Chemistry

General Instructions
• Reading time – 5 minutes
• Working time – 3 hours
• Write using black or blue pen
• Draw diagrams using pencil
• Board-approved calculators may be used
• A data sheet and a Periodic Table are provided at the back of this paper
• Write your Centre Number and Student Number at the top of pages 9, 11, 15, 17 and 21

Total marks – 100

Section I  Pages 2–23
75 marks
This section has two parts, Part A and Part B
Part A – 15 marks
• Attempt Questions 1–15
• Allow about 30 minutes for this part
Part B – 60 marks
• Attempt Questions 16–28
• Allow about 1 hour and 45 minutes for this part

Section II  Pages 25–35
25 marks
• Attempt ONE question from Questions 29–33
• Allow about 45 minutes for this section
Section I
75 marks

Part A – 15 marks
Attempt Questions 1–15
Allow about 30 minutes for this part

Use the multiple-choice answer sheet for Questions 1–15.

1 Which of the following radiations is measured with a Geiger counter?
   (A) Beta
   (B) Infrared
   (C) Microwave
   (D) Ultraviolet

2 What are the volumes of one mole of argon, Ar, and one mole of fluorine, F₂, at 0°C and 100 kPa?

   \[
   \begin{array}{|c|c|}
   \hline
   \text{Volume (litres)} & \\
   \text{Ar} & \text{F}_2 \\
   \hline
   (A) & 12.40 & 24.79 \\
   (B) & 22.71 & 22.71 \\
   (C) & 22.71 & 45.42 \\
   (D) & 24.79 & 24.79 \\
   \hline
   \end{array}
   \]

3 Which term describes the relationship between oxygen and ozone?
   (A) Allotropes
   (B) Conjugates
   (C) Isomers
   (D) Isotopes
4 What is the main constituent of the atmosphere at ground level?

(A) Water
(B) Oxygen
(C) Nitrogen
(D) Carbon dioxide

5 Why is ethanol used in preference to water as the main ingredient of perfume?

(A) Ethanol is cheaper to produce.
(B) Ethanol has no detectable odour.
(C) Ethanol dissolves esters more readily.
(D) Ethanol has a significantly lower density.

6 What is the specific heat of a compound?

(A) The quantity of heat required to boil 1 g of the compound
(B) The quantity of heat required to melt 1 g of the compound
(C) The quantity of heat required to increase the temperature of the compound by 1°C
(D) The quantity of heat required to increase the temperature of 1 g of the compound by 1°C

7 Which of the following changes will always shift this equilibrium reaction to the right?

\[ 2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \quad \Delta H = -52 \text{ kJ} \]

(A) Adding a catalyst
(B) Increasing the pressure
(C) Increasing the temperature
(D) Adding more of the reactant

8 According to the Arrhenius theory of acids and bases, an acid is a substance that

(A) tastes sour.
(B) is capable of donating a hydrogen ion.
(C) can accept a pair of electrons to form a co-ordinate covalent bond.
(D) increases the concentration of hydrogen ions in an aqueous solution.
9. Which of the following lower atmosphere pollutant gases is produced directly by the smelting of mineral ores?

(A) Carbon monoxide
(B) Nitrogen dioxide
(C) Ozone
(D) Sulfur dioxide

10. The molar heat of combustion of ethanol is 1367 kJ mol\(^{-1}\).

What quantity of ethanol must be combusted to raise the temperature of 1.0 kg water from 50°C to boiling point at sea level (assuming no loss of heat to the surroundings)?

(A) 6.5 g
(B) 7.0 g
(C) 209 g
(D) 300 g

11. In which of the following alternatives are the three compounds listed in order of increasing boiling point?

(A) Pentane, butan-1-ol, propanoic acid
(B) Propanoic acid, butan-1-ol, pentane
(C) Propanoic acid, pentane, butan-1-ol
(D) Butan-1-ol, propanoic acid, pentane
Samples of water were collected from a river at four different sites: forest, mine, town and estuary.

The results of various analyses of the water samples are shown.

<table>
<thead>
<tr>
<th></th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.8</td>
<td>6.8</td>
<td>7.8</td>
<td>5.9</td>
</tr>
<tr>
<td>Total Dissolved Solids (mg/L)</td>
<td>305</td>
<td>85</td>
<td>7600</td>
<td>290</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand (mg/L)</td>
<td>32</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E. coli (CFU/100 mL)</td>
<td>18</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Using the data from the table above identify each of the sampling sites.

(A) Town  Forest  Estuary  Mine
(B) Estuary  Forest  Town  Mine
(C) Mine  Town  Forest  Estuary
(D) Town  Mine  Estuary  Forest
Some reactions of the metals Q, R and S are given below.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Reaction in air</th>
<th>Reaction with water</th>
<th>Reaction with dilute hydrochloric acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>Burns to form metallic oxide</td>
<td>Reacts with steam to form hydrogen</td>
<td>Hydrogen is formed</td>
</tr>
<tr>
<td>R</td>
<td>Reacts slowly to form metallic oxide</td>
<td>Does not react</td>
<td>Does not react</td>
</tr>
<tr>
<td>S</td>
<td>Reacts to form metallic oxide</td>
<td>Does not react</td>
<td>Hydrogen is formed</td>
</tr>
</tbody>
</table>

In a galvanic cell, Q⁺, R⁺ and S⁺ would represent cations of these metals.

Which galvanic cell will produce the greatest voltage?

(A) ![Diagram A](image)

(B) ![Diagram B](image)

(C) ![Diagram C](image)

(D) ![Diagram D](image)
20 mL of $0.08 \text{ mol L}^{-1}$ HCl is mixed with 30 mL of $0.05 \text{ mol L}^{-1}$ NaOH.

What is the pH of the resultant solution?

(A) 1.1
(B) 2.7
(C) 4.0
(D) 7.0

A 2.45 g sample of lawn fertiliser was analysed for its sulfate content. After filtration and drying, 2.18 g of barium sulfate was recovered.

What is the % w/w of sulfate in the lawn fertiliser?

(A) 16.8
(B) 36.6
(C) 46.2
(D) 89.0
Question 16 (5 marks)

The process of fractional distillation is used to separate crude oil into different fractions. One of the compounds obtained from fractional distillation is \( \text{C}_{10}\text{H}_{22} \).

This compound undergoes catalytic cracking as follows:

\[
\text{C}_{10}\text{H}_{22} \rightarrow \text{C}_8\text{H}_{18} + \text{C}_2\text{H}_4
\]

(a) Complete the table below to identify the products and the homologous series to which they belong.

<table>
<thead>
<tr>
<th>Name of compound</th>
<th>Name of series</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{C}<em>8\text{H}</em>{18} )</td>
<td>( \text{C}_2\text{H}_4 )</td>
</tr>
</tbody>
</table>

(b) Using examples from your first-hand investigation, explain how you distinguished between these two series of compounds. Include a relevant equation in your answer.

...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
.............................................................................................................................
Question 17 (5 marks)

Using TWO examples, analyse how the features of catchment areas will determine the water treatment necessary to make the water safe to drink.

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

 marks
Question 18 (5 marks)

(a) Draw Lewis electron dot structures for oxygen and ozone.

(b) Account for the differences in the properties of oxygen and ozone on the basis of their molecular structure and bonding.
**Question 19** (5 marks)

A laboratory assesses the amount of zinc in dietary supplement tablets.

A chemist prepared 4 tablet samples for analysis by dissolving the tablets individually in 10% nitric acid. Each tablet solution was made up to a final volume of 100 mL. Five standard solutions of zinc were also prepared.

The absorbances of the standard and sample solutions were determined by atomic absorption spectroscopy at 213.9 nm.

The results are presented in the table.

<table>
<thead>
<tr>
<th>Standard zinc solutions (mg L⁻¹)</th>
<th>Absorbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>1.00</td>
<td>0.170</td>
</tr>
<tr>
<td>2.00</td>
<td>0.330</td>
</tr>
<tr>
<td>3.00</td>
<td>0.503</td>
</tr>
<tr>
<td>4.00</td>
<td>0.680</td>
</tr>
<tr>
<td>Tablet samples: mean absorbance</td>
<td>0.280</td>
</tr>
</tbody>
</table>

(a) Plot a calibration curve for the standard zinc solutions on the grid.

---

Marking:

- 3 marks for the calibration curve on the grid.
Question 19 (continued)

(b) Using the mean absorbance of the tablet samples, calculate the mean amount of zinc per tablet in mg.

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

End of Question 19

Question 20 (3 marks)

1.22 g of an unknown gas has a volume of 15.0 L at 100 kPa and 25°C.

(a) Calculate the molar mass of the gas.

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

(b) Identify the gas.

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

Marks

2

2

1
Question 21 (4 marks)

The graph shows the concentration of CCl$_3$F known as CFC-11, as measured at the Cape Grim Baseline Air Pollution Station, in north-western Tasmania.

(a) Explain the changes in concentration of CFC-11 as illustrated by the graph.

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

(b) Why is it important to monitor the concentration of CFC-11?

................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
Question 22 (5 marks)

The following extract was taken from the website of a leading car manufacturer.

Awaiting copyright

Critically evaluate the extract with reference to ethanol being a ‘carbon-neutral’ fuel. Support your answer with relevant chemical equations.
Question 23 (4 marks)

Using Le Chatelier’s principle, justify the choice of temperature and pressure conditions used to optimise the yield in the Haber process.

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

4 marks
Question 24 (5 marks)

The table shows four fuels and their various properties.

<table>
<thead>
<tr>
<th>Property</th>
<th>Petrol</th>
<th>Kerosene</th>
<th>Hydrogen</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat of combustion (kJ mol⁻¹)</td>
<td>5460</td>
<td>10 000</td>
<td>285</td>
<td>1370</td>
</tr>
<tr>
<td>Boiling point (°C)</td>
<td>126</td>
<td>300</td>
<td>−253</td>
<td>78</td>
</tr>
<tr>
<td>Density (g mL⁻¹)</td>
<td>0.69</td>
<td>0.78</td>
<td>n/a</td>
<td>0.78</td>
</tr>
<tr>
<td>Average molar mass (g mol⁻¹)</td>
<td>114</td>
<td>210</td>
<td>2</td>
<td>46</td>
</tr>
</tbody>
</table>

(a) Which fuel provides the greatest amount of energy per gram?
...............................................................................................................................
...............................................................................................................................

(b) A car has an 80 L petrol tank. Calculate the energy released by the complete combustion of one full tank of petrol.
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................

(c) How many litres of hydrogen gas at 25°C and 100 kPa would be needed to supply the same amount of energy as 80 L of petrol?
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................

- 18 -
Question 25 (5 marks)

A galvanic cell under standard conditions is represented below.

(a) On the diagram, clearly label the anode, the cathode and the direction of electron flow.  

(b) Write a balanced net ionic equation for the overall cell reaction.

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

(c) Calculate the standard cell potential (E°).  

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

(d) Explain any colour changes observed in this cell as the reaction proceeds.  

..............................................................................................................................................
..............................................................................................................................................
..............................................................................................................................................
..............................................................................................................................................
Question 26 (4 marks)

Explain how a buffer works with reference to a specific example in a natural system.  

.........................................................................................................................................
.........................................................................................................................................
.........................................................................................................................................
.........................................................................................................................................
.........................................................................................................................................
.........................................................................................................................................
.........................................................................................................................................
.........................................................................................................................................
**Question 27** (4 marks)

(a) Classify these salts as forming acidic, basic or neutral solutions.  

<table>
<thead>
<tr>
<th>Salt</th>
<th>Classification of solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium chloride</td>
<td></td>
</tr>
<tr>
<td>Sodium ethanoate</td>
<td></td>
</tr>
<tr>
<td>Sodium chloride</td>
<td></td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td></td>
</tr>
</tbody>
</table>

(b) From the table, choose a salt that forms an acidic or basic solution, and justify its classification. Include an equation to illustrate your answer.

...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
...............................................................................................................................
Question 28 (6 marks)

A standard solution was prepared by dissolving 1.314 g of sodium carbonate in water. The solution was made up to a final volume of 250.0 mL.

(a) Calculate the concentration of the sodium carbonate solution.

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

This solution was used to determine the concentration of a solution of hydrochloric acid. Four 25.00 mL samples of the acid were titrated with the sodium carbonate solution. The average titration volume required to reach the end point was 23.45 mL.

(b) Write a balanced equation for the titration reaction.

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

(c) Calculate the concentration of the hydrochloric acid solution.

...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................  
...............................................................................................................................
2008 HIGHER SCHOOL CERTIFICATE EXAMINATION

Chemistry

Section II

25 marks
Attempt ONE question from Questions 29–33
Allow about 45 minutes for this section

Answer the question in a writing booklet. Extra writing booklets are available.
Show all relevant working in questions involving calculations.

<table>
<thead>
<tr>
<th>Question 29</th>
<th>Industrial Chemistry</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 30</td>
<td>Shipwrecks, Corrosion and Conservation</td>
<td>28–29</td>
</tr>
<tr>
<td>Question 31</td>
<td>The Biochemistry of Movement</td>
<td>30–31</td>
</tr>
<tr>
<td>Question 32</td>
<td>The Chemistry of Art</td>
<td>32–33</td>
</tr>
<tr>
<td>Question 33</td>
<td>Forensic Chemistry</td>
<td>34–35</td>
</tr>
</tbody>
</table>
(a) The following diagram illustrates the process used to extract sulfur from underground deposits.

(i) Copy and complete this table in your writing booklet to identify which fluid is pumped through each pipe.

<table>
<thead>
<tr>
<th>Pipe</th>
<th>Fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe 1</td>
<td></td>
</tr>
<tr>
<td>Pipe 2</td>
<td></td>
</tr>
<tr>
<td>Pipe 3</td>
<td></td>
</tr>
</tbody>
</table>

(ii) Explain why this process can be used to extract sulfur.

(iii) What possible environmental issues are associated with this process?
Question 29 (continued)

(b) A first-hand investigation was performed to observe the electrolysis of sodium chloride.

(i) Describe an appropriate procedure. 3

(ii) Identify the reactions that occur at the anode and at the cathode and give equations for these reactions. 2

(iii) What condition would need to be changed to produce sodium metal as a product? 1

(c) Consider the following mixture of gases in a closed 5.0 L vessel at 730°C.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Quantity (mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>2.00</td>
</tr>
<tr>
<td>H₂O</td>
<td>1.25</td>
</tr>
<tr>
<td>CO</td>
<td>0.75</td>
</tr>
<tr>
<td>H₂</td>
<td>0.75</td>
</tr>
</tbody>
</table>

The following reaction occurs:

\[
\text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}(g) + 3\text{H}_2(g) \quad \Delta H = +206 \text{ kJ}
\]

The equilibrium constant, K, is 0.26 at 730°C.

(i) Determine whether the system is at equilibrium. 3

(ii) Explain how conditions in this reaction could be adjusted to increase the quantity of products. 3

(d) Synthetic detergents have been developed over the past 60 years. 7

Compare anionic, cationic and non-ionic synthetic detergents in terms of their use and chemical composition and the impact that these detergents have had on the environment.

End of Question 29
Question 30 — Shipwrecks, Corrosion and Conservation (25 marks)

(a) Underground gas pipelines are often made of steel. To prevent the pipe from rusting it is connected at regular intervals to metal rods.

(i) Identify a suitable metal for the rod and explain how this prevents corrosion of the pipe. Support your answer with relevant chemical equations.

(ii) Suggest TWO other methods that could be used to protect the pipe from corrosion and explain how each of these methods is effective.

(b) A first-hand investigation was performed to compare the rate of corrosion of iron and a named steel.

(i) Describe an appropriate procedure.

(ii) Explain the results obtained using relevant equations.

(iii) How can steel composition be modified to increase corrosion resistance?

Question 30 continues on page 29
Question 30 (continued)

(c) A 1.0 mol L\(^{-1}\) solution of silver nitrate was electrolysed using platinum electrodes.

Silver was produced at one electrode and a gas was produced at the other.

(i) Draw a labelled diagram to represent this cell.  

(ii) Identify the reactions that occur at the anode and the cathode and give equations for these reactions.  

(iii) Identify FOUR factors that affect the rate of deposition of silver.  

(d) Several maritime archaeological projects exist around Australia. Compare the conservation and restoration techniques used in TWO of these projects with reference to the chemistry applied.

End of Question 30
Question 31 — The Biochemistry of Movement (25 marks)

(a) The following flowchart outlines a specific section of an important biochemical process.

(i) Identify X and Y in your writing booklet.  1

(ii) Identify this biochemical process and the specific section outlined by the flowchart.  2

(iii) With reference to X and Y explain the role of the co-factors NADH and FADH₂. Include equations in your answer.  3

(b) A first-hand investigation was performed to observe the effects of changes in temperature on the reaction of a named enzyme.

(i) Describe an appropriate procedure.  3

(ii) Sketch an appropriate graph to represent the results.  2

(iii) Identify the group of biochemical compounds to which this enzyme belongs.  1

Question 31 continues on page 31
(c) The nutrition information below appeared on the packaging of a food item.

(i) Identify THREE major nutrient groups listed in the panel that are required for human cellular metabolic processes.

(ii) Quantitatively compare the total energy of the contents of this package with the suggested average daily adult intake.

(iii) Explain how the contents of this package could meet the metabolic requirements of human Type 1 skeletal muscle fibres.

(d) With reference to the body’s metabolic processes, analyse how modern athletes might modify their diet over time to cope with a change in focus from less strenuous exercise to sprinting.

End of Question 31
Question 32 — The Chemistry of Art (25 marks)

(a) The diagram below shows the ground state electron configuration of two complexes of cobalt in aqueous solution.

\[
\text{[CoCl}_4\text{]}^{2-} \quad \text{blue solution} \\
\text{[Co(H}_2\text{O)}_6\text{]}^{2+} \quad \text{red solution}
\]

(i) Identify the block in the periodic table to which cobalt belongs and write the electron configuration of cobalt metal in its ground state.

(ii) Explain the difference in the colour of the two complexes.

(iii) Why are solutions of zinc complexes colourless?

(b) A first-hand investigation was performed to demonstrate the oxidising strength of potassium permanganate.

(i) Describe an appropriate procedure.

(ii) Explain the results obtained with the use of half equations.

(iii) A solution of potassium permanganate was added to solutions of the following three compounds: potassium iodide, potassium bromide and potassium fluoride.

Identify which of these solutions would react with the potassium permanganate.

Question 32 continues on page 33
Question 32 (continued)

(c) An acidified solution of VO$_2^+(aq)$ is poured into a flask containing zinc metal. When the flask is swirled the following sequence of colour changes is observed.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>yellow</td>
<td>VO$_2^+(aq)$</td>
</tr>
<tr>
<td>green</td>
<td>VO$^{2+}(aq)$</td>
</tr>
<tr>
<td>blue</td>
<td>V$^{3+}(aq)$</td>
</tr>
<tr>
<td>violet</td>
<td>V$^{2+}(aq)$</td>
</tr>
</tbody>
</table>

(i) Sketch the expected absorption spectrum for the violet V$^{2+}(aq)$ solution and justify the shape of the curve you have drawn.  

(ii) Use the following unbalanced half equations to give the overall equation for the colour change from yellow to violet.

\[
\begin{align*}
\text{Zn}(s) & \rightarrow \text{Zn}^{2+}(aq) + e^- \\
\text{VO}_2^{+}(aq) + \text{H}^+(aq) + e^- & \rightarrow \text{V}^{2+}(aq) + \text{H}_2\text{O}(l)
\end{align*}
\]

(iii) Identify the class of reaction to which the reactions in part (ii) belong.

(d) A painting is discovered in a disused storeroom of a local museum. The style suggests the painting is approximately 500 years old.

Describe some methods a chemist would use to identify pigments in the painting and to check the estimated age of the painting.

End of Question 32
(a) At a crime scene secured by police, it appears a motor vehicle has been driven into a plate glass window. Display cases inside the window are empty and the vehicle is gone. The forensic examiner made the following annotated sketch.

(i) Identify FOUR pieces of evidence that could be collected to help solve the crime. 2 marks

(ii) Identify TWO instrumental techniques and explain how each could be used to analyse the evidence collected from this crime scene. 4 marks

Question 33 continues on page 35
Question 33 (continued)

(b) A first-hand investigation was performed to identify reducing and non-reducing sugars.

(i) Describe an appropriate procedure.  

(ii) Account for the results obtained in terms of the chemical differences between reducing and non-reducing sugars.  

(iii) Suggest an instrumental method for identifying different sugars.

(c) An athlete provided a urine sample to be tested for steroids. The sample and the steroid standards were treated and then analysed by gas chromatography with mass spectrometric detection.

Below are chromatograms of a standard mixture containing four different steroids, and the sample from the athlete.

(i) Identify which steroid, if any, the athlete has taken.  

(ii) What properties of compounds would lead a forensic chemist to use high pressure liquid chromatography over gas chromatography?  

(iii) Describe the principle of operation of the mass spectrometer. Include a diagram in your answer.

(d) With reference to a named example, explain the theory behind emission spectra and how such information could be useful in determining the origins of a mixture.

End of paper
Avogadro constant, $N_A$ .................................................. $6.022 \times 10^{23}$ mol$^{-1}$

Volume of 1 mole ideal gas: at 100 kPa and

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Volume (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>22.71</td>
</tr>
<tr>
<td>25</td>
<td>24.79</td>
</tr>
</tbody>
</table>

Ionisation constant for water at 25°C (298.15 K), $K_w$ .............. $1.0 \times 10^{-14}$

Specific heat capacity of water .................................................. $4.18 \times 10^3$ J kg$^{-1}$ K$^{-1}$

Some useful formulae

$\text{pH} = -\log_{10}[\text{H}^+]$

$\Delta H = -m C \Delta T$

Some standard potentials

$\text{K}^+ + e^- \rightarrow \text{K}(s)$, $-2.94$ V
$\text{Ba}^{2+} + 2e^- \rightarrow \text{Ba}(s)$, $-2.91$ V
$\text{Ca}^{2+} + 2e^- \rightarrow \text{Ca}(s)$, $-2.87$ V
$\text{Na}^+ + e^- \rightarrow \text{Na}(s)$, $-2.71$ V
$\text{Mg}^{2+} + 2e^- \rightarrow \text{Mg}(s)$, $-2.36$ V
$\text{Al}^{3+} + 3e^- \rightarrow \text{Al}(s)$, $-1.68$ V
$\text{Mn}^{2+} + 2e^- \rightarrow \text{Mn}(s)$, $-1.18$ V
$\text{H}_2\text{O} + e^- \rightarrow \frac{1}{2}\text{H}_2(\text{g}) + \text{OH}^-$, $-0.83$ V
$\text{Zn}^{2+} + 2e^- \rightarrow \text{Zn}(s)$, $-0.76$ V
$\text{Fe}^{2+} + 2e^- \rightarrow \text{Fe}(s)$, $-0.44$ V
$\text{Ni}^{2+} + 2e^- \rightarrow \text{Ni}(s)$, $-0.24$ V
$\text{Sn}^{2+} + 2e^- \rightarrow \text{Sn}(s)$, $-0.14$ V
$\text{Pb}^{2+} + 2e^- \rightarrow \text{Pb}(s)$, $-0.13$ V
$\text{H}^+ + e^- \rightarrow \frac{1}{2}\text{H}_2(\text{g})$, $0.00$ V
$\text{SO}_4^{2-} + 4\text{H}^+ + 2e^- \rightarrow \text{SO}_4^{(\text{aq})} + 2\text{H}_2\text{O}$, $0.16$ V
$\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}(s)$, $0.34$ V
$\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O} + 2e^- \rightarrow 2\text{OH}^-$, $0.40$ V
$\text{Cu}^+ + e^- \rightarrow \text{Cu}(s)$, $0.52$ V
$\frac{1}{2}\text{I}_2(\text{s}) + e^- \rightarrow \text{I}^-$, $0.54$ V
$\frac{1}{2}\text{I}_2(\text{aq}) + e^- \rightarrow \text{I}^-$, $0.62$ V
$\text{Fe}^{3+} + e^- \rightarrow \text{Fe}^{2+}$, $0.77$ V
$\text{Ag}^+ + e^- \rightarrow \text{Ag}(s)$, $0.80$ V
$\frac{1}{2}\text{Br}_2(\text{l}) + e^- \rightarrow \text{Br}^-$, $1.08$ V
$\frac{1}{2}\text{Br}_2(\text{aq}) + e^- \rightarrow \text{Br}^-$, $1.10$ V
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+ + 2e^- \rightarrow \text{H}_2\text{O}$, $1.23$ V
$\frac{1}{2}\text{Cl}_2(\text{g}) + e^- \rightarrow \text{Cl}^-$, $1.36$ V
$\frac{1}{2}\text{Cr}_2\text{O}_7^{2-} + 7\text{H}^+ + 3e^- \rightarrow \text{Cr}^{3+} + \frac{7}{2}\text{H}_2\text{O}$, $1.36$ V
$\frac{1}{2}\text{Cl}_2(\text{aq}) + e^- \rightarrow \text{Cl}^-$, $1.40$ V
$\text{MnO}_4^- + 8\text{H}^+ + 5e^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}$, $1.51$ V
$\frac{1}{4}\text{F}_2(\text{g}) + e^- \rightarrow \text{F}^-$, $2.89$ V

Aylward and Findlay, SI Chemical Data (5th Edition) is the principal source of data for this examination paper. Some data may have been modified for examination purposes.
## Periodic Table of the Elements

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Symbol of element</th>
<th>Name of element</th>
<th>Atomic Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>Hydrogen</td>
<td>1.008</td>
</tr>
<tr>
<td>2</td>
<td>He</td>
<td>Helium</td>
<td>4.003</td>
</tr>
<tr>
<td>3</td>
<td>Li</td>
<td>Lithium</td>
<td>6.941</td>
</tr>
<tr>
<td>4</td>
<td>Be</td>
<td>Beryllium</td>
<td>9.012</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>Boron</td>
<td>10.81</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>Carbon</td>
<td>12.01</td>
</tr>
<tr>
<td>7</td>
<td>N</td>
<td>Nitrogen</td>
<td>14.01</td>
</tr>
<tr>
<td>8</td>
<td>O</td>
<td>Oxygen</td>
<td>16.00</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>Fluorine</td>
<td>19.00</td>
</tr>
<tr>
<td>10</td>
<td>Ne</td>
<td>Neon</td>
<td>20.18</td>
</tr>
<tr>
<td>11</td>
<td>Na</td>
<td>Sodium</td>
<td>22.99</td>
</tr>
<tr>
<td>12</td>
<td>Mg</td>
<td>Magnesium</td>
<td>24.31</td>
</tr>
<tr>
<td>13</td>
<td>Al</td>
<td>Aluminium</td>
<td>26.98</td>
</tr>
<tr>
<td>14</td>
<td>Si</td>
<td>Silicon</td>
<td>28.09</td>
</tr>
<tr>
<td>15</td>
<td>P</td>
<td>Phosphorus</td>
<td>30.97</td>
</tr>
<tr>
<td>16</td>
<td>S</td>
<td>Sulfur</td>
<td>32.07</td>
</tr>
<tr>
<td>17</td>
<td>Cl</td>
<td>Chlorine</td>
<td>35.45</td>
</tr>
<tr>
<td>18</td>
<td>Ar</td>
<td>Argon</td>
<td>39.95</td>
</tr>
<tr>
<td>19</td>
<td>K</td>
<td>Potassium</td>
<td>39.10</td>
</tr>
<tr>
<td>20</td>
<td>Ca</td>
<td>Calcium</td>
<td>40.08</td>
</tr>
<tr>
<td>21</td>
<td>Sc</td>
<td>Scandium</td>
<td>44.96</td>
</tr>
<tr>
<td>22</td>
<td>Ti</td>
<td>Titanium</td>
<td>47.87</td>
</tr>
<tr>
<td>23</td>
<td>V</td>
<td>Vanadium</td>
<td>50.94</td>
</tr>
<tr>
<td>24</td>
<td>Cr</td>
<td>Chromium</td>
<td>52.00</td>
</tr>
<tr>
<td>25</td>
<td>Mn</td>
<td>Manganese</td>
<td>54.94</td>
</tr>
<tr>
<td>26</td>
<td>Fe</td>
<td>Iron</td>
<td>55.85</td>
</tr>
<tr>
<td>27</td>
<td>Co</td>
<td>Cobalt</td>
<td>58.93</td>
</tr>
<tr>
<td>28</td>
<td>Ni</td>
<td>Nickel</td>
<td>58.69</td>
</tr>
<tr>
<td>29</td>
<td>Cu</td>
<td>Copper</td>
<td>63.55</td>
</tr>
<tr>
<td>30</td>
<td>Zn</td>
<td>Zinc</td>
<td>65.41</td>
</tr>
<tr>
<td>31</td>
<td>Ga</td>
<td>Gallium</td>
<td>69.72</td>
</tr>
<tr>
<td>32</td>
<td>Ge</td>
<td>Germanium</td>
<td>72.64</td>
</tr>
<tr>
<td>33</td>
<td>As</td>
<td>Arsenic</td>
<td>74.92</td>
</tr>
<tr>
<td>34</td>
<td>Se</td>
<td>Selenium</td>
<td>78.96</td>
</tr>
<tr>
<td>35</td>
<td>Br</td>
<td>Bromine</td>
<td>79.90</td>
</tr>
<tr>
<td>36</td>
<td>Kr</td>
<td>Krypton</td>
<td>83.80</td>
</tr>
<tr>
<td>37</td>
<td>Rb</td>
<td>Rubidium</td>
<td>85.47</td>
</tr>
<tr>
<td>38</td>
<td>Sr</td>
<td>Strontium</td>
<td>87.62</td>
</tr>
<tr>
<td>39</td>
<td>Y</td>
<td>Yttrium</td>
<td>88.91</td>
</tr>
<tr>
<td>40</td>
<td>Zr</td>
<td>Zirconium</td>
<td>91.22</td>
</tr>
<tr>
<td>41</td>
<td>Nb</td>
<td>Niobium</td>
<td>92.91</td>
</tr>
<tr>
<td>42</td>
<td>Mo</td>
<td>Molybdenum</td>
<td>95.94</td>
</tr>
<tr>
<td>43</td>
<td>Tc</td>
<td>Technetium</td>
<td>[97.91]</td>
</tr>
<tr>
<td>44</td>
<td>Ru</td>
<td>Ruthenium</td>
<td>101.1</td>
</tr>
<tr>
<td>45</td>
<td>Rh</td>
<td>Rhodium</td>
<td>102.9</td>
</tr>
<tr>
<td>46</td>
<td>Pd</td>
<td>Palladium</td>
<td>106.4</td>
</tr>
<tr>
<td>47</td>
<td>Ag</td>
<td>Silver</td>
<td>107.9</td>
</tr>
<tr>
<td>48</td>
<td>Cd</td>
<td>Cadmium</td>
<td>112.4</td>
</tr>
<tr>
<td>49</td>
<td>In</td>
<td>Indium</td>
<td>114.8</td>
</tr>
<tr>
<td>50</td>
<td>Sn</td>
<td>Tin</td>
<td>118.7</td>
</tr>
<tr>
<td>51</td>
<td>Sb</td>
<td>Antimony</td>
<td>121.8</td>
</tr>
<tr>
<td>52</td>
<td>Te</td>
<td>Tellurium</td>
<td>127.6</td>
</tr>
<tr>
<td>53</td>
<td>I</td>
<td>Iodine</td>
<td>126.9</td>
</tr>
<tr>
<td>54</td>
<td>Xe</td>
<td>Xenon</td>
<td>131.3</td>
</tr>
<tr>
<td>55</td>
<td>Cs</td>
<td>Cesium</td>
<td>132.9</td>
</tr>
<tr>
<td>56</td>
<td>Ba</td>
<td>Barium</td>
<td>137.3</td>
</tr>
<tr>
<td>57</td>
<td>La</td>
<td>Lanthanoids</td>
<td>178.5</td>
</tr>
<tr>
<td>58</td>
<td>Ce</td>
<td>Lanthanum</td>
<td>180.9</td>
</tr>
<tr>
<td>59</td>
<td>Pr</td>
<td>Cerium</td>
<td>183.8</td>
</tr>
<tr>
<td>60</td>
<td>Nd</td>
<td>Neodymium</td>
<td>186.2</td>
</tr>
<tr>
<td>61</td>
<td>Pm</td>
<td>Promethium</td>
<td>190.2</td>
</tr>
<tr>
<td>62</td>
<td>Sm</td>
<td>Samarium</td>
<td>192.2</td>
</tr>
<tr>
<td>63</td>
<td>Eu</td>
<td>Europium</td>
<td>195.1</td>
</tr>
<tr>
<td>64</td>
<td>Gd</td>
<td>Gadolinium</td>
<td>197.0</td>
</tr>
<tr>
<td>65</td>
<td>Tb</td>
<td>Terbium</td>
<td>200.6</td>
</tr>
<tr>
<td>66</td>
<td>Dy</td>
<td>Dysprosium</td>
<td>204.4</td>
</tr>
<tr>
<td>67</td>
<td>Ho</td>
<td>Holmium</td>
<td>207.2</td>
</tr>
<tr>
<td>68</td>
<td>Er</td>
<td>Erbium</td>
<td>209.0</td>
</tr>
<tr>
<td>69</td>
<td>Tm</td>
<td>Thulium</td>
<td>[209.0]</td>
</tr>
<tr>
<td>70</td>
<td>Yb</td>
<td>Ytterbium</td>
<td>[210.0]</td>
</tr>
<tr>
<td>71</td>
<td>Lu</td>
<td>Lutetium</td>
<td>[222.0]</td>
</tr>
<tr>
<td>87</td>
<td>Fr</td>
<td>Actinium</td>
<td>223.0</td>
</tr>
<tr>
<td>88</td>
<td>Ra</td>
<td>Radium</td>
<td>[226]</td>
</tr>
<tr>
<td>89</td>
<td>Ac</td>
<td>Actinium</td>
<td>[227]</td>
</tr>
<tr>
<td>90</td>
<td>Th</td>
<td>Thorium</td>
<td>232.0</td>
</tr>
<tr>
<td>91</td>
<td>Pa</td>
<td>Protactinium</td>
<td>231.0</td>
</tr>
<tr>
<td>92</td>
<td>U</td>
<td>Uranium</td>
<td>238.0</td>
</tr>
<tr>
<td>93</td>
<td>Np</td>
<td>Neptunium</td>
<td>[237]</td>
</tr>
<tr>
<td>94</td>
<td>Pu</td>
<td>Plutonium</td>
<td>[244]</td>
</tr>
<tr>
<td>95</td>
<td>Am</td>
<td>Americium</td>
<td>[243]</td>
</tr>
<tr>
<td>96</td>
<td>Cm</td>
<td>Curium</td>
<td>[247]</td>
</tr>
<tr>
<td>97</td>
<td>Bk</td>
<td>Berkelium</td>
<td>[247]</td>
</tr>
<tr>
<td>98</td>
<td>Cf</td>
<td>Californium</td>
<td>[251]</td>
</tr>
<tr>
<td>99</td>
<td>Es</td>
<td>Einsteinium</td>
<td>[252]</td>
</tr>
<tr>
<td>100</td>
<td>Fm</td>
<td>Fermium</td>
<td>[257]</td>
</tr>
<tr>
<td>101</td>
<td>Md</td>
<td>Mendelevium</td>
<td>[258]</td>
</tr>
<tr>
<td>102</td>
<td>No</td>
<td>Nobelium</td>
<td>[259]</td>
</tr>
<tr>
<td>103</td>
<td>Lr</td>
<td>Lawrencium</td>
<td>[262]</td>
</tr>
</tbody>
</table>

### Lanthanoids

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Symbol of element</th>
<th>Name of element</th>
<th>Atomic Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>57</td>
<td>La</td>
<td>Lanthanum</td>
<td>138.9</td>
</tr>
<tr>
<td>58</td>
<td>Ce</td>
<td>Cerium</td>
<td>140.1</td>
</tr>
<tr>
<td>59</td>
<td>Pr</td>
<td>Neodymium</td>
<td>140.9</td>
</tr>
<tr>
<td>60</td>
<td>Nd</td>
<td>Promethium</td>
<td>144.2</td>
</tr>
<tr>
<td>61</td>
<td>Pm</td>
<td>Samarium</td>
<td>[145]</td>
</tr>
<tr>
<td>62</td>
<td>Sm</td>
<td>Europium</td>
<td>150.4</td>
</tr>
<tr>
<td>63</td>
<td>Eu</td>
<td>Gadolinium</td>
<td>152.0</td>
</tr>
<tr>
<td>64</td>
<td>Gd</td>
<td>Terbium</td>
<td>157.3</td>
</tr>
<tr>
<td>65</td>
<td>Tb</td>
<td>Dysprosium</td>
<td>158.9</td>
</tr>
<tr>
<td>66</td>
<td>Dy</td>
<td>Holmium</td>
<td>162.5</td>
</tr>
<tr>
<td>67</td>
<td>Ho</td>
<td>Erbium</td>
<td>164.9</td>
</tr>
<tr>
<td>68</td>
<td>Er</td>
<td>Ytterbium</td>
<td>167.3</td>
</tr>
<tr>
<td>69</td>
<td>Tm</td>
<td>Lutetium</td>
<td>169.8</td>
</tr>
<tr>
<td>70</td>
<td>Yb</td>
<td>Ytterbium</td>
<td>173.0</td>
</tr>
<tr>
<td>71</td>
<td>Lu</td>
<td>Lutetium</td>
<td>175.0</td>
</tr>
</tbody>
</table>

### Actinoids

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Symbol of element</th>
<th>Name of element</th>
<th>Atomic Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>89</td>
<td>Ac</td>
<td>Thorium</td>
<td>227.0</td>
</tr>
<tr>
<td>90</td>
<td>Th</td>
<td>Protactinium</td>
<td>232.0</td>
</tr>
<tr>
<td>91</td>
<td>Pa</td>
<td>Uranium</td>
<td>231.0</td>
</tr>
<tr>
<td>92</td>
<td>U</td>
<td>Neptunium</td>
<td>238.0</td>
</tr>
<tr>
<td>93</td>
<td>Np</td>
<td>Plutonium</td>
<td>[237]</td>
</tr>
<tr>
<td>94</td>
<td>Pu</td>
<td>Americium</td>
<td>[243]</td>
</tr>
<tr>
<td>95</td>
<td>Am</td>
<td>Curium</td>
<td>[247]</td>
</tr>
<tr>
<td>96</td>
<td>Cm</td>
<td>Berkelium</td>
<td>[247]</td>
</tr>
<tr>
<td>97</td>
<td>Bk</td>
<td>Californium</td>
<td>[251]</td>
</tr>
<tr>
<td>98</td>
<td>Cf</td>
<td>Einsteinium</td>
<td>[252]</td>
</tr>
<tr>
<td>99</td>
<td>Es</td>
<td>Ferrum</td>
<td>[257]</td>
</tr>
<tr>
<td>100</td>
<td>Fm</td>
<td>Mendelevium</td>
<td>[258]</td>
</tr>
<tr>
<td>101</td>
<td>Md</td>
<td>Nobelium</td>
<td>[259]</td>
</tr>
<tr>
<td>102</td>
<td>No</td>
<td>Lawrencium</td>
<td>[262]</td>
</tr>
</tbody>
</table>

For elements that have no stable or long-lived nuclides, the mass number of the nuclide with the longest confirmed half-life is listed between square brackets. The International Union of Pure and Applied Chemistry Periodic Table of the Elements (October 2005 version) is the principal source of data. Some data may have been modified.