
# CHEMICAL BONDING

## THEORY QUESTIONS

**BY**

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## Contents

# Shape of Molecules

**1** The elements sodium to sulfur react with chlorine. The melting points of some of the chlorides formed are shown.

| chloride | NaCl | $MgCl_2$ | $AlCl_3$ | $SiCl_4$ | $PCl_3$ | $SCl_2$ |
|---|---|---|---|---|---|---|
| melting point/K | 1074 | 987 | 463 | 203 | 161 | 195 |

**(a)** Predict the shapes of $AlCl_3$ and $PCl_3$.

Draw diagrams to show the shapes, name the shapes and state the bond angles.

| $AlCl_3$ | $PCl_3$ |
|---|---|
| shape ..... | shape ..... |
| angle ..... | angle ..... |

[4]

w/17/qp22

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**1** The elements sodium to chlorine, in the third period, all form oxides.

**(a)** Draw a diagram to show the shape of the molecule of each of the oxides, $SO_3$ and $Cl_2O$.
Name each shape.
In $SO_3$ each oxygen atom forms a double bond with the sulfur atom.

| $SO_3$ | $Cl_2O$ |
|---|---|
| ..... | ..... |

[4]

s/18/qp23

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**(d) (i)** Draw a dot-and-cross diagram of the ammonium ion. Show the outer electrons only.
Use the following code for your electrons.
- • electrons from nitrogen
- × electrons from hydrogen

[2]

**(ii)** State the shape of an ammonium ion and give the H–N–H bond angle.

shape .....

bond angle .....
[2]

s/16/qp23

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Hydrogen sulphide, $H_2S$, is a foul-smelling compound found in the gases from volcanoes. Hydrogen sulphide is covalent, melting at –85 °C and boiling at –60 °C.

**(c) (i)** Draw a 'dot-and-cross' diagram to show the structure of the $H_2S$ molecule.

**(ii)** Predict the shape of the $H_2S$ molecule.

.....

9701_s/05/qp2

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**(c)** The bonding in hydrazine is similar to that in ammonia.

**(i)** Showing outer-shell electrons only, draw a 'dot-and-cross' diagram of an ammonia molecule.

**(ii)** Draw a diagram to show the three-dimensional shape of an ammonia molecule.

**(iii)** Draw a diagram to show the shape of a hydrazine molecule.
Show clearly which atom is joined to which and show clearly the value of **one** bond angle.

[4]

**(d)** Deduce the oxidation state of nitrogen in hydrazine.

.....

[1]

9701_s/10/qp23

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A greenhouse gas which is present in very small amounts in the atmosphere is sulfur hexafluoride, $SF_6$, which is used in high voltage electrical switchgear.

**(e)** What shape is the $SF_6$ molecule?

.....

[1]

9701_s/11/qp22

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**(f)** Another sulfur compound which is present in the Earth's atmosphere is carbonyl sulfide, OCS. The sequence of atoms in the molecule is oxygen-carbon-sulfur and the molecule is **not** cyclic.

**(i)** Draw a 'dot-and-cross' diagram of the OCS molecule.
Show outer electrons only.

**(ii)** Suggest a value for the O–C–S bond angle.

.....

[2]

9701_s/12/qp21

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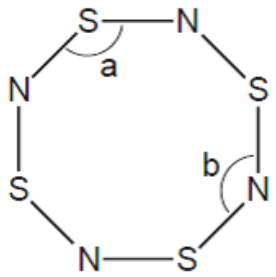
**(c)** Sulfur forms the compound $S_4N_4$ with nitrogen. The structure of $S_4N_4$ is shown below. Assume all bonds shown are single bonds.




**(i)** Determine the number of lone pairs of electrons around a nitrogen atom and a sulfur atom in $S_4N_4$.

nitrogen atom .....

sulfur atom .....

**(ii)** Which bond angle, a or b, in the $S_4N_4$ molecule will be smaller? Explain your answer.

.....

.....

[2]

9701_s/12/qp22

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**(e)** Sulfur reacts with fluorine to form $SF_6$. State the shape and bond angle of $SF_6$.

shape of $SF_6$ .....

bond angle of $SF_6$ .....

[2]

9701_s/14/qp21

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**(e)** Phosphorus reacts with chlorine to form $PCl_5$.

State the shape of and two different bond angles in a molecule of $PCl_5$.

shape of $PCl_5$ .....

bond angles in $PCl_5$ ..... .....

[2]

9701_s/14/qp22

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**1** Carbon disulfide, $CS_2$, is a volatile, flammable liquid which is produced in small quantities in volcanoes.

**(a)** The sequence of atoms in the $CS_2$ molecule is sulfur to carbon to sulfur.

**(i)** Draw a 'dot-and-cross' diagram of the carbon disulfide molecule.
Show outer electrons only.

**(ii)** Suggest the shape of the molecule and state the bond angle.

shape .....

bond angle .....

[3]

9701_s/13/qp23

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1 Valence Shell Electron Pair Repulsion theory (VSEPR) is a model of electron-pair repulsion (including lone pairs) that can be used to deduce the shapes of, and bond angles in, simple molecules.

**(a)** Complete the table below by using simple hydrogen-containing compounds. One example has been included.

| number of bond pairs | number of lone pairs | shape of molecule | formula of a molecule with this shape |
|---|---|---|---|
| 3 | 0 | trigonal planar | $BH_3$ |
| 4 | 0 | | |
| 3 | 1 | | |
| 2 | 2 | | |

[3]

**(b)** Tellurium, Te, proton number 52, is used in photovoltaic cells.

When fluorine gas is passed over tellurium at 150 °C, the colourless gas $TeF_6$ is formed.

**(i)** Draw a 'dot-and-cross' diagram of the $TeF_6$ molecule, showing outer electrons only.

**(ii)** What will be the shape of the $TeF_6$ molecule?

.....

**(iii)** What is the F–Te–F bond angle in $TeF_6$?

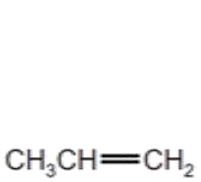
.....

[3]

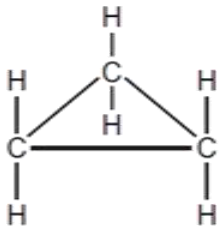
[Total: 6]

9701_w/13/qp21

**2** The molecular formula $C_3H_6$ represents the compounds propene and cyclopropane.



propene



cyclopropane

**(a)** What is the H–C–H bond angle at the terminal $=CH_2$ group in propene?

..... [1]

9701_w/13/qp21

1 Ammonia, $NH_3$, and methane, $CH_4$, are the hydrides of elements which are next to one another in the Periodic Table.

**(a)** In the boxes below, draw the 'dot-and-cross' diagram of a molecule of **each** of these compounds. Show outer electrons only.
State the shape of **each** molecule.

| $NH_3$ | $CH_4$ |
|---|---|
| shape | shape |

[3]

**(c)** When ammonia gas is mixed with hydrogen chloride, white, solid ammonium chloride is formed.

State **each type** of bond that is present in one formula unit of ammonium chloride and how many of each type are present.
You may draw diagrams.

.....

.....

.....

.....

..... [3]

[Total: 10]

9701_w/13/qp23

**(c) (i)** Sulfur dioxide and sulfur trioxide both contain only S=O double bonds.

Draw labelled diagrams to show the shapes of these two molecules.

$SO_2$ $SO_3$

[2]

**(ii)** For your diagrams in **(i)**, name the shapes and suggest the bond angles.

$SO_2$ shape ..... $SO_3$ shape .....

$SO_2$ bond angle ..... $SO_3$ bond angle .....

[2]

9701_w/14/qp21

# Bond Stregnth

2 Each of the Group VII elements chlorine, bromine and iodine forms a hydride.

(a) (i) Outline how the relative thermal stabilities of these hydrides change from HC*l* to HI.

.....

.....

(ii) Explain the variation you have outlined in **(i)**.

.....

.....

.....

[3]

9701_w/12/qp21

# Coordinate Dative Bonds

**(c)** Aluminium reacts with chlorine to form a white, solid chloride that contains 79.7% chlorine and sublimes (changes straight from a solid to a gas) at 180 °C.

**(i)** Describe the structure and bonding in this compound. Suggest how it explains the low sublimation temperature.

.....

.....

.....

.....

..... [2]

w/15/qp21

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**(e)** When solid aluminium chloride is heated above 451 K, a vapour is formed which has $M_r = 267$.
When this vapour is heated above 1100 K, the vapour has $M_r = 133.5$.

**(i)** What are the molecular formulae of these two forms of aluminium chloride?

at 460 K ..... at 1150 K .....

**(ii)** Draw a 'dot-and-cross' diagram of the form of aluminium chloride that exists at the **higher** temperature.

**(iii)** Draw a displayed formula of the form of aluminium chloride that exists at the **lower** temperature. Indicate clearly the different types of bonds present.

[5]

9701_w/07/qp2

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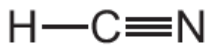
# Sigma and Pi Bonds

**(ii)** A molecule of hydrogen cyanide, HCN, is shown.



The bonding between the carbon and nitrogen atoms consists of one sigma (σ) bond and two pi (π) bonds.

Sketch the shape of the sigma bond and one of the pi bonds in the space below.
Show clearly the position of the atomic nuclei in each diagram.

sigma (σ)

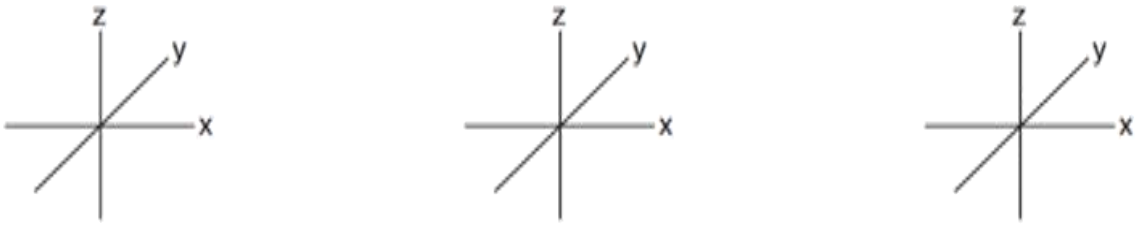
pi (π)

[2]

m/16/qp22

1 This question is about the bonding of covalent compounds.

**(a)** On the axes below, sketch the shapes of a 1s, a 2s, and a $2p_x$ orbital.




1s 2s $2p_x$

[3]

**(b)** Covalent bonding occurs when two atoms share a pair of electrons. Covalent bonding may also be described in terms of orbital overlap with the formation of σ bonds.

**(i)** How are the two atoms in a covalent bond held together? In your answer, state which particles are attracted to one another and the nature of the force of attraction.

.....

.....

**(ii)** Draw sketches to show orbital overlap that produces the σ bonding in the $H_2$ **and** HC*l* molecules.


[4]

**(c)** The bond in the HC*l* molecule is said to be 'polar'.

**(i)** What is meant by the term *bond polarity*?

.....

**(ii)** Explain why the HC*l* molecule is polar.

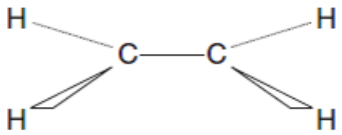
.....

.....

[2]

**(d)** The bonding in ethene may be described as a mixture of σ and π bonding.

Each carbon atom in ethene forms three σ bonds as shown below.




**On the diagram**, sketch the π bond that is also present in ethene. [1]

9701_w/07/qp2

# Intermolecular Forces, Bond Polarity

**(ii)** Explain why the melting point of $SiCl_4$ is higher than that of $PCl_3$.

.....

.....

..... [2]

**(iii)** Draw the 'dot-and-cross' diagram of a molecule of $SiCl_4$.
Show outer electrons only.

[1]

w/17/qp22

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**2** The halogens, chlorine, bromine and iodine, and their compounds, show a variety of similarities and trends in their physical and chemical properties.

**(a) (i)** Give the colours and states of chlorine, bromine and iodine at room temperature and pressure.

| halogen | colour | state |
|---|---|---|
| chlorine | | |
| bromine | | |
| iodine | | |

[2]

**(ii)** The halogens become less volatile down the group.

Explain this trend in volatility.

.....

.....

..... [2]

s/17/qp23

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**(b) (i)** Name the strongest type of intermolecular force in ice.

..... [1]

**(ii)** Draw a fully labelled diagram of two water molecules in ice, showing the force in **(i)** and how it forms.

[3]

s/17/qp21

2 The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

| element | bond energy / kJ mol$^{-1}$ | standard enthalpy change of atomisation, $\Delta H_{at}^{\ominus}$ / kJ mol$^{-1}$ | boiling point of element / K | boiling point of **hydrogen halide** / K |
|---|---|---|---|---|
| fluorine, F–F | 158 | 79 | 85 | 293 |
| chlorine, C*l*–C*l* | 242 | 121 | 238 | 188 |
| bromine, Br–Br | 193 | 112 | 332 | 206 |
| iodine, I–I | 151 | 107 | 457 | 238 |

**(b) (i)** Explain the trend in the boiling points of the hydrogen halides, HC*l*, HBr and HI.

.....

.....

..... [2]

**(ii)** Suggest why the hydrogen halide HF does not follow the trend in boiling points shown by HC*l*, HBr and HI.

.....

.....

..... [2]

s/16/qp22

**(b)** Ammonia is polar whereas methane is non-polar. The physical properties of the two compounds are different.

**(i)** Explain, using ammonia as the example, the meaning of the term *bond polarity*.

.....

.....

.....

**(ii)** Explain why the ammonia molecule is polar.

.....

.....

**(iii)** State **one** physical property of ammonia which is caused by its polarity.

.....

.....

[4]

w/13/qp23

**(c)** Chlorine reacts with both bromine and iodine to form BrCl and ICl respectively. The melting points of chlorine and the two chlorides are shown in the table.

| substance | $Cl_2$ | BrCl | ICl |
|---|---|---|---|
| m.p./°C | –101 | –66 | 24 |

**(i)** Showing outer electrons only draw a 'dot-and-cross' diagram of the bonding in ICl.

**(ii)** Suggest why the melting points increase from $Cl_2$ to ICl.

.....

.....

.....

**(iii)** Suggest which of these three molecules has the largest permanent dipole. Explain your answer.

.....

.....

.....

[5]

9701_s/13/qp22

**(c)** Chlorine reacts with both bromine and iodine to form BrCl and ICl respectively. The melting points of chlorine and the two chlorides are shown in the table.

| substance | $Cl_2$ | BrCl | ICl |
|---|---|---|---|
| m.p./°C | –101 | –66 | 24 |

**(i)** Showing outer electrons only draw a 'dot-and-cross' diagram of the bonding in ICl.

**(ii)** Suggest why the melting points increase from $Cl_2$ to ICl.

.....

.....

.....

**(iii)** Suggest which of these three molecules has the largest permanent dipole. Explain your answer.

.....

.....

.....

[5]

9701_s/13/qp22

2 Hydrogen halides are compounds formed when halogens (Group 17 elements) react with hydrogen. The bond polarity of the hydrogen halides decreases from HF to HI.

Some relevant data are shown in the table.

| hydrogen halide | HF | HC*l* | HBr | HI |
|---|---|---|---|---|
| boiling point / °C | 19 | –85 | –67 | –35 |
| H–X bond energy / kJ mol$^{-1}$ | 562 | 431 | 366 | 299 |

**(a) (i)** Explain the meaning of the term *bond polarity*.

.....

.....

..... [1]

**(ii)** Suggest why the boiling point of HF is **much** higher than the boiling points of the other hydrogen halides.

.....

.....

.....

.....

..... [2]

**(iii)** Describe and explain the relative thermal stabilities of the hydrogen halides.

.....

.....

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.....

.....

..... [3]

m/17/qp22

Hydrogen sulphide, $H_2S$, is a foul-smelling compound found in the gases from volcanoes. Hydrogen sulphide is covalent, melting at –85 °C and boiling at –60 °C.

**(c)** **(i)** Draw a 'dot-and-cross' diagram to show the structure of the $H_2S$ molecule.

**(ii)** Predict the shape of the $H_2S$ molecule.

.....

**(iii)** Oxygen and sulphur are both in Group VI of the Periodic Table.

Suggest why the melting and boiling points of water, $H_2O$, are much higher than those of $H_2S$.

.....

.....

..... [4]

9701_s/05/qp2

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**(iii)** Draw a diagram to show the dipole present in the propanone molecule.

[3]

9701_s/11/qp21

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**(e)** Ethane, $CH_3CH_3$, and fluoromethane, $CH_3F$ are *iso*-electronic, that is they have the same total number of electrons in their molecules.

Calculate the **total** number of electrons in one molecule of $CH_3F$.

[1]

**(f)** The boiling points of these two compounds are given below.

| compound | bp/K |
|---|---|
| $CH_3CH_3$ | 184.5 |
| $CH_3F$ | 194.7 |

Suggest explanations for the following.

**(i)** the close similarity of the boiling points of the two compounds

.....

.....

**(ii)** the slightly higher boiling point of $CH_3F$

.....

.....

[2]

9701_s/11/qp23

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**3** With the prospect that fossil fuels will become increasingly scarce in the future, many compounds are being considered for use in internal combustion engines. One of these is DME or dimethyl ether, $CH_3OCH_3$. DME is a gas which can be synthesised from methanol. Methanol can be obtained from biomass, such as plant waste from agriculture.

**(d)** DME is a gas at room temperature while ethanol is a liquid.

**(i)** Which intermolecular force exists between ethanol molecules, which causes ethanol to be a liquid at room temperature?

.....

**(ii)** Draw a diagram that clearly shows this intermolecular force.
Your diagram should show any lone pairs or dipoles present that you consider to be important. You should represent at least two molecules in your diagram.

[4]

9701_s/12/qp23

# Types of Bonds

**(b) (i)** Explain, in terms of structure and bonding, why the melting point of $SiCl_4$ is much lower than that of $NaCl$.

.....

.....

.....

.....

..... [3]

w/17/qp22

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**1** Aluminium is a metal in Period 3 and Group III of the Periodic Table.

**(a)** Describe the structure of solid aluminium.

.....

.....

..... [2]

**(b)** A common use of aluminium is to make the conducting cables in long distance overhead power lines.

**(i)** Suggest two properties of aluminium that make it suitable for this use.

.....

.....

..... [2]

The cables are attached to pylons by ceramic supports.

**(ii)** Describe the structure of a ceramic material.

.....

..... [1]

**(iii)** State the property of a ceramic material that makes it suitable for this use.

.....

..... [1]

w/15/qp21

**(b) (i)** Explain why the melting point of MgO is higher than that of $Na_2O$.

.....

.....

.....

.....

..... [2]

**(ii)** Explain why the melting point of $SiO_2$ is much higher than that of $SO_3$.

.....

.....

.....

.....

.....

..... [2]

s/18/qp23

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**(iv)** Suggest why there is a general **decrease** in the melting points of the elements down Group 2.

.....

.....

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.....

..... [3]

s/18/qp22

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2 Structure and bonding can be used to explain many of the properties of substances.

**(a)** Copper, ice, silicon(IV) oxide, iodine and sodium chloride are all crystalline solids.

Complete the table with:
- the name of a type of bonding found in each crystalline solid,
- the type of lattice structure for each crystalline solid.

| crystalline solid | type of bonding | type of lattice structure |
|---|---|---|
| copper | | |
| ice | | |
| silicon(IV) oxide | | |
| iodine | | |
| sodium chloride | | |

[5]

s/17/qp21

**(d)** Sodium and silicon also react directly with chlorine to produce the chlorides shown.

| chloride | melting point / °C | difference between the electronegativities of the elements |
|---|---|---|
| NaCl | 801 | 2.2 |
| $SiCl_4$ | –69 | 1.3 |

**(i)** Describe what you would **see** during the reaction between sodium and chlorine.

.....

.....

..... [2]

**(ii)** Explain the differences between the melting points of these two chlorides in terms of their structure **and** bonding. You should refer to the difference between the electronegativities of the elements in your answer.

NaCl structure **and** bonding .....

.....

$SiCl_4$ structure **and** bonding .....

.....

explanation .....

.....

.....

.....

.....

..... [4]

s/15/qp21

**(c)** Cerium is a lanthanoid metal that shows similar chemical reactions to some elements in the third period. Most of cerium's compounds contain $Ce^{3+}$ or $Ce^{4+}$ ions.

**(i)** Cerium shows the same structure and bonding as a typical metal.

Draw a labelled diagram to show the structure and bonding in cerium.

[2]

**(ii)** Cerium(IV) oxide, $CeO_2$, is a ceramic.

Suggest **two** physical properties of cerium(IV) oxide.

1. .....

2. .....

[2]

m/17/qp22

1 **(a)** Salt, sodium chloride, forms transparent colourless crystals. Describe the bonding in sodium chloride crystals, give the formula of each particle and sketch part of the crystal structure.

[3]

**(b)** Explain why crystals of sodium chloride do not conduct electricity, but molten sodium chloride does.

.....

.....

.....[2]

9701_w/03/qp2

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3 The oxides of the third period include the following:

$Na_2O$; MgO; $Al_2O_3$; $SO_2$; $SO_3$.

**(a)** Showing outer electrons only, draw a dot-and-cross electron diagram for magnesium oxide, MgO.

[1]

9701_w/02/qp2

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1 **(a)** Salt, sodium chloride, forms transparent colourless crystals. Describe the bonding in sodium chloride crystals, give the formula of each particle and sketch part of the crystal structure.

[3]

**(b)** Explain why crystals of sodium chloride do not conduct electricity, but molten sodium chloride does.

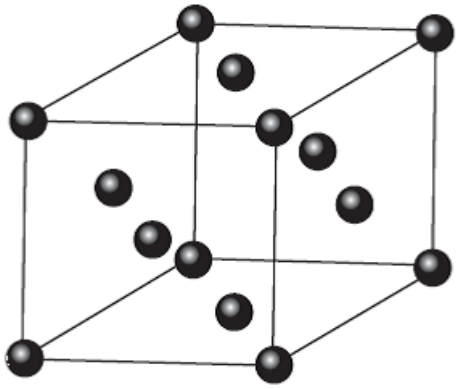
.....

.....

.....[2]

9701_w/03/qp2

2 Copper and iodine are both solids which have different physical and chemical properties. Each element has the same face-centred crystal structure which is shown below.



The particles present in such a crystal may be atoms, molecules, anions or cations. In the diagram above, the particles present are represented by ●.

**(a)** Which type of particles are present in the iodine crystal? Give their formula.

particle .....

formula ..... [2]

**(b)** When separate samples of copper or iodine are heated to 50 °C, the copper remains as a solid while the iodine turns into a vapour.

**(i)** Explain, in terms of the forces present in the solid structure, why copper remains a solid at 50 °C.

.....

.....

.....

**(ii)** Explain, in terms of the forces present in the solid structure, why iodine turns into a vapour when heated to 50°C.

.....

.....

.....

[4]

**(c) (i)** Although copper is a relatively unreactive metal, when it is heated to a high temperature in an excess of chlorine, copper(II) chloride is formed.

How does chlorine behave in this reaction?

.....

**(ii)** When a mixture of copper and iodine is heated to a high temperature, no reaction occurs.

Suggest a reason for this difference.

.....

.....

[2]

[Total: 8]

9701_w/06/qp2

1 The elements carbon and silicon are both in Group IV of the Periodic Table.
Carbon is the second most abundant element by mass in the human body and silicon is the second most common element in the Earth's crust.

Carbon and silicon each form an oxide of general formula $XO_2$.
At room temperature, $CO_2$ is a gas while $SiO_2$ is a solid with a high melting point.

**(a)** Briefly explain, in terms of the chemical bonds and intermolecular forces present in **each** compound, why $CO_2$ is a gas and $SiO_2$ is a solid at room temperature.

.....

.....

.....

..... [3]

**(b)** Draw a simple diagram to show the structure of $SiO_2$. Your diagram should contain at least **two** silicon atoms **and** show clearly how many bonds each atom forms.

[2]

Carbon exists in a number of forms, one of which is a conductor of electricity and one of which is a non-conductor of electricity. Silicon is the main component of most semi-conductors.

**(d)** Graphite is the form of carbon that is a conductor of electricity. Give a simple explanation for this property.

.....

..... [1]

When carbon and silicon(IV) oxide are heated together at about 2000 °C, silicon carbide, SiC, is formed. Silicon carbide is a hard material which is widely used as an abrasive and in ceramics.

**(e)** **(i)** Construct an equation for the reaction of carbon and silicon(IV) oxide.

.....

**(ii)** SiC has a similar structure to one of the common forms of carbon.
Which form is this? Give a reason for your answer.

form .....

reason .....
[2]

9701_w/09/qp22

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Sodium hydride, NaH, is a colourless crystalline solid which melts at 800 °C and has the same crystal structure as sodium chloride which has a melting point of 808 °C. When molten sodium chloride is electrolysed using graphite electrodes, a shiny deposit, **D**, forms on the cathode and a greenish-yellow gas is evolved from the anode. When molten sodium hydride is electrolysed, under suitable conditions using graphite electrodes, the same shiny deposit **D** is formed on the cathode and a colourless gas, **G**, is evolved from the anode.

**(b)** **(i)** Describe with the aid of a diagram the bonding in a sodium chloride crystal.

**(ii)** Suggest the type of bonding that is present in sodium hydride.

.....

**(iv)** Draw a 'dot-and-cross' diagram for sodium hydride. Show outer electrons only.

At room temperature, the chlorides of silicon, phosphorus and sulfur are all low melting point solids or low boiling point liquids that can be seen to react with water.

**(d)** **(i)** Suggest what type of bonding is present in sulfur dichloride, $SCl_2$.

.....

9701_w/09/qp22

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**(f)** The chloride **A** melts at 73.4 °C while magnesium chloride melts at 714 °C.

**(i)** What type of bonding is present in magnesium chloride?

.....

**(ii)** Suggest what type of bonding is present in **A**.

..... [2]

9701_w/10/qp23

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**(c)** When ammonia gas is mixed with hydrogen chloride, white, solid ammonium chloride is formed.

State **each type** of bond that is present in one formula unit of ammonium chloride and how many of each type are present.
You may draw diagrams.

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..... [3]

[Total: 10]

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