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 80.
- 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.
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. The correct sequence for the processes that occur in a mass spectrometer is
   - □ A  vaporization, ionization, acceleration, deflection and detection.
   - □ B  vaporization, acceleration, ionization, deflection and detection.
   - □ C  ionization, vaporization, acceleration, deflection and detection.
   - □ D  ionization, vaporization, deflection, acceleration and detection.
   (Total for Question = 1 mark)

2. Which of the following ions would be deflected most in a mass spectrometer?
   - □ A  $^{35}\text{Cl}^+$
   - □ B  $^{37}\text{Cl}^+$
   - □ C  $^{37}\text{Cl}^{2+}$
   - □ D  $(^{35}\text{Cl} —^{37}\text{Cl})^+$
   (Total for Question 2 = 1 mark)

3. A particle with a single positive charge and with the electronic configuration $1s^2 \ 2s^2 \ 2p^6$ is
   - □ A  a sodium ion.
   - □ B  a fluoride ion.
   - □ C  an oxide ion.
   - □ D  a potassium ion.
   (Total for Question 3 = 1 mark)
4. In which of the following electronic configurations are only two of the electrons unpaired?

- A: 1s² 2s²
- B: 1s² 2s² 2p³
- C: 1s² 2s² 2p⁴
- D: 1s² 2s² 2p⁵

(Total for Question 4 = 1 mark)

5. Which of the following contains a dative covalent bond?

- A: N₂
- B: NH₃
- C: NH₂⁻
- D: NH₄⁺

(Total for Question 5 = 1 mark)

6. Which of the following ions has the **largest** ionic radius?

- A: F⁻
- B: Mg²⁺
- C: Na⁺
- D: O²⁻

(Total for Question 6 = 1 mark)

7. Which of the following observations provides the best evidence for the presence of ionic bonding in an unknown substance?

- A: in the solid state.
- B: in the solid state and in aqueous solution.
- C: in the solid state and when molten.
- D: when molten but not in the solid state.

(Total for Question 7 = 1 mark)
8  Which of the following can be determined, for an unknown alkene, using **only** percentage composition by mass data?

- [x] A  Molecular formula
- [ ] B  Empirical (simplest) formula
- [ ] C  Both the molecular formula and the empirical (simplest) formula
- [ ] D  Structural formula

*(Total for Question 8 = 1 mark)*

9  1.12 g of iron reacts with oxygen to form 1.60 g of an oxide of iron.
Use relative atomic masses: Fe = 56, O = 16.

What is the formula of this oxide of iron?

- [ ] A  FeO₅
- [x] B  Fe₂O₇
- [ ] C  Fe₃O₂
- [ ] D  Fe₂O₃

*(Total for Question 9 = 1 mark)*

10 In an experiment, 1.226 g of potassium chlorate(V), KClO₃, was heated. A mass of 0.320 g of oxygen gas, O₂, was collected.

\[ 2\text{KClO}_3(s) \rightarrow 2\text{KCl}(s) + 3\text{O}_2(g) \]

Use the molar mass of KClO₃ = 122.6 g mol⁻¹ and relative atomic mass O = 16.

The percentage yield of oxygen in this experiment is

- [ ] A  17.4%
- [ ] B  26.1%
- [x] C  66.7%
- [ ] D  100%

*(Total for Question 10 = 1 mark)*
11 Oxygen gas, $O_2$, can be converted into ozone, $O_3$, by passing it through an electric discharge.

\[ 3O_2(g) \rightarrow 2O_3(g) \]

In an experiment, a volume of 300 cm$^3$ of oxygen was used but only 10% of the oxygen was converted into ozone. All volumes were measured at the same temperature and pressure.

The total volume of gas present at the end of the experiment, in cm$^3$, was

- A 200
- B 210
- C 290
- D 300

(Total for Question 11 = 1 mark)

12 1.40 g of an alkene gave 3.77 g of a dichloroalkane on reaction with chlorine.

What is the molecular formula of the alkene?

- A $C_2H_4$
- B $C_3H_6$
- C $C_4H_8$
- D $C_6H_{12}$

(Total for Question 12 = 1 mark)

13 The standard enthalpy change for the combustion of graphite is $-393.5$ kJ mol$^{-1}$ and that of diamond is $-395.4$ kJ mol$^{-1}$.

What is the standard enthalpy change for the reaction below, in kJ mol$^{-1}$?

\[ C(s, \text{graphite}) \rightarrow C(s, \text{diamond}) \]

- A $-1.9$
- B $+1.9$
- C $-788.9$
- D $+788.9$

(Total for Question 13 = 1 mark)
14 The standard enthalpy change of neutralization when an acid reacts with an alkali is the number of kilojoules released by the

- **A** formation of one mole of salt.
- **B** formation of one mole of water.
- **C** neutralization of one mole of acid.
- **D** neutralization of one mole of alkali.

(Total for Question 14 = 1 mark)

15 Consider the following bond enthalpy values.

<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond enthalpy / kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>O—O</td>
<td>+146</td>
</tr>
<tr>
<td>O—H</td>
<td>+463</td>
</tr>
<tr>
<td>O═O</td>
<td>+496</td>
</tr>
</tbody>
</table>

For the reaction

\[ \text{H—O—O—H(g)} \rightarrow \text{H—O—H(g)} + \frac{1}{2} \text{O═O(g)} \]

the enthalpy change, in kJ mol⁻¹, is

- **A** −102
- **B** +102
- **C** +350
- **D** +394

(Total for Question 15 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.
16 Using the data in the table below, calculate the standard enthalpy change, in kJ mol⁻¹, for the reaction between carbon disulfide, CS₂, and oxygen shown in the following equation.

\[
CS_2(g) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)
\]

<table>
<thead>
<tr>
<th>Substance</th>
<th>Standard enthalpy change of formation, ΔHf / kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS₂(g)</td>
<td>+110</td>
</tr>
<tr>
<td>CO₂(g)</td>
<td>−390</td>
</tr>
<tr>
<td>SO₂(g)</td>
<td>−290</td>
</tr>
</tbody>
</table>

☐ A  -570
☐ B  -790
☐ C  -860
☐ D  -1080

(Total for Question 16 = 1 mark)

17 (a) Which of the following represents a step in the mechanism during the reaction between ethene and hydrogen bromide?

☐ A  \( C_2H_4 + Br^+ \rightarrow C_2H_4Br^+ \)

☐ B  \( C_2H_4 + HBr \rightarrow C_2H_5^+ + Br^- \)

☐ C  \( C_2H_4 + HBr \rightarrow C_2H_5^- + Br^+ \)

☐ D  \( C_2H_4 + HBr \rightarrow C_2H_4Br^- + H^+ \)

(b) The mechanism of the reaction between ethene and hydrogen bromide is

☐ A  electrophilic addition.

☐ B  electrophilic substitution.

☐ C  nucleophilic addition.

☐ D  nucleophilic substitution.

(Total for Question 17 = 2 marks)
18 Which of the following pairs are cis-trans isomers?

- **A** 1 and 2
- **B** 1 and 4
- **C** 2 and 3
- **D** 3 and 4

(Total for Question 18 = 1 mark)

19 What is the systematic name for the hydrocarbon shown below?

- **A** 1,4-dimethylbutane
- **B** 2,3-dimethylbutane
- **C** 2,3-dimethylhexane
- **D** 1,1,2,2-tetramethylethane

(Total for Question 19 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS
Crude oil is composed mainly of alkanes, which are saturated hydrocarbons.

(a) (i) Define the term hydrocarbon.

(ii) State what is meant by the term saturated, as applied to a hydrocarbon.

(b) Crude oil can be separated into fractions.

(i) What property allows crude oil to be separated by fractional distillation?

(ii) Many chemists are of the opinion that we should use fuels such as biodiesel rather than petrol and diesel.

Suggest one reason to support this opinion.
(c) A molecule of a hydrocarbon, X, can be cracked to form one molecule of pentane, C₅H₁₂, and two molecules of ethene only.

(i) Deduce the molecular formula of X.

(ii) Give one reason why cracking reactions are carried out in industry and suggest why high temperatures are used in this process other than to speed up the reaction.

(d) Butane, C₄H₁₀, is a hydrocarbon which is used as a fuel. It is a gas under standard conditions.

(i) Explain what is meant by the term fuel.

(ii) Write an equation for the complete combustion of butane under standard conditions. Include state symbols in your answer.
(iii) Write an equation for the **incomplete** combustion of butane to form carbon monoxide and water only. State symbols are not required.

(iv) Under what conditions would you expect incomplete combustion to occur?

(e) Butane can react with bromine, in the presence of ultraviolet radiation, according to the following equation.

\[ C_4H_{10} + Br_2 \rightarrow C_4H_9Br + HBr \]

(i) Calculate the atom economy by mass for the formation of \( C_4H_9Br \).

Use the expression

\[
\text{atom economy} = \frac{\text{molar mass of the desired product}}{\text{sum of the molar masses of all products}} \times 100 \%
\]

Use the Periodic Table as a source of data.

Final answer \( \ldots \ldots \ldots \% \)
Describe the mechanism of the reaction between butane and bromine that forms the products given in the equation below.

\[ \text{C}_4\text{H}_{10} + \text{Br}_2 \rightarrow \text{C}_4\text{H}_9\text{Br} + \text{HBr} \]

In your answer you should include

- equations for each step of the mechanism (curly arrows are not required)
- the name of each step occurring in the mechanism.

(Total for Question 20 = 21 marks)
Lattice energies can be calculated from experimental data using Born-Haber cycles.

In the table below are the enthalpy changes needed to calculate the lattice energy of sodium oxide, Na₂O.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Enthalpy change</th>
<th>Value / kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1st electron affinity of oxygen</td>
<td>−141</td>
</tr>
<tr>
<td>B</td>
<td>2nd electron affinity of oxygen</td>
<td>+790</td>
</tr>
<tr>
<td>C</td>
<td>1st ionization energy of sodium</td>
<td>+496</td>
</tr>
<tr>
<td>D</td>
<td>enthalpy change of atomization of sodium</td>
<td>+108</td>
</tr>
<tr>
<td>E</td>
<td>enthalpy change of atomization of oxygen, ½O₂(g)</td>
<td>+249</td>
</tr>
<tr>
<td>F</td>
<td>enthalpy change of formation of sodium oxide</td>
<td>−414</td>
</tr>
<tr>
<td>G</td>
<td>lattice energy of sodium oxide</td>
<td></td>
</tr>
</tbody>
</table>

(a) Define the term **lattice energy**.

(2)
(b) (i) Write the correct letters from the table of data to label the Born-Haber cycle below.

\[ \text{2Na}^+(g) + \text{O}(g) + 2e^- \]

\[ \text{2Na}(g) + \text{O}(g) \]

\[ \text{2Na}(g) + \frac{1}{2}\text{O}_2(g) \]

\[ \text{2Na}(s) + \frac{1}{2}\text{O}_2(g) \]

\[ \text{Na}_2\text{O}(s) \]

(3)

(ii) Calculate the lattice energy of sodium oxide, enthalpy change $\Delta G$, in kJ mol$^{-1}$.

Answer = ......................................................... kJ mol$^{-1}$
*(c)* Predict whether the lattice energy of magnesium oxide, MgO, is more or less exothermic than the lattice energy of magnesium sulfide, MgS.

Justify your answer in terms of the sizes and the charges of the ions involved.

(Total for Question 21 = 11 marks)
22 Nickel is an element in the d-block of the Periodic Table.

(a) Complete the electronic configuration of a nickel atom using the s, p, d notation.

\[ 1s^2 \]

(b) A sample of nickel is made up of three isotopes. The percentage abundances are shown in the table below.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Percentage abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{58}\text{Ni})</td>
<td>69.02</td>
</tr>
<tr>
<td>(^{60}\text{Ni})</td>
<td>27.32</td>
</tr>
<tr>
<td>(^{62}\text{Ni})</td>
<td>3.66</td>
</tr>
</tbody>
</table>

Calculate the relative atomic mass of nickel. Give your answer to two decimal places.
(c) Nickel reacts with carbon monoxide, CO, to give the compound nickel carbonyl, Ni(CO)$_4$.

\[ \text{Ni(s) } + \text{4CO(g) } \rightarrow \text{Ni(CO)}_4\text{(g)} \]

(i) Calculate the volume of carbon monoxide, in dm$^3$, measured at room temperature and pressure, that is required to react completely with 5.87 g of nickel.

[Relative atomic mass: Ni = 58.7  
Molar volume of a gas = 24 dm$^3$ mol$^{-1}$ at room temperature and pressure.]

(ii) Calculate the number of carbon monoxide molecules present in the volume of gas you have calculated in (c)(i).

[The Avogadro constant, $L = 6.02 \times 10^{23}$ mol$^{-1}$]
(d) Nickel(II) nitrate, Ni(NO₃)₂, can be made by several different methods.

**Method 1**

Nickel(II) oxide, NiO, was reacted with dilute nitric acid according to the equation

\[
\text{NiO(s)} + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Ni(NO}_3)_2(\text{aq}) + \text{H}_2\text{O(l)}
\]

(i) Calculate the volume of 2.00 mol dm⁻³ dilute nitric acid, in cm³, that was required to exactly neutralize 1.494 g of nickel(II) oxide.

Use the relative atomic masses: Ni = 58.7, O = 16.0

(ii) Why was excess nickel(II) carbonate used?

(iii) Why must the beaker be much larger than the volume of acid used?
(iv) Write a balanced equation for the reaction between nickel(II) carbonate and dilute nitric acid, including state symbols. 

(2) 

*(v)* For **Method 2**, describe the practical steps that you would take to obtain pure dry crystals of hydrated nickel(II) nitrate, $\text{Ni(NO}_3\text{)}_2\cdot6\text{H}_2\text{O}$, from a mixture of nickel(II) nitrate solution and unreacted solid nickel(II) carbonate. 

(4) 

(Total for Question 22 = 18 marks)
23 This question concerns the Periodic Table.

(a) An atom of argon has mass number 40. Complete the table below showing the numbers of sub-atomic particles in this atom of argon. Use the Periodic Table as a source of data.

<table>
<thead>
<tr>
<th>Sub-atomic particles present in one atom of $^{40}$Ar</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>protons</td>
<td></td>
</tr>
<tr>
<td>electrons</td>
<td></td>
</tr>
<tr>
<td>neutrons</td>
<td></td>
</tr>
</tbody>
</table>

(b) An atom of potassium has mass number 39. Explain why argon is placed before potassium in the modern Periodic Table.

(c) In the context of the Periodic Table, explain what is meant by the term **periodicity**.
(d) The graph shows the variation in melting temperatures of the elements across Period 3 (Na to Ar) of the Periodic Table.

(i) Name one of the elements above that is composed of simple molecules at room temperature and pressure.

(ii) Silicon has a giant atomic structure. Explain how this structure results in the high melting temperature shown on the graph.
(iii) Explain why the melting temperature of magnesium is higher than that of sodium. 

(Total for Question 23 = 10 marks)
### The Periodic Table of Elements

#### Key
- **1.0 H** hydrogen
- **6.9 Li** lithium
- **9.0 Be** beryllium
- **11.0 Na** sodium
- **23.0 Mg** magnesium
- **39.1 K** potassium
- **87.6 Rb** rubidium
- **132.9 Cs** caesium
- **[223]** Fr
d- **[226]** Ra
- **[227]** Ac
- **140 Ce** cerium
- **141 Pr** praseodymium
- **144 Nd** neodymium
- **[147]** Sm
- **150 Eu** europium
- **152 Gd** gadolinium
- **159 Tb** terbium
- **165 Dy** dysprosium
- **167 Ho** holmium
- **169 Er** erbium
- **173 Yb** ytterbium
- **175 Lu** lutetium
- **232 Th** thorium
- **[231]** Pa
- **[238]** U
- **[237]** Np
- **[242]** Pu
- **[243]** Am
- **[247]** Cm
- **[245]** Bk
- **[251]** Cf
- **[254]** Es
- **[253]** Fm
- **[256]** Md
- **[254]** No
- **[257]** Lr

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

* Lanthanide series
* Actinide series