4.2 BONDING AND STRUCTURE

Learning outcomes

Candidates should be able to:

1. describe, in simple terms, the lattice structure of a crystalline solid which is:
(a) giant ionic, including sodium chloride and magnesium oxide
(b) simple molecular, including iodine, buckminsterfullerene C_{60} and ice
(c) giant molecular, including silicon(IV) oxide, graphite and diamond
(d) giant metallic, including copper
2. describe, interpret and predict the effect of different types of structure and bonding on the physical properties of substances, including melting point, boiling point, electrical conductivity and solubility
3. deduce the type of structure and bonding present in a substance from given information

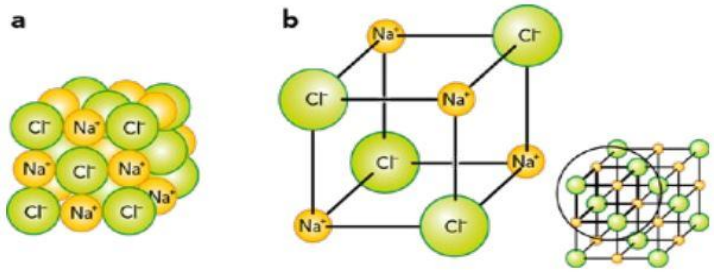
Introduction

Many ionic, metallic and covalent compounds are crystalline. The regular structure of crystals is due to the regular packing of the particles within the crystal. We call this regularly repeating arrangement of ions, atoms or molecules a **crystal lattice**.

Ionic lattices

Ionic lattices have three-dimensional arrangements of alternating positive and negative ions. Compounds with ionic lattices are sometimes called giant ionic structures.

The ionic lattices for sodium chloride are cubic. In sodium chloride, each sodium ion is surrounded by six oppositely charged chloride ions. The chloride ions are much larger than the sodium ions. The sodium ions fit into the spaces between the chloride ions so that they are as close as possible to them.

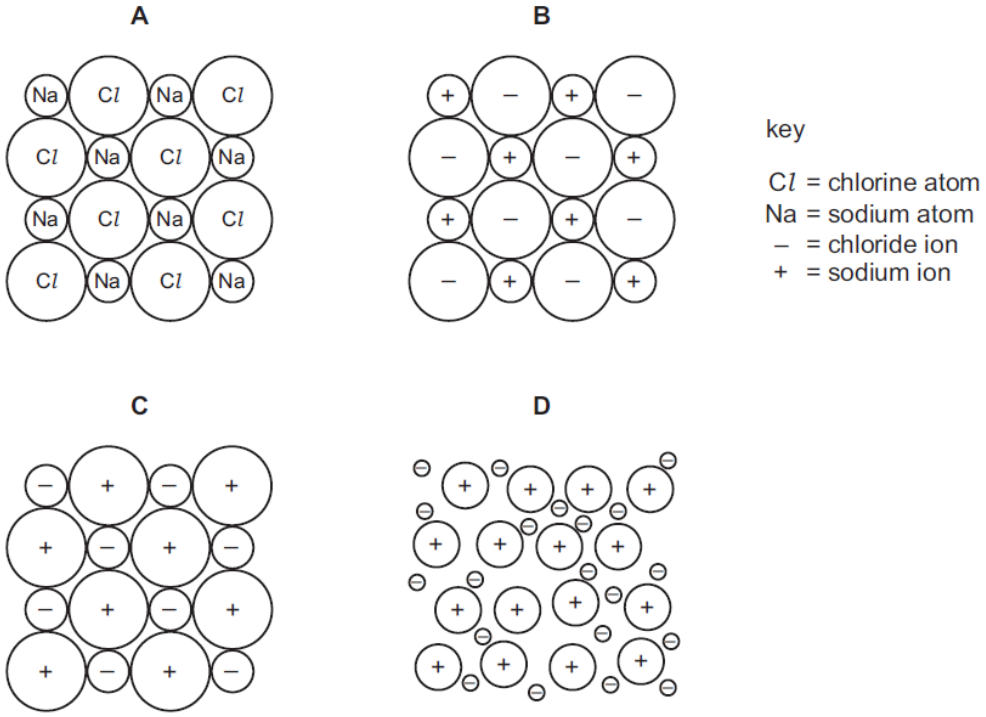


Magnesium oxide has the same lattice structure as sodium chloride. Magnesium ions replace sodium ions and the oxide ions replace the chloride ions.

The properties of ionic compounds reflect their structure as well as their bonding

- They are hard.
- They are brittle.
- They have high melting points and high boiling points.
- Many ionic compounds are soluble in water because they can form ion–dipole bonds.
- They only conduct electricity when molten or in solution.

1. Which diagram represents the lattice structure of sodium chloride?



1. Lithium sulfide, Li_2S, is a crystalline solid with a melting point of 938 ° C. It conducts electricity when it is molten.
   (i) Give the formulae of the particles present in solid lithium sulfide. [1]

   (ii) Explain, in terms of the structure of the crystalline solid, why lithium sulfide has a high melting point. [2]

2. Radium, Ra, is an element found in Group 2 of the Periodic Table. It is a crystalline solid at room temperature and conducts electricity.
   Radium chloride, $RaCl_2$, has a melting point of 900°C and is soluble in water.
   Predict the lattice structure of $RaCl_2(s)$ based on the properties described.[1]

3. Some of the common chlorides of Period 3 elements are shown in the list.

   NaCl $MgCl_2$ $AlCl_3$ $SiCl_4$ PCl_5

   From this list, identify all the chlorides that have giant ionic structures in the solid state [1]

4. Complete the following table with information for sodium chloride and phosphorus (V) chloride.

	sodium chloride	phosphorus(V) chloride
state at room temp		

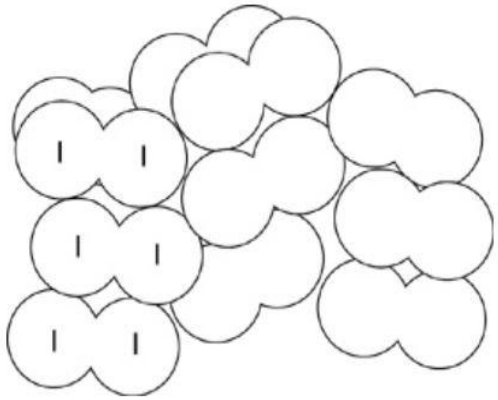
5. Bi_2O_3 is a yellow, insoluble solid that melts at 1090 K. The molten compound conducts electricity. Deduce the structure and bonding of Bi_2O_3. Explain your answer. [2]

2. In the sodium chloride lattice the number of chloride ions that surround each sodium ion is called the coordination number of the sodium ions.
What are the coordination numbers of the sodium ions and the chloride ions in the sodium chloride lattice?

	coordination number of chloride ions	coordination number of sodium ions
A	4	6
B	6	4
C	6	6
D	8	6

Simple molecular lattices

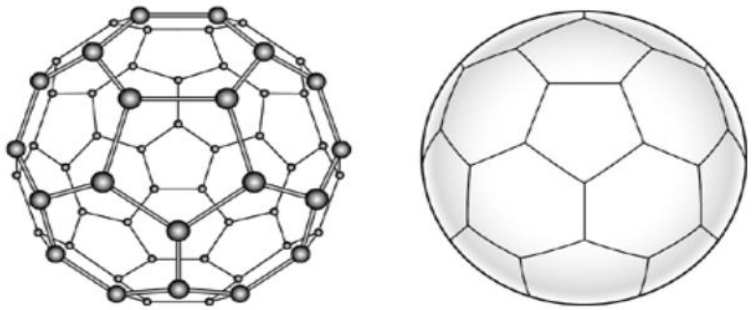
Substances with a simple molecular structure, such as **iodine**, can also form crystals. This reflects the regular packing of the molecules in a lattice structure.



The distance between the nuclei of neighbouring iodine molecules is greater than the distance between the nuclei within the iodine molecule. This is because the forces between the molecules are weak intermolecular forces, whereas the forces between the atoms within the molecule are strong covalent
bonds. Very little energy is needed to overcome the weak intermolecular forces between the molecules.
The lattice is easily broken down when iodine crystals are heated, so iodine has a low melting point. Iodine is a volatile substance too.

Ice also forms a crystalline lattice.

Buckminsterfullerene (C_{60}) is a simple molecular structure. The C_{60} molecule has the shape of a football. The carbon atoms are arranged at the corners of 20 hexagons and 12 pentagons.



6. PCl$_5$, PCl$_3$ and NCl$_3$ are halides of Group 15 elements.
PCl$_5$ can be formed from the reaction of phosphorus with chlorine. PCl$_5$ has a melting point of 161 °C.
State the type of structure and bonding shown by liquid PCl_5. [1]

7. POCl$_3$ shows similar chemical properties to PCl$_5$.
POCl$_3$ has a melting point of 1°C and a boiling point of 106°C.
POCl$_3$ reacts vigorously with water, forming misty fumes and an acidic solution.
Explain how this information suggests the structure and bonding of POCl$_3$ is simple covalent. [2]

Giant structure: have network of either covalent bonds (molecular giant structures), metallic bonds (metallic giant structures) or ionic bonds (ionic giant structures). The network of strong bonds is hard to break and so the melting and boiling points of these structures are generally very high.

Giant molecular structures

Some covalently bonded structures have a three-dimensional network of covalent bonds throughout the whole structure. We call these structures **giant molecular structures** or **giant covalent structures**.

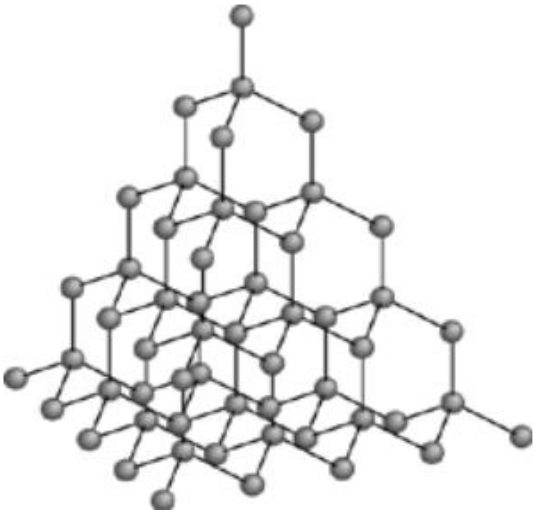
Diamond

In diamond, each carbon atom forms four covalent bonds with other carbon atoms.

The carbon atoms are positioned around each other in a tetrahedral arrangement. The network of carbon atoms extends almost unbroken throughout the whole structure. The regular arrangement of the atoms gives diamond a crystalline structure.

Properties of diamond

- High melting and boiling points
- Hardness
- Does not conduct electricity



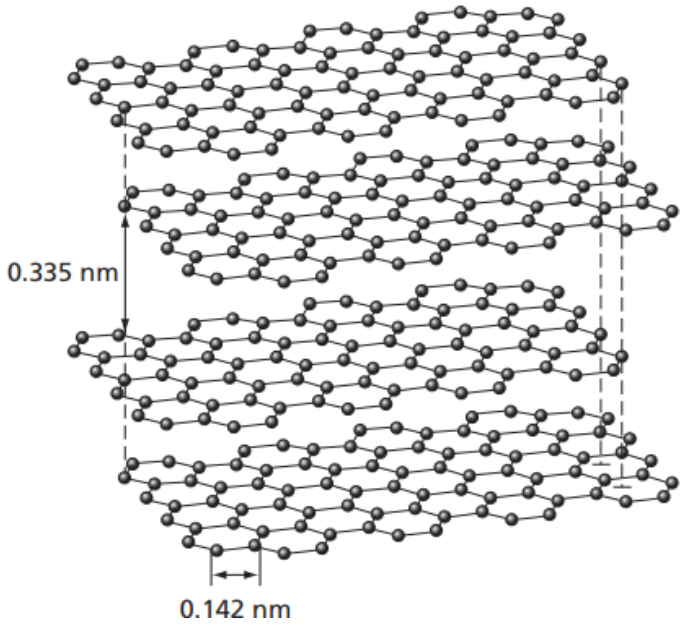
Graphite

In graphite, the carbon atoms are arranged in planar layers. Within the layers, the carbon atoms are arranged in hexagons. Each carbon atom is joined to three other carbon atoms by strong covalent bonds. The fourth electron of each carbon atom occupies a p orbital. These p orbitals on every carbon atom in each planar layer overlap sideways. A cloud of delocalised electrons is formed above and below the plane of the carbon rings. These electron clouds join up to form extended delocalised rings of electrons.

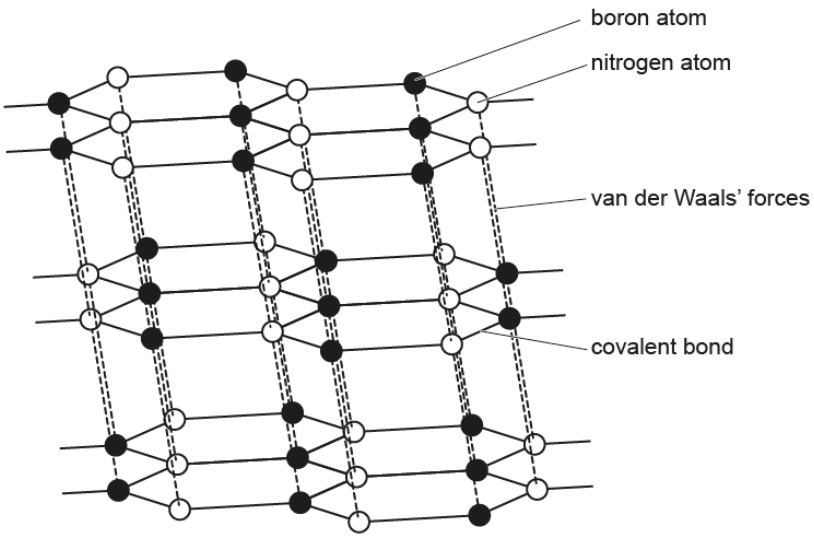
The layers of carbon atoms are kept next to each other by weak instantaneous dipole-induced dipole forces.

Properties of graphite

- High melting and boiling points
- Softness
- Good conductor of electricity



8. Boron nitride is a white solid that melts above 2900 °C.
The following figure shows part of the lattice structure of a crystal of boron nitride.



(i) Use the above figure to deduce the empirical formula of boron nitride. [1]

(ii) Suggest the identity of another crystalline solid that has atoms arranged in layers similar to that of solid boron nitride. [1]

9. Diamond and graphite are both crystalline solids made from carbon atoms. Graphite conducts electricity. Diamond does not conduct electricity.
(i) Name the type of lattice structure present in the crystalline solids diamond and graphite.

..... [1]

(ii) Explain how graphite conducts electricity.

.....

..... [1]

(iii) Explain why diamond does not conduct electricity.

.....

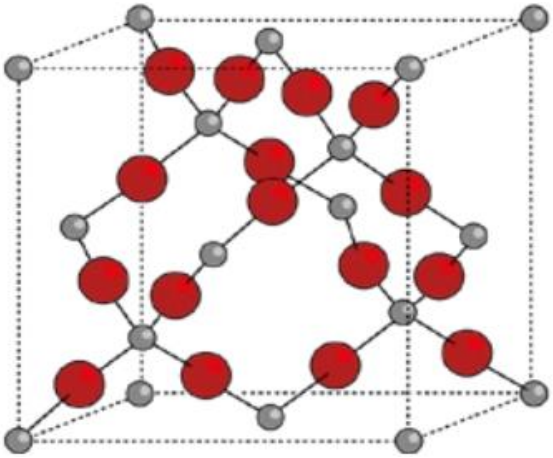
..... [1]

3. In which carbon allotrope are all electrons localised?

A buckminsterfullerene
B diamond
C graphite
D graphene

Silicon(IV) oxide

There are several forms of silicon(IV) oxide. The silicon(IV) oxide found in the mineral quartz has a structure similar to diamond.



Each silicon atom is bonded to four oxygen atoms but each oxygen atom is bonded to only two silicon atoms. So the formula for silicon(IV) oxide is SiO_2. Silicon dioxide has properties similar to that of diamond.
It forms hard, colourless crystals with high melting and boiling points and it does not conduct electricity.
Sand is largely silicon(IV) oxide.

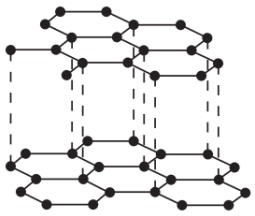
Most giant molecular structures do not conduct electricity. One exception is graphite.
Most do not conduct heat but diamond is a good conductor of heat.

Allotropes are different crystalline forms of the same elements. The term only applies to solids. E.g, diamond, graphite and buckminsterfullerene are allotropes of carbon.

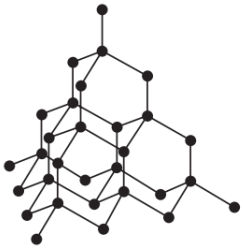
10. Describe the lattice structure of silicon(IV) oxide.
Your answer should include reference to the arrangement of the silicon and oxygen atoms and the bonds between them. [2]

4. P, Q and R represent three different structures of an element.

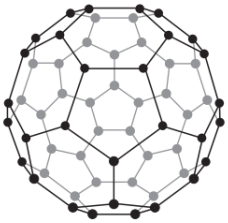
P



Q



R



Which structures are giant molecular?

A P, Q and R **B** P and Q only **C** P and R only **D** Q and R only

5. Which oxide has a simple structure rather than a giant structure?

A MgO B Al_2O_3 C SiO_2 D P_4O_{10}

6. Which statement explains why buckminsterfullerene has a lower melting point than graphite?

A Buckminsterfullerene exists as discrete molecules with weak intermolecular bonding.
B Graphite is partly ionic as its structure contains mobile electrons and it conducts electricity.
C The carbon–carbon bonds in buckminsterfullerene are shorter and more strained.
D The mobile electrons in graphite mean it has a metallic structure.

7. The table shows properties of four solids held together by different types of bonding.
Which row correctly describes the properties of a solid with a giant covalent structure?

	melting point	solubility in polar solvents
A	high	insoluble
B	high	soluble
C	low	insoluble
D	low	soluble

8. The table shows the physical properties of four substances.
Which substance has a giant covalent structure?

	melting point / °C	boiling point / °C	electrical conductivity of solid	electrical conductivity of liquid	electrical conductivity of aqueous solution
A	–119	39	poor	poor	insoluble
B	–115	–85	poor	poor	good
C	993	1695	poor	good	good
D	1160	2230	poor	poor	insoluble

9. Diamond, graphite and buckminsterfullerene are different forms of the element carbon.
Which statement is correct for all three substances?

A Bond angles of 120° are present.
B Delocalised electrons are present.
C Giant molecular crystalline lattice structures are present.
D σ bonds are present.

10. Solid carbon dioxide, CO_2, is similar to solid iodine, I_2, in its structure.
Which statement about solid CO_2 and solid SiO_2 is correct?

A Both solid CO_2 and solid SiO_2 exist in a lattice structure.
B Both solid CO_2 and solid SiO_2 have a simple molecular structure.
C Both solid CO_2 and solid SiO_2 have atoms joined by single covalent bonds.
D Both solid CO_2 and solid SiO_2 change spontaneously to gas at s.t.p.

11. Carbon and silicon are elements in Group 14.
(i) Describe in simple terms the structure of solid C_{60}. [2]

(ii) C_{60} sublimes (turns directly from solid to gas) at approximately 800 K.
$C_{60}(s) \rightarrow C_{60}(g)$
Diamond also sublimes, but only above 3800 K.
$C_{diamond}(s) \rightarrow C(g)$
Explain why C_{60} and diamond sublime at such different temperatures. [4]

11. In the structure of solid SiO_2
each silicon atom is bonded to x oxygen atoms
each oxygen atom is bonded to y silicon atoms
each bond is a z type bond.

What is the correct combination of x, y and z in these statements?

	x	y	z
A	2	1	covalent
B	2	1	ionic
C	4	2	covalent
D	4	2	ionic

12. In which substance are covalent bonds broken as it melts?

A silicon(IV) oxide B ice C iodine D ethanol

13. Consider the following statements.

1 Silicon dioxide has a higher melting point than sulfur dioxide.
2 Ammonia has a higher boiling point than phosphine, PH_3.

Which statements are correct?

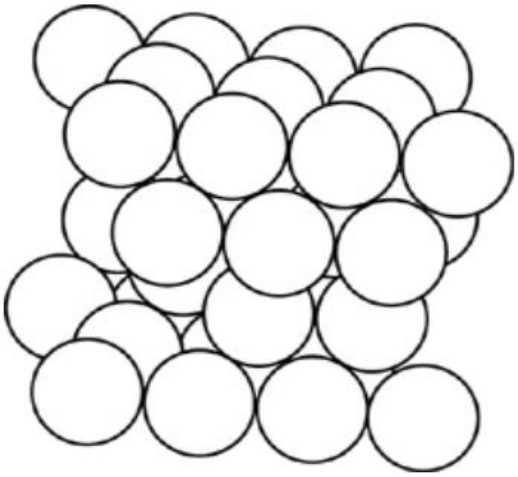
A both statement 1 and statement 2
B statement 1 only
C statement 2 only
D neither statement 1 nor statement 2

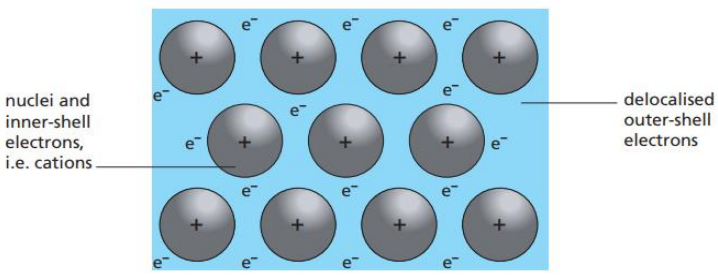
14. Which row describes silicon dioxide?

	Electrical conductivity in liquid state	solubility in water
A	non-conductor	Insoluble
B	non-conductor	Soluble
C	conductor	Insoluble
D	conductor	Soluble

Metallic lattices

The ions are often packed in hexagonal layers or in a cubic arrangement.
Following figure shows part of a lattice of copper ions arranged in layers.





When a force is applied, the layers can slide over each other. But in a metallic bond, the attractive forces between the metal ions and the delocalised electrons act in all directions. So, when the layers slide, new metallic bonds are easily re-formed between ions in new lattice positions and the delocalised electrons. The delocalised electrons continue to hold the ions in the lattice together. The metal now has a different shape. This explains why metals are malleable and ductile.

12. Magnesium has a melting point of 650°C and high electrical conductivity.
Explain these properties of magnesium by referring to its structure and bonding. [2]

13. Copper has a melting point of 1085°C and a high electrical conductivity.
Explain these properties of copper by referring to its structure and bonding. [2]

14. 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		

15. The melting points of some solids are shown in the following table.

solid	melting point/K
magnesium	923
phosphorus	317
sodium chloride	1074
sulfur	392

(i) State the type of bonding present in magnesium and in sodium chloride.

bonding in magnesium .....

bonding in sodium chloride.....[1]

(ii) Explain the difference in the melting points of magnesium and sodium chloride. [1]

(iii) Explain the difference in the melting points of phosphorus and sulfur in terms of structure and bonding. [2]

16. The strength of interaction between particles determines whether the substance is a solid, liquid or gas at room temperature.
(a) Lithium sulfide, Li_2S, is a crystalline solid with a melting point of 938°C. It conducts electricity when it is molten.
(i) Give the formulae of the particles present in solid lithium sulfide. [1]

(ii) Explain, in terms of the structure of the crystalline solid, why lithium sulfide has a high melting point. [2]

17. Boron carbide is a hard crystalline solid that has a melting point greater than 2000 °C.
Suggest the structure and bonding in boron carbide. [1]

18. Silicon reacts with nitrogen gas to form Si_3N_4.
Si_3N_4 is a solid with a melting point of 1900 °C. It is insoluble in water and does not conduct electricity when molten.
Suggest the type of bonding in and structure of Si_3N_4. Explain your answer. [3]

15. Information about two substances is given.

Substance	electrical conductivity	effect of adding to water	melting point / K
P	good when solid and when molten	reacts vigorously to produce an alkaline solution	454
Q	does not conduct in any state	reacts vigorously to produce an acidic solution	317

Which row describes the structure and bonding in substances P and Q?

	P	Q
A	giant metallic	simple molecular
B	simple molecular	giant metallic
C	giant ionic	simple molecular
D	giant metallic	giant ionic

16. The table shows physical properties of four substances, W, X, Y and Z.

	melting point / °C	boiling point / °C	electrical conductivity of solid	electrical conductivity of liquid	electrical conductivity in water
W	993	1695	poor	good	good
X	–119	39	poor	poor	insoluble
Y	1535	2750	good	good	insoluble
Z	1610	2230	poor	poor	insoluble

What are the identities of W, X, Y and Z?

	W	X	Y	Z
A	MgO	C_2H_5Br	Fe	Al_2O_3
B	MgO	HCl	K	Al_2O_3
C	NaF	C_2H_5Br	Fe	SiO_2
D	NaF	HCl	K	SiO_2

17. Below are four solids. Which of these contain more than one kind of bonding?

a. Diamond b. sodium chloride c. ice d. iron

18. Which type of bonding is **never** found in elements?

A covalent **B** ionic **C** metallic **D** van der Waals' forces

19. Which solid has a simple molecular lattice?

A calcium fluoride **B** nickel **C** silicon(IV) oxide **D** sulfur

20. The element tin exists in two forms, grey tin and white tin.
Some properties of grey tin and white tin are shown.

	grey tin	white tin
boiling point / K	2543	2533
electrical conductivity	none in solid or liquid	good in solid and liquid
malleability	brittle	malleable

Which structural change might take place when grey tin changes to white tin?

A giant covalent to giant ionic
B giant covalent to giant metallic
C giant ionic to giant covalent
D giant ionic to giant metallic

19. Element E is a Period 5 element. E reacts with oxygen to form an insoluble white oxide that has a melting point of 1910°C. The oxide of E conducts electricity only when liquid.
E also reacts readily with $Cl_2(g)$ to form a white solid that reacts exothermically with water. The resulting solution reacts with aqueous silver nitrate to form a white precipitate that dissolves in dilute ammonia.
(i) Suggest the type of bonding shown by the oxide of E. Explain your answer. [2]

(ii) Suggest the type of bonding shown by the chloride of E. Explain your answer. [2]

20. Solid sodium conducts electricity. Sodium oxide conducts electricity when molten but not when solid.
(i) Name the type of bonding present in sodium and in sodium oxide.

bonding in sodium .....

bonding in sodium oxide ..... [1]

(ii) Explain how solid sodium conducts electricity.

.....

..... [1]

(iii) Explain why sodium oxide conducts electricity when molten.

.....

……..... [1]

*****This is not a complete note. It is to guide you. It is recommended to study the prescribed textbooks along with this material. *****