\
\text{H} - \text{C} - \text{O} \rightarrow \text{H} - \text{C} - \text{OH} & \quad \text{H}^+ (\text{aq}) \\
\end{align*}
```

2-hydroxyethanoic acid

When the final product is 2-hydroxy-2-methylbutanoic acid, the starting carbonyl compound is

A  propanal
B  propanone
C  butanal
D  butanone.

23.

\begin{center}
\includegraphics[width=0.5\textwidth]{skeletal_formula.png}
\end{center}

is the skeletal formula for

A  3,4,4-trimethylbutan-1-ol
B  2,3-dimethylpentan-5-ol
C  3,4-dimethylpentan-1-ol
D  4,5-dimethylhexan-1-ol.
24. One mole of which of the following compounds will react with the largest volume of 1 mol·L⁻¹ hydrochloric acid?

A. \( \text{CH}_3\text{NHCH}_3 \)
B. \( \text{H}_2\text{NCH}_2\text{NH}_2 \)
C. \( \text{HOOCCCH}_2\text{NH}_2 \)
D. \( \text{HOOC-} \begin{array}{c} \text{NH}_2 \\ \text{C} \end{array} \)

25. Which of the following is not an example of a hydrolysis reaction?

A. \( \text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} \)
B. \( \text{CH}_3\text{CN} + 2\text{H}_2\text{O} \rightarrow \text{CH}_3\text{COOH} + \text{NH}_3 \)
C. \( \text{CH}_3\text{COOCH}_3 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{COOH} + \text{CH}_3\text{OH} \)
D. \( \text{C}_6\text{H}_5\text{COOCH}_3 + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_5\text{COOH} + \text{CH}_3\text{OH} \)

26. Spectral studies of an organic compound indicated the presence of a di-substituted benzene ring, two methyl groups and a molecular weight of 134.
Which of the following is a possible structure for the compound?

A. \( \begin{array}{c} \text{CH}_3 \\ \text{C} \end{array} \)

B. \( \begin{array}{c} \text{CH}_3 \\ \text{CHO} \end{array} \)

C. \( \begin{array}{c} \text{CH}_3\text{CH}_2 \\ \text{COCH}_3 \end{array} \)

D. \( \begin{array}{c} \text{CH}_3 \\ \text{CH}_2\text{CHO} \end{array} \)
27. Which of the following compounds has a geometric isomer?

A
H\_2C\_\_\_CH
\_\_Cl
Cl

B
H\_\_\_\_C\_\_Cl
\_H

C
H\_\_\_\_C\_Cl
\_\_\_Cl

D
H\_\_\_\_C\_\_\_\_\_\_\_\_Cl

28. A simplified mass spectrum of an organic compound is shown.

Which of the following compounds produces this spectrum?

A  Propane
B  Propan-1-ol
C  Propan-2-ol
D  Propanone

29. An analysis of an organic compound found in meteorite rocks shows the following percentage composition by mass:

C = 37.5%  H = 12.5%  O = 50%

The empirical (simplest) formula for the compound is

A  CH\_4O
B  C\_3H\_2O\_4
C  C\_3H\_12O\_3
D  CH\_2O\_2.
30. Salbutamol is used to treat asthma. It behaves like the body’s natural active compound by binding to receptors on the muscles of the air passages. This relaxes the muscles and gives relief from breathing difficulties. Salbutamol is

A an agonist
B an antagonist
C a pharmacaphore
D a receptor.
Chemistry
Section 1 — Answer Grid and Section 2

Duration — 2 hours 30 minutes

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)
Surname
Number of seat

Date of birth
Day
Month
Year
Scottish candidate number

Reference may be made to the Chemistry Higher and Advanced Higher Data Booklet.

Total marks — 100

SECTION 1 — 30 marks
Attempt ALL questions.
Instructions for completion of Section 1 are given on Page two.

SECTION 2 — 70 marks
Attempt ALL questions

Write your answers clearly in the spaces provided in this booklet. Additional space for answers and rough work is provided at the end of this booklet. If you use this space you must clearly identify the question number you are attempting. Any rough work must be written in this booklet. You should score through your rough work when you have written your final copy.

Use blue or black ink.

Before leaving the examination room you must give this booklet to the Invigilator; if you do not, you may lose all the marks for this paper.
SECTION 1—30 marks

The questions for Section 1 are contained in the question paper on Page four. Read these and record your answers on the answer grid on Page three opposite. Do NOT use gel pens.

1. The answer to each question is either A, B, C or D. Decide what your answer is, then fill in the appropriate bubble (see sample question below).

2. There is only one correct answer to each question.

3. Any rough working should be done on the additional space for answers and rough work at the end of this booklet.

Sample Question
To show that the ink in a ball-pen consists of a mixture of dyes, the method of separation would be:

A fractional distillation
B chromatography
C fractional crystallisation
D filtration.

The correct answer is B—chromatography. The answer B bubble has been clearly filled in (see below).

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

Changing an answer

If you decide to change your answer, cancel your first answer by putting a cross through it (see below) and fill in the answer you want. The answer below has been changed to D.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

If you then decide to change back to an answer you have already scored out, put a tick (✓) to the right of the answer you want, as shown below:

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>✓</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

or

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>O</td>
<td>✓</td>
<td>O</td>
</tr>
</tbody>
</table>
1. Atomic spectroscopy is a useful analytical tool for identifying and quantifying the elements present in a sample. It also provides information about atomic structure.

(a) When a high voltage is applied to a lamp filled with helium gas, a line of red light, wavelength 706 nm, is observed through a spectroscope.

(i) Explain how the line of red light is produced.  

(ii) Calculate the energy, in kJmol\(^{-1}\), associated with this wavelength.  

(b) A helium atom has two electrons in its ground state. One of the electrons can be described by the four quantum numbers 1, 0, 0, \(\frac{1}{2}\). What four quantum numbers describe the other electron?
1. (continued)

(c) (i) Using orbital box notation, write the electronic configuration for a phosphorus atom in its ground state.

(ii) Explain how your answer is consistent with Hund’s rule.

(iii) When a phosphorus atom becomes excited an electron can move to the 4s orbital.
What four quantum numbers describe the excited electron?

(d) Mercury atoms are much larger than those of helium or phosphorus. A small section of the atomic emission spectrum for mercury is shown below.

```
400nm

```

Why does this spectrum have multiple lines?

(e) Sir Isaac Newton was thought to have suffered from mercury poisoning and when his hair was analysed the level of mercury was found to be 73 ppm. The unit ppm stands for parts per million and refers to 1 mg per kg.
Calculate the number of moles of mercury in a $1.0 \times 10^{-6}$ g sample of Newton’s hair.
2. A common dietary supplement taken by athletes and slimmers is called chromium picolinate \([\text{Cr(pic)}_3]\). The structure of the picolinate ion, pic, is

\[
\text{pic} = \begin{array}{c}
\text{N} \\
\text{C} \\
\text{O} \\
\text{O} \\
\text{N}
\end{array}
\]

(a) What feature of the picolinate ion makes it suitable for use as a ligand? 1

(b) In the body, it is thought that the chromium in \([\text{Cr(pic)}_3]\) is changed into chromium(VI) by the action of hydrogen peroxide.

(i) What is the oxidation state of chromium in \([\text{Cr(pic)}_3]\)? 1

(ii) What is the role of hydrogen peroxide in this reaction? 1

(c) A simpler complex of chromium is \([\text{Cr(CN)}_6]^{3+}\). What is its systematic name? 1
3. The dicarboxylic acid, oxalic acid, has molecular formula \( \text{H}_2\text{C}_2\text{O}_4 \). It can be prepared by reacting calcium oxalate with sulfuric acid.

\[
\text{H}_2\text{SO}_4(\text{aq}) + \text{CaC}_2\text{O}_4(\text{s}) + x\text{H}_2\text{O(l)} \rightarrow \text{CaSO}_4 \cdot x\text{H}_2\text{O(s)} + \text{H}_2\text{C}_2\text{O}_4(\text{aq})
\]

(a) Draw a structural formula for oxalic acid.  

(b) 4·94 g of \( \text{CaSO}_4 \cdot x\text{H}_2\text{O} \) was dehydrated to produce 3·89 g of \( \text{CaSO}_4 \).

Determine the value of \( x \).  

(c) The equation for the reaction between oxalic acid and sodium hydroxide solution is

\[
\text{H}_2\text{C}_2\text{O}_4(\text{aq}) + 2\text{NaOH(\text{aq})} \rightarrow \text{Na}_2\text{C}_2\text{O}_4(\text{aq}) + 2\text{H}_2\text{O(l)}
\]

A student used a standard solution of 0·0563 mol\( \text{l}^{-1} \) oxalic acid to standardise 20·0 cm\(^3\) of approximately 0·1 mol\( \text{l}^{-1} \) sodium hydroxide solution.

The raw results for the titration are given in the table.

<table>
<thead>
<tr>
<th></th>
<th>1st attempt</th>
<th>2nd attempt</th>
<th>3rd attempt</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Final burette reading/cm(^3)</strong></td>
<td>17·2</td>
<td>33·8</td>
<td>16·6</td>
</tr>
<tr>
<td><strong>Initial burette reading/cm(^3)</strong></td>
<td>0·0</td>
<td>17·2</td>
<td>0·1</td>
</tr>
<tr>
<td><strong>Titre/cm(^3)</strong></td>
<td>17·2</td>
<td>16·6</td>
<td>16·5</td>
</tr>
</tbody>
</table>

Calculate the accurate concentration of the sodium hydroxide solution.  

(d) Oxalic acid is a primary standard but sodium hydroxide is not. State one characteristic of sodium hydroxide that makes it unsuitable as a primary standard.
4. Before a pH electrode can be used to measure the pH of a solution it must be calibrated by placing it in a series of buffer solutions of known pH.

One buffer solution used to calibrate a pH electrode was made by dissolving 2.24g of potassium propanoate, \( \text{C}_3\text{H}_5\text{COOK} \), in 250cm\(^3\) of 0.20molt\(^{-1}\) propanoic acid.

(a) What property of buffer solutions makes them ideal for calibrating pH electrodes? 1

(b) Calculate the pH of the buffer solution described above. 3
5. The following table of results was obtained for the reaction below.

\[ \text{H}_2\text{O}_2(\text{aq}) + 2\text{HI}(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{I}_2(\text{aq}) \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>([\text{H}_2\text{O}_2]/\text{mol}\text{l}^{-1})</th>
<th>([\text{HI}]/\text{mol}\text{l}^{-1})</th>
<th>Initial rate/\text{mol}\text{l}^{-1}\text{s}^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(3\cdot2 \times 10^{-4})</td>
<td>(4\cdot1 \times 10^{-4})</td>
<td>(4\cdot3 \times 10^{-9})</td>
</tr>
<tr>
<td>2</td>
<td>(6\cdot4 \times 10^{-4})</td>
<td>(4\cdot1 \times 10^{-4})</td>
<td>(8\cdot6 \times 10^{-9})</td>
</tr>
<tr>
<td>3</td>
<td>(3\cdot2 \times 10^{-4})</td>
<td>(8\cdot2 \times 10^{-4})</td>
<td>(8\cdot6 \times 10^{-9})</td>
</tr>
<tr>
<td>4</td>
<td>(6\cdot4 \times 10^{-4})</td>
<td>(8\cdot2 \times 10^{-4})</td>
<td>(1\cdot72 \times 10^{-8})</td>
</tr>
</tbody>
</table>

(a) The order of reaction with respect to \(\text{H}_2\text{O}_2\) is 1st order. Determine the order of reaction with respect to \(\text{HI}\).  

(b) Write the rate equation for the reaction.  

(c) Calculate a value for the rate constant, \(k\), including the appropriate units.
6. Molten iron, made in a blast furnace, often contains sulfur and phosphorus impurities which must be removed.

Bubbling carbon dioxide gas through molten iron removes the sulfur.

The carbon dioxide gas is produced by the decomposition of calcium carbonate.

\[
\text{CaCO}_3 (s) \rightarrow \text{CaO} (s) + \text{CO}_2 (g)
\]

<table>
<thead>
<tr>
<th>Substance</th>
<th>Standard enthalpy of formation, ( \Delta H^0 )/kJ mol(^{-1})</th>
<th>Standard entropy, ( S^0 )/JK(^{-1}) mol(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2)</td>
<td>-393.5</td>
<td>213.8</td>
</tr>
<tr>
<td>CaCO(_3)</td>
<td>-1206.9</td>
<td>92.9</td>
</tr>
<tr>
<td>CaO</td>
<td>-635.1</td>
<td>38.1</td>
</tr>
</tbody>
</table>

For the decomposition of calcium carbonate, use the data in the table to calculate

(a) the standard enthalpy change, \( \Delta H^0 \), in kJ mol\(^{-1}\) 

(b) the standard entropy change, \( \Delta S^0 \), in JK\(^{-1}\) mol\(^{-1}\) 

(c) the theoretical temperature at which the reaction just becomes feasible.
7. The commercial medicine, paracetamol, can be created as shown in the reaction sequence below.

**Step 1: Nitration**
\[
\text{HO} - \text{C} - \text{H} \quad \text{dilute } \text{H}_2\text{SO}_4 \quad \text{NaNO}_3 \quad \text{HO} - \text{C} - \text{NO}_2
\]

**Step 2: Reduction**
\[
\text{HO} - \text{C} - \text{NO}_2 \quad \text{NaBH}_4 \quad \text{Pd} / 1 \text{ mol l}^{-1} \text{NaOH} \quad \text{HO} - \text{C} - \text{NH}_2 \quad 74\% \text{ yield}
\]

**Step 3: Amide formation**
\[
\text{HO} - \text{C} - \text{NH}_2 \quad \text{Ethanoic anhydride} \quad \text{Water, room temperature} \quad \text{HO} - \text{C} - \text{N}\text{O}\text{C} - \text{CH}_3
\]

Paracetamol

(a) State the name of an alternative reducing agent to NaBH₄ that could be used to carry out Step 2.

(b) State the chemical formula for paracetamol.
7. (continued)

(c) A student carried out Step 3 by reacting 4-aminophenol with excess ethanoic anhydride. The paracetamol obtained was purified by recrystallisation. A small sample was then used to determine the melting point whilst another sample was used for thin layer chromatography.

(i) Assuming a 60% yield for Step 3, calculate the minimum mass of 4-aminophenol required to react with ethanoic anhydride to produce 1·10 g of paracetamol.

(ii) Describe the steps the student would take to recrystallise the paracetamol.

(d) The quantity of paracetamol in a sample can be determined by refluxing an accurate mass of paracetamol with sulfuric acid to form 4-aminophenol, followed by titration with the oxidising agent ammonium cerium(IV) sulfate.

\[
\begin{align*}
\text{HO} & \quad \text{N} & \quad \text{H} & \quad \text{H}_2\text{O} / H_2\text{SO}_4 & \quad \text{HO} \\
\text{HO} & \quad \text{N} & \quad \text{CH}_3 & \quad \text{HO} & \quad \text{NH}_2
\end{align*}
\]

4-aminophenol

Ethanoic acid

Draw a diagram of the apparatus used to carry out the reflux as described.
8. The percentage of iron in an iron supplement can be determined by colorimetry. An extract from a laboratory manual for preparing a sample for colorimetric analysis is shown below.

**Iron tablet preparation**

1. Place 1 iron tablet into a beaker along with 25 cm$^3$ of 6 mol l$^{-1}$ HCl (aq) and boil gently for 15 min.
2. Filter into a 100 cm$^3$ volumetric flask.
3. Add 3 cm$^3$ o-phenanthroline, and dilute to 100 cm$^3$ with water.
4. Measure the absorbance of this solution at 508 nm.

The iron in the tablet reacts with o-phenanthroline as shown:

![Chemical reaction diagram]

\[ \text{o-phenanthroline} \quad + \quad \text{Fe}^{2+} \quad \xrightleftharpoons{\text{equilibrium}} \quad \text{Fe}^{2+} \quad \quad \lambda_{\text{max}} = 508 \text{ nm} \]

(a) State the purpose of the compound, o-phenanthroline.

(b) Describe all further steps a student would have to take in order to determine the concentration of iron in the iron tablet using the technique of colorimetry.
8. (continued)

(c) The recommended daily allowance (RDA) of iron is 14.8 mg.

An iron tablet was treated as per steps 1–4 in the guide above. The 100 cm$^3$ solution prepared was found to have an iron concentration of $4.67 \times 10^{-3}$ mol l$^{-1}$. Calculate the % of RDA supplied by this iron tablet.

(d) An alternative method of iron determination involves titrating with a standard solution of potassium permanganate, since permanganate ions react with iron (II) according to the following equation:

$$\text{MnO}_4^-_{(aq)} + 8H^+_{(aq)} + 5\text{Fe}^{2+}_{(aq)} \rightarrow \text{Mn}^{2+}_{(aq)} + 5\text{Fe}^{3+}_{(aq)} + 4\text{H}_2\text{O}_{(l)}$$

Another brand of iron tablet was treated as per the instructions above. 10 cm$^3$ aliquots from the 100 cm$^3$ iron tablet solution were titrated with 0.002 mol l$^{-1}$ standard potassium permanganate solution. The average titre was found to be 20.3 cm$^3$. Calculate the mass of iron present in this tablet.
9. In the winter of 1987 over a hundred people became extremely ill within hours after dining on cultured blue mussels in restaurants around Prince Edward Island in Canada. After much research, chemists eventually isolated and identified the toxin to be domoic acid, a structural formula of which is shown below.

Using your knowledge of chemistry, suggest how domoic acid could be isolated and identified from contaminated mussels.
10. 1-Bromobutane and 2-bromo-2-methylpropane are isomers which can be converted to their corresponding alcohols using hydroxide ions.

   (a) The conversion of 2-bromo-2-methylpropane to 2-methylpropan-2-ol involves an $S_N1$ mechanism.

   Outline the two steps in this mechanism using structural formulae.  

   (b) Explain why the conversion of 1-bromobutane to butan-1-ol is unlikely to proceed by an $S_N1$ mechanism.
11. Blood clotting is a natural chemical reaction which helps to stop bleeding. In some cases, the blood can clot when not required leading to blockages in the veins. A potential treatment to stop blood clotting like this involves blocking the enzyme known as FXa which is one enzyme responsible for creating blood clots.

The structure of a commercial FXa inhibitor, Rivaroxaban, is shown below.

(a) Explain whether this molecule is acting as an agonist or antagonist.
11. (continued)

(b) Rivaroxaban can be synthesised by the reaction of the amine shown below with a carboxylic acid.

(i) State whether this is a primary, secondary or tertiary amine. 1

(ii) Explain why solutions of this compound would be expected to have an alkaline pH. 1

(iii) Draw a structural formula for the carboxylic acid that can react with this amine to form Rivaroxaban. 1
12. The following simplified spectra were obtained for a pure organic compound containing carbon, hydrogen and oxygen only.

![Infra-red spectrum](image)

![Mass spectrum](image)

![Proton NMR spectrum](image)

The proton NMR spectrum was analysed and the data are presented in the table below.

<table>
<thead>
<tr>
<th>Chemical shift</th>
<th>Area under the peak</th>
<th>H atom ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>6.9</td>
<td>X</td>
</tr>
<tr>
<td>2.5</td>
<td>4.5</td>
<td>Y</td>
</tr>
<tr>
<td>9.8</td>
<td>2.3</td>
<td>Z</td>
</tr>
</tbody>
</table>

(a) Identify the functional group causing the absorption at 1730 cm\(^{-1}\) in the infrared spectrum.
12. (continued)

(b) Identify a possible ion fragment responsible for the peak at m/z 29 in the mass spectrum.

(c) From the proton NMR spectrum what is the whole number ratio of hydrogen atoms, X:Y:Z?

(d) From the information above draw a structural formula for this compound.
13. Hybridisation of atomic orbitals is necessary to explain the bonding in hydrocarbon families such as the alkanes, alkenes and aromatic hydrocarbons. Using your knowledge of chemistry, discuss this statement.
<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>3.</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>4.</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>5.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>6.</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>7.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>8.</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>9.</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>10.</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>11.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>12.</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>13.</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>14.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>15.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>16.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>17.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>18.</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>19.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>20.</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>21.</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>22.</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>23.</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>24.</td>
<td>B</td>
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</tr>
<tr>
<td>25.</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>26.</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>27.</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>28.</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>29.</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>30.</td>
<td>A</td>
<td>1</td>
</tr>
</tbody>
</table>
### Question 1

<table>
<thead>
<tr>
<th>Question</th>
<th>Expected response</th>
<th>Max mark</th>
<th>Additional guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>An electron is excited/promoted to a higher energy level. (1 mark) When the electron falls to a lower energy level/ground state, energy (corresponding to red light) is emitted. (1 mark)</td>
<td>2</td>
<td>Alternatively, calculate the frequency first using $c = \lambda f$, and then calculate energy using $E = Lhc$. i.e. $f = \frac{3 \times 10^8}{706 \times 10^{-9}}$ $f = 4.25 \times 10^{14}$ s$^{-1}$ $E = Lhc$ $= 6.02 \times 10^{23} \times 6.63 \times 10^{-34} \times 4.25 \times 10^{14}$ $= 169600$ J mol$^{-1}$</td>
</tr>
<tr>
<td>(b)</td>
<td>$1, 0, 0, -\frac{1}{2}$</td>
<td>1</td>
<td>In other words, everything is the same except we put a negative sign in front of the $\frac{1}{2}$ to show that the spin is in the opposite direction.</td>
</tr>
<tr>
<td>(c)</td>
<td><img src="image" alt="Orbitals" /> Full or half-head arrows would be acceptable.</td>
<td>1</td>
<td>The (three degenerate) 3p orbitals are filled singly. 3p orbitals are filled in such a way as to maximise the number of parallel spins.</td>
</tr>
<tr>
<td>(d)</td>
<td>Many different electron transitions (in the visible region) Many different energy levels</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(e)</td>
<td>73 mg per kg = $73 \times 10^{-3}$ g per 1000 g $= 7.3 \times 10^{-11}$ g of Hg in $10^{-6}$ g of hair (1 mark) Number of mol $= \frac{7.3 \times 10^{-11}}{200.6}$ $= 3.64 \times 10^{-13}$ (mol) (1 mark)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Expected response</td>
<td>Max mark</td>
<td>Additional guidance</td>
</tr>
<tr>
<td>----------</td>
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<td>----------</td>
<td>---------------------</td>
</tr>
<tr>
<td>2. (a)</td>
<td>Lone pairs/electrons available to form dative covalent bonds</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(b) (i)</td>
<td><strong>III or 3 or 3⁺ or 3⁻</strong></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(b) (ii)</td>
<td>Oxidising agent/to oxidise Cr(III)/electron acceptor</td>
<td>1</td>
<td>The hydrogen peroxide has caused the chromium to change from Cr³⁺ to Cr⁶⁺. In other words, the hydrogen peroxide has caused this oxidation.</td>
</tr>
<tr>
<td>(c)</td>
<td>Hexacyanochromate(II)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3. (a)</td>
<td><img src="image" alt="Diagram of oxalic acid" /></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>Number of moles of CaSO₄ = ( \frac{3.89}{136.1} ) = 0.0286</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of moles of H₂O = ( \frac{1.05}{18} ) = 0.05831 (1 mark)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value of ( x = 2 ) (1 mark)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>Moles of oxalic acid = ( 16.55 \times 10^{-3} \times 0.0563 ) = 0.0932 mol l⁻¹ (1 mark)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conc. of NaOH = ( \frac{9.32 \times 10^{-4} \times 2}{0.020} ) = 0.0932 mol l⁻¹ (1 mark)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td>Not available in high purity/not stable in solid or Solution/solid is deliquescent/hygroscopic/low gfm/absorbs water/absorbs CO₂</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4. (a)</td>
<td>pH remains/stays the same/doesn't change/reasonably constant if small volumes of acid or alkali are added</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>pH = pKa - log ( \frac{[acid]}{[salt]} )</td>
<td>3</td>
<td>The pH equations are in the SQA data booklet. Make sure you know when to use the appropriate equation.</td>
</tr>
<tr>
<td></td>
<td>Moles of salt = ( \frac{2.24}{112.1} ) = 0.0200</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conc. of salt = ( \frac{0.0200}{0.25} ) = 0.08 mol l⁻¹ (1 mark)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>pH = 4.87 - log ( \frac{0.2}{0.08} ) (1 mark)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( 4.87 - 0.398 = 4.5 ) (1 mark)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Expected response</td>
<td>Max mark</td>
<td>Additional guidance</td>
</tr>
<tr>
<td>----------</td>
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<td>---------------------</td>
</tr>
<tr>
<td>5.  (a)</td>
<td>1st order</td>
<td>1</td>
<td>Compare experiments 1 and 3. Doubling [HI] leads to a doubling of the rate, i.e. the reaction is 1st order w.r.t. HI.</td>
</tr>
<tr>
<td>(b)</td>
<td>Rate = ( k[H_2O_2][HI] )</td>
<td>1</td>
<td>If you make a mistake in part (a) you will still gain credit for a correct rate equation which corresponds to the orders you calculated in (a).</td>
</tr>
</tbody>
</table>
| (c)      | \( k = \frac{\text{Rate}}{[H_2O_2][HI]} = \frac{4 \times 10^{-9}}{(3 \times 2 \times 10^{-4})(4.1 \times 10^{-4})} \)  
\( = 0.0328 \text{ mol}^{-1} \text{ Ls}^{-1} \)  
\( (1 \text{ mark for answer; 1 mark for units}) \) | 2        | The value for \( k \) is calculated by rearranging the rate equation and substituting in data from any horizontal line in the table. Here, line 1 is used. |
| 6.  (a)  | 178.3 kJ mol\(^{-1}\) | 1        | Calculated from \( \Sigma H_p - \Sigma H_r = (-63.1 + -393.5) - (-1206.9) \) |
| (b)      | 159 JK\(^{-1}\)mol\(^{-1}\) | 1        | Calculated from \( \Sigma S_p - \Sigma S_r = (38.1 + 213.8) - (92.9) \) |
| (c)      | \( \Delta G^\circ = \Delta H^\circ - T \Delta S^\circ \)  
just feasible when \( \Delta G^\circ = 0 \)  
\( \Delta H^\circ - T \Delta S^\circ = 0 \)  
\( T \Delta S^\circ = \Delta H^\circ \)  
\( T = \frac{178.3 \times 1000}{159} \)  
\( = 1121.4 \text{ K} \)  
\( (1 \text{ mark}) \) | 3        | Since \( \Delta H^\circ \) is in kJ and \( \Delta S^\circ \) is in J, you must change either the enthalpy or entropy so that you are using the same energy units. In the marking scheme, the enthalpy has been \( \times 1000 \) so that it has units in J. |
| 7.  (a)  | LiAlH\(_4\) | 1        | |
| (b)      | C\(_6\)H\(_7\)O\(_2\)N | 1        | |
| (c)      | (i) Moles of paracetamol = \( \frac{1.10}{151} = 0.0073 \)  
\( (1 \text{ mark}) \)  
60% of \( x = 0.073 \)  
\( x = \frac{0.0073}{0.6} = 0.0121 \text{ moles} \)  
\( (1 \text{ mark}) \)  
Moles of 4AP = 0.0121  
Mass of 4AP = 0.0121 \( \times 109 = 1.32 \text{ g} \)  
\( (1 \text{ mark}) \) | 3        | The formula for 4-aminophenol is C\(_6\)H\(_7\)ON which has a gfm of 109. |
| (ii)     | The impure paracetamol should be dissolved in (the minimum volume of) a hot solvent.  
\( (1 \text{ mark}) \)  
This hot solution should be filtered and the filtrate cooled.  
\( (1 \text{ mark}) \) | 2        | |
<table>
<thead>
<tr>
<th>Question</th>
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<th>Max mark</th>
<th>Additional guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d)</td>
<td><img src="image" alt="Diagram" /></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1 mark for correct apparatus; 1 mark for correct labels)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. (a)</td>
<td>Creates a coloured compound or Creates a compound which absorbs in the visible region</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>Solutions of accurate iron concentration are made up and the absorbance of each is measured. (1 mark) A calibration curve of concentration vs absorbance is drawn. (1 mark) The absorbance of the iron tablet solution is measured and the calibration graph is then used to determine the concentration corresponding to this absorbance. (1 mark)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>Moles of iron = $4.67 \times 10^{-3} \times 0.1$ $= 4.67 \times 10^{-4}$ Mass of iron = $4.67 \times 10^{-4} \times 55.8 = 0.0261$ g $%\ RDA = \frac{0.0261}{0.0148} \times 100 = 176%$</td>
<td>2</td>
<td>1 mark for concept of $55.8 \times$ calculated moles of iron. 1 mark for arithmetic.</td>
</tr>
<tr>
<td>(d)</td>
<td>Moles $\text{KMnO}_4 = 0.002 \times 0.0203 = 4.06 \times 10^{-5}$ Moles of iron = $2.03 \times 10^{-4}$ in $10\text{ cm}^3$ Moles of iron = $2.03 \times 10^{-3}$ in $100\text{ cm}^3$ Mass of iron = $2.03 \times 10^{-3} \times 55.8 = 0.113$ g</td>
<td>3</td>
<td>1 mark for stoichiometry. 1 mark for scaling 1:10. 1 mark for arithmetic.</td>
</tr>
<tr>
<td>Question</td>
<td>Expected response</td>
<td>Max mark</td>
<td>Additional guidance</td>
</tr>
<tr>
<td>----------</td>
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<td>---------------------</td>
</tr>
</tbody>
</table>
| 9.       | This is an open-ended question. Please refer to the specimen paper marking instructions. | 3        | **Suggestions from the author**  
The functional groups of this molecule suggest that it would be polar. Thus, you could carry out a solvent extraction using water/an alcohol along with a non-polar solvent such as hexane. Shaking these in a separating funnel would allow the toxin to go into the water/alcohol layer. Non-polar compounds would stay in the hexane layer. Perhaps the toxin could be reacted with an alkali (e.g. NaOH) to form a salt which would precipitate from the solution and could be filtered. This could be turned back into the toxin by reaction with an excess of acid.  
**Identification:**  
If solid, mp analysis and compare with data booklet values. Carry out full spectroscopic analysis. IR would show specific peaks – discuss these using the data booklet. Likewise, there would be a unique H NMR pattern – discuss/compare to reference compounds. |
| 10. (a)  | ![Chemical Structure](image)  
(1 mark for correct structural formulae for both reactant and product; 1 mark for intermediate) | 2        | Accept valid equivalent using shortened structural formulae. |
| (b)      | 1-bromobutane would form a primary carbocation which is too unstable. | 1        | |
| 11. (a)  | Antagonist  
Blocking the body’s natural response  
(1 mark) | 2        | |
| (b) (i)  | Primary  
(1 mark) | 1        | |
<table>
<thead>
<tr>
<th>Question</th>
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<th>Max mark</th>
<th>Additional guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ii)</td>
<td>Amines are weak bases</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(iii)</td>
<td>![Chemical Structure]</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>12. (a)</td>
<td>Carbonyl</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>$\text{C}_2\text{H}_5^+$ or $\text{CHO}^+$</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>3 : 2 : 1</td>
<td>1</td>
<td>Mass spec shows gfm of 58. Fits the NMR ratio of 3 : 2 : 1 and the peak for the aldehyde H on the NMR is consistent with the expected chemical shift as per the data booklet.</td>
</tr>
<tr>
<td>(d)</td>
<td>![Chemical Structure]</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
| 13.      | This is an open-ended question. Please refer to the specimen paper marking instructions. | 3        | **Suggestions from the author**

This is an opportunity for you to display your knowledge of hybridisation. You could start your answer by giving the electronic configuration for C: $1s^22s^22p^2$. 

Orbital box notation: 

```
\[ \begin{array}{c}
1s \\
2s \\
2p \\
\end{array} \]
```

This would limit C atoms to two bonds.

Hybridisation involves:
- promotion of a 2s electron to the vacant p orbital
- mixing the 2s and 2p orbitals to create hybrid orbitals of equal energy.

You could then discuss the different types of hybrids using examples to illustrate your answer.

For example:
- Alkanes: mixing of the s with three p orbitals to create sp$^3$ hybrids. Discuss how these overlap in a molecule such as ethane: overlap of sp$^3$ with sp$^3$ to create the C-C sigma bond; overlap of sp$^3$ with s orbital from H to form the C-H sigma bonds.
<table>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Alkenes: discuss an alkene such as ethene and explain how the unhybridised p orbitals overlap to form pi bonds.</td>
</tr>
</tbody>
</table>