

Solids, Liquids and Gases

- No problem session tomorrow
- Grant says hand in problem sets next week
- Problems for next week: Ch. 38:11, 15, 37, 52, 55

Solids, Liquids and Gases

- Gases are compressible with volume approximately inversely proportional to pressure; no fixed form
- Liquids are approximately incompressible and have no fixed form
- Solids are incompressible and have a fixed form

Solids, Liquids and Gases

- Bonds between atoms are generally strongest in solids and weakest in gases
- Gases are most likely to have molecules-multi-atomic units containing a small number of atoms
- Solids are most likely to have macroscopic units, for example, crystals or grains

Atomic Bonds

- Atoms are able to form bonds with other atoms
- Strongest bonds are ionic
- Ionic bonds generally form between an atom which has high electron affinity and one which is a willing electron donor
- High electron affinity results from a nearly complete valence shell
- Willing electron donor is an element with a nearly open valence shell
- Inert gases have complete shells and neither accept nor donate electrons

Ionic Bonds

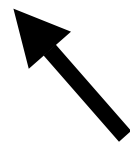
- How do you tell if a bond is ionic?
- Ionic bonds are strong and thus have high melting points
- Ionic bonds yield large molecular dipole moments, that is, large values of ϵ_0
- Examples of highly ionic bonds are NaCl, KF, CsI, etc.

Covalent Bonds

- Covalent bonds result from “electron sharing”
- Need a two-electron wave function with high probability for finding electrons **between** the positive nuclei
- Wave functions that are spatially symmetric under electron interchange satisfy the requirements for covalent bonds

Fermion Wave Functions

- Fermion wave functions must be overall anti-symmetric under particle interchange
- Wave functions have both a spatial symmetry and a spin symmetry
- Overall, anti-symmetry requires either
 - Space anti-symmetric—Spin symmetric
 - Space symmetric—Spin anti-symmetric



Covalent Bond

Covalent Bonds

- Covalent bond in hydrogen has two 1S electrons with anti-symmetric spins
- Orbital angular momentum is zero; spin angular momentum is zero; total angular momentum is zero
- Spatial wave function is symmetric; electrons are mostly between protons; binding energy is 4.52 eV
- Bond is saturated

Van der Waals Bonds

- Van der Waals bonds result from dipole-dipole attraction
- Much weaker than ionic bonds which are monopole-monopole attraction because dipole fields $1/r^3$ and the force of a field on a dipole is proportional to the field gradient
- Molecules can have permanent dipole moments (polar molecules; different electron affinities) or induced dipole moments (non-polar molecules)

Van der Waals Bonds

- Van der Waals forces are stronger for polar molecules
- Van der Waals bonds are sufficiently weak that liquid and solid phases require low temperatures

Hydrogen Bond

- Similar to covalent bond, except that proton is shared rather than an electron
- Results from wave function with high probability for finding a proton (stripped hydrogen atom) between two electronegative nuclei (for example, oxygen)
- Commonly found in biological organics and polymers; important in 3-d structures

Metallic Bonds

- Metals have a lattice of positive nuclei immersed in an “electron gas” composed of contributed valence electrons
- High mobility of electrons in gas leads to high thermal and electrical conductivities
- Bonds are strong (high melting points, high tensile strength) because of electric forces

Molecular Spectra

- Molecules have energy levels due to both rotation and vibration
- Molecular energy level differences are much smaller than atomic energy level differences
- Emission and absorption lines are in the radio part of the E-M spectrum

Molecular Spectra

- Examples:
- Microwave ovens cause vibration of water molecules thus transferring heat into food
- Molecular hydrogen has a 21cm emission line that is often measured using radio telescopes

Estimating Molecular Energy Levels

- Rotational energy levels

$$E = \frac{1}{2} I \omega^2 = \frac{L^2}{2I} = \frac{l(l+1)\hbar^2}{2I}$$

$$r_0 = r_1 + r_2$$

$$\mu = \frac{m_1 m_2}{m_1 + m_2}$$

$$I = \mu r_0^2$$

Tekel

- **Book of Daniel: Chapter 5**
- 24: Then was the part of the hand sent from him; and this writing was written.
- 25: And this is the writing that was written, MENE, MENE, TEKEL, UPHARSIN.
- 26: This is the interpretation of the thing: MENE; God hath numbered thy kingdom, and finished it.
- 27: TEKEL; Thou art weighed in the balances, and art found wanting.
- 28: PERES; Thy kingdom is divided, and given to the Medes and Persians.
- 29: Then commanded Belshazzar, and they clothed Daniel with scarlet, and put a chain of gold about his neck, and made a proclamation concerning him, that he should be the third ruler in the kingdom.
- 30: In that night was Belshazzar the king of the Chaldeans slain.
- 31: And Darius the Median took the kingdom, being about threescore and two years old.