CHEMISTRY 9701

THEORY QUESTIONS

AS: Atomic Structure and Chemical Bonding

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Atomic Structure & Chemical Bonding

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?

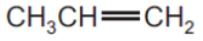
.....

[3]

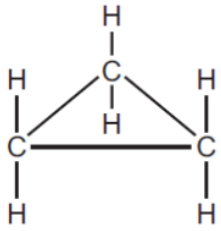
[Total: 6]

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]

(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*.

.....

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(ii) Explain why the ammonia molecule is polar.

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.....

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

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.....

[4]

(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]

9701_w/13/qp23

1 **(a)** Successive ionisation energies for the elements magnesium to barium are given in the table.

element	1st ionisation energy / kJ mol^{-1}	2nd ionisation energy / kJ mol^{-1}	3rd ionisation energy / kJ mol^{-1}
Mg	736	1450	7740
Ca	590	1150	4940
Sr	548	1060	4120
Ba	502	966	3390

(i) Explain why the first ionisation energies decrease down the group.

.....

.....

.....

..... [3]

(ii) Explain why, for each element, there is a large increase between the 2nd and 3rd ionisation energies.

.....

.....

..... [2]

9701_w/14/qp21

(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.

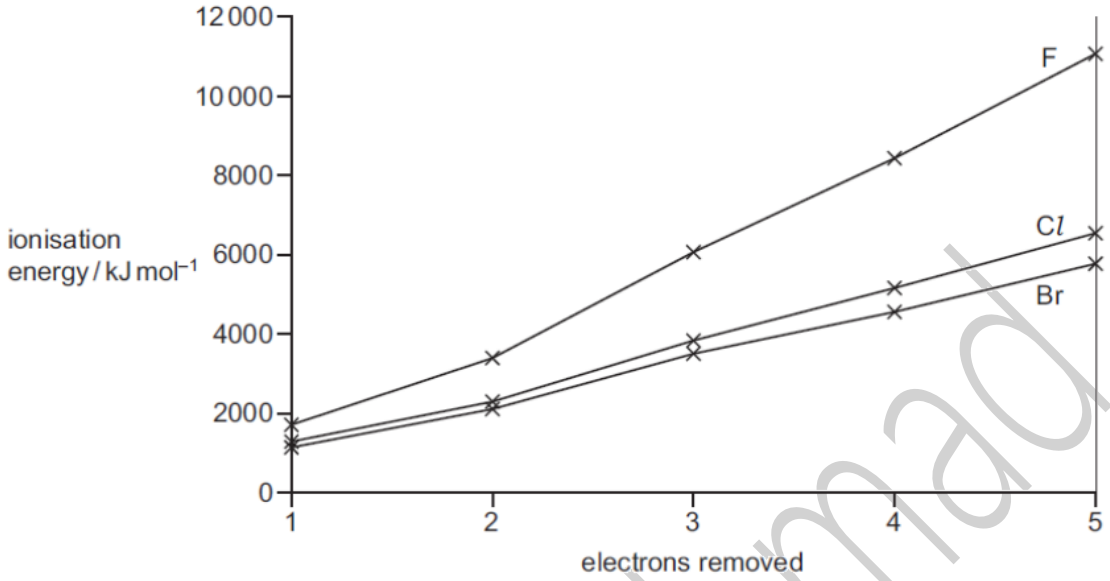
SO_2 shape ..... SO_3 shape .....

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

[2]

9701_w/14/qp21

1 **(a)** Successive ionisation energies for the elements fluorine, F, to bromine, Br, are shown on the graph.



(i) Explain why the first ionisation energies decrease down the group.

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.....

.....

..... [3]

(ii) Explain why there is an increase in the successive ionisation energies of fluorine.

.....

.....

..... [2]

(b) Group VII is the only group in the Periodic Table containing elements in all three states of matter at room conditions.

State and explain, in terms of intermolecular forces, the trend in the boiling points of the elements down Group VII.

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.....

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.....

..... [4]

(ii) Another interhalogen compound has the formula IC*l*.

Draw a 'dot-and-cross' diagram of a molecule of this compound, showing outer shell electrons only. Explain whether or not you would expect this molecule to be polar.

.....

.....

..... [2]

9701_w/14/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

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

1 **(a)** Explain what is meant by the term *ionisation energy*.

.....

.....

..... [3]

(b) The first seven ionisation energies of an element, **A**, in $kJ\,mol^{-1}$, are

1012 1903 2912 4957 6274 21 269 25 398.

(i) State the group of the Periodic Table to which **A** is most likely to belong. Explain your answer.

.....

.....

.....

..... [2]

(ii) Complete the electronic configuration of the element in Period 2 that is in the same group as **A**.

$1s^2$ ..... [1]

9701_s/14/qp21

(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

(e) Phosphorus reacts with chlorine to form PCl_5.

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

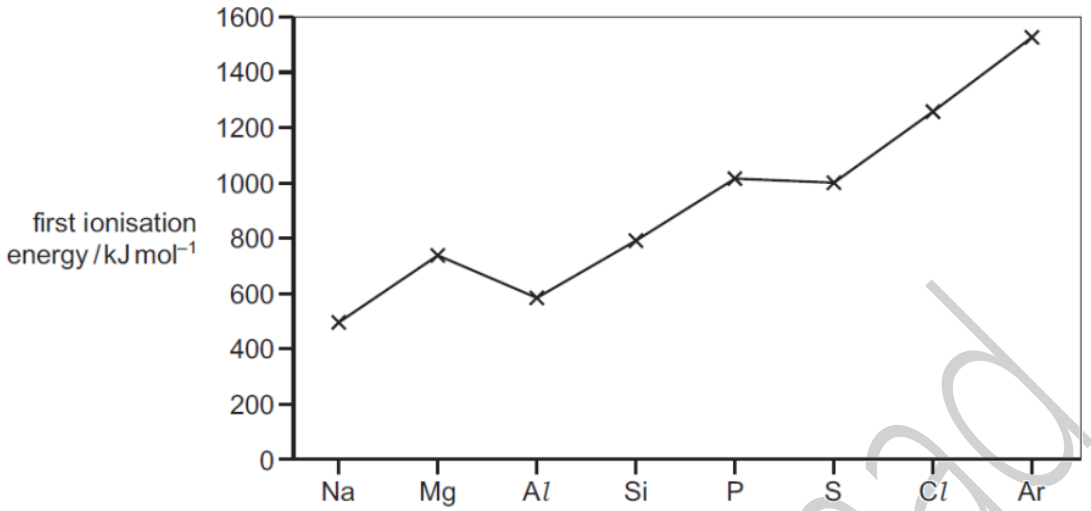
shape of PCl_5 .....

bond angles in PCl_5 ....

[2]

9701_s/14/qp22

(b) The graph below shows the variation of the first ionisation energies across Period 3.



(i) Explain why the first ionisation energy of Ar is greater than that of Cl.

.....

..... [1]

(ii) Explain why the first ionisation energy of Al is less than that of Mg.

.....

..... [1]

(iii) Explain why the first ionisation energy of S is less than that of P.

.....

..... [1]

9701_s/14/qp22

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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 HCl to HI.

.....

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

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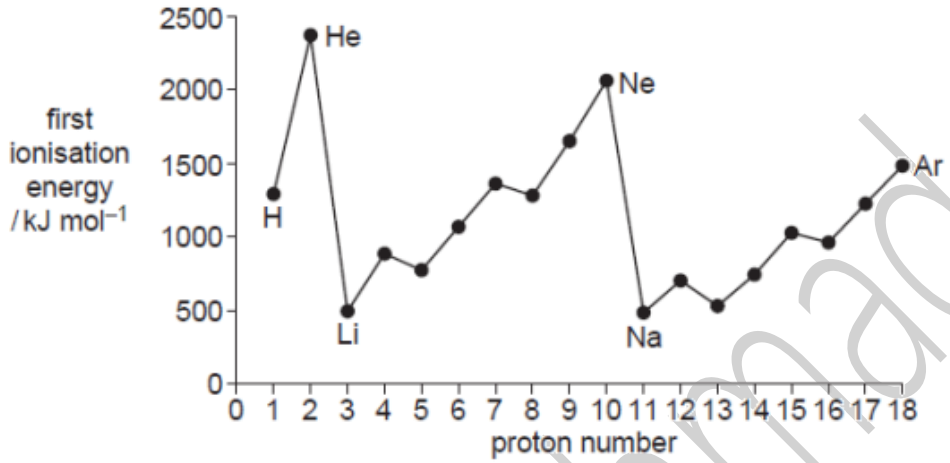
.....

[3]

9701_w/12/qp21

3 The Periodic Table we currently use is derived directly from that proposed in 1869 by Mendeleev who had noticed patterns in the physical and chemical properties of the elements he had studied.

The diagram below shows the first ionisation energies of the first 18 elements of the Periodic Table.



(a) Give the equation, including state symbols, for the first ionisation energy of carbon.

.....

[2]

(b) **(i)** Explain why sodium has a lower first ionisation energy than magnesium.

.....

.....

(ii) Explain why magnesium has a higher first ionisation energy than aluminium.

.....

.....

(iii) Explain why helium, He, and neon, Ne, occupy the two highest positions on the diagram.

.....

.....

(iv) Explain why the first ionisation energy of argon, Ar, is lower than that of neon, which is lower than that of helium.

.....

.....

.....

[8]

(c) Isotopes of polonium, proton number 84, are produced by the radioactive decay of several elements including thorium, Th, proton number 90.

The isotope ^{213}Po is produced from the thorium isotope ^{232}Th.

Complete the table below to show the atomic structures of the isotopes ^{213}Po and ^{232}Th.

	number of		
isotope	protons	neutrons	electrons
^{213}Po			
^{232}Th			

[3]

Radiochemical reactions, such as nuclear fission and radioactive decay of isotopes, can be represented by equations in which the nucleon (mass) numbers must balance and the proton numbers must also balance.

For example, the nuclear fission of uranium-235, $^{235}_{92}U$, by collision with a neutron, $^{1}_{0}n$, produces strontium-90, xenon-143 and three neutrons.

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{90}_{38}Sr + {}^{143}_{54}Xe + 3\,{}^{1}_{0}n$$

In this equation, the nucleon (mass) numbers balance because: 235 + 1 = 90 + 143 + (3x1).

The proton numbers also balance because: 92 + 0 = 38 + 54 + (3x0).

(d) In the first stage of the radioactive decay of $^{232}_{90}Th$, the products are an isotope of element *E* and an alpha-particle, $^{4}_{2}He$.

(i) By considering nucleon and proton numbers only, construct a balanced equation for the formation of the isotope of *E* in this reaction.

$$^{232}_{90}Th \longrightarrow \text{.....} + {}^{4}_{2}He$$

Show clearly the nucleon number and proton number of the isotope of *E*.

nucleon number of the isotope of *E* .....

proton number of the isotope of *E* .....

(ii) Hence state the symbol of the element *E*.

.....

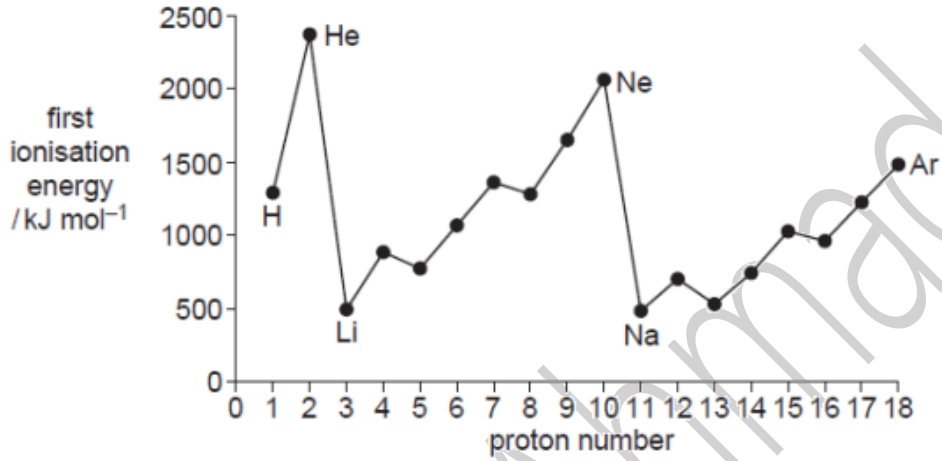
[3]

[Total: 10]

9701_w/11/qp23

2 The Periodic Table we currently use is derived directly from that proposed in 1869 by Mendeleev who had noticed patterns in the physical and chemical properties of the elements he had studied.

The diagram below shows the first ionisation energies of the first 18 elements of the Periodic Table.



(a) Give the equation, including state symbols, for the first ionisation energy of sulfur.

..... [2]

(b) Explain why there is a **general** increase in first ionisation energies across the Period from sodium to argon.

.....

.....

.....

..... [3]

(c) **(i)** Explain why the first ionisation energy of magnesium is greater than that of aluminium.

.....

.....

.....

(ii) Explain why the first ionisation energy of phosphorus is greater than that of sulfur.

.....

.....

..... [4]

9701_w/11/qp21

3 Astronomers using modern spectroscopic techniques of various types have found evidence of many molecules, ions and free radicals in the dust clouds in Space. Many of the species concerned have also been produced in laboratories on Earth.

Two such species are the dicarbon monoxide molecule, C_2O, and the amino free radical, NH_2.

(a) (i) Dicarbon monoxide can be produced in a laboratory and analysis of it shows that the sequence of atoms in this molecule is carbon-carbon-oxygen and there are no unpaired electrons, but one of the atoms is only surrounded by six electrons.

Draw a 'dot-and-cross' diagram of C_2O and suggest the shape of the molecule.

shape .....

9701_w/10/qp23

(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

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

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

Radium, proton number 88, and uranium, proton number 92, are radioactive elements.

The isotope ^{226}Ra is produced by the radioactive decay of the uranium isotope ^{238}U.

(c) Complete the table below to show the atomic structures of the isotopes ^{226}Ra and ^{238}U.

	number of		
isotopes	protons	neutrons	electrons
^{226}Ra			
^{238}U			

[3]

(d) Radium, like other Group II elements, forms a number of ionic compounds.

(i) What is the formula of the radium cation?

.....

(ii) Use the *Data Booklet* to suggest a value for the energy required to form one mole of the gaseous radium cation you have given in **(i)** from one mole of gaseous radium atoms. Explain your answer.

.....

.....

..... [3]

9701_w/09/qp21

(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.

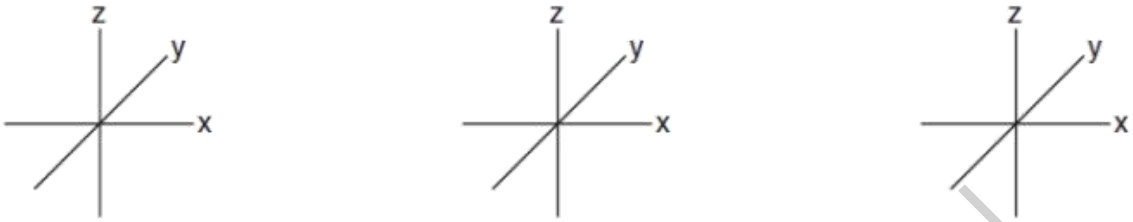
(iii) Draw a displayed formula of the form of aluminium chloride that exists at the **lower** temperature. Indicate clearly the different types of bonds present.

[5]

9701_w/07/qp2

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.

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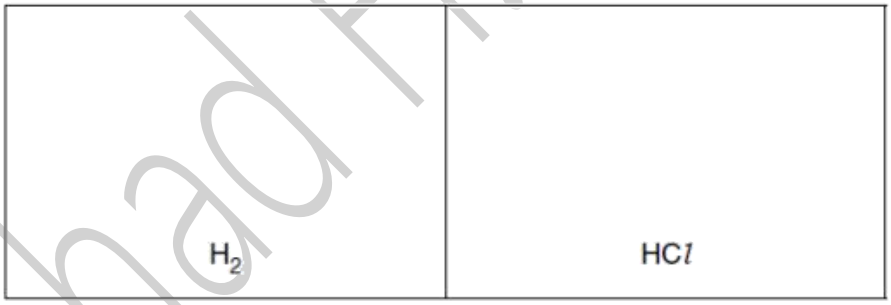
.....

(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.

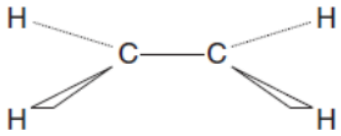
.....

.....

[2]

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

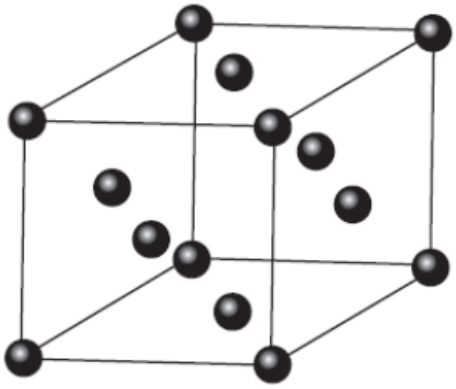
Each carbon atom in ethene forms three σ bonds as shown below.



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

9701_w/07/qp2

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.

.....

.....

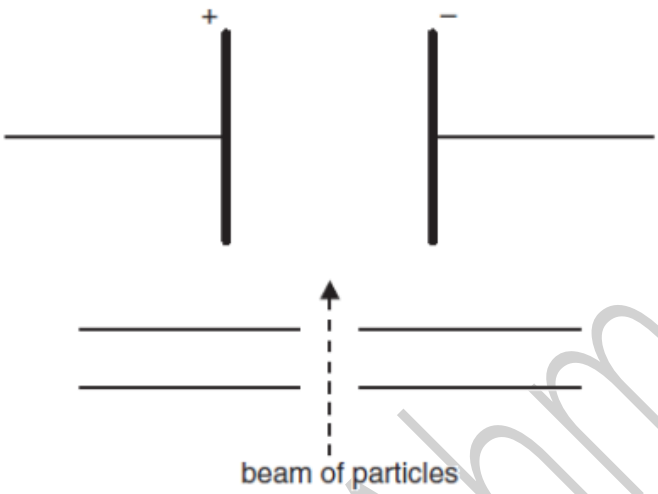
[2]

[Total: 8]

9701_w/06/qp2

1 In the 19th and 20th centuries, scientists established the atomic theory and showed that three sub-atomic particles, electron, neutron and proton, exist. The masses and charges of these three particles were subsequently determined.

When separate beams of electrons, neutrons or protons are passed through an electric field in the apparatus below, they behave differently.



(a) (i) Which of these three particles will be deflected the most by the electric field?

.....

(ii) In which direction will this particle be deflected?

.....

(iii) Explain your answer.

.....

.....

[4]

(b) (i) Define the term *proton number*.

.....

.....

(ii) Why is the proton number of an atom of an element usually different from the nucleon number of an atom of the element?

.....

.....

[2]

(c) Protons and neutrons have been used in nuclear reactions which result in the formation of artificial elements. In such processes, protons or neutrons are accelerated to high speeds and then fired like 'bullets' at the nucleus of an atom of an element.

Suggest why neutrons are more effective than protons as 'nuclear bullets'.

.....

..... [2]

(d) In some cases, when neutrons are fired at atoms of an element, the neutrons become part of the nucleus of those atoms.

What effect does the presence of an extra neutron have on the chemical properties of the new atoms formed? Explain your answer.

.....

.....

..... [2]

[Total: 10]

9701_w/06/qp2

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2 Carbon disulphide, CS_2, is a volatile, stinking liquid which is used to manufacture viscose rayon and cellophane.

(a) The carbon atom is in the centre of the CS_2 molecule.

Draw a 'dot-and-cross' diagram of the carbon disulphide molecule.

Show outer electrons only.

[2]

(b) Suggest the shape of the molecule and give its bond angle.

shape .....

bond angle ..... [2]

9701_w/05/qp2

1 The first six ionisation energies of an element **X** are given below.

ionisation energy / kJ mol^{-1}					
first	second	third	fourth	fifth	sixth
950	1800	2700	4800	6000	12300

(a) Define the term *first ionisation energy*.

.....

.....

.....

..... [3]

(b) Write an equation, with state symbols, for the **second** ionisation energy of element **X**.

..... [2]

(c) Use the data given above to deduce in which Group of the Periodic Table element **X** is placed. Explain your answer.

Group .....

explanation .....

.....

.....

..... [3]

The first ionisation energies (I.E.) for the elements of Group IV are given below.

element	C	Si	Ge	Sn	Pb
1st I.E. / kJ mol^{-1}	1090	786	762	707	716

(d) Explain the trend shown by these values in terms of the atomic structure of the elements.

.....

.....

.....

.....

..... [4]

[Total: 12]

9701_w/05/qp2

(b) Hydrochloric acid is manufactured by burning the hydrogen formed in this electrolysis in chlorine and dissolving the product in water.

(i) Construct an equation for the burning of hydrogen in chlorine.

.....

(ii) When the product of **(i)** dissolves in water there is a change in bonding. Explain with the aid of an equation what change in bonding has occurred.

[2]

(c) Describe, with the aid of equations including state symbols, what happens when

(i) hydrochloric acid is added to aqueous silver nitrate,

.....

.....

(ii) an excess of aqueous ammonia is added to the resulting mixture.

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.....

.....[5]

9701_w/04/qp2

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

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

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?

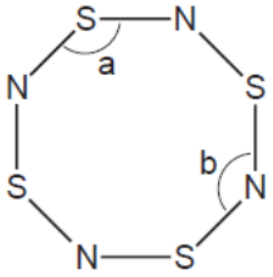
.....

(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

(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

(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

(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

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

[3]

9701_s/11/qp21

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

2 The alkali metals are a series of six elements in Group I of the Periodic Table. The first ionisation energy of these elements shows a marked trend as the Group is descended.

(a) Define the term *first ionisation energy*.

.....

.....

..... [2]

(b) **(i)** State and explain the trend in first ionisation energy as Group I is descended.

.....

.....

.....

(ii) Suggest how this trend helps to explain the increase in the reactivity of the elements as the Group is descended.

.....

.....

[3]

(c) In a redox reaction, 0.83 g of lithium reacted with water to form 0.50 dm^3 of aqueous lithium hydroxide.

$$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$$

(i) Calculate the amount, in moles, of lithium that reacted.

9701_s/10/qp23

1 Hydrazine, N_2H_4, can be used as a rocket fuel and is stored as a liquid. It reacts exothermically with oxygen to give only gaseous products.

(iii) Suggest why using hydrazine as a rocket fuel could be regarded as being 'environmentally friendly'.

.....

.....

[4]

(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.

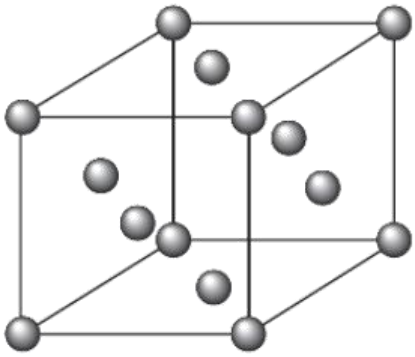
[4]

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

..... [1]

9701_s/10/qp23

2 Copper, proton number 29, and argon, proton number 18, are elements which have different physical and chemical properties.
In the solid state, each element has the same face-centred cubic 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 types of particle are present in the copper and argon crystals?
In each case, give their formula.

element	particle	formula
copper		
argon		

[2]

At room temperature, copper is a solid while argon is a gas.

(b) Explain these observations in terms of the forces present in **each** solid structure.

.....

.....

.....

.....

.....

..... [4]

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

When a mixture of argon and chlorine is heated to a high temperature, no reaction occurs.

(c) (i) How does chlorine behave in its reaction with copper?

.....

(ii) Suggest a reason for the lack of a reaction between argon and chlorine.

.....

.....

[2]

The melting points of the noble gases neon to xenon are given below.

	Ne	Ar	Kr	Xe
melting point/K	25	84	116	161

(d) Explain why there is an increase in melting point from neon to xenon.

.....

.....

..... [2]

[Total: 10]

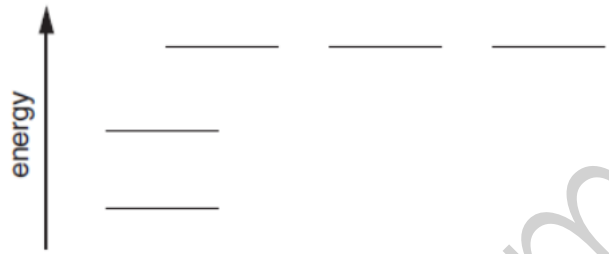
9701_s/10/qp22

1 In the 19th and 20th centuries, experimental results showed scientists that atoms consist of a positive, heavy nucleus which is surrounded by electrons.

Then in the 20th century, theoretical scientists explained how electrons are arranged in orbitals around atoms.

(a) The diagram below represents the energy levels of the orbitals present in atoms of the second period (Li to Ne).

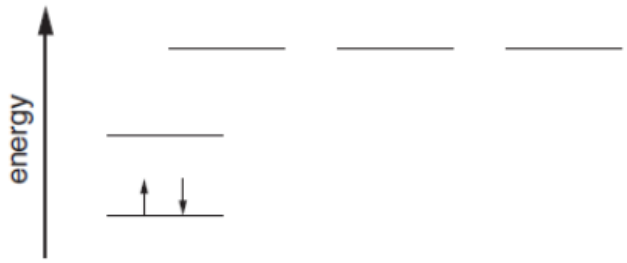
(i) Label the energy levels to indicate the principal quantum number **and** the type of orbital at each energy level.



(ii) On the axes below, draw a sketch diagram of **one** of each **different type (shape)** of orbital that is occupied by the electrons in a second-period element.

Label each type.

(iii) Complete the electronic configurations of nitrogen atoms and oxygen atoms on the energy level diagrams below.
Use arrows to represent electrons.



nitrogen

oxygen

[6]

(b) **(i)** Use the *Data Booklet* to state the value of the first ionisation energy of nitrogen and of oxygen.

N ..... kJ mol^{-1} O ..... kJ mol^{-1}

(ii) Explain, with reference to your answer to **(a)(iii)**, the relative values of these two ionisation energies.

.....

.....

.....

[3]

[Total: 9]

9701_s/10/qp22

1 Elements and compounds which have small molecules usually exist as gases or liquids.

(a) Chlorine, Cl_2, is a gas at room temperature whereas bromine, Br_2, is a liquid under the same conditions.

Explain these observations.

.....

.....

..... [2]

(b) The gases nitrogen, N_2, and carbon monoxide, CO, are isoelectronic, that is they have the same number of electrons in their molecules.

Suggest why N_2 has a lower boiling point than CO.

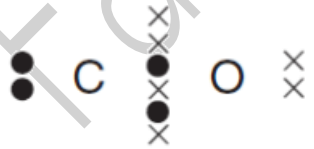
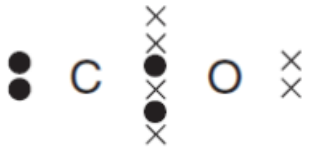
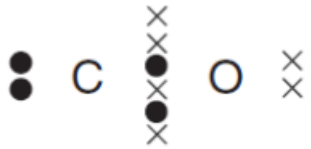
.....

.....

..... [2]

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

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.

(i) a co-ordinate bond	**(ii)** a covalent bond	**(iii)** a lone pair
		

[3]

(d) Hydrogen cyanide, HCN, is a gas which is also isoelectronic with N_2 and with CO. Each molecule contains a strong triple bond with the following bond energies.

bond	bond energy/kJ mol^{-1}
–C≡N in HCN	890
N≡N	994
C≡O	1078

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 N_2 is not.

Suggest a reason for this.

.....

..... [1]

9701_s/10/qp21

(ii) Use the *Data Booklet* to calculate the enthalpy change that occurs when one mole of gaseous magnesium ions, Mg^{2+}, is formed from one mole of gaseous magnesium atoms.

Include a sign in your answer.

enthalpy change = ... kJ mol^{-1}
[3]

(c) Magnesium burns in nitrogen to give magnesium nitride, a yellow solid which has the formula Mg_3N_2.

Magnesium nitride reacts with water to give ammonia and magnesium hydroxide.

(i) Construct an equation for the reaction of magnesium nitride with water.

.....

(ii) Does a redox reaction occur when magnesium nitride reacts with water?

Use the oxidation numbers of nitrogen to explain your answer.

.....

.....

.....

.....

[4]

9701_s/09/qp2

1 Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, Al, is in the third period of the Periodic Table; copper and titanium are both transition elements.

(a) Complete the electronic configuration of aluminium and of titanium, proton number 22.

Al	$1s^2$
Ti	$1s^2$

[1]

Aluminium reacts with chlorine.

(b) **(i)** Outline how, starting from aluminium powder, this reaction could be carried out in a school or college laboratory to give a small sample of aluminium chloride. A diagram is not necessary.

.....

.....

.....

(ii) Describe what you would see during this reaction.

.....

.....

(iii) At low temperatures, aluminium chloride vapour has the formula Al_2Cl_6.
Draw a 'dot-and-cross' diagram to show the bonding in Al_2Cl_6.
Show outer electrons only.
Represent the aluminium electrons by •.
Represent the chlorine electrons by ***x***.

[6]

Copper forms two chlorides, $CuCl$ and $CuCl_2$.

(c) When copper is reacted directly with chlorine, only $CuCl_2$ is formed.
Suggest an explanation for this observation.

.....

..... [1]

Titanium also reacts with chlorine.

(d) When an excess of chlorine was reacted with 0.72 g of titanium, 2.85 g of a chloride **A** was formed.

(i) Calculate the amount, in moles, of titanium used.

(ii) Calculate the amount, in moles, of chlorine atoms that reacted.

(iii) Hence, determine the empirical formula of **A**.

(iv) Construct a balanced equation for the reaction between titanium and chlorine.

.....
[4]

(e) At room temperature, the chloride of titanium, **A**, is a liquid which does not conduct electricity.

What does this information suggest about the bonding and structure in **A**?

.....

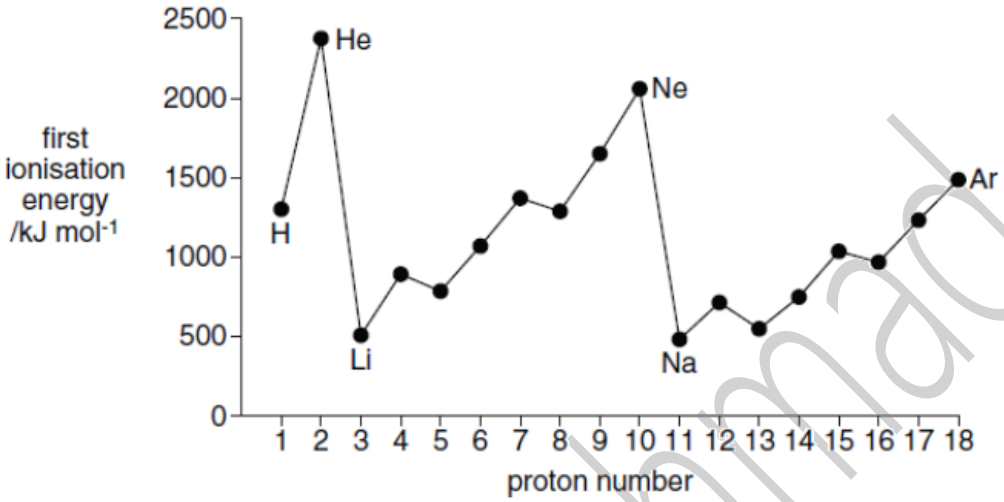
.....

..... [2]

[Total: 14]

2 The Periodic Table we currently use is derived directly from that proposed by Mendeleev in 1869 after he had noticed patterns in the chemical properties of the elements he had studied.

The diagram below shows the first ionisation energies of the first 18 elements of the Periodic Table as we know it today.



(a) Give the equation, including state symbols, for the first ionisation energy of fluorine.

.....[2]

(b) Explain why there is a general increase in first ionisation energies from sodium to argon.

.....

.....

.....

.....[3]

(c) **(i)** Explain why the first ionisation energy of aluminium is less than that of magnesium.

.....

.....

.....

(ii) Explain why the first ionisation energy of sulphur is less than that of phosphorus.

.....

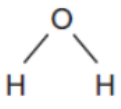
.....

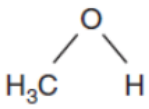
.....

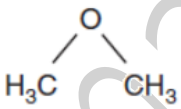
[4]

9701_s/08/qp2

1 The structural formulae of water, methanol and methoxymethane, CH_3OCH_3, are given below.







(a) (i) How many lone pairs of electrons are there around the oxygen atom in methoxymethane?

.....

(ii) Suggest the size of the C–O–C bond angle in methoxymethane.

.....

[2]

The physical properties of a covalent compound, such as its melting point, boiling point, vapour pressure, or solubility, are related to the strength of attractive forces between the molecules of that compound.

These relatively weak attractive forces are called intermolecular forces. They differ in their strength and include the following.

A interactions involving permanent dipoles

B interactions involving temporary or induced dipoles

C hydrogen bonds

(b) By using the letters **A**, **B**, or **C**, state the **strongest** intermolecular force present in **each** of the following compounds.
For each compound, write the answer on the dotted line.

ethanal	CH_3CHO	.....
ethanol	CH_3CH_2OH	.....
methoxymethane	CH_3OCH_3	.....
2-methylpropane	$(CH_3)_2CHCH_3$	.....

[4]

(c) Methanol and water are completely soluble in each other.

(i) Which intermolecular force exists between methanol molecules and water molecules that makes these two liquids soluble in each other?

.....

(ii) Draw a diagram that clearly shows this intermolecular force. Your diagram should show any lone pairs or dipoles present on either molecule that you consider to be important.

[4]

(d) When equal volumes of ethoxyethane, $C_2H_5OC_2H_5$, and water are mixed, shaken, and then allowed to stand, two layers are formed.

Suggest why ethoxyethane does not fully dissolve in water. Explain your answer.

.....

.....

.....

.....[2]

[Total: 12]

9701_s/08/qp2

1 Ethene, C_2H_4, and hydrazine, N_2H_4, are hydrides of elements which are adjacent in the Periodic Table. Data about ethene and hydrazine are given in the table below.

	C_2H_4	N_2H_4
melting point/°C	–169	+2
boiling point/°C	–104	+114
solubility in water	insoluble	high
solubility in ethanol	high	high

(a) Ethene and hydrazine have a similar arrangement of atoms but differently shaped molecules.

(i) What is the H-C-H bond angle in ethene?

.....

(ii) Draw a 'dot-and-cross' diagram for hydrazine.

(iii) What is the H-N-H bond angle in hydrazine?

.....

[4]

(b) The melting and boiling points of hydrazine are much higher than those of ethene. Suggest reasons for these differences in terms of the intermolecular forces **each** compound possesses.

.....

.....

.....

.....

.....[3]

(c) Explain, with the aid of a diagram showing lone pairs of electrons and dipoles, why hydrazine is very soluble in ethanol.

[3]

Ethene and hydrazine each react with HC*l*.

(d) When ethene is reacted with HC*l*, C_2H_5Cl is the only product.

(i) Using structural formulae, give an equation for the reaction between ethene and HC*l*.

(ii) What type of reaction occurs between HC*l* and ethene?

.....

(iii) Explain why there is no further reaction between C_2H_5Cl and HC*l*.

.....

[3]

(e) When aqueous hydrazine is reacted with HC*l*, a solid compound of formula N_2H_5Cl may be isolated. When an excess of HC*l* is used, a second solid, $N_2H_6Cl_2$, is formed.

(i) Suggest what type of reaction occurs between hydrazine and HC*l*.

.....

(ii) What feature of the hydrazine molecule enables this reaction to occur?

.....

(iii) Suggest why one molecule of hydrazine is able to react with one or two molecules of HC*l*.

.....

.....

[3]

[Total: 16]

2 The unsaturated hydrocarbon ethyne (acetylene), C_2H_2, is widely used in 'oxy-acetylene torches' for cutting and welding metals. In the torch, ethyne is burned in oxygen to produce a flame with a temperature of 3400 K.

(a) Ethyne is a linear molecule with a triple bond, C≡C, between the two carbon atoms.

Draw a 'dot-and-cross' diagram of an ethyne molecule.

[1]

9701_s/06/qp2

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

1 Iron and cobalt are adjacent elements in the Periodic Table. Iron has three main naturally occurring isotopes, cobalt has one.

(a) Explain the meaning of the term *isotope*.

.....

.....

..... [2]

(b) The most common isotope of iron is ^{56}Fe; the only naturally occurring isotope of cobalt is ^{59}Co.

Use the *Data Booklet* to complete the table below to show the atomic structure of ^{56}Fe and of ^{59}Co.

	number of		
isotope	protons	neutrons	electrons
^{56}Fe			
^{59}Co			

[3]

9701_s/04/qp2

(d) In the boxes below, draw diagrams to show the shapes of an ammonia molecule and an ammonium ion. Clearly show the bond angles on your diagrams.

ammonia	ammonium ion

[4]

9701_s/04/qp2

1 **(a)** Define *an isotope* in terms of its sub-atomic particles.

.....

.....

[1]

9701_s/03/qp2

(c) Ethanol is miscible with water because of hydrogen bonding between molecules of ethanol and water. Draw a diagram, including dipoles, to show the hydrogen bonding between a molecule of ethanol and a molecule of water.

[2]

[Total : 8]

9701_s/02/qp2

1 Sir James Jeans, who was a great populariser of science, once described an atom of carbon as being like six bees buzzing around a space the size of a football stadium.

(a) (i) Suggest what were represented by the six bees in this description.

.....

(ii) Explain (in terms of an atom of carbon) what stopped the bees from flying away from the space of the football stadium.

.....

.....

(iii) What is missing from Jeans' description when applied to an atom of carbon?

.....

.....

[3]

(b) The diagram below represents the energy levels of the orbitals in atoms of the second period, lithium to neon.

(i) Label the energy levels to indicate the principal quantum number and the type of orbital at each energy level.

(ii) In the space below, sketch the shapes of the two types of orbital.

(iii) Complete the electron configurations of nitrogen and oxygen on the energy level diagrams below, using arrows to represent electrons.

nitrogen

oxygen

(iv) Explain, with reference to your answer to **(iii)**, the relative values of the first ionisation energies of nitrogen and oxygen. The values are given in the *Data Booklet* and should be quoted in your answer.

.....

.....

.....

.....

[6]

(c) (i) State the formulae of the negatively charged ions formed by these elements in simple binary compounds (nitrides and oxides).

.....

(ii) Why do nitrogen and oxygen form negative ions, but not positive ions, in simple binary compounds?

.....

.....

.....

[2]

[Total : 11]

9701_s/02/qp2