

Chapter 4.6: Aggregates - Bonding and Properties

An aggregate is a collection of molecules, ions or atoms that is described by the physical and chemical characteristics of that substance.

Eg] One Na atom does not have a MP of 97.8°C. You must have a large number of interacting sodium atoms before the properties arise.

The interactions between the units in an aggregate are what lead to the physical and chemical characteristics of the substance.

Aggregates are usually crystalline solids.

Substances are usually classified in terms of the unit bonding that makes up the aggregate.

1 – Ionic Substances – ***eg] NaCl MgO***

structural units are oppositely charged ions and the bond is ionic.

2 – Molecular Substances – (both polar and non-polar)

eg] non-polar – S_8 polar – H_2O

structural units are ***molecules*** and the attractive forces between the molecules are called intermolecular forces.

3 – Network or Macromolecular solids – gigantic networks of atoms held together by covalent bonds.

Eg] polymers, diamonds

4 – Metallic Substances – eg] ***Na, Fe, Sn***

The structural unit is the atomic kernel (positive ion). These are held together by metallic bonds. (sea of electrons)

1 - Ionic Substances - Is it proper to talk about an NaCl molecule? ***NO! They are networks of oppositely charged ions.***

Properties of Ionic Substances

A -**High** MP and BP, **low** volatility

B -**does not conduct** electricity when solid

C -**does conduct** electricity when liquid

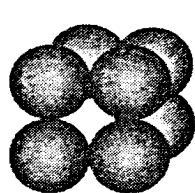
D -**soluble** in water to form
(electrolytic)solutions

E - brittle

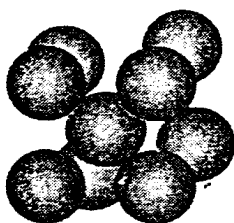
- the above properties can almost all be attributed to the high strength of the ionic bond.

- the solid phase of ionic substances are crystalline (repetitive unit cells). The unit cell is simply the most basic repeating unit. The position of the atom or ion in the unit cell is called a lattice point and the 3-D array of lattice points is called the lattice structure.

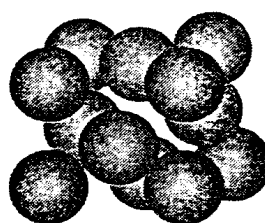
- unit cells - simple, face centred cubic and body centred cubic(determined by X-ray diffraction)



Simple cubic



Body-centred cubic



Face-centred cubic

The crystal lattice energy is ***the energy liberated when one mole of gaseous ions forms a crystal. The crystal is more stable than the gaseous ions.***

- the crystal lattice energy of ionic substances ***is very high because it involves the bringing together of opposite charges***

- the high crystal lattice energy leads to high MP, BP and low volatility – (see property A)

Are the melting and boiling points of all ionic substances really high?

eg] MgCl_2 ***MP = 2800°C***

NaCl

MP = 800°C

This difference in MP must be because the crystal lattice energies of different ionic substances are quite dissimilar, but why are they dissimilar?

Physics tells us that the force of attraction between two static charges is given as:

$$F_e = \frac{kq_1q_2}{r^2}$$

- a) so for larger ionic radii – *the force of attraction is low, so crystal lattice energy is low so there is a low MP and BP*

eg] CsCl MP = 646°C

NaCl MP = 800°C

- b) so for larger charges – *the force of attraction is greater so MP and BP are increased*

eg] MgO MP = 2800°C

NaCl MP = 800°C

Why do solid ionic crystals not conduct? (property B)

- *electrons are locked on the ions*
- *ions are stuck (solid)*
- *no charge flow*

Why do melted ionic substances act as moderate conductors? (property C)

- *electrons are locked on the ions*
- *ions can move slowly*
- *can get charge flow (limited):viscosity*

Why do solvated ionic substances conduct? (property D)

- *electrons are locked on ions*
- *ions are free to move through polar solvent: eg. Water*
- *can get charge flow (significant)*

Why are ionic crystals brittle? (property E) (Hint: think of the packing)

Strong bonds but once they're moved the ions repel each other. Definite boundaries along the edges of unit cells.

2 – Molecular Crystals.

In general the intramolecular forces (those within the molecule) are much greater than the intermolecular forces (those between molecules) in the molecular crystal.

The lattice points are occupied by neutral molecules. (polar or non-polar)

There is a much wider variation in the properties of molecular substance than ionic substance because *the lattice points are complex molecules – not simple ions.*

Examples of molecular solids include: *CO₂ (dry ice)*
H₂O (ice)
Frozen methane

In general:

- A – neither the solid crystals nor the liquids conduct electricity
- B – These molecular crystals have very low BP, MP and high volatility
- C – the solids tend to be soft and waxy
- D – there is a large amount of energy required after melting or boiling to decompose the substances chemically.

Why don't molecular substances conduct when solid or liquid?
(property A)

- *electrons locked on molecule*
- *molecule carries no charge so even if molecule moves there is no charge flow*

Why do molecular solids have low BP, MP and high volatility?
(property B)

-weak intermolecular forces but these force vary widely

eg] H₂O BP = 100°C
CO₂ BP = -80°C

Why are molecular solids soft and waxy? (property C)

Weak intermolecular forces allow for deformation with pressure (soft) and allows sections to peel off (waxy).

Why does it take so much energy after melting or boiling to decompose the substance? (property D)

Eg] Water boils at 100°C but doesn't decompose until 2000°C. The intermolecular forces are much weaker than the intramolecular forces.

How does shape of a molecule affect the properties?

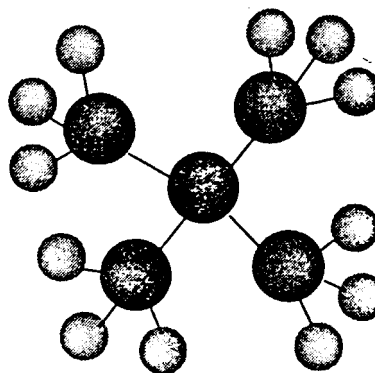
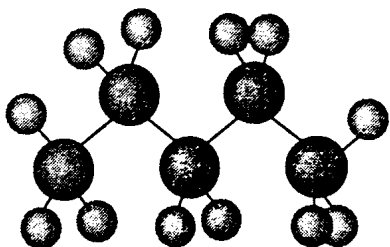
normal pentane

vs.

neo pentane

C_5H_{12}

C_5H_{12}



***BP = 36°C
MP = -130°C***

Liquid – large straight chain allows for a high degree of contact which results in strong intermolecular forces making a higher BP

Solid – the long “floppy chains do not pack well resulting in a low crystal lattice energy and low MP

***BP = 9°C
MP = -20°C***

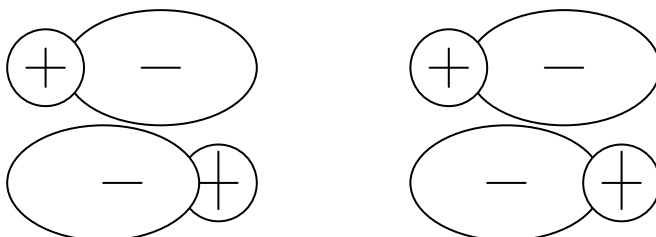
Liquid – compact sphere
- low contact
- low intermolecular forces
- low BP

Solid – sphere can easily occupy a lattice point so there is a higher MP

2b – What are these so called weak intermolecular forces anyway?

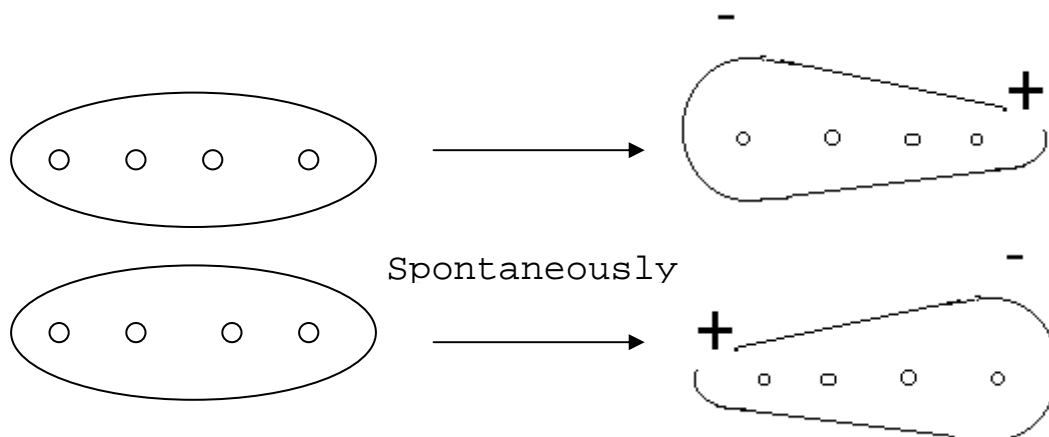
Dipole Forces

- *polar molecules will align themselves so that oppositely charge ends are facing each other.*
- *not nearly as strong as the full charges of ionic bonds*



Van der Waals Forces

- these occur between every type of molecule (even 0 electronegativity difference molecules)
- they are the result of temporarily induced dipoles due to the fluctuation in electron charge density



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- covalent bonds are 100's of times stronger than Van der Waals
- the magnitude of the Van der Waals forces therefore depends on *the size of the electron cloud*

Molecule	Number of Electrons	Boiling Point (°C)
CH ₄	10	-161
SiH ₄	18	-112
GeH ₄	36	-90
SnH ₄	54	-52

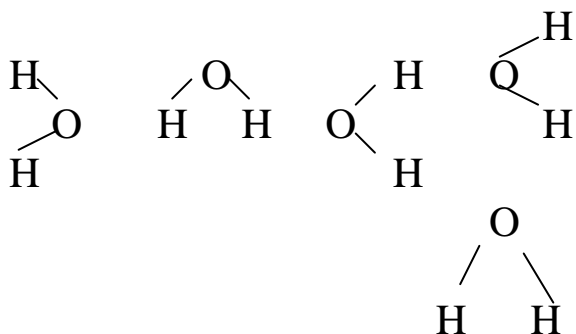
Hydrogen Bonds - Examine the following:

EN diff	Form	#e	BP	EN diff	Form	#e	BP	EN diff	Form	#e	BP
3.04	NH₃	10	-33	3.44	H₂O	10	+100	3.98	HF	10	+19.4
2.19	PH ₃	18	-85	2.58	H ₂ S	18	-60	3.10	HCl	18	-85
2.18	AsH ₃	36	-55	2.55	H ₂ Se	36	-42	2.96	HBr	36	-67
2.05	SbH ₃	54	-17	2.1	H ₂ Te	54	-2	2.66	HI	54	-36

The higher boiling point of the first row indicates ***a greater intermolecular force.***

Hydrogen Bond – the relatively strong intermolecular force that results from electrostatic interaction between a hydrogen of one molecule and a highly electronegative atom (***N, O or F***) of another molecule.

The high electronegativity results ***in a practically bare proton (hydrogen nuclei). This is a small charge but a very high charge density. This positive charge is then attracted to nearby electron rich (negative) atoms.***



Hydrogen bonds are approximately 10 times as strong as Van der Waals forces

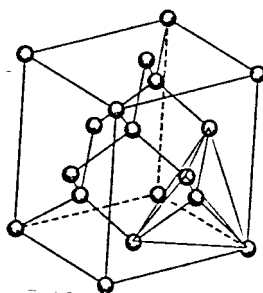
Can be used to explain why water is more dense than ice (thankfully) and to explain the high surface tension of water and biomolecular shapes. See page 263.

3 - Network or Macromolecular Solids

- one, two or three dimensional networks of atoms

3D Network Solids

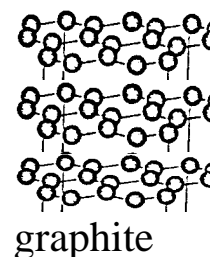
- eg] diamond, quartz, silicon carbide (carborundum)
 - High MP (*always very high MP*) (ionics have a high MP but networks have very high MP)
 - Extreme hardness
 - In diamond all C-C bond angles are 109.28° and all C-C bonds are equal strength
 - A diamond is one very large molecule extended three dimensionally



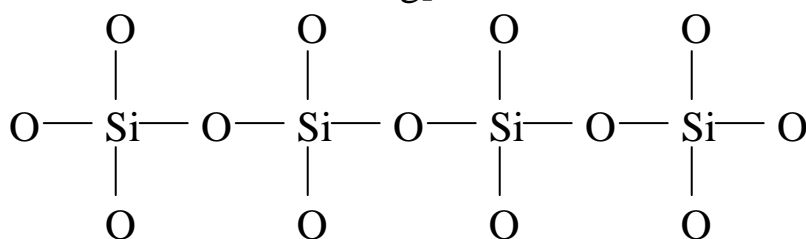
- The network of atoms (each C bonded to four others) accounts for the extreme hardness and high BP.
- When the highly directional bonds are broken by an applied stress, they cannot be reformed and the crystal cleaves.

2D Network Solids

- more than one type of bond exists
- graphite (pure carbon) – the bonds between the plane can be broken easily so the planes tend to slide over each other making graphite a good lubricant
- graphite conducts in one direction – along the π bond plane not perpendicular to it
- soft due to weak bonds between



1D Network Solids – eg] asbestos



4 - Metallic Crystals or Metallic Bonds

- the properties of metals cannot be accounted for by ionic or covalent bonds

Metals in general have the following properties:

- Lustre (reflectivity)
 - Good conductors (heat and electricity)
 - Workability (malleability, ductility)
 - electron emission by heat or light
 - covalent bonds are one directional and their fixed length would resist the workability (therefore metals are not bonded covalently)
- ionic bonds are extremely resistant to deformation (therefore metals are not bonded ionically)
- Van der Waals forces are much too weak to explain the stability of metals
- We must therefore have a different type of bond called a metallic bond - positive atomic kernels in a sea of free moving electrons.

Lustre - the free electrons oscillate at the same frequency as incoming light and because they then become accelerating charges they emit light of the same incident frequency making it look reflective.

Conductivity - the tiny free electrons can move readily under applied voltage. At high temperatures the atomic kernel vibration interferes with electron flow.

Heat Conductivity- again the free electrons can carry off excess kinetic energy from one area of the metal to another.

Workability - the non-directional bond nature allows one plane of atomic kernels to slide over another plane with no change to the immediate environment of the atomic kernel. This results in no added internal stress, so the metal does not crack.

Electron Emission - when enough heat energy is added, an electron may gain enough energy to be bounced out of the lattice. When light of the proper frequency interacts with an electron, the energy is sufficient to bump the electron out.

