Covalent bonding

Question Paper

Level	Pre U
Subject	Chemistry
Exam Board	Cambridge International Examinations
Topic	Covalent bonding-Chemical forces
Booklet	Question Paper

Time Allowed: **72 minutes**

Score: **/60**

Percentage: **/100**

Grade Boundaries:

1. This question is about oxygen and its compounds.

(a) O_2 and O_3 are allotropes of oxygen.

Explain what is meant by the term *allotrope*.

.....

..... [1]

(b) A molecule of O_3 contains a dative covalent bond.

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

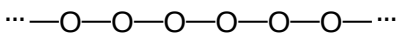
.....

..... [1]

(ii) Suggest a dot-cross diagram to show the bonding in O_3.

[2]

(c) A recent study (reported in *Proceedings of the National Academy of Sciences, USA*, 2012) has predicted that oxygen under 2 TPa of pressure (1 TPa = 10^{12} Pa = 10^{7} bar) can exist as the long-chain polymer shown.



At room temperature and pressure such a polymer will spontaneously turn into O_2.

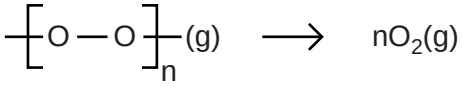
(i) What is meant by the term *bond energy*?

.....

.....

..... [3]

(ii) Calculate the energy change that accompanies the conversion of polymeric oxygen to O_2, per mole of oxygen molecules formed.



bond	bond energy / kJ mol^{-1}
O−O	144
O=O	498

energy change = ... kJ mol^{-1} [2]

(d) H^+ ions do not exist in isolation in water. They bond to water molecules to form hydronium ions, H_3O^+.

(i) Predict and explain the shape of the hydronium ion.

.....

.....

..... [2]

(ii) Which molecule with four atoms has the same total number of electrons as the hydronium ion?

..... [1]

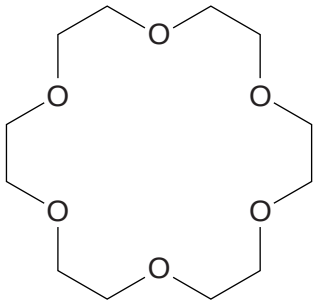
(e) A proton in an H_3O^+ ion can form a hydrogen-bond with a water molecule to form an $H_5O_2^+$ cation.

(i) Draw the $H_5O_2^+$ cation, labelling the hydrogen-bond. Include relevant lone pairs, dipoles and bond angles.

[4]

(ii) The hydronium ion, H_3O^+, may be solvated inside the macrocyclic 18-crown-6 molecule shown.

Draw the hydronium ion inside the macrocycle, showing how it is attached to the ring.



[1]

[Total: 17]

2. The compound whose bonding most resembles pure ionic bonding is caesium fluoride.

(a) Write down the formula of caesium fluoride.

.....[1]

(b) Draw a dot-cross diagram to show the bonding in caesium fluoride. Show outer electrons only.

[2]

(c) Explain why caesium fluoride is the compound whose bonding most closely resembles pure ionic.

.....

.....[1]

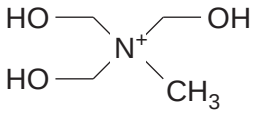
(d) Virtually all ionic compounds are solids at room temperature and pressure. However, researchers have designed ionic compounds whose ionic bonding is so weak that they are liquids under these conditions. Ionic liquids are often easy to handle as solvents as they are non-volatile; they have also recently found use in solar cells for this reason.

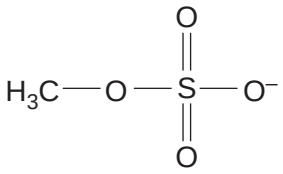
Explain what is meant by *non-volatile*.

.....[1]

(e) In the pure ionic bonding model, the ionic bond energy is proportional to the charge on each ion and inversely proportional to the distance between the charges, which are considered to be located at the centre of ions.

The structure of an ionic substance which is a liquid at room temperature and has been used in thermometers (reported in *Green Chemistry*, 2008) is shown below.





Suggest two features of these ions that account for the compound having such a low melting point.

1. .....

2. .....[1]

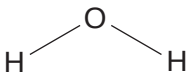
(f) Hydrogen-bonding is weaker than ionic or covalent bonding, but accounts for many important intermolecular attractions.

State two anomalous properties of water that are the result of hydrogen-bonding.

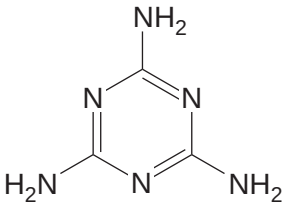
1. .....

2. .....[2]

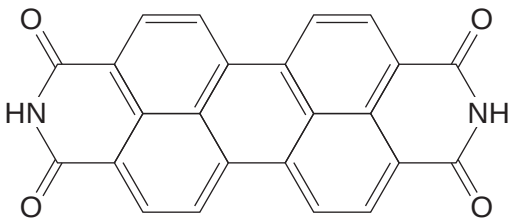
(g) Draw a second molecule of water and a hydrogen-bond between the two molecules. Indicate the bond angle around the hydrogen atom involved in the hydrogen-bond. Include all relevant lone pairs and dipoles.



(h) Hydrogen-bonding is directional (i.e. a specific link between two atoms can be drawn) and has many applications in linking together molecules in an organised way. This linking has been put to use recently by researchers designing self-assembling surface networks for applications in nanotechnology (reported in *Nature*, 2008).



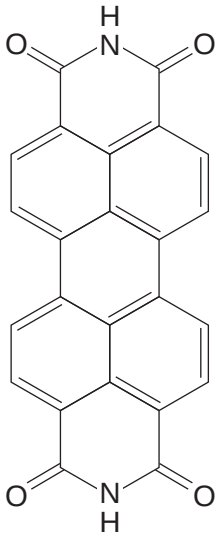
1,3,5-triazine-2,4,6-triamine (melamine)



perylene-3,4,9,10-tetracarboxylic diimide (PTCDI)

Fig. 3.1

The two molecules in Fig. 3.1 were chosen for the self-assembling network. A molecule of melamine and a molecule of PTCDI attach together strongly via three hydrogen bonds. Suggest where these **three** hydrogen-bonds form by drawing the melamine below in the correct orientation, with the hydrogen-bonds connecting the relevant atoms.



[2]

[Total: 13]

3. **(a)** Chemists have recently established that four molecules of water are required for the dissociation of a single molecule of HC*l* (reported in *Science*, 2009).

Given that 1.00 dm^3 of water contains 55.6 mol of H_2O, calculate the maximum mass of hydrogen chloride, HC*l*, that should therefore dissociate in 1.00 dm^3 of water.

..... g [1]

(b) Commercial concentrated hydrochloric acid, HC*l*(aq), fumes strongly on exposure to moist air and so is also known as 'fuming hydrochloric acid'.

1.00 cm^3 of fuming hydrochloric acid was transferred with a graduated pipette to a 100 cm^3 volumetric flask. The volume was made up to 100 cm^3 with deionised water. The solution was labelled **F**. 10.0 cm^3 of solution **F** was neutralised by 24.75 cm^3 of 0.0500 mol dm^{-3} of aqueous sodium hydroxide.

Calculate the concentration of HC*l* in the fuming hydrochloric acid in mol dm^{-3}. Give your final answer to **three** significant figures.

..... mol dm^{-3} [4]

(c) Historically, hydrochloric acid, HC*l*(aq), was produced by mixing concentrated sulfuric acid with sodium chloride and dissolving the gas produced in water.

(i) Write an equation for the production of gaseous hydrogen chloride by this method.

.....[1]

Hydrobromic acid, HBr(aq), cannot be prepared in the same way as hydrochloric acid because a redox reaction occurs between hydrogen bromide and sulfuric acid.

(ii) Write a balanced equation for the reaction of hydrogen bromide with sulfuric acid.

..... [1]

(iii) Identify the oxidising agent in the reaction. Justify your answer using oxidation numbers.

.....

.....

..... [2]

(d) **(i)** State and explain the trend in bond strength for the gases hydrogen chloride, hydrogen bromide and hydrogen iodide, in that order.

.....

.....[1]

(ii) State and explain the trend in acidic strength of hydrochloric acid, hydrobromic acid and hydroiodic acid.

.....

.....

.....[1]

(iii) Describe and explain the variation in boiling point of the gases hydrogen fluoride, hydrogen chloride, hydrogen bromide and hydrogen iodide.

.....

.....

.....

..... [2]

[Total: 13]

4. **(a)** Nitrogen and phosphorus are both found in Group 15.

Phosphorus forms more than one allotrope.

(i) Draw a dot-cross diagram to show the bonding in nitrogen, N_2. Show outer electrons only.

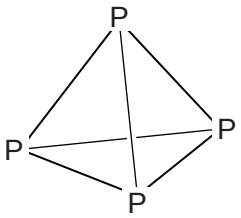
[1]

(ii) What is meant by the term *allotrope*?

.....

..... [1]

(iii) White phosphorus is a solid and exists as P_4 molecules with a tetrahedral structure as shown.



Using the data in Table 1.1 work out the enthalpy change for the following conversion. Include a sign in your answer.

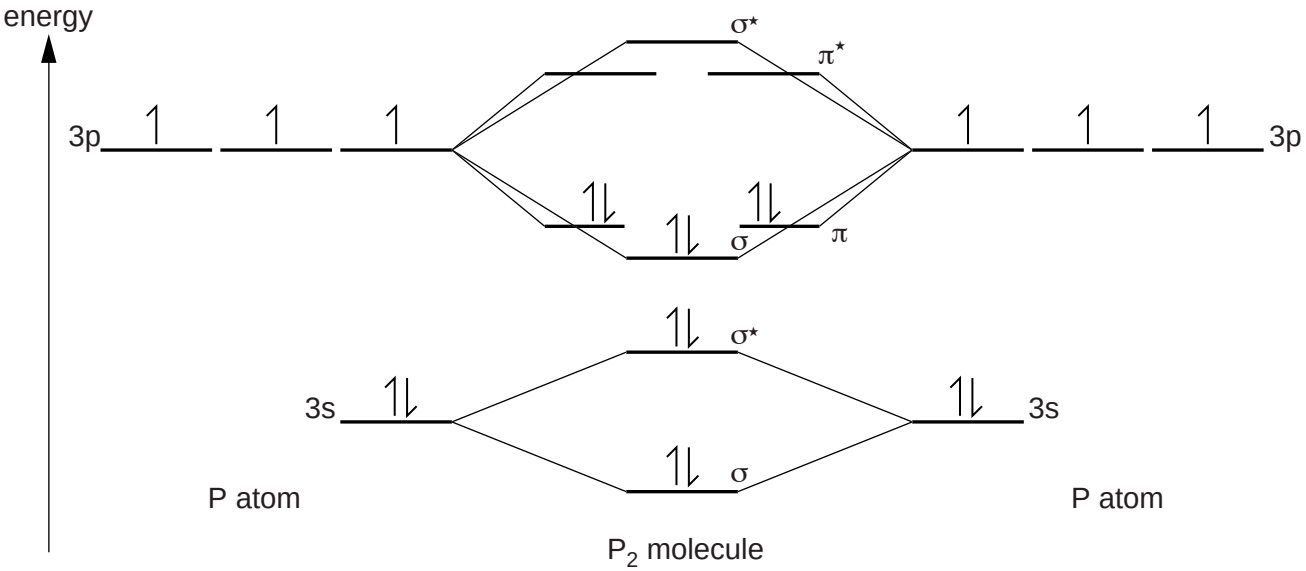
$$P_4(s) \longrightarrow 2P_2(g)$$

Table 1.1

	energy change / kJ mol^{-1}
P−P bond energy	198
P≡P bond energy	485
enthalpy of vaporisation of P_4	12

$\Delta_r H^{\ominus}$ = ... kJ mol^{-1} [3]
sign

(iv) Chemists have recently managed to prepare P_2 molecules in the solid state, trapped in an organic framework (reported in *Nature Chemistry*, 2010). The labelled molecular orbital diagram represents the bonding in P_2, which has a bond order of 3.



Using similar techniques P_2^{2+} and P_2^{+} were also trapped and characterised.

Using the molecular orbital diagram or otherwise, give the bond order in these species.

Bond order in P_2^{2+} = ... Bond order in P_2^{+} = ... [2]

(b) Carbon and silicon are both members of Group 14.

(i) What is meant by the term *first ionisation energy*?

.....

.....

..... [3]

(ii) Explain why the first ionisation energy of silicon is lower than that of carbon.

.....

.....

.....

..... [3]

(iii) State the type of covalent bond typically seen in

- single bonds, ...
- additional bonds in a multiple bond. ..... [1]

(iv) Carbon readily forms multiple bonds with itself, while silicon does not form these bonds so easily.

The first compound containing a Si=Si double bond was synthesised in 1972. One such compound contains the following percentages by mass.

C 41.3% H 10.3%

Find the empirical formula of this compound and draw a possible structure, given that it contains only one Si=Si double bond.

structure empirical formula ..... [3]

[Total: 17]