The names of eight substances are given.

aluminium oxide                calcium oxide                ethanol                nitrogen
iron(III) oxide                methane                        oxygen                silicon(IV) oxide

Answer the following questions about these substances. Each substance may be used once, more than once or not at all.

State which substance is:

(a) the main constituent of natural gas

..............................................................................................................................................  [1]

(b) a reactant in respiration

..............................................................................................................................................  [1]

(c) the main constituent of bauxite

..............................................................................................................................................  [1]

(d) a product of photosynthesis

..............................................................................................................................................  [1]

(e) a greenhouse gas

..............................................................................................................................................  [1]

(f) a macromolecular solid.

..............................................................................................................................................  [1]

[Total: 6]
2 (a) $^{22}_{11}$Na, $^{23}_{11}$Na and $^{24}_{11}$Na are isotopes of sodium.

(i) Describe how these sodium isotopes are the same and how they are different in terms of the total number of protons, neutrons and electrons in each.

same ....................................................................................................................................... 
............................................................................................................................................... 

different .................................................................................................................................. 
................................................................................................................................................. [3]

(ii) Why do all three isotopes have an overall charge of zero?

................................................................................................................................................. [1]

(iii) Why do all three isotopes have the same chemical properties?

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

(iv) Why do sodium ions have a charge of +1?

................................................................................................................................................. [1]

(b) Carbon is an element which exists in different forms.

(i) Name two forms of the element carbon that have giant covalent structures.

................................................................................................................................................. and ............................................................................................................................................. [1]

(ii) Name the oxide of carbon that is a toxic gas.

...................................................................................................................................................... [1]
This question is about phosphorus and compounds of phosphorus.

(a) Phosphorus has the formula $P_4$. Some properties of $P_4$ are shown.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>melting point/$^\circ$C</td>
<td>45</td>
</tr>
<tr>
<td>boiling point/$^\circ$C</td>
<td>280</td>
</tr>
<tr>
<td>electrical conductivity</td>
<td>non-conductor</td>
</tr>
<tr>
<td>solubility in water</td>
<td>insoluble</td>
</tr>
</tbody>
</table>

(i) Name the type of bonding that exists between the atoms in a $P_4$ molecule.
.................................................................................................................................................................................. [1]

(ii) Explain, in terms of attractive forces between particles, why $P_4$ has a low melting point.
.................................................................................................................................................................................. [1]

(iii) Explain why phosphorus is a non-conductor of electricity.
.................................................................................................................................................................................. [1]

(b) Phosphorus, $P_4$, reacts with air to produce phosphorus(V) oxide, $P_4O_{10}$.

(i) Write a chemical equation for this reaction.
.................................................................................................................................................................................. [2]

(ii) What type of chemical reaction is this?
.................................................................................................................................................................................. [1]

(c) Phosphorus(V) oxide, $P_4O_{10}$, is an acidic oxide.

Phosphorus(V) oxide, $P_4O_{10}$, reacts with aqueous sodium hydroxide to form a salt containing the phosphate ion, $PO_{4}^{3-}$. Water is the only other product.

Write a chemical equation for the reaction between phosphorus(V) oxide and aqueous sodium hydroxide.
.................................................................................................................................................................................. [2]
(d) Phosphine has the formula \( \text{PH}_3 \).

Complete the dot-and-cross diagram to show the electron arrangement in a molecule of phosphine. Show outer shell electrons only.

![Diagram](image)

(e) Phosphine, \( \text{PH}_3 \), has a similar chemical structure to ammonia, \( \text{NH}_3 \).

Ammonia acts as a base when it reacts with sulfuric acid.

(i) What is meant by the term base?

........................................................................................................................................ [1]

(ii) Write a chemical equation for the reaction between ammonia and sulfuric acid.

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

[Total: 13]
Methanol is made industrially by reacting carbon monoxide with hydrogen. The gases react at a temperature of 250 °C and a pressure of 75 atmospheres.

\[
\text{CO(g)} + 2\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH(g)}
\]

The forward reaction is exothermic.

(a) Suggest a source of hydrogen for this industrial process.

.............................................................................................................................................. [1]

(b) Complete the table using only the words increases, decreases or no change.

<table>
<thead>
<tr>
<th>effect on the rate of the reverse reaction</th>
<th>effect on the equilibrium yield of CH\textsubscript{3}OH(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>adding a catalyst</td>
<td>no change</td>
</tr>
<tr>
<td>increasing the temperature</td>
<td>increases</td>
</tr>
<tr>
<td>decreasing the pressure</td>
<td></td>
</tr>
</tbody>
</table>

[4]

(c) Methanol is a member of the homologous series of alcohols.

(i) State two general characteristics of a homologous series.

1 ..........................................................................................................................................

2 ...........................................................................................................................................

[2]

(ii) Draw the structures of two different alcohols, each containing three carbon atoms. Show all of the atoms and all of the bonds.

Name these two alcohols.

name ...................................................... name ......................................................

[4]
(iii) What term is used to describe compounds with the same molecular formula but different structural formulae?

.......................................................................................................................................................................................... [1]

(d) Alcohols react with carboxylic acids to produce esters.

(i) The structure of ester X is shown.

![Structure of ester X]

Name ester X.

.......................................................................................................................................................................................... [1]

(ii) Give the name of the carboxylic acid and the alcohol that react together to produce ester X.

Carboxylic acid ...........................................................................................................................................................................

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

(iii) Ester Y is different from ester X but also has the formula C₃H₆O₂.

Draw the structure of ester Y. Show all of the atoms and all of the bonds.

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

[Total: 17]
Copper(II) sulfate crystals, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, are hydrated.

Copper(II) sulfate crystals are made by reacting copper(II) carbonate with dilute sulfuric acid.

The equation for the overall process is shown.

$$\text{CuCO}_3 + \text{H}_2\text{SO}_4 + 4\text{H}_2\text{O} \rightarrow \text{CuSO}_4 \cdot 5\text{H}_2\text{O} + \text{CO}_2$$

**step 1** Powdered solid copper(II) carbonate is added to 50.0 cm$^3$ of 0.05 mol/dm$^3$ sulfuric acid until the copper(II) carbonate is in excess.

**step 2** The excess of copper(II) carbonate is separated from the aqueous copper(II) sulfate.

**step 3** The aqueous copper(II) sulfate is heated until the solution is saturated.

**step 4** The solution is allowed to cool and crystallise.

**step 5** The crystals are removed and dried.

(a) Calculate the maximum mass of the copper(II) sulfate crystals, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, that can form using the following steps.

- Calculate the number of moles of $\text{H}_2\text{SO}_4$ in 50.0 cm$^3$ of 0.05 mol/dm$^3$ $\text{H}_2\text{SO}_4$.

  .................................................................. mol

- Determine the number of moles of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ that can form.

  .................................................................. mol

- The $M_r$ of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ is 250.

  Calculate the maximum mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ that can form.

  .................................................................. g
(b) Steps 1–5 were done correctly but the mass of crystals obtained was less than the maximum mass.

Explain why.

....................................................................................................................................................................... [1]

(c) State two observations that would indicate that the copper(II) carbonate is in excess in step 1.

1 ............................................................................................................................................................

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

(d) When the reaction in step 1 is done using lumps of copper(II) carbonate instead of powder, the rate of reaction decreases. All other conditions are kept the same.

Give a reason for this. Explain your answer in terms of particles.

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

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

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

(e) Name a different substance, other than copper(II) carbonate, that could be added to dilute sulfuric acid to produce copper(II) sulfate in step 1.

............................................................................................................................................................ [1]

(f) Name the process used to separate the aqueous copper(II) sulfate from the excess of copper(II) carbonate in step 2.

............................................................................................................................................................ [1]

(g) The solution of aqueous copper(II) sulfate was heated until it was saturated in step 3.

(i) Suggest what is meant by the term saturated solution.

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

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

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

(ii) What evidence would show that the solution was saturated in step 3?

............................................................................................................................................................ [1]

(iii) Why should the aqueous copper(II) sulfate not be heated to dryness in step 3?

............................................................................................................................................................ [1]

[Total: 14]
(a) Predict the physical state and colour of astatine at room temperature and pressure.

physical state ........................................................................................................................................[2]

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

(b) When chlorine reacts with aqueous potassium bromide a displacement reaction occurs.

(i) Describe the colour change of the solution.

from ..............................................................  to .................................................................[2]

(ii) Write a chemical equation for this reaction.

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

(c) Reactions occur when some aqueous solutions of halogens are added to aqueous solutions of halides.

Use the key to complete the table to show the results of adding halogens to halides.

key
✓ = reaction
x = no reaction

<table>
<thead>
<tr>
<th>halogens</th>
<th>KCl(aq)</th>
<th>KBr(aq)</th>
<th>KI(aq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl₂(aq)</td>
<td>x</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Br₂(aq)</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I₂(aq)</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

[2]

[Total: 8]
7  (a) Displacement reactions occur between metals and metal ions. Displacement reactions can be used to determine the order of reactivity of metals such as lead (Pb), nickel (Ni), and silver (Ag).

The ionic equation for a displacement reaction is shown:

\[
\text{Ni(s) + Pb}^{2+}(\text{aq}) \rightarrow \text{Pb(s) + Ni}^{2+}(\text{aq})
\]

The ionic half-equations for this reaction are shown:

\[
\text{Ni(s) \rightarrow Ni}^{2+}(\text{aq}) + 2e^-
\]
\[
Pb^{2+}(\text{aq}) + 2e^- \rightarrow \text{Pb(s)}
\]

The ionic half-equations show that electrons are donated by nickel atoms and accepted by lead ions.

(i) Identify the reducing agent in the displacement reaction. Give a reason for your answer.

reducing agent ..........................................................................................................................
reason ...........................................................................................................................................

(ii) What is the general term given to the type of reaction in which electrons are transferred from one species to another?

.................................................................................................................................................... [1]

(b) The ionic equation for another displacement reaction is shown.

\[
Pb(s) + 2Ag^+(aq) \rightarrow 2Ag(s) + Pb^{2+}(aq)
\]

Write the two ionic half-equations for this reaction.

1 ..................................................................................................................................................
2 ....................................................................................................................................................

(c) Use the information in (a) and (b) to put the three metals lead, nickel and silver in order of reactivity.

....................................................................................................................................................
most reactive
..................................................................................................................................................
..................................................................................................................................................
least reactive

[1]
(d) Nickel is a transition element. Nickel is stronger than sodium.

Describe **two** other differences in the physical properties of nickel and sodium.

1 ................................................................................................................................................

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

(e) Predict **one** difference in the appearance of aqueous solutions of nickel compounds compared to aqueous solutions of sodium compounds.

................................................................................................................................................ [1]

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

(f) Copper is refined (purified) by electrolysis. Nickel can be refined using a similar method.

(i) The diagram shows the refining of nickel by electrolysis.

Complete the labels in the boxes.

![Diagram of electrolysis](image)

- anode made of ..........................................
- cathode made of ..........................................
- power supply
- electrolyte of ............................................. [3]

(ii) Indicate, by writing N on the diagram, where nickel is produced.  

[1]

[Total: 13]
The volume of one mole of any gas is 24 dm$^3$ at room temperature and pressure (r.t.p.).