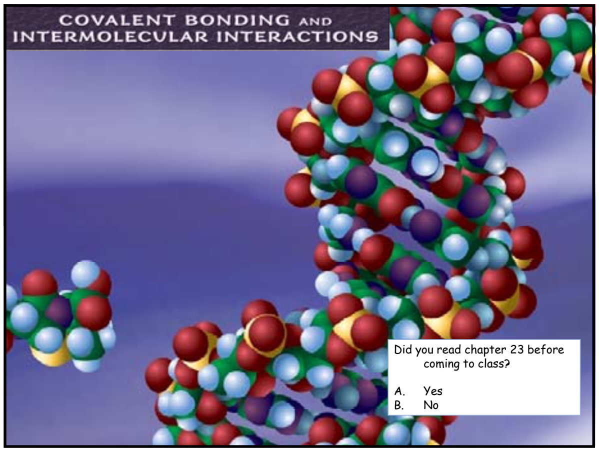
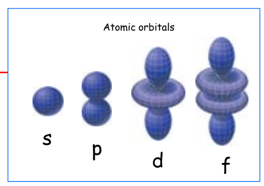


Review of bond types

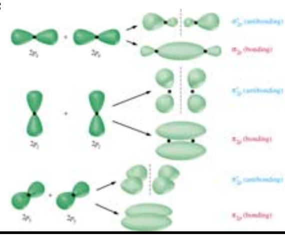
- Metallic bonding: many atoms collectively share orbitals and electrons
- Ionic bonding: metals easily give up electrons to nonmetals, which "want" them
- Today add a 3rd type: covalent bonding

Molecular Orbitals



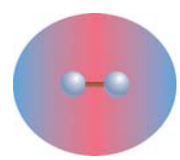
- Orbitals are electron probability standing waves
- Shape of orbital depends on placement of the different nuclei.
- New standing wave patterns (new shapes) when there are multiple nuclei
- Molecular orbitals follow same rules as atomic orbitals:
  - 2 e⁻ / orbital (opposite spins)
  - Fill lowest energy orbitals first

Molecular orbitals



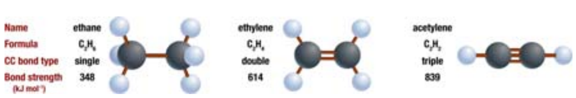
Sharing Electrons to Form Covalent Bonds

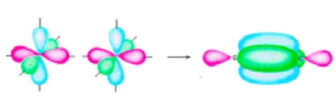
- Resulting molecular orbitals are lower in energy than atomic orbitals
- Often corresponds to filled shells for each atom in bond
- Result: usually molecules rather than network structures.
- Standard Example: $H + H \rightarrow H_2$



Sharing of More Than One Electron Pair: Multiple Bonds

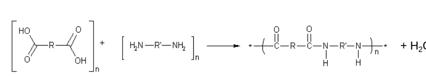
- Multiple bonds are stronger than single bonds (although a double bond is not twice as strong as a single bond)
- By convention we represent single bonds with a single line, double bonds with two lines, and triple bonds with three lines.
- High electron density between multiply-bonded atoms makes them relatively reactive





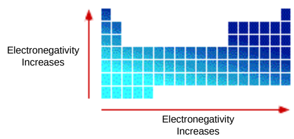
Demonstration of covalent bonding: Nylon formation

- The preferred fabric for parachutes and women's stockings prior to WWII was silk. This was running in short supply, so synthetic fibers were developed.



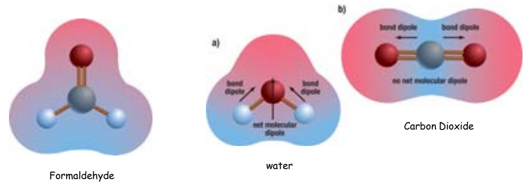
Electron sharing is not equal for unlike atoms

- Different elements have different ability to attract electrons (“electronegativity”)
- Electronegativity increases toward the upper right of periodic table (ignoring noble gases)



Polar Molecules

- Charge map for H_2O
- For a molecule to be polar,
  - Bonds must have unequal sharing: “dipoles”
  - Bond dipoles must not “cancel”
- Water is polar (demo)



Which of the fundamental interactions is important for forces between molecules?

A. The weak nuclear interaction
B. The strong nuclear interaction
C. The electromagnetic interaction
D. The gravitational interaction

Which of the following are important for determining the strength of electromagnetic forces?

A. The distance between the charges
B. The magnitude of the charges
C. The mass of the particles
D. Both A & B

Comparing the distances between two bound atoms in a molecule and the distances between molecules, which is greater (on average)?

A. The distance between bound atoms
B. The distance between molecules
C. They are the same

Which forces do you expect to be greatest?

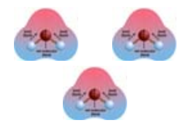
A. Bonding forces between atoms *within* a molecule
B. Attractive forces between *different molecules*
C. There is no way to know

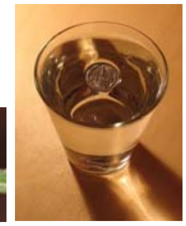
Intermolecular Forces

- "Between" different molecules
- Caused by permanent or temporary charges on molecules
- Much weaker than covalent bonding interactions
- Wide range of strengths explains wide range of boiling, melting points of covalent materials

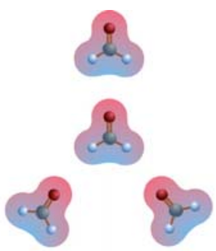
Hydrogen Bonding

- H bound to N, O, or F
- Among strongest intermolecular interactions
- Happens because H is small and has only 1 electron, and the atom it is bound to is quite electronegative. H is essentially a "bare" proton
- The most important H-bond: water



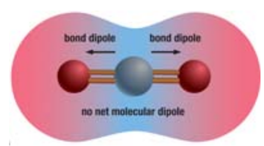


Dipole-dipole interactions

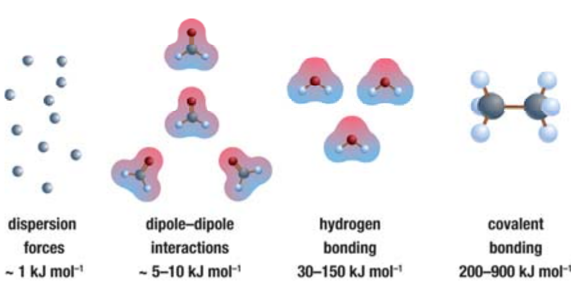


Dispersion forces arise from "temporary dipoles" due to fluctuations in the electron distribution

- Electron distribution not static
- Formation of temporary dipoles
- +/- combination is favored
- Very weak
- Name: "dispersion" or van Der Waals interactions
- Since carbon dioxide has no net dipole, it reacts only through these dispersion forces

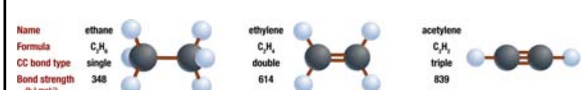


Relative Strengths of Intermolecular Interactions



Sharing of More Than One Electron Pair: Multiple Bonds

- Multiple bonds are stronger
- High electron density between multiply-bonded atoms makes them relatively reactive



What causes nitrogen (N_2) molecules to liquefy?

A. Covalent bonds between the molecules
B. Hydrogen bonds between the molecules
C. Dispersion forces between the molecules
D. Attraction of the permanent dipole in one molecule to the dipole in another

Example: Nitrogen

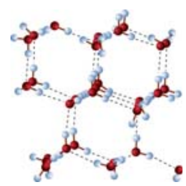
- Properties
  - Chemically unreactive
  - Boiling point 77 K (-196 °C; -321 °F)
  - Colorless
- Why?
  - Triple bond
  - What are strongest *intermolecular* forces?
  - No low-lying molecular orbitals

What is the best explanation for the high freezing point of water (in comparison to Nitrogen)?

A. Covalent bonds between the water molecules
B. Hydrogen bonds between the water molecules
C. Dispersion forces between the water molecules

Example: Water

- Properties
  - Fairly reactive, "universal" solvent
  - Boils at 273 K (0 °C; 32 °F)
  - More dense as liquid than solid
  - Can react with itself: $2H_2O = H_3O^+ + OH^-$
    - Water conducts electricity (but very poorly)
    - This reaction goes only to a very small extent (1 molecule in 10 million!)
- Why?
  - Highly polar, so dissolves ionic materials
  - Extensive hydrogen bonding interactions dissolve nonionic materials like sugars, lead to high boiling point, unusual crystal structure



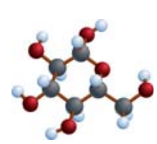
Acids and bases

- Solutions with large hydronium (H_3O^+) ion concentration are acids. Solutions with a small concentration of hydronium and large concentrations of hydroxide (OH^-) are bases
- pH measures acidity
  - 7 is neutral
  - Less than 7 is acidic, more than 7 is basic
  - It is a log scale: change of one in pH is 10^1 change in concentration. Change of 2 in pH is 10^2 change in concentration.
- Solubility often dramatically increases for acids.
- Toothpaste has pH of about 8. Is it an acid or base?

$acid^+ + base^- \rightarrow salt + water$

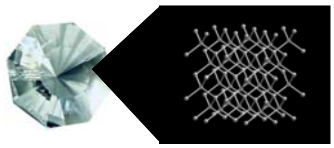
Glucose (a Kind of Sugar)

- Properties
  - Crystalline, molecular solid
  - Melts, then decomposes on heating
  - Sticky
- Why?
  - Many hydrogen bonds hold molecules together in crystal
  - Many H-bonds add up, so melting point is relatively high (compared to water, for example)
  - H-bonds make molecules "sticky"



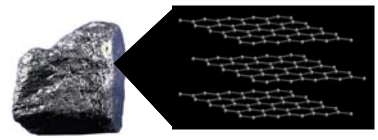
Diamond (Pure Carbon)

- Properties
  - Very hard
  - Crystalline
  - Colorless
  - Decomposes rather than melting
- Why?
  - Covalent network material; like a giant molecule all held together by strong bonds
    - Makes diamond hard
    - Prevents melting
  - No low-lying unoccupied molecular orbitals (unless impurities are present)



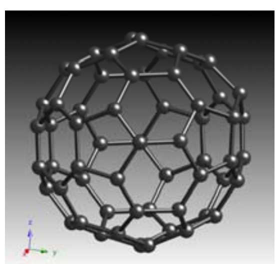
Graphite (Another form of Pure Carbon)

- Properties
  - Soft
  - Crystalline
  - Dark color
- Why?
  - Planes of strongly bound carbon atoms
  - Planes held to each other by very weak intermolecular forces
  - Many low-energy unoccupied molecular orbitals



Buckminsterfullerene (a Third Form of Pure Carbon)

- Discoverers won Nobel Prize in Chemistry



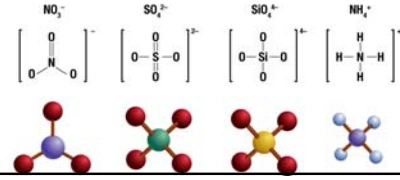
Molecular Ions

- Covalent bonding within the ion
- Stronger covalent bonds if number of electrons doesn't match total nuclear charge ⇒ resulting molecule is charged
- These charged molecules assemble together in crystal lattice like ionic materials
- Examples: nitrate, silicate

Name	nitrate	sulfate	silicate	ammonium
Formula	NO_3^-	SO_4^{2-}	SiO_4^{4-}	NH_4^+

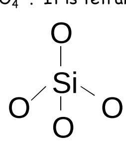
Chemical Drawing

Molecular Model



Minerals

- Over 90% of the earth's crust is made up of silicates.
- The basic building block is the molecular ion SiO_4^{4-}. It is tetrahedral in shape.



- Example: Olivine is a common mineral with the formula:

  $(Mg, Fe)_2SiO_4$

  (Magnesium and Iron are nearly the same size and can substitute for each other.)