THE ARCHITECTURE OF MATTER

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C

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Royal Society of Chemistry

CHEMISTRY CASSETTES

A-level series

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USING CHEMISTRY CASSETTES

Please read this before you start.

This Chemistry Cassette learning programme has two components — an audio-cassette and a workbook. They are designed to be used together so make sure that you have both of them before you start.

The cassette will fit any standard audio-cassette player. You will have to turn it over to Side B when you are about half-way through the programme.

So that you can easily find material in the workbook it has been divided into numbered sections called 'frames'. These frames contain diagrams, tables, problems (questions), etc. Graham and John will give you the appropriate frame number whenever they want you to look at something in the workbook.

The programme has been designed so that you can use it either in class or on your own. If you are working on your own you will be able to go through at your own pace. Switch off the tape player whenever you want time to think, to write notes, or to answer questions. Use the rewind control if there is something that you don't understand on a first hearing and that you want to go over again.

Every now and then you will be presented with a problem. You can either attempt this straight away or wait until you get to the end of the tape. Each problem is printed in a relevant frame of the workbook. All the answers are at the end.

ACKNOWLEDGMENTS

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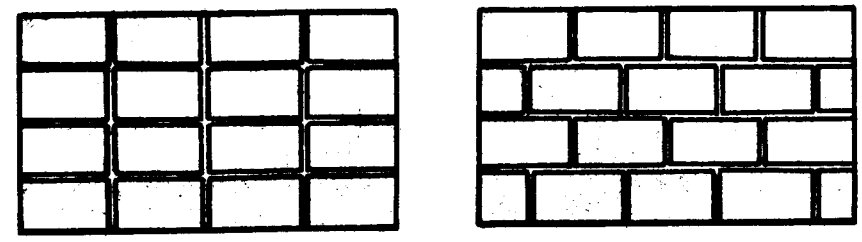
Frame 7 - Nuffield Chelsea Curriculum Trust
Frame 8 - Dr Brian Johnson
Frame 29 - Luton College of Higher Education.

SUMMARY

As with other programmes in this series, the authors' intention is to explore major themes that link several areas of chemistry. In this programme they consider the stucture of matter and the ways in which the properties of substances depend on their structures.

CONTENTS

1 Two ways of arranging bricks in a wall.



Which arrangement will give the stronger wall?

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2 Factors affecting the properties of a substance.

The properties of a substance are dictated by:

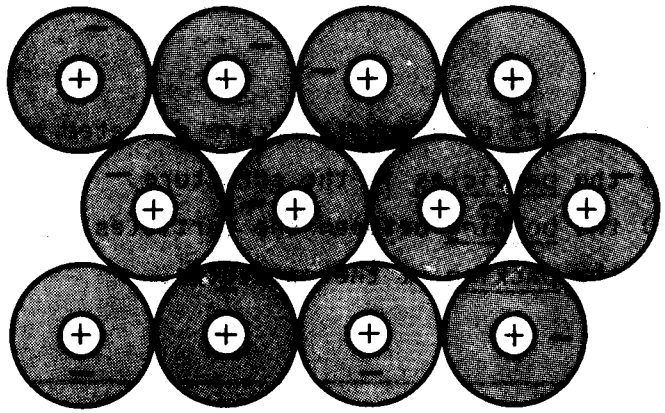
1) the particles in the structure,
2) the bonding between the particles,
3) the packing of the particles.

---

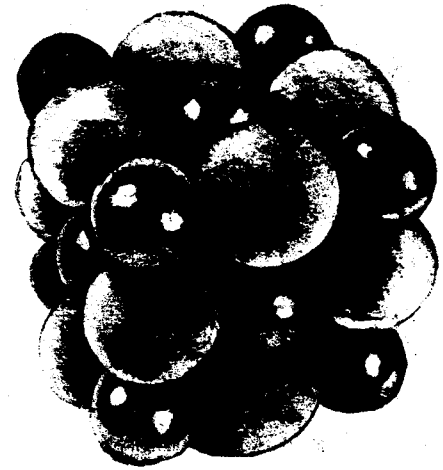
3 The four types of solid structure and their constituent particles.

Constituent particles	Solid structure	Type of substance	Examples
Atoms	Giant metallic	Metal element	Na, Fe, Cu
Ions	Giant ionic	Metal/non-metal compound	Na^+Cl^-, $Ca^{2+}O^{2-}$
Atoms in large molecules	Giant molecular	Non-metal element or Non-metal/non-metal compound	C(graphite), C(diamond), poly(ethene), sand
Atoms in small molecules	Simple molecular	Non-metal element or Non-metal/non-metal compound	I_2, S_8, H_2O, CO_2

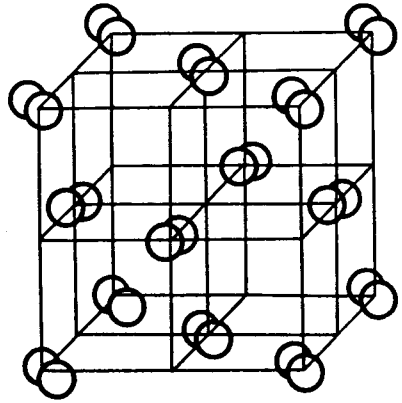
4 A simple model of metallic structure



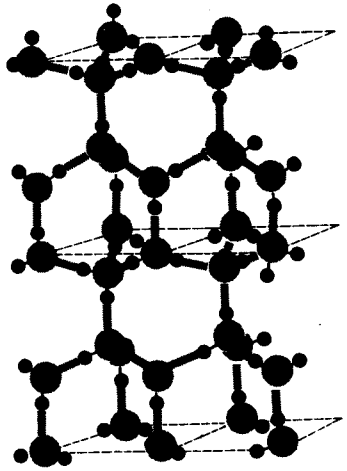
5 A model of the structure of salt (Na^+Cl^-)



6 The crystal structures of iodine and ice.



indicates the centre of an I_2 molecule

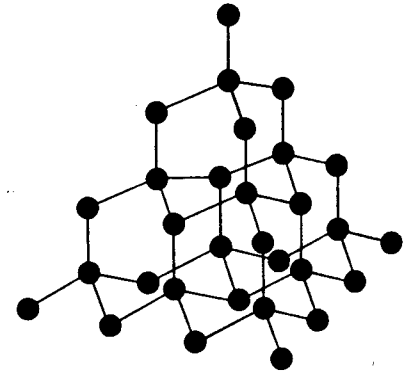


oxygen atom

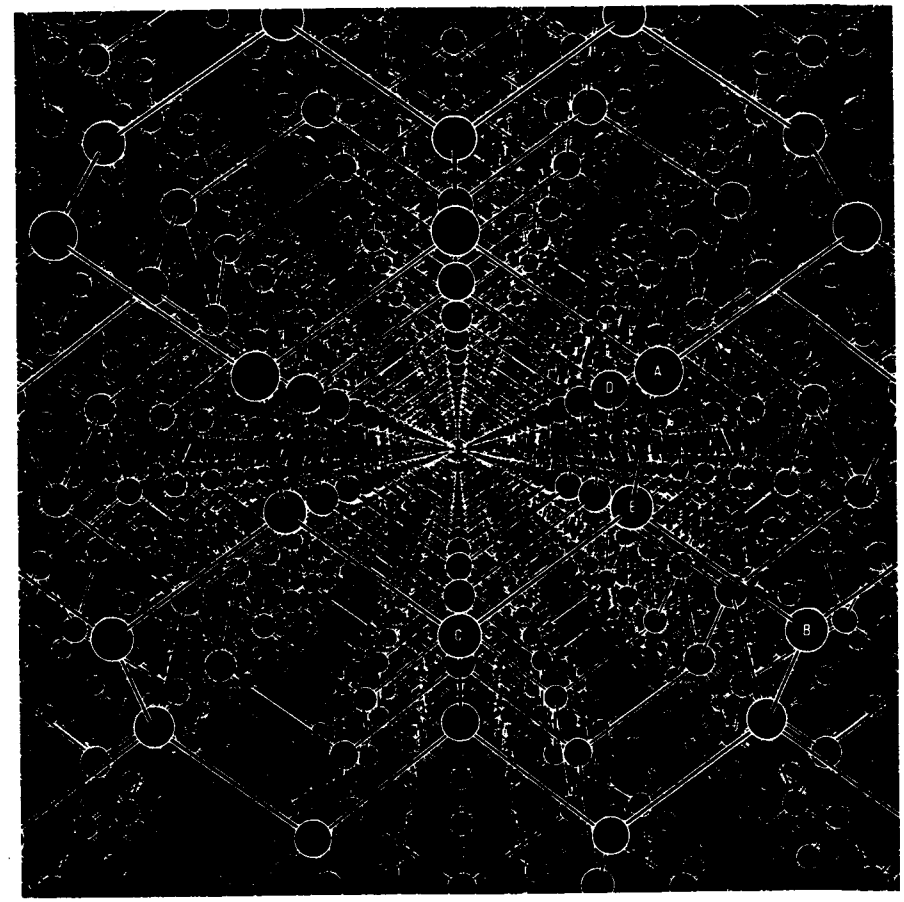
hydrogen atom

hydrogen bond

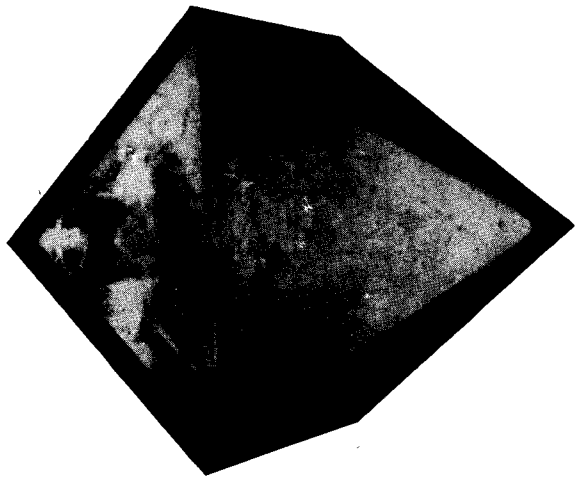
7 (a) The tetrahedral arrangement of carbon atoms in diamond.



(b) A worm's eye view of the giant structure in diamond.



8 A natural uncut diamond weighing 120g.



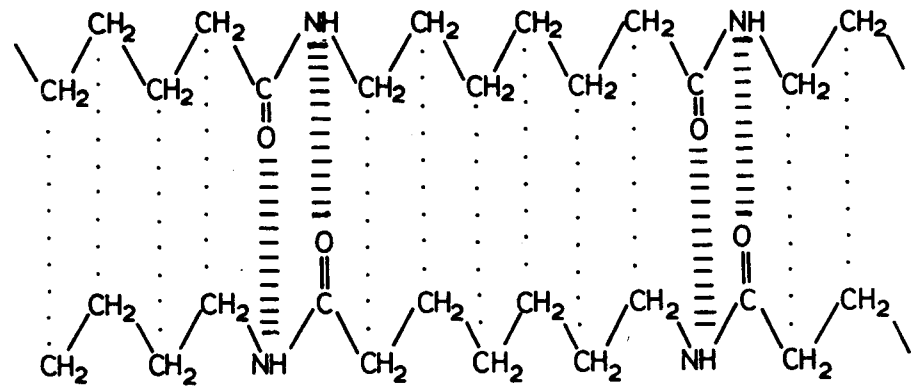
PROBLEM 1 How many atoms does this molecule contain?

9 A summary of the four main types of structure.

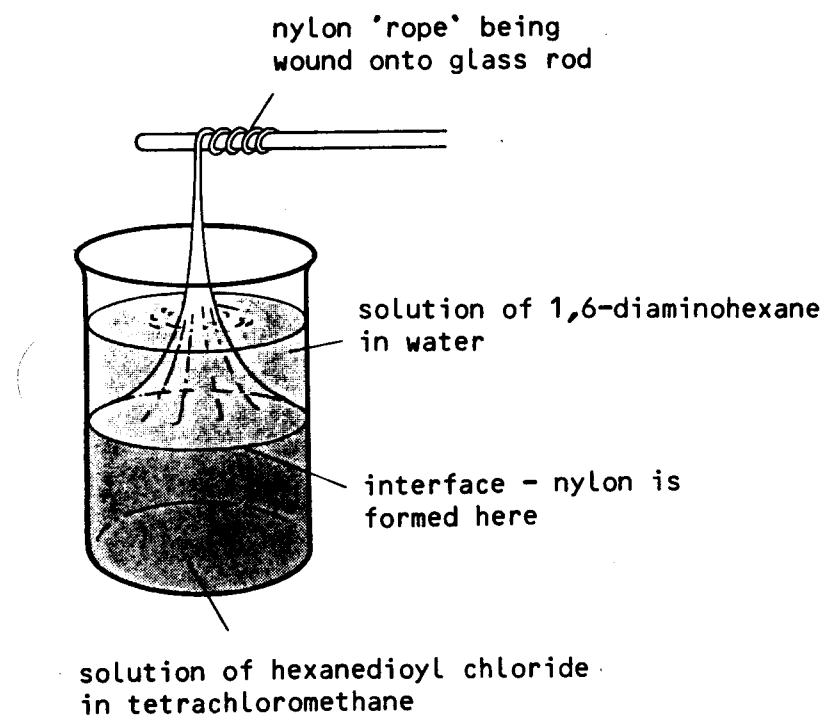
Type	Description	Examples	Hardness and/or malleability	Volatility	Conductivity (solid)	Conductivity (molten)
Giant metallic	Lattice of positive ions in a delocalised electron cloud.	copper, iron.				
Giant ionic	Regular lattice of positive and negative ions held by electrostatic attraction.	salt (NaCl) lime (CaO) limestone ($CaCO_3$) chalk ($CaCO_3$).				
Simple molecular	Small molecules. Atoms held within molecules by strong covalent bonds, but weak forces between molecules.	iodine, ice, sugar.				
Giant molecular	Large molecules containing thousands of atoms held together by strong covalent bonds.	diamond, sand.				

PROBLEM 2 Complete this table.

10 The molecular structure of nylon.



11 The 'nylon rope trick'.



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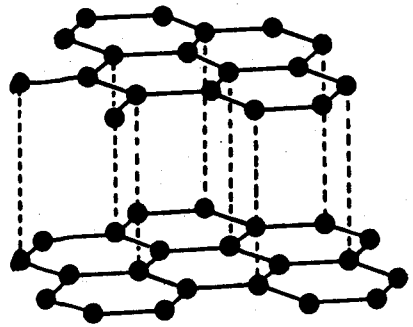
The structure of graphite.



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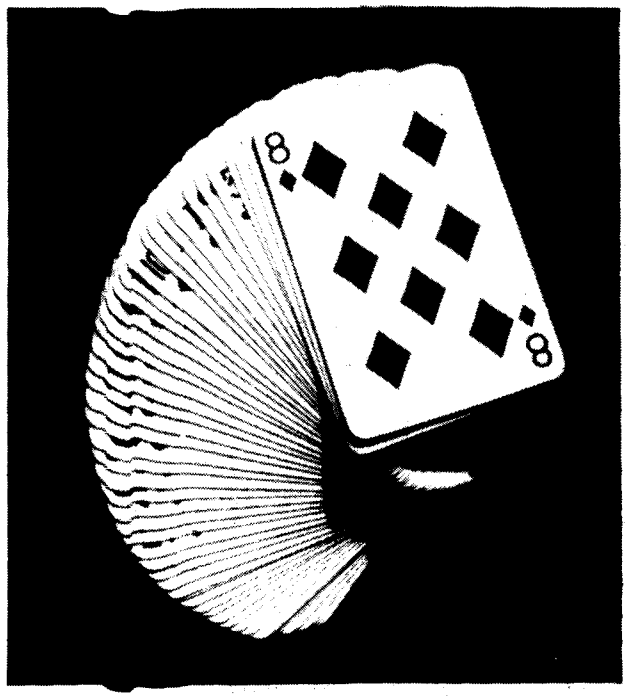
Playing cards slip over each other in the same way as graphite sheets slip.



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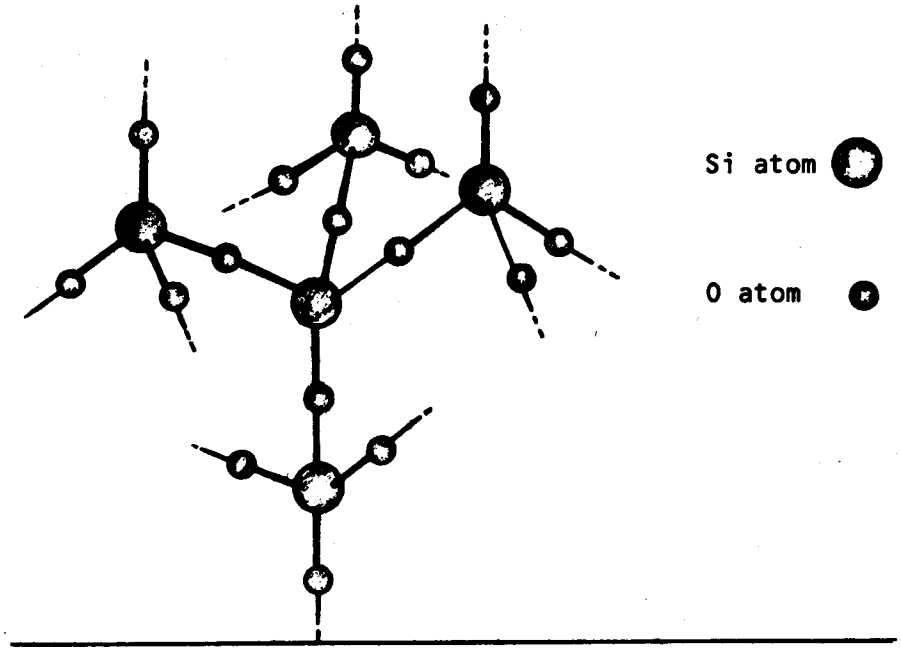
The structure of sand - silica, SiO_2



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PROBLEM 3 Classify these giant molecular structures as one-dimensional, two-dimensional or three-dimensional:

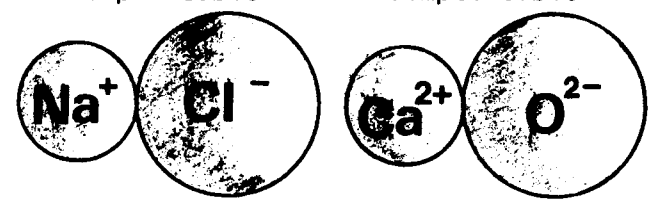
polyester
mica
keratin (hair protein)
carborundum (silicon carbide)
quartz

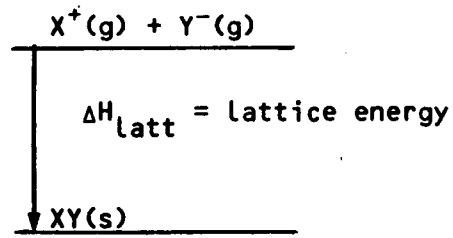
16 Important physical properties of materials.

- Volatility (melting, boiling, vaporization)
- Solubility (in water and other solvents)
- Conductivity (thermal and electrical)
- Hardness (including malleability)
- Density

17 Why does lime have a higher melting point than salt?

	SALT	LIME
Formula	Na^+Cl^-	$Ca^{2+}O^{2-}$
Melting point /°C	808	2600
Structure	Simple cubic	Simple cubic
Ionic radius /nm	0.095 0.181	0.099 0.140
Interionic distance /nm	0.267	0.239
Lattice energy /kJ mol^{-1}	-776	-3523





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PROBLEM 4 What other factors will affect the lattice energy besides the charge on an ion?

PROBLEM 5 Would you expect calcium oxide to have a higher or lower melting point than magnesium oxide? Explain your answer.

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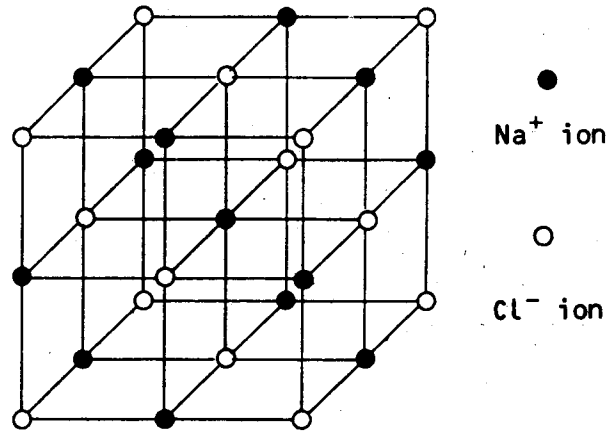
19 The arrangement of Na^+ and Cl^- ions in sodium chloride.



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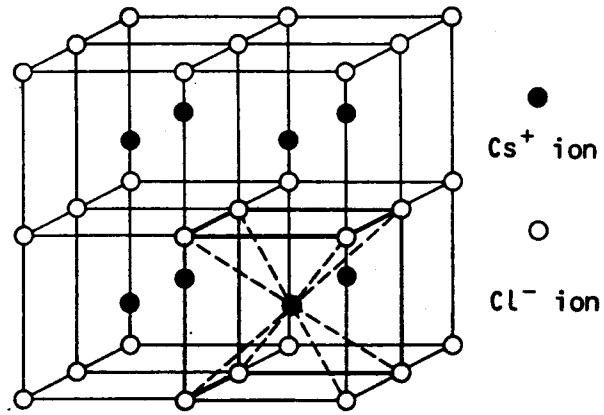
20 The arrangement of Cs^+ and Cl^- ions in caesium chloride.



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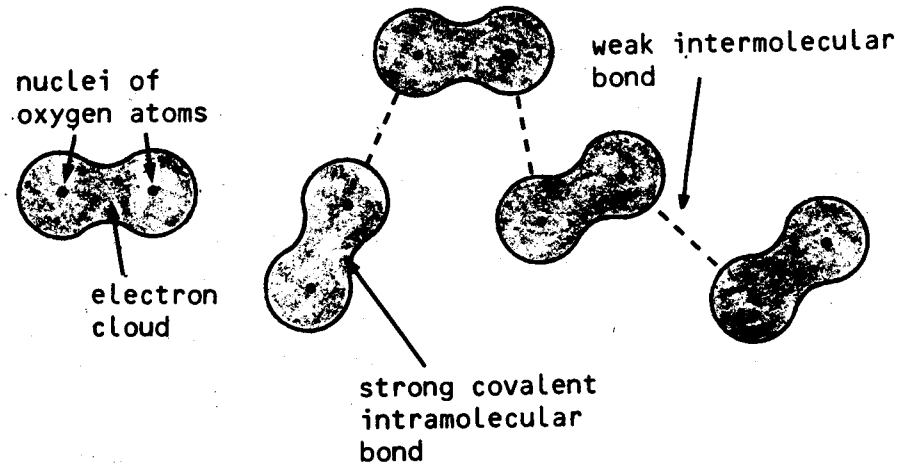
21 The relationship of co-ordination numbers in ionic crystals to radius ratio (r_+/r_-)

Radius ratio r_+/r_-	Co-ordination number predicted	Example
>0.73	8:8	caesium chloride, CsCl
between 0.73 and 0.41	6:6	sodium chloride, NaCl
<0.41	4:4	Zinc sulphide, ZnS

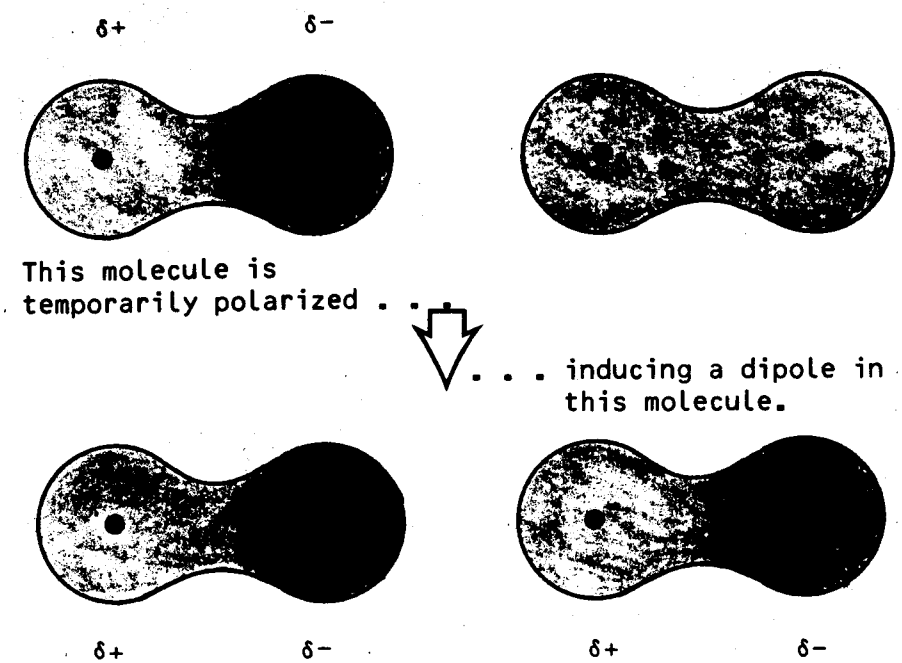
PROBLEM 6 Use the table above to predict the co-ordination numbers for:
(a) caesium iodide (b) rubidium iodide
(c) beryllium oxide.

Ionic radii/nm Be^{2+} 0.030 I^- 0.219
Cs^+ 0.167 O^{2-} 0.146
Rb^+ 0.148

22 Inter- and intramolecular bonding in oxygen, O_2.

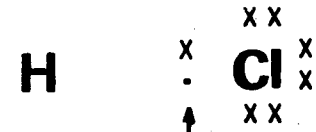


23 The origin of intermolecular forces in oxygen.



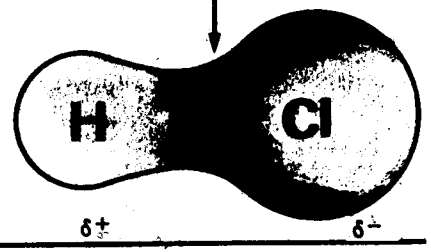
24 The permanent dipole in hydrogen chloride, HCl.

'dot-cross' representation

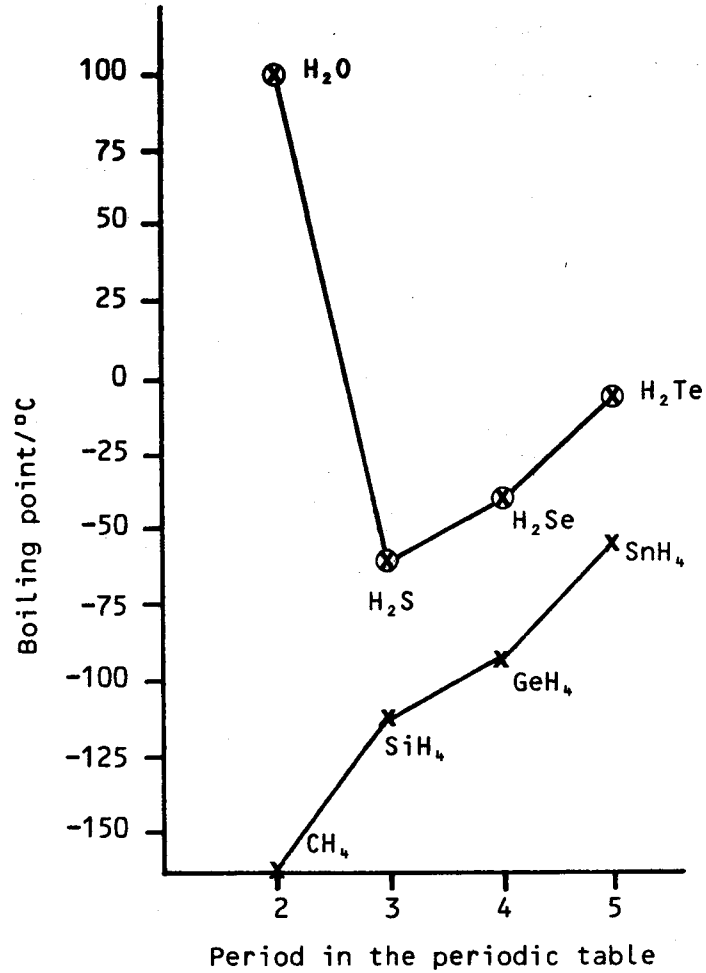


shared electrons nearer chlorine than hydrogen

'electron cloud' representation

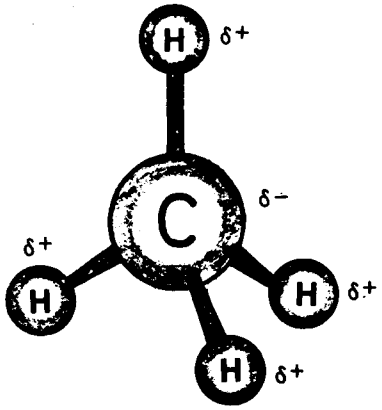


25 The boiling points of hydrides in Groups IV and VI of the periodic table.

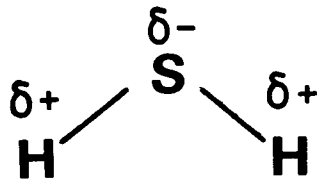


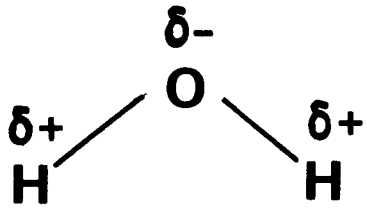
26 The methane molecule, CH_4.

Although there may be small dipoles in individual C-H bonds the symmetry of the molecule means that they cancel out, giving an overall non-polar molecule.

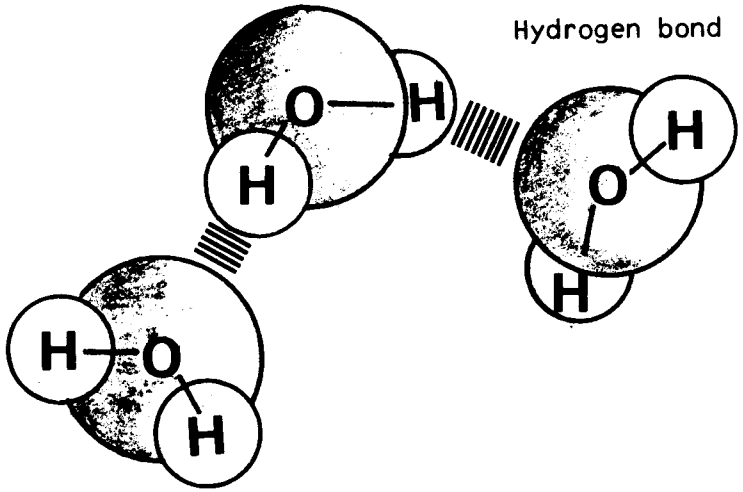


27 The permanent dipoles in molecules of hydrogen sulphide and water.





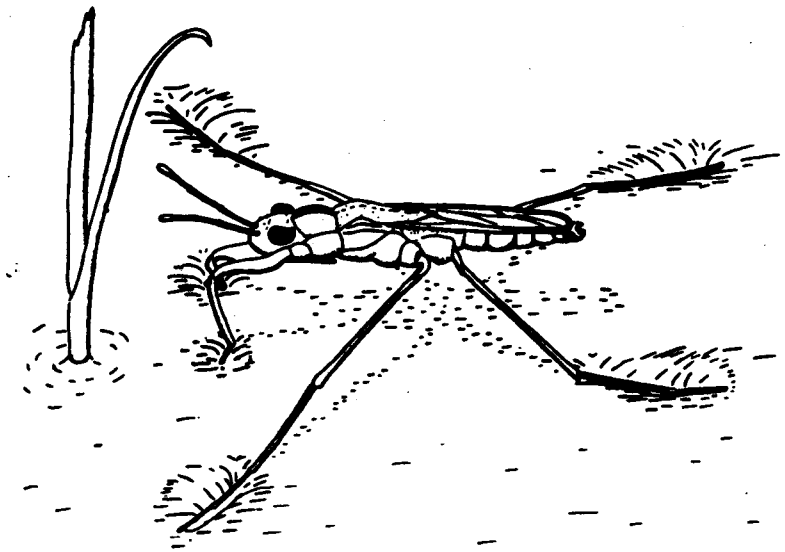
28 Hydrogen bonds between water molecules.



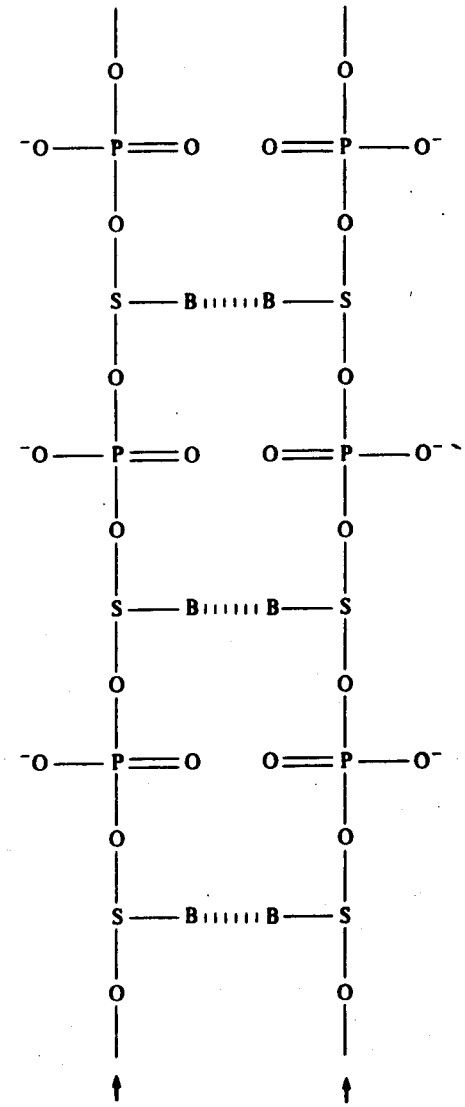
PROBLEM 7 Use the data given below to plot a graph, similar to the one on frame 25, for the hydrides of the elements in Group 5. Comment on the shape of your graph.

Boiling points/°C:
NH_3 −33; PH_3 −88; AsH_3 −55; SbH_3 −17.

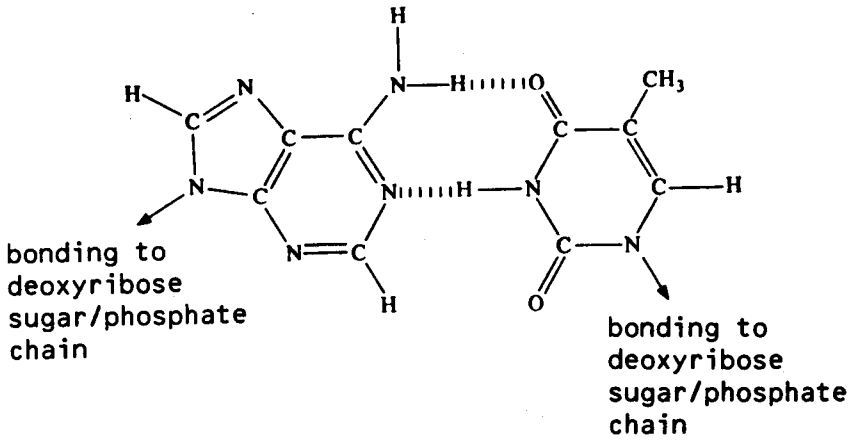
29 A water beetle skating on the surface of a pond.



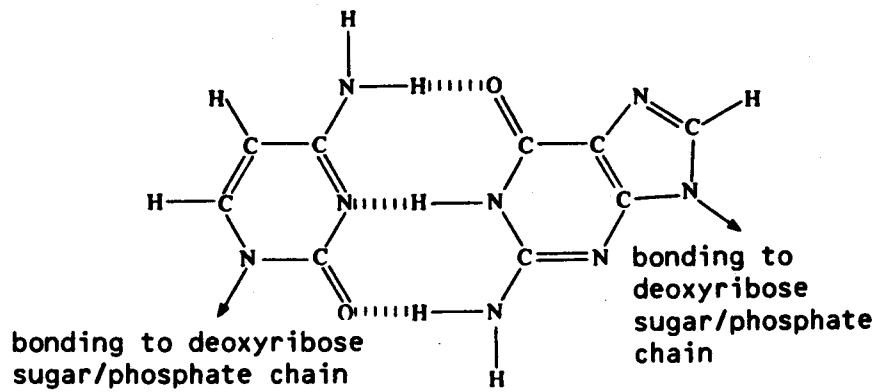
30 A simplified structure of DNA. S represents a sugar molecule; B represents an organic base.



31 Hydrogen-bonded base pairs in DNA

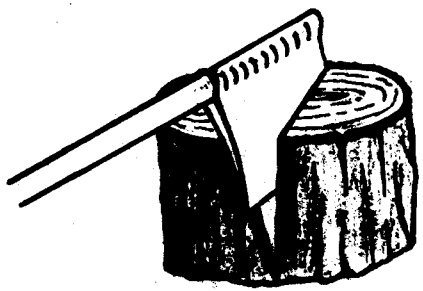


Adenine Thymine

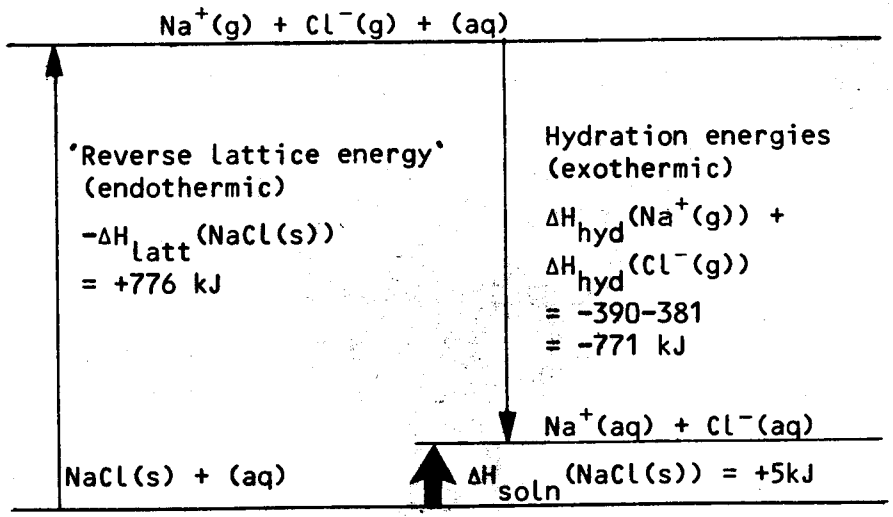


Cytosine Guanine

32 Splitting a log along the grain of the wood.



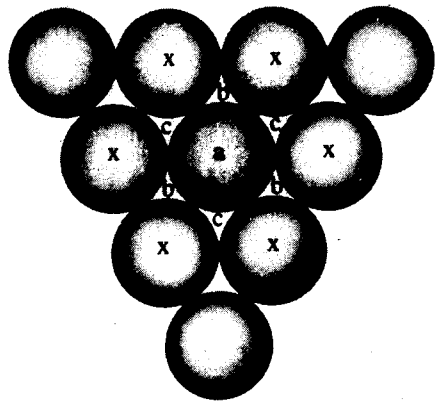
33 An energy cycle for the solubility of sodium chloride in water.



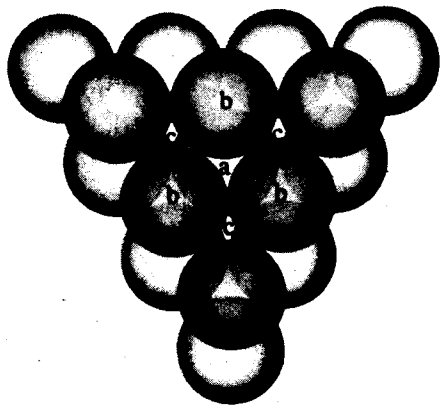
PROBLEM 8 Use the data below to calculate the heat of solution of potassium iodide.

Lattice energy of KI = -643 kJ mol^{-1}
Heat of hydration of K^+ = -305 kJ mol^{-1}
Heat of hydration of I^- = -307 kJ mol^{-1}

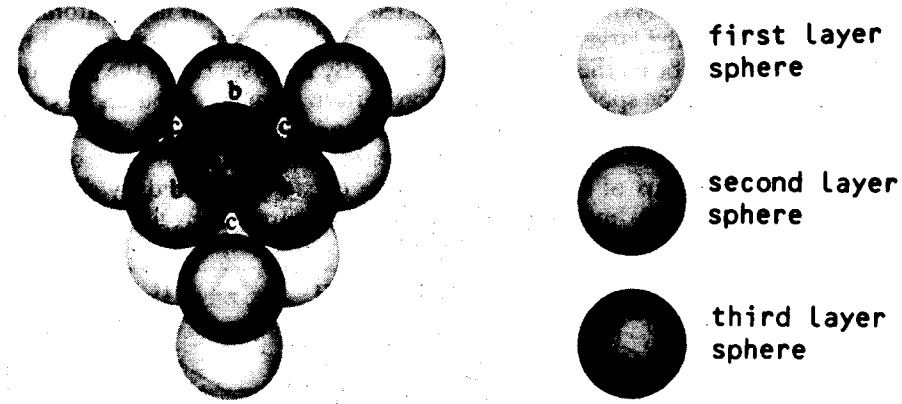
34 A layer of close-packed atoms.



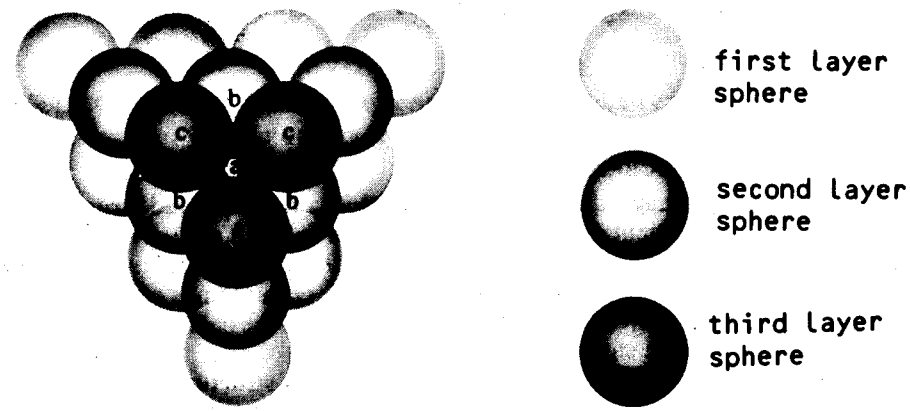
35 First and second layers of close-packed atoms.



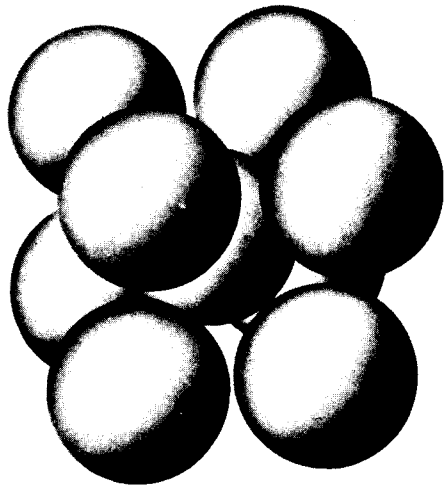
36 First, second and third layers of close-packed atoms - abababab arrangement.



37 First, second and third layers of close-packed atoms - abcabc arrangement.



38 The body-centred cubic metal structure.



39 The electron structures and conductivities of sodium, magnesium, aluminium and silicon.

	Na	Mg	Al	Si
Electron structure	2, 8, 1	2, 8, 2	2, 8, 3	2, 8, 4
Thermal conductivity /J cm^{-1} s^{-1} K^{-1}	1.34	1.6	2.1	0.84
Atomic electrical conductivity x 1000 /ohm^{-1} cm^{-4}	10	16	38	4

PROBLEM 9 Why does the electrical conductivity rise from sodium to magnesium to aluminium?

PROBLEM 10 Why is the electrical conductivity of silicon much lower than that of the three metals?

PROBLEM 11 Why does the thermal conductivity rise from sodium to magnesium and from magnesium to aluminium?

ANSWERS TO PROBLEMS

PROBLEM 1

Mass of diamond = 120 g

Number of atoms $= \frac{120}{12} \times 6 \times 10^{23}$

$= 6 \times 10^{24}$

PROBLEM 2

Type	Description	Examples	Hardness and/or malleability	Volatility	Conductivity (solid)	Conductivity (molten)
Giant metallic	Lattice of positive ions in a delocalised electron cloud.	copper, iron.	hard, malleable.	involatile.	good.	good.
Giant ionic	Regular lattice of positive and negative ions held by electrostatic attraction.	salt (NaCl) lime (CaO) limestone ($CaCO_3$) chalk ($CaCO_3$).	hard, brittle.	involatile.	very poor.	good.
Simple molecular	Small molecules. Atoms held within molecules by strong covalent bonds, but weak forces between molecules.	iodine, ice, sugar.	soft.	volatile.	very poor.	very poor.
Giant molecular	Large molecules containing thousands of atoms held together by strong covalent bonds.	diamond, sand.	very hard.	very involatile.	very poor.	very poor.

PROBLEM 3

polyester	1-dimensional
mica	2-dimensional
keratin	1-dimensional
carborundum	3-dimensional
quartz	3-dimensional

PROBLEM 4

The size of the ion and the way the ions are packed.

PROBLEM 5

Calcium oxide has a lower melting point (2600°C) than magnesium oxide (2900°C). Although both Mg^{2+} and Ca^{2+} have the same charge, the smaller Mg^{2+} ion can get closer to the O^{2-} ion, leading to a stronger bond.

PROBLEM 6

Compound	Radius ratio r_+/r_-	Predicted co-ordination
CsI	0.76	8:8
RbI	0.68	6:6
BeO	0.21	4:4

PROBLEM 7

The graph shows that ammonia has a higher boiling point than expected on the basis of the trend shown by the other three compounds. This reflects the hydrogen bonding in ammonia.

PROBLEM 8

$$\Delta H_{soln} = -(\Delta H_{latt}) + \Delta H_{hyd}(K^+) + \Delta H_{hyd}(I^-)$$
$$= +643 \quad -305 \quad -307$$
$$= +31 \text{ kJ mol}^{-1}$$

PROBLEM 9

Electrical conductivity in metals is related to mobile electrons. Since the outermost electrons are the most mobile, electrical conductivity rises from Na to Mg to Al because they have 1, 2 and 3 outermost electrons respectively.

PROBLEM 10

The outermost electrons of silicon are localized in covalent bonds and therefore are not free to move. (However, under certain conditions silicon can behave as a semi-conductor.)

PROBLEM 11

Heat is transferred through metals by the thermal motion of mobile electrons. The thermal conductivity therefore rises in this way for the same reason as the electrical conductivity (Problem 9).