BONDING AND PROPERTIES

1. IONIC SUBSTANCES AND IONIC BONDS

Properties

- do not conduct an electric current in the solid state, why?
- in the liquid phase, i.e when molten, they are relatively good conductor of an electric current, why?
- when soluble in water form good electrolytes, why?
- relatively high M.P. and B.P. (>500°C, >100°C)
- do not readily vaporize at room temperatures. These solids have relatively low volatility, low vapour pressure, this also indicates that a....
- brittle, easily broken under stress, why?

Ionic Bonds

- Ionic solids are generally stable and the bonds are relatively strong.
- electrostatic attraction between oppositely charged ions forming a 3-d crystalline lattice structure
- crystal lattice energy is the energy liberated when one mole of an ionic crystal is formed from the gaseous ions, high stability reached when energy is lost.
- lattice energy is dependent on two factors: (1)
  (2)
- weaker bonds correspond to smaller lattice energies and less stable structures

2. MOLECULAR CRYSTALS

Covalent bonding, the sharing of electrons is known as an **intra molecular** force.

Properties

- neither solids nor liquids conduct an electric current. This indicates ...
- many exist as gases at room temperature or as volatile solids and liquids, indicating ...
- M.P. and B.P. are relatively low, thus indicating ...
- Solids are soft and waxy
- Large amount of energy required to decompose in simple substance, indicating ...

Intra molecular: these forces are within the molecule.

So far we have dealt mainly with these, however we will now look at **intermolecular** forces. These are the forces that exist **between** one molecule and another. They are often referred to as **Van der Waals** forces after Johannes Van der Waals, a Dutch scientist who studied these forces and lived between 1837 and 1923. However, we will refer to the individual forces using separate names. Intermolecular forces are responsible for changes of state, and all other physical properties such as melting point, boiling point, solubility and conductivity.

Solid ⟶ liquid ⟶ gas

Strong intermolecular forces ... Weak intermolecular forces

Intermolecular Forces of Attractions (IMFA's)

1) **The Dipole-Dipole Force**
These forces exist between polar molecules, i.e those with a permanent dipole. The negatively charged end of one molecule is attracted to the positively charged part of another. (That's why it is called dipole-dipole, there must be at least two molecules with dipoles) These forces are not that strong, only about 1% of the strength of your average covalent bond. The strength will depend on... Difference in electronegativity, i.e. strength of the dipole moment

2) **The London Dispersion Forces**
Named after Fritz London
- found in ALL molecules
- the only intermolecular force present in non-polar molecules
- extremely weak
- due to temporarily induced dipoles
- two factors affect strength of London forces:

1)- increase with number of electrons ... E.g. $F_2 < Cl_2 < Br_2 < I_2$
2)- increase with surface area of molecule ... Linear vs. branched chain molecule

3) **The Hydrogen Bond**
This is just a special case of the dipole-dipole interaction. This is what happens when you have BIG dipoles. A necessary condition of these interactions is to have hydrogen bonded to the big three highly electronegative elements: F, O, N.
The hydrogen is basically stripped of its electrons leaving ________________. This means the positive end will form an attraction to just about anything negative...like...

Assignment
1. What type of IMFA are found in each of the following molecules:
a) CO_2 (b) CH_2Cl_2 (c) NH_3 (d) CH_4 (e) C_2H_5OH (f) I_2

2. The normal boiling points of N_2, O_2, and NF_3 are –196°C, -183°C, and -129°C, respectively. Explain why the boiling point of NF3 is substantially higher than the boiling points of nitrogen and oxygen.

3. For the following substances, determine which one has a higher melting point.
(a)Xe or Ne (b) SbH_3 or AsH_3 (c) CH_4 or C_4H_{10} (d) I_2 or F_2 (e) NH_3 or PH_3

4.One of the following substances is a liquid at room temperature, whereas the others are gases. Which one do you think is a liquid? CH_3OH C_3H_8 N_2 N_2O

5.The mass of methanol (CH_3OH) is very close to that of ethane (CH_3CH_3). Which of these substances will have the higher boiling point. Explain.

6. List the following metals in order of increasing bond strength:
(a) Na, Cs, Rb, K. (b) Ca, Mg, Ba, Sr.

7. Explain why metal solids are easier to bend and stretch than other substances such as NaCl, I_2 or $CaCO_3$.

8. Place the following elements in order of increasing London dispersion forces: Xe, Ar, Kr.

9. Which substance pair should have a higher melting point: (a) I_2 or Br_2, (b) O_2 or Cl_2. Justify!
10. Which substance pair should have a higher melting point: (a) NaF or LiF, (b) CaO or BaS

3. NETWORK (MACROMOLECULAR) SOLIDS

This is a type of solid we have not really talked about before, but one in which you are all familiar. It is possible to have a 1,2 or 3 dimensional network of atoms all joined with single **covalent bonds**. The element contained in the bond could be the same or different.

(i) Three Dimensional Network Solids

Properties:
highly stable, extremely hard, poor electric conductors, insoluble in most solvents, very high melting points. Example: diamond: m.p. 3550°C, b.p. 4827°C
Examples:
diamond, quartz, silicon carbide
Structure:
3-D array of carbon atoms joined by very strong covalent bonds extending uniformly throughout the entire crystal.
- in diamond each C atom joined in tetrahedral arrangement to four other C atoms, all bonds are the same length, all bond angles are 109.5°, - sp^3 hybridization

(ii) Two Dimensional Network Solids

Properties:
- high M.P. and B.P.
- soft, good conductor of electricity, why?

Examples:
- graphite, mica

Structures:
- two types of bonds present
- strong covalent bonds in planar arrangement, thus suggesting ...
- each carbon atom joined to two others by a single covalent bond: sp^2 hybridization, 120^0 bond angle, explaining ...
- delocalized electrons in π-bond, this means that graphite is able to...
- weak bonds between layers, meaning that graphite ...
- Van der Waals forces → softness, slipperiness

Buckminsterfullerene

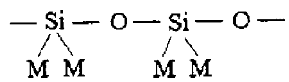
In the 1980's, several research teams around the world pieced together the discovery of a third allotrope — buckminesterfullerene, C_{60}, molecules of carbon in the form of spheres. The molecules were arranged as though a layer of graphite had curled into a ball. The researchers were puzzled as to how this could happen until they realized that some pentagons in the array of hexagons would do the trick. One group asked the mathematics department at their university if they had heard of this geometrical shape, only to realize that it was exactly the pattern of the panels on a soccer ball!

The molecule was christened buckminesterfullerene after the geodesic domes designed by the architect Richard Buckminester Fuller. Other related molecules have been found including C_{70} in the shape of a rugby ball and also tube-shaped molecules.

Although they look odd, these molecules can undergo normal chemical reactions and chemists are beginning to make derivatives of them and look for uses of these new allotropes.

(iii) One Dimensional Network Solids

Examples: - asbestos type minerals
Structures: - Si and O atoms covalently bonded in long chains with metal atoms attached to the silicon atoms



4. Metallic Crystals

Properties:
- luster (shiny), high electric conductivity, high heat conductivity, work ability, malleability, ductility. How can these properties be explained?

Examples: - copper, iron, calcium, sodium

Structures:
- all metals have vacant orbitals and low ionization energies
- three dimensional, closely packed lattice-work of atomic kernels, (ions), surrounded by a sea, (cloud) of delocalized, mobile valence electrons. The e^{-1} cloud can move throughout the crystal. The electrons are not considered to be bonded to any ion in particular. This makes them __________________ electrons. They are therefore free to move around.

The electron cloud is held within the crystal by the electrostatic attraction of the positive atomic kernels, ions, this serves as the "glue" that holds the nuclei together and is known as the - THE METALLIC BOND.

The strength of the metallic bond increases with nuclear charge and number of outer electrons: Fe > Ca > Na, see explanation below ...

It is the mobility of the electrons that allow metals to conduct heat and electricity.

Mobility of electrons helps explain malleability and ductility. One plane of ions can slip over another and in so doing, the electrons flow along with the layers...the electron cloud just distorts.

These mobile electrons are able to absorb and re-emit light of all wavelengths, therefore they are good reflectors of light.

The **melting points** and **boiling points** generally depend on the number of valence electrons. The more valence electrons there are the more "glue" the higher the m.p. or b.p.

Alloys

These are substances having metallic properties which contain more than one element. They can act as an example of a __________________ solution. They are mixtures and not chemical compounds because the metals are not combined in a fixed percentage by mass.

Alloys are made because they have desirable properties. In general pure metals are soft, flexible and excellent conductors of heat and electricity. Alloys are generally harder, and less flexible because the atoms contained within it are of different sizes and so the planes of atoms do not slide over each other easily. These are known as substitutional alloys.

Examples: **Bronze** Cu (75%) Sn (25%)

Pewter Sn (85.5%) Cu (6.8%) Bi (6%) Sb (1.7%)

18K gold (yellow) Au (75%) Ag (12.5%) Cu (12.5)

18K gold (white) Au (75%) Ni (16.5) Zn (5%) Cu (3.5%)

When the alloying atom is much smaller than the atoms to which is being added, it may fit into the spaces between the atoms. These are known as the interstitial alloys. These tend to be very hard and brittle. The alloying atoms should be quite small. (H, C, N, B) Examples Steels: Mainly Iron with a small (<2%) percentage of carbon.

Sometimes the alloys will be a combination of alloy types, for instance, stainless steel contains mainly iron with 18% Cr, 1% Ni and 0.4% C.

Group VIIIA solids which are composed of the Noble gases. They are held together by weak London dispersion forces, hence their properties include...

Assignment

1) Tin (IV) Chloride, $SnCl_4$, has soft crystals with a melting point of -30.2°C. The liquid is non-conducting. What type of crystal is formed by $SnCl_4$?

2) Elemental boron is a semi-conductor, is very hard, and has a melting point of 2250°C. What type of crystal is formed by boron?

3) Titanium (IV) Bromide forms soft orange-yellow crystals that melt at 39°C to give a liquid that doesn't conduct electricity. The liquid boils at 230°C. What type of crystal does $TiBr_4$ form?

4) Columbium is another name for one of the elements. This element is shiny, soft, ductile. It melts at 2468°C and the solid conducts electricity. What kind of solid does columbium form?

5)Elemental phosphorus consists of soft, white, "waxy" crystals that are easily crushed and melt at 44°C. The solid does not conduct electricity. What type of crystal does phosphorus form?

6. The metalloid silicon, Si, forms an oxide with the formula SiO_2. The hard white crystals melt at ~ 2000 K and the resulting liquid does not conduct electricity.

a) What type of crystal does SiO_2 form?

b) Describe the attractive force holding together a SiO_2 crystal.

c) Explain the observed boiling point and the hardness of the SiO_2 crystal in terms of its bonding and structure.

7. You are given a white substance that sublimes at 3000 ^{O}C; the solid is a nonconductor of electricity and is insoluble in water. Which type of solid might this substance be?

8. Covalent bonding occurs in both molecular and covalent network solids. Why do these two kinds of solids differ so greatly in their hardness and melting point?

9. Ethan-1,2-diol, CH_2 (OH)-CH_2(OH), the major component of antifreeze, is a slightly viscous liquid that is not very volatile at room temperature and boils at 198 ^{O}C. Pentane, C_5H_{12}, which has about the same molar mass, is a nonviscous liquid that is highly volatile at room temperature and whose boiling point is 36 ^{O}C. Explain the differences in the physical properties of the two substances.

10. For each of the following pairs of substances, predict which will have the higher melting point and indicate why: (a) HF, HCl (b) SiO_2, CO_2 (c) KO_2, SiO_2 (d) Ar, Xe (e) Se, CO (f) NaF, MgF_2

Bond Types and Properties - Summary Table

Property	Ionic	Molecular Covalent	Giant Covalent	Metallic
Melting Point, Boiling Point, Latent Heat of Fusion	High – each +ion is attracted to many –ions and vice-versa. Attraction is hard to break and is spread throughout crystal.	Low – there is little attraction between individual molecules (v-d-W, d-d, h-b), and they can be easily separated.	High – each atom is attracted to others by covalent bonds right throughout the crystal – to melt solid, to break all bonds.	High – each atom is held in place by 12 others by metallic bond right throughout crystal, .: must break bonds to melt solid.
Solubility in Water	Usually good – as water is an insulator and can reduce the attraction of the ions for each other, hydration of ions ($H_e > L_e$)	Varies – molecules easily separated from each other, so may dissolve in water or other solvents.	Insoluble – as it would be necessary to break the covalent bonds which would require much energy.	Insoluble – too difficult to break metallic bonds and separate the atoms.
Conductivity: Solid	Poor – as the ions are fixed in position by electrostatic attraction and can not move.	Poor – as the only charged particles (the electrons) are held tight to their own atoms and can not move.	Poor – see molecular covalent.	Good – as the electrons in the sea of delocalised electron cloud can move easily from atom to atom.
Conductivity: Molten (liquid)	Good – as the ions are now free to move and (as they are charged) so they can carry the current.	Poor – the same reason as the solid.	Poor – the same reason as the solid.	Good – the electrons can still move freely.
Conductivity: In Solution in water, $_{(aq)}$	Good – the same reason as liquid.	Poor – the same reason as the solid.	Insoluble	Insoluble

Note:
All atoms, and therefore all elements and compounds, contain protons and electrons, which are both charged. The protons are always fixed in position in the nucleus and cannot move, the electrons are held firmly on the atom, ion or in the compound and cannot move except in metals.

The particles which carry the charge in ionic substance are the ions.

Acids are a special case of molecular covalent. Their properties are the same as other molecular covalent – except that they conduct electricity when they are dissolved in water, because they react with the water forming ions – i.e. they ionize.