Essay Questions on Bonding and Properties of Substances

Assignment I

The properties of substances are largely the result of the type of bond and bond strength between particles of which they are composed. Critically discuss this statement and in your answer refer specifically to the following substances: Silica, graphite, NaCl, I_2 and metallic Cu.

Model Answer

Properties, type and strength of bonding:
Properties could be physical or chemical

Physical Properties
M.p., b.p., latent heat, solubility in water and other solvents, conductivity when solid / liquid / gas / in solution, density, malleability, softness or hardness.
Physical properties normally relate directly to bonding between particles.

Melting point, boiling point, latent heat

a) if strong bonds exist throughout the crystal these are high
eg SiO_2, diamond (covalent), NaCl (Ionic), Cu (metallic)
NB: this is due both to strength of bond and to being continuous throughout crystals. Must break strong bonds before melting etc.

b) Where small individual molecules (strong covalent bonds inside molecules) or atoms are held intermolecularly by weak bonds such as Van der Walls, dipole-dipole, hydrogen bonds then mp, bp, pH are low. Their numerical value depends on the strength of the intermolecular bond involved (V-d-W < d – d < h- b.). Melting etc involves only breaking weak intermolecular bond, not strong covalent bonds inside molecule, eg, I_2, to separate particles.

Solubility – The energy given out when the substance is solvated must be sufficient to supply the energy need to break bonds between particles.

a) Ionic compounds e.g. NaCl strong bonds throughout crystal, but energy needed to break these can be obtained from energy given out when ions are hydrated by water (water is also a good insulator… insulates ions from each other). Organic solvents mainly do not solvate ions therefore cannot overcome lattice energy.
b) Macromolecular compounds (SiO_2, C) and metals (Cu) – need large energy to break bonds which stretch throughout crystal. Little or no solvation energy because solvent molecules not attracted to individual atoms therefore insoluble.
c) Molecular compounds (I_2) – weak intermolecular forces may be overcome by interaction with solvent, or may not. Eg I_2 slightly soluble in water, more soluble in organic solvents

Conductivity

For a substance to conduct there must be charged particles free to move since charged particles must relate to presence/absence of electrons. This will relate to type though, not strength of bonding.

a) Covalent compounds – macro (SiO_2) or simple (I_2) normally have no free electrons or ions therefore do not conduct.
b) Ionic compounds (NaCl) – charged particles held firmly in place in solid therefore non-conducting. When molten or in solution, their ions free to move and carry current.
c) Metals – bond made up of freely moving electrons
Graphite – electrons between sheets are delocalised and free to move therefore in both cases electrons can carry current in solid. Metals also conduct when molten for same reason – graphite has too high a melting point to be tested.

Hardness

Relates to strength and direction of bonds. Cleavage occurs between planes of particles (graphite, I_2, NaCl). If bonds stretch in all direction then hard (diamond)

Density

Close packed particles give high density – related to this rather than to bonding (metals, close packed therefore high density, ionic fairly close, molecular usually loosely packed)

Chemical Properties include reaction with air, water, acids, alkalis, metals, nonmetals.

These do not relate directly to strength and type of bonding, eg oxides some ionic and covalent ones react with water. Others do not regardless of strength of bond (through ionic oxides if they react give alkalis and covalent oxides give acids)

Assignment II

Give an account of the forces which hold together the particles (atoms, ions or molecules) in:
a) a simple crystalline solid
b) a metal
c) water
d) the compound $Cu(NH_3)_4SO_4.H_2O$
Discuss how the physical properties of these materials are related to the forces operating in them.

Model Answer

All forces are electrostatic in nature. Different strengths because different charges and distances involved.
a) salt: ionic bonds, formation of ions by electron transfer to give complete outer shells.
Example:

b) metal
metallic bonds – outer electrons free to move into empty orbitals / subshells on adjacent atoms throughout crystal. Force is attraction between positive ions and delocalised electron cloud.

c) water
covalent bond in molecule, Lewis diagram of electron density: attraction between nuclei and shared electrons:

Attraction between molecules: hydrogen bonding ... attraction between $H^{\delta+}$ (because of electronegativity of oxygen) and lone pairs on adjacent $O^{\delta-}$.

d) $Cu(NH_3)_4^{+2}$ and SO_4^{-2} : ionic bonds, attraction as in (a)
Inside NH_3 and SO_4: covalent bonds as in (c)
Cu^{+2} to NH_3: dative bonding between lone pair on nitrogen and empty orbitals around Cu.
Force between nuclei again. Diagram:

SO_4^{-2} to H_2O: hydrogen bonding, see (c), diagram:

Physical Properties
(a) – Salt:
soluble in water because good insulator and hydration of ions gives energy to break lattice.
Conductivity: none in the solid state because no free charged particles, good when molten or when in aqueous solution because ions free to move.
High m.p., b.p., latent heat because strong forces throughout crystal.

(b) – Metal
Insoluble because insufficient hydration to overcome force of attraction.
Good conductors because electrons free to move in solid or molten ... sea of delocalised electron cloud.
High m.p, b.p, and l.h usually because strong bonds throughout – stronger when close packed and when more electrons involved in metallic bonding.

(c) – Water
Poor conductor – no free charged particles except from self - ionisation (auto-ionisation) of water: $2\ H_2O_{(l)} \rightleftharpoons H_3O^{+1}_{(aq)} + OH^{-1}_{(aq)}$
Low m.p, b.p, l.h since forces between molecules not very strong but higher than expected for covalent molecules since hydrogen bonding stronger than van-der - Waals.

(d) – $Cu(NH_3)_4SO_4.H_2O$
Solubility in water see (c)
Good conductor in solution, poor when solid, see (a)
m.p, b.p., l.h, expected to be high but decomposition may occur first, breaking of H-bonds (weakest) losing water then possibly loss of NH_3, etc.

Assignment III

Covalent substances tend to be volatile, of low melting point, soluble in non-aqueous solvents but not in water and non-electrolytes, whereas electrovalent substances tend to have the opposite properties. Discuss this statement critically, referring particularly to SiO_2, HCl, NaCl, $CHCl_3$, and NH_4Cl.