Chem Factsheet

Number 162

How to Answer Questions about Structure and Bonding

You need to know and understand all related ideas before you can gain maximum credit when answering exam questions on any particular topic. To help you, there follow two summary flow-charts on the essential ideas under the topic heading, "structure and bonding". However, applying these correctly to exam questions is really what this FactSheet is about. After studying this FactSheet you should be able to pick up a few more marks – or a lot!

Summary of bonding classification

BONDING
(how particles of a substance are joined to each other to produce various types of structure)

COVALENT
(the electrostatic attraction between the positive nuclei of a pair atoms and the negative charge density of shared electrons between the atoms)

These strong bonds hold atoms together - either in molecules or in giant atomic structures of non-metal elements and non-metal/non-metal compounds

Strength of covalent bonds explains the very high melting and boiling points of giant atomic structures but does NOT influence the melting and boiling points of molecular substances

IONIC
(the electrostatic attraction between oppositely charged ions usually formed by electron transfer from metal to non-metal)

These strong bonds hold oppositely charged ions (metal cations and non-metal anions) together in metal/ non-metal compounds with giant ionic structures

Strength of ionic bonding explains the high melting and boiling points of compounds with giant ionic structures

METALLIC
(the electrostatic attraction between fixed cations and a mobile 'sea' of delocalised electrons between the cations)

These strong bonds hold cations to delocalised electrons in all metallic elements

Strength of metallic bonding explains the high melting and boiling points of most metals with giant metallic structures

INTERMOLECULAR FORCES
(weak electrostatic attractions between molecules)

VAN DER WAAL'S FORCES
(transient dipole-induced dipole attractions arising from momentary uneven electron distributions)

and DIPOLE-DIPOLE ATTRACTIONS
(electrostatic attractions between molecules with permanent dipoles)

or HYDROGEN BONDS
(electrostatic attraction between a δ+ hydrogen atom on one molecule and a lone pair on a δ- fluorine, oxygen or nitrogen atom on an adjacent molecule)

DATIVE / COORDINATE BOND
A covalent bond where both shared electrons are provide from a lone pair on just one of the bonded atoms

Remember, "bonding and structure" go hand in hand but structure is the result of bonding and not vice-versa. More importantly, both are designed and used to explain the variations in observable properties of substances – high or low melting points, high or low electrical conductivities etc.

The sample questions that follow are taken from past AS and A2 exam papers from a variety of exam boards. In each case the question is accompanied by the examiner's mark scheme and some comments on its interpretation and application as an aid to your understanding of what a question is after and how best to structure your answers. In each case the actual question is in italics. **Underlining is used in the mark scheme extracts to indicate the keywords/phrases required for the mark.**

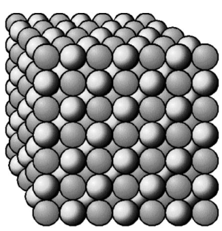
Summary of structure classification

STRUCTURE
(the way in which the particles of a substance are arranged relative to each other)

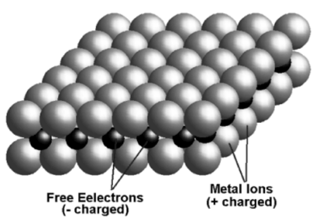
GIANT
(a continuous 3D lattice of particles)

MOLECULAR
(small groups of atoms joined by covalent bonds into discrete particles - molecules)

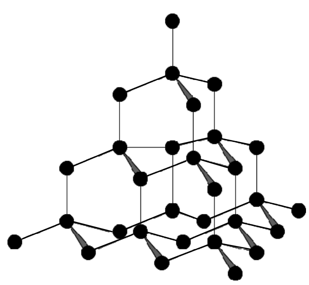
IONIC	METALLIC	ATOMIC	MOLECULAR
(alternating, oppositely charged ions held by the electrostatic attraction between them - ionic bonding)	(metal cations in a 'sea' of mobile, delocalised electrons held by the electrostatic attraction between the cations and the negatively charged electrons between them)	(atoms joined by covalent bonds in a continuous lattice)	
Typical of most compounds of a metal combined with a non-metal.	Typical of all metallic elements.	Only found in diamond, graphite, silicon and silicon dioxide.	Typical of most non-metal elements and most compounds of non-metals combined with other non-metals (plus a few metal plus non-metal compounds
• High melting and boiling points - as ionic bonding is a strong force • Non-conductors when solid - as no mobile charged particles • Conduct when molten or aqueous (as ions are free to move) and are decomposed by the current - electrolysis.	• Good conductors - due to mobile electrons • Generally high melting and boiling points - as metallic bonding is a strong force * Malleable and ductile - as metallic bonding allows rows of cations to slide over each other.	• High melting and boiling points - as covalent bonds are strong forces • Non-conductors - as no mobile charged particles - except for graphite which has mobile, delocalised electrons between layers of carbon atoms.	• Low melting and boiling points - as intermolecular forces are weak • Non-conductors - as no mobile charged particles • Brittle when solid.



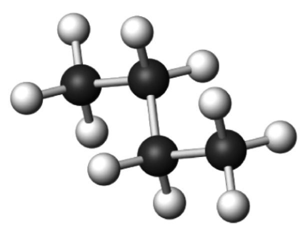
A typical giant ionic structure - sodium chloride



A typical giant metallic structure



A typical giant covalent structure - diamond



A typical molecular structure - butane

Typical Exam Questions

Table 1 shows the electronegativity values of four different elements

Table 1

	H	C	N	O
Electronegativity	2.1	2.5	3.0	3.5

1. (a) State the meaning of the term electronegativity (2 marks)

It's typical for a definition such as this to be worth two marks – in this case they are earned for:

1. The ability/tendency/power of an atom to attract/ withdraw electron density/a pair of electrons
2. From a covalent bond/shared pair of electrons

(b) State the strongest type of intermolecular force in methane (CH_4) and in ammonia (NH_3) (2 marks)

The fact that the question refers to 'intermolecular forces' immediately narrows each answer down to three possibilities; namely van der Waal's forces, dipole-dipole attractions or hydrogen bonds.

If you didn't remember that methane is non-polar, the similarity between the electronegativity values for carbon and hydrogen should remind you that this is the case, which means that only van der Waal's forces are possible for methane.

The much larger difference in electronegativity between nitrogen and hydrogen should help to remind you that ammonia will be polar and, as a δ+ hydrogen and a δ- nitrogen are involved, the strongest intermolecular force present will be hydrogen bonding.

(c) Use the values in Table 1 to explain how the strongest type of intermolecular force arises between two molecules of ammonia (3 marks)

1. The first mark here is for a clear reference to the large difference in electronegativity between the N and the H
2. The second mark comes from stating that this gives rise to a dipole in the molecule with the N being δ- and the H being δ+
3. The third mark requires a specific reference to the hydrogen bond forming as an attraction between the lone pair on the N and the δ+ H

(d) Phosphorus is in the same group of the Periodic Table as nitrogen. A molecule of PH_3 reacts with an H^+ ion to form a PH_4^+ ion. Name the type of bond formed when PH_3 reacts with H^+ and explain how this bond is formed (3 marks)

The reference to phosphorus being in the same group as nitrogen should make you relate PH_3 to NH_3, with which you should be familiar. The key here is to recognise that the P will have a lone pair and that these two electrons will be shared with the $H^{\pm}$ giving rise to a dative / co-ordinate bond.)

(e) Arsenic is in the same group as nitrogen. It forms the compound AsH_3. The boiling point pf AsH_3 is -62.5°C and the boiling point of NH_3 is -33.0°C. Suggest why the boiling point of AsH_3 is lower than that of NH_3. (1 mark)

It would be easy to spend too long on this and write too much but the clue is that there is only one mark available so all that is needed is to state that ammonia can form hydrogen bonds while the AsH_3 cannot.

(f) State what is meant by the term polar when applied to a covalent bond (1 mark)

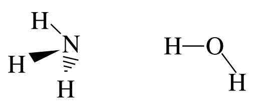
A simple statement that this refers to an uneven/unequal sharing of electrons is all that is needed for one mark

(g) Consider the covalent bonds in molecules of hydrogen and water. State whether the covalent bonds in each case are polar or non-polar and explain your answers. (3 marks)

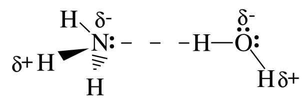
You need to remember that polarity will only arise when electrons are shared between atoms with different electronegativities so:

1. The first mark is for correctly stating that hydrogen molecule (H_2) will contain non-polar bonds whilst water contains polar ($^{ª-}$O-H$^{ª+}$) bonds (both statements needed for one mark – make sure you don't only state one idea and assume that the other one is implied).
2. The second mark is for explaining the lack of polarity in the hydrogen molecule as the H atoms have the same electronegativity
3. The third mark is for explaining the polarity in a water molecule as being due to the oxygen atom being much more electronegative than the hydrogen(s).

(h) Ammonia is very soluble in water as it is able to form hydrogen bonds with water molecules. Complete the diagram below to show how an ammonia molecule forms a hydrogen bond with a water molecule. Include partial charges and all the lone pairs of electrons. (3 marks)



It is very surprising that many candidates throw marks away by failing to follow specific instructions in a question! The key requirements here, which would be overlooked by many, are the need to include partial charges and **all** lone pairs.



1. The first mark is for showing at least one dipole on **each** molecule
2. The second mark is for a combination of the lone pair on the N **and** correctly showing the hydrogen bond – a solid line or an arrow would **not** be accepted
3. The third mark is for showing **both** the lone pairs on the oxygen atom

Practice Questions

1. The table below shows the boiling points of the elements sodium to chlorine in Period 3 of the Periodic Table.

Element	Na	Mg	Al	Si	P	S	Cl
Boiling point/°C	883	1107	2467	2355	280	445	-35
Bonding							
Structure							

(a) Complete the *bonding* row of the table using
- **M** to represent *metallic bonding*
- **C** to represent *covalent bonding* [1]

(b) Complete the *structure* row of the table using
- **S** for *simple molecular structure*
- **G** for *giant structure* [1]

(c) Explain what is meant by *metallic bonding*. You should include a diagram as part of your answer. [3]

(d) Explain, in terms of their structure and bonding, why the boiling point of:
(i) Phosphorus is much **lower** than that of silicon [2]
(ii) Aluminium is much **higher** than that of caesium[2]

2. Diamond and graphite are both giant, covalent forms of carbon.
(a) State how the structures of diamond and graphite are different. Briefly explain why diamond is very hard and why graphite is soft, able to act as a lubricant, and as an electrical conductor. [7]

(b) On heating a mixture of sodium and iodine, the elements react together to form sodium iodide as shown in the equation below:
$Na + I_2 \rightarrow 2NaI$

The melting points of iodine and sodium iodide are 114°C and 662°C respectively.

For each of the substances sodium, iodine and sodium iodide, state the type of bonding present and explain the nature of the attractive forces holding each solid together. Briefly explain why the melting point of iodine is much lower than that of sodium iodide [7]

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Answers

1. (a) (b)

Element	Na	Mg	Al	Si	P	S	Cl
Boiling point/°C	883	1107	2467	2355	280	445	-35
Bonding	M	M	M	C	C	C	C
Structure	G	G	G	G	S	S	S

(One mark for each fully correct row✓✓)

(c) Positive ions / metal ions / cations ✓ (just '+' in a circle in the diagram is not enough – must be labelled with one of the three possible answers shown or referred to as such in explanation).
Surrounded by free / delocalised / sea of electrons) ✓as above, just '-' in the diagram is not enough for this mark unless also labelled).
Attraction between the above (referred to in the explanation).✓ Note that the word 'force' alone is not enough as his could refer to a repulsion or an attraction).

(d) Si has stronger forces / P has weaker forces✓
Si: covalent bonds / giant covalent✓
P: weak forces between molecules /intermolecular forces / van der Waal's ✓ [3 → 2 max]

(e) Al has stronger (metallic) bonding✓
Al has 3 outer electrons, Mg has 2 / Al has more (outer) electrons than Mg✓
Al ions are smaller and more positive / Al ions have greater charge density✓ [3 → 2 max]

2. (a) **M1**: diamond = 3D /each C bonds to 4 C atoms / co-ord. number = 4 / has a tetrahedral structure. (If any indication that bonding is anything *other* than covalent then M1 = 0 and consequentially, M3 = 0)
M2: graphite = 2D / planar/layers / trigonal planar / each C bonds to 3 C atoms / co-ord. number = 3 (If any indication that bonding is anything *other* than covalent then M2 = 0 and consequentially, M5 = 0)
M3: diamond is hard as (covalent) bonds have to be broken
M4: graphite lubricates as layers slide over each other.......
M5: as only weak forces / van der Waal's forces between <u>layers</u>
M6: graphite conducts because it has delocalised/mobile electrons...... (Not just 'free', or 'sea or 'electrons' or 'non-bonding electrons')
M7: that can move between the layers (clear idea of electrons moving in a specific direction as opposed to randomly)

(b) **M1**: bonding in sodium = metallic
M2: <u>attraction</u> between <u>positive</u> ions and delocalised / mobile electrons
M3: bonding in iodine = covalent
M4: molecules / I_2 held together by <u>van der Waal's attractions</u>
M5: bonding in sodium iodide = ionic
M6: attraction between <u>positive ion</u> and <u>negative ion</u> / electrostatic attraction
(NB for M1 to M6, if a type of bonding is correctly identified but, later, contradicted by an incorrect reference then BOTH marks are lost e.g if sodium's bonding is identified as 'metallic' but then later there is a reference to 'sodium molecules / van der Waal's forces / ionic bonds then consequentially 0 marks for **M1** <u>and</u> **M2**)
M7: van der Waal's forces are much weaker than the ionic bonding (in NaI)