READ THESE INSTRUCTIONS FIRST

Write your name, Centre number and candidate number on all the work you hand in.
Write in dark blue or black pen.
You may use a pencil for any diagrams, graphs, or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.
DO NOT WRITE ON ANY BARCODES.

Answer all questions.
You may lose marks if you do not show your working or if you do not use appropriate units.
A Data Booklet is provided.

The number of marks is given in brackets [ ] at the end of each question or part question.
At the end of the examination, fasten all your work securely together.
1 Elements and compounds which have small molecules usually exist as gases or liquids.

(a) Chlorine, Cl₂, is a gas at room temperature whereas bromine, Br₂, is a liquid under the same conditions.

Explain these observations.

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.............................................................................................................................. [2]

(b) The gases nitrogen, N₂, and carbon monoxide, CO, are isoelectronic, that is they have the same number of electrons in their molecules.

Suggest why N₂ has a lower boiling point than CO.

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(c) A ‘dot-and-cross’ diagram of a CO molecule is shown below. Only electrons from outer shells are represented.

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  C  O
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In the table below, there are three copies of this structure. On the structures, draw a circle round a pair of electrons that is associated with each of the following.

<table>
<thead>
<tr>
<th></th>
<th>(i) a co-ordinate bond</th>
<th>(ii) a covalent bond</th>
<th>(iii) a lone pair</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image1" alt="C O" /></td>
<td><img src="image2" alt="C O" /></td>
<td><img src="image3" alt="C O" /></td>
</tr>
</tbody>
</table>

[3]
(d) Hydrogen cyanide, HCN, is a gas which is also isoelectronic with N₂ and with CO. Each molecule contains a strong triple bond with the following bond energies.

<table>
<thead>
<tr>
<th>bond</th>
<th>bond energy / kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>–C≡N in HCN</td>
<td>890</td>
</tr>
<tr>
<td>N≡N</td>
<td>994</td>
</tr>
<tr>
<td>C≡O</td>
<td>1078</td>
</tr>
</tbody>
</table>

Although each compound contains the same number of electrons and a strong triple bond in its molecule, CO and HCN are both very reactive whereas N₂ is not.

Suggest a reason for this.

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(e) HCN reacts with ethanal, CH₃CHO.

(i) Give the displayed formula of the organic product formed.

(ii) What type of reaction is this?

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(iii) Draw the mechanism of this reaction. You should show all full and partial charges and represent the movement of electron pairs by curly arrows.

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[Total: 13]
2 The diagram below shows, for a given temperature \( T \), a Boltzmann distribution of the kinetic energy of the molecules of a mixture of two gases that will react together, such as nitrogen and hydrogen.

The activation energy for the reaction, \( E_a \), is marked.

(a) On the graph above,

(i) draw a new distribution curve, clearly labelled \( T' \), for the same mixture of gases at a higher temperature, \( T' \);

(ii) mark clearly, as \( H \), the position of the activation energy of the reaction at the higher temperature, \( T' \).

(b) Explain the meaning of the term activation energy.

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The reaction between nitrogen and hydrogen to produce ammonia in the Haber process is an example of a large-scale gaseous reaction that is catalysed.

(c) (i) State the catalyst used and give the operating temperature and pressure of the Haber process.

- catalyst ......................................................
- temperature ...............................................
- pressure ....................................................

(ii) On the energy axis of the graph opposite, mark the position, clearly labelled C, of the activation energy of the reaction when a catalyst is used.

(iii) Use your answer to (ii) to explain how the use of a catalyst results in reactions occurring at a faster rate.

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(d) Two reactions involving aqueous NaOH are given below.

\[ \text{CH}_3\text{CHBrCH}_3 + \text{NaOH} \rightarrow \text{CH}_3\text{CH(OH)CH}_3 + \text{NaBr} \quad \text{reaction 1} \]

\[ \text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O} \quad \text{reaction 2} \]

In order for reaction 1 to occur, the reagents must be heated together for some time. On the other hand, reaction 2 is almost instantaneous at room temperature.

Suggest brief explanations why the rates of these two reactions are very different.

reaction 1 .........................................................................................................................................

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reaction 2 .........................................................................................................................................

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[Total: 12]
3 This question refers to the elements shown in the portion of the Periodic Table given below.

(a) From this table, identify in each case one element that has the property described. Give the symbol of the element in each case.

(i) The element that has a molecule which contains exactly eight atoms.

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(ii) The element that forms the largest cation.

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(iii) An element that floats on water and reacts with it.

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(iv) An element that reacts with water to give a solution that can behave as an oxidising agent.

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(v) An element whose nitrate gives a brown gas on thermal decomposition.

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[5]
(b)  (i) Give the formula of the oxide of the most electronegative element.

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(ii) Several of these elements form more than one acidic oxide.
Give the formulae of two such oxides formed by the same element.

................................. and .............................  [3]

The formulae and melting points of the fluorides of the elements in Period 3, Na to Cl, are
given in the table.

<table>
<thead>
<tr>
<th>formula of fluoride</th>
<th>NaF</th>
<th>MgF₂</th>
<th>AlF₃</th>
<th>SiF₄</th>
<th>PF₅</th>
<th>SF₆</th>
<th>ClF₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>m.p./K</td>
<td>1268</td>
<td>990</td>
<td>1017</td>
<td>183</td>
<td>189</td>
<td>223</td>
<td>170</td>
</tr>
</tbody>
</table>

(c)  (i) Suggest the formulae of two fluorides that could possibly be ionic.

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(ii) What is the shape of the SF₆ molecule?

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(iii) In the sequence of fluorides above, the oxidation number of the elements increases
from NaF to SF₆ and then falls at ClF₅.
Attempts to make ClF₇ have failed but IF₇ has been prepared.
Suggest an explanation for the existence of IF₇ and for the non-existence of ClF₇.

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[4]

[Total: 12]
4 (a) Complete the following reaction scheme which starts with propene. In each empty box, write the structural formula of the organic compound that would be formed.
(b) Under suitable conditions, compound E will react with compound B.

(i) What functional group is produced in this reaction?

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(ii) How is this reaction carried out in a school or college laboratory?

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[3]

[Total: 10]
Isomerism occurs in many organic compounds. The two main forms of isomerism are structural isomerism and stereoisomerism. Many organic compounds that occur naturally have molecules that can show stereoisomerism, that is cis-trans or optical isomerism.

(a) (i) Explain what is meant by structural isomerism.
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(ii) State two different features of molecules that can give rise to stereoisomerism.
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[3]

Unripe fruit often contains polycarboxylic acids, that is acids with more than one carboxylic acid group in their molecule.

One of these acids is commonly known as tartaric acid, HO₂CCH(OH)CH(OH)CO₂H.

(b) Give the structural formula of the organic compound produced when tartaric acid is reacted with an excess of NaHCO₃.

[1]

Another acid present in unripe fruit is citric acid,

\[
\text{HO}_2\text{CCH}_2\text{CCH}_2\text{CO}_2\text{H}
\]

(c) Does citric acid show optical isomerism? Explain your answer.
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.......................................................................................................................................................................................... [1]
A third polycarboxylic acid present in unripe fruit is a colourless crystalline solid, W, which has the following composition by mass: C, 35.8%; H, 4.5%; O, 59.7%.

(d) (i) Show by calculation that the empirical formula of W is \( \text{C}_4\text{H}_6\text{O}_5 \).

(ii) The \( M_r \) of W is 134. Use this value to determine the molecular formula of W.

A sample of W of mass 1.97 g was dissolved in water and the resulting solution titrated with 1.00 mol dm\(^{-3}\) NaOH. 29.4 cm\(^3\) were required for complete neutralisation.

(e) (i) Use these data to deduce the number of carboxylic acid groups present in one molecule of W.

(ii) Suggest the displayed formula of W.