Physical Properties Explained (hopefully)

Melting and Boiling Points:

- in order to melt or boil a compound, the solid form of the compound must be broken up into small particles
- what these particles are, depend on the type of compound

	Solid Structure	Small Particles
Ionic Solid	**cations and anions** held together by **intramolecular** ionic bonds in a crystal lattice macromolecule	individual cations and anions (must overcome STRONG intramolecular force)
Covalent Network Solid	**neutral** octet satisfied **atoms** held together by **intramolecular** covalent bonds in crystal lattice macromolecule	individual neutral atoms (must overcome STRONG intramolecular force)
Metallic Solid	**metal cations** in an **electron soup** held together in a flexible arrangement called a macromolecule, **intramolecular** metallic bond	individual metallic cations (must overcome STRONG intramolecular force)
Molecular Solid	neutral **discrete covalent molecules** held together in a molecular crystal lattice by **intermolecular** forces (not a macromolecule)	individual discrete covalent molecules (must overcome WEAK intermolecular force)

- in a liquid, the “small particles” are still attracted to each other, but can move around (not fixed or rigidly bonded)
- in a gas, all attractive forces as mentioned in the right column of the table have been completely overcome and spaces between the particles has become immense compared to the size of the particles (i.e., a mere 18.02 mL of water will produce 22.414 L of a gas at S.T.P. - mostly empty space)
- how difficult it is to melt or boil a substance comes down to how difficult it is to overcome the attractive forces as listed in the third column of the above table, the more difficult, the greater the energy needed and the higher the temperatures required
- therefore, ionic compounds, covalent network compounds and metallic substances all have relatively high melting points (M.P.) and boiling points (B.P.), since STRONG intramolecular forces must be overcome to achieve small particles (i.e., NaCl melts at 801 ^{o}C, C_n (diamond) melts at 3820 ^{o}C)
- therefore, molecular solids of discrete covalent molecules have relatively low M.P. and B.P. because only WEAK intermolecular forces must be overcome to achieve small particles (individual discrete covalent molecules)
    - note that the intramolecular bond within each discrete covalent molecule is unaffected (i.e. water boils at 100 ^{o}C, while the H to O covalent bond will not break until about 4000 ^{o}C
    - note that the stronger the intermolecular forces (i.e. polar

vs non-polar) the higher the M.P. and B.P. due to interactions between δ^+ and δ^- on adjacent molecules

Physical Appearance And Response to Physical Stress:

Macroscopic properties can always be explained by the underlying atomic structure.

Crystallinity: crystalline appearance, clear but could be coloured

- must have a crystal lattice structure (regularly repeating arrangement atoms, ions or molecules)

Ionic Solid: NaCl

$$\begin{array}{cccc} Na^{1+} & Cl^{1-} & Na^{1+} & Cl^{1-} \\ Cl^{1-} & Na^{1+} & Cl^{1-} & Na^{1+} \\ Na^{1+} & Cl^{1-} & Na^{1+} & Cl^{1-} \\ Cl^{1-} & Na^{1+} & Cl^{1-} & Na^{1+} \end{array}$$

- cations and anions occupy the lattice points
- held together by ionic bonds (intramolecular forces ∴ macromolecule)

Covalent Network Solid: $C_n(s)$ "diamond"

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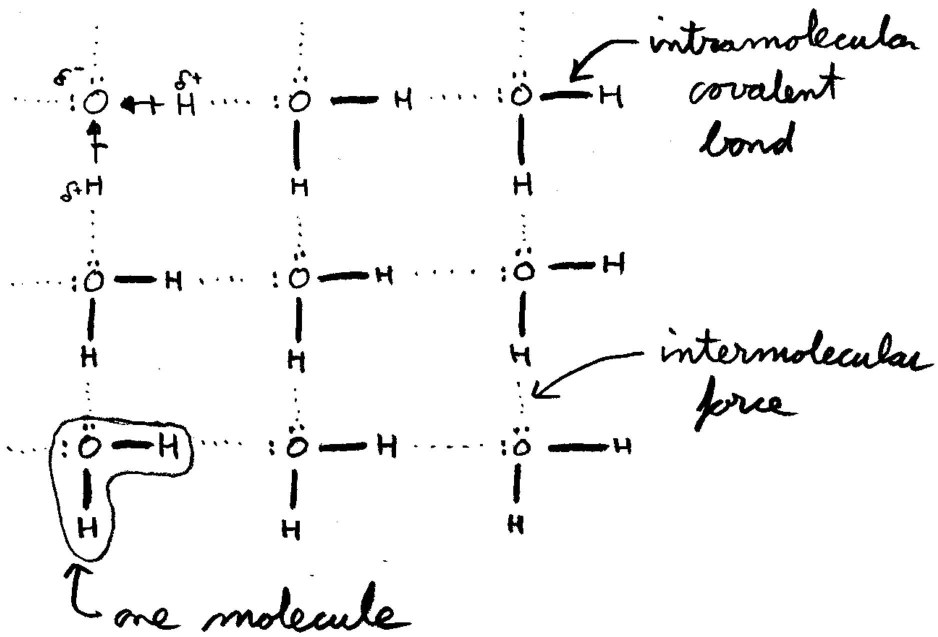
     |     |     |     |
  —  C  —  C  —  C  —  C  —
     |     |     |     |
  —  C  —  C  —  C  —  C  —
     |     |     |     |
  —  C  —  C  —  C  —  C  —
     |     |     |     |
  —  C  —  C  —  C  —  C  —
     |     |     |     |
```

C_n Diamond is a Covalent Network Crystal

– neutral octet satisfied atoms occupy the lattice points

– held together by covalent bonds (intramolecular forces $\therefore$ macromolecule)

Molecular Solid: H_2O "ice"



- neutral molecules occupy the lattice points
- the molecules are constructed using covalent bonding (intramolecular)
- the molecules attract to each other through intermolecular forces
- only intermolecular forces need be overcome to break a molecular lattice

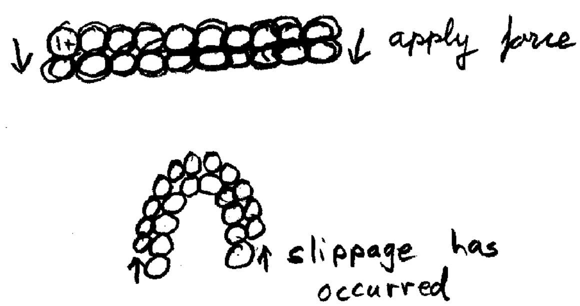
Cleavage: the ability of a crystalline substance to fracture when stressed (hit it with a hammer) to form flat surfaces.

– a fracture along the existing planes in the lattice structure can produce flat surfaces

Malleability and Ductility of Metals:

– a metal, when stressed will bend (malleable) and can be drawn into wires (ductility)

eg Ag (forms Ag^{1+} ions plus e^{1-} soup)



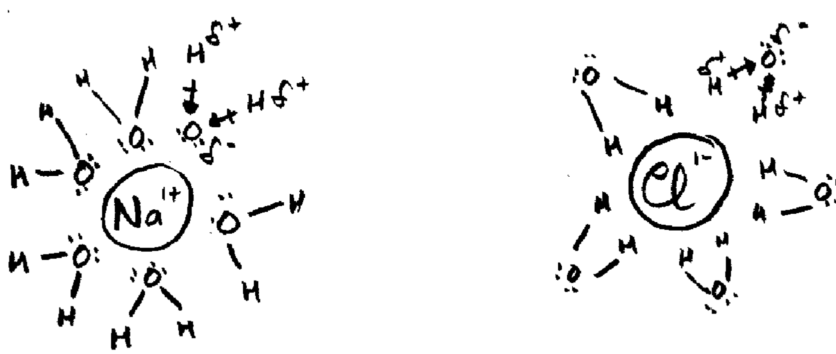
– when stressed, metal ions can slip past each other without interrupting the metallic bond (note that the electrons remain in constant wandering motion the whole time)

Other Things That Can Happen When Stressed:

- crystalline solids will often shatter instead of cleave, the lattice structure is rigid in inflexible, it will break instead of bend
- for molecular solids composed of non-polar discrete covalent molecules, a wax like consistency is observed (obvious when stressed - eg butter), insufficient bond polarizations to establish a good lattice structure (jumble of molecules instead)

Solubility: The ability of a substance to disintegrate and mix thoroughly at the atomic/molecular level. In order for a substance (solute) to dissolve in a second substance (solvent) there must be replacement forces. The forces that are broken in the solid must be replaced by new solvent solute forces. LIKE DISSOLVES LIKE (increases the chance for good replacement forces)

- many ionic compounds will dissolve well in water because the polar water molecules can interact with individual ions and provide a replacement force



Note that the solubility of ionic compounds varies greatly depending on the strength of the solid (lattice energy) vs the strength of the water ion interaction (hydration energy). Lattice energy and hydration energy depend on many factors beyond the scope of this course.

hydration > lattice ➜➜ soluble

lattice > hydration ➜➜ insoluble

- covalent network solids do not dissolve (covalent bond forces are impossible to replace
- metallic substances will dissolve in mercury (form an amalgam) or will dissolve in other metals to form alloys (must heat and melt the metals first in order to do this) (metallic bond force is replaced by a new metallic bond force)
- discrete covalent molecules that are non-polar dissolve in other discrete covalent molecules that are non-polar (oil dissolves in gas)
- discrete covalent molecules that are polar dissolve in other discrete covalent molecules that are polar (sugar dissolves in water)

Conductivity: In order for conductivity to occur, free moving charged particles must be present. The charged particles could be ions or electrons

- metals conduct in solid and liquid state due to the presence of free moving electron (metallic bond includes a soup of free moving electrons)
- ionic liquids (molten ionic compound) conducts because of the presence of free moving ions (no longer locked in a lattice structure)
- aqueous ionic solutions conducts because of the presence of free moving ions (no longer locked in a lattice structure - free moving in

solution)

– graphite conducts with a plane due to delocalized pi bonding electrons
– graphite does not conduct between planes because electrons are confined to pi resonance with each plane
– some discrete covalent molecules conduct in solution due to partial dissociation to form ions