Ch. 11 Notes ~ STATES OF MATTER

NOTE: Vocabulary terms are in **boldface and underlined**. Supporting details are in *italics.*

States of Matter: SOLID, LIQUID, GAS, PLASMA

I. Kinetic Theory of Matter
   A. **kinetic energy** *(K.E.)*
      1) *energy of motion*
      2) *equation: $KE = \frac{1}{2} mv^2$*
   B. **Kinetic-Molecular Theory of Matter (KMT)**

- *Matter is composed of PARTICLES.*
- *Particle movement is rapid, constant, and random* (**Brownian motion**)
- *All collisions are perfectly ELASTIC (complete energy transfer).*

   C. Comparison of physical states
      1) gases have the least restriction on motion compared to the other phases of matter, so they have the most particle movement
      2) solids have the most restriction on motion compared to the other phases of matter, so they have the least particle movement

II. **Gases**—*matter with variable shape and variable volume*
   A. kinetic theory of gases

- *Gases are composed of PARTICLES.*
- *Particle movement is rapid, constant, and random* (**Brownian motion**)
- *All collisions are perfectly ELASTIC (complete energy transfer).*

   B. characteristics of gases
      1) low density—mostly space between particles
      2) fluidity—flowing movement
      3) compression and expansion
         a) **compression**—particles can be *pressed together*
         b) **expansion**—particles can be allowed to *move apart*
      4) diffusion and effusion
         a) **diffusion**—*random movement and intermingling of particles to even out the concentration throughout the area*
         b) **effusion**—*gas particles escaping through a tiny hole in the container*
            i. **Graham's Law**: *the effusion or diffusion rate of a gas is indirectly (inversely) proportional to the square root of the molar mass of the gas* (Thomas Graham, 1805-1869)
            ii. larger particles move slower; smaller particles move faster

$$\frac{\text{Rate A}}{\text{Rate B}} = \frac{\sqrt{\text{molar mass B}}}{\sqrt{\text{molar mass A}}}$$

at constant temperature

EXAMPLE 1) Carbon dioxide has a molar mass of 44.01 g/mol. Ammonia (NH_3) has a molar mass of 17.03 g/mol. What is a ratio of their diffusion rates?

CO_2 = A (mentioned first) NH_3 = B (mentioned second)

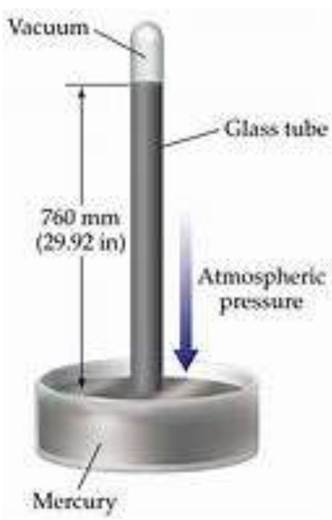
$$\frac{\text{Rate } CO_2}{\text{Rate } NH_3} = \frac{\sqrt{17.03 \text{ g/mol}}}{\sqrt{44.01 \text{ g/mol}}} = \sqrt{0.3869575\ldots} = \boxed{0.6221} \quad \text{OR} \quad \frac{\sqrt{17.03}}{\sqrt{44.01}} = \frac{\sqrt{4.12674\ldots}}{\sqrt{6.63400\ldots}} = \boxed{0.6221}$$

*** decimal answers <1 show that gas A moves slower than gas B (“low is slow”)
*** answers >1 show that gas A moves faster than gas B

C. gas pressure

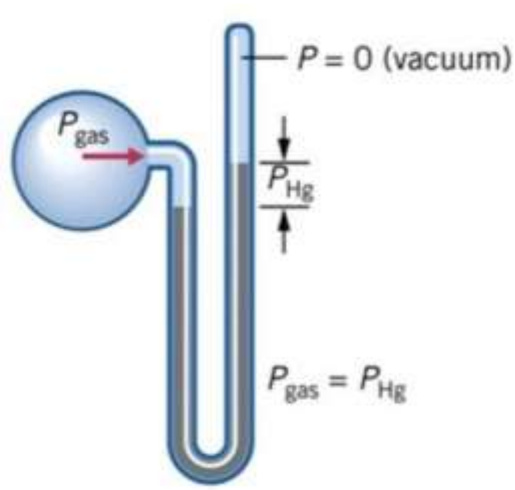
1) **gas pressure**—*collisions* of gas particles on objects
2) **atmospheric pressure**—*collisions of “air” particles* on objects
3) SI unit of pressure = Pa (Pascal), named after Blaise Pascal (1623-1662)
4) pressure measuring instruments
   a) **barometers** measure atmospheric pressure
   b) **manometers** measure pressure of enclosed gases

MERCURY BAROMETER



Source: Washington.edu

CLOSED-END MANOMETER



Source: Jespersen

5) standard pressure: (this is the “P” from STP)

STANDARD ATMOSPHERIC PRESSURE, 5 ways:
1 atm* **101.3 kPa** **14.7 psi**
760 mm Hg* **760 torr***
*atm, mm Hg, and torr standards are exact sig.figs.

The unit of torr is named after Evangelista Torricelli (1608-1647)

6) (Dalton’s Law of partial pressures will be addressed later, in the gas chapter)
7) examples of pressure conversions

EXAMPLE 2) Convert a pressure of 847 mm Hg to kPa.

$$847 \text{ mm Hg} \times \frac{101.3 \text{ kPa}}{760 \text{ mm Hg}} = \boxed{113 \text{ kPa}}$$

EXAMPLE 3) What is 8.9 psi expressed in atm?

$$8.9\ \cancel{psi} \times \frac{1\ atm}{14.7\ \cancel{psi}} = \boxed{0.61\ atm}$$

EXAMPLE 4) 344 mm Hg = _____ psi

$$344\ mm\ Hg \times \frac{14.7\ psi}{760\ \cancel{mm\ Hg}} = \boxed{6.65\ psi}$$

III. Forces of attraction

A. *intermolecular forces (intermolecular attractions)—forces between molecules*

B. categories

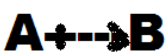
1) *ionic* (between cations and anions)
2) *covalent* (between molecules)
3) *metallic* (metal cations and delocalized electrons)

C. terms for review

1) polar (bond)—having an unequal sharing of electrons
2) *polar (molecule)*—having partially positive and partially negative areas

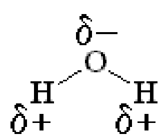
partially positive = δ+ *partially negative* = δ-

3) *dipole*–a polar molecule

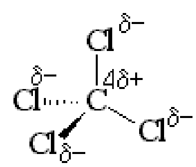


POLAR molecule (dipole)

NONPOLAR molecule



POLAR (asymmetrical)



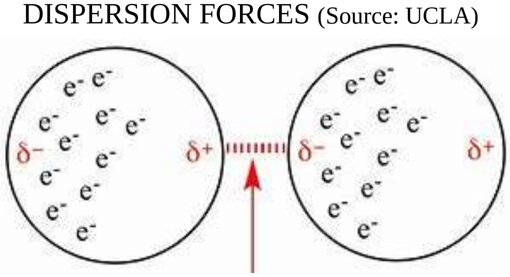
NONPOLAR (symmetrical)

Source: webchem.net

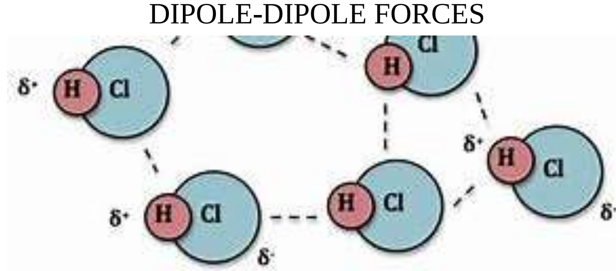
D. types of intermolecular forces

1) *van der Waals forces*—usually used to describe all intra- and inter-molecular forces other than covalent and ionic bonds (Johannes van der Waals, 1837-1923)
2) **dispersion forces**, also called **London forces** after Fritz London (1900-1954)
   a) the *weakest* force between molecules
   b) between *two nonpolar* molecules
   c) temporary dipoles form
3) **dipole interactions** (also called **dipole-dipole forces**)
   a) between *two polar* molecules
   b) between permanent dipoles

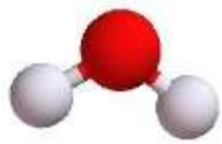
DISPERSION FORCES (Source: UCLA)



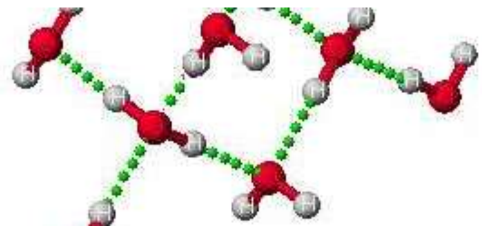
DIPOLE-DIPOLE FORCES



4) **hydrogen bonds**—*an attraction between hydrogen and an unshared pair of an electronegative element on a neighboring molecule*
   a) shown as a dotted line between molecules
   b) not an actual bond between atoms
   c) *strongest* intermolecular force



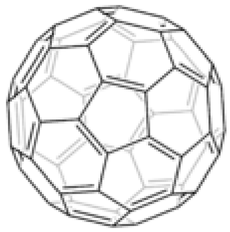
WATER MOLECULE



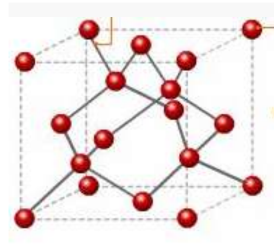
HYDROGEN BONDING between water molecules (dotted lines)

IV. **Liquids**— *matter with variable shape and fixed volume*
A. characteristics
1) density: more dense than gases
2) compressibility: much more difficult to compress than gases
3) fluidity—flowing movement
4) **viscosity**—*the resistance of a liquid to flow*
   a) viscosity increases with increased attractive forces (directly proportional)
   b) viscosity increases with increased particle size (directly proportional)
   c) viscosity increases with increased particle chain length, if applicable (directly proportional)
   d) viscosity decreases with increased temperature (indirectly proportional)
5) **surface tension**—*attraction between molecules on the surface of a liquid*
   a) surface tension makes water bead
   b) **surfactants** *(surface-active agents)—"wetting agents" which decrease surface tension* by breaking hydrogen bonds (soaps)
6) cohesion and adhesion
   a) **cohesion**—*attractive forces between identical molecules*
   b) **adhesion**—*attractive forces between different molecules*
7) **capillary action**—*moving upward, against gravity* (up through roots, etc.)

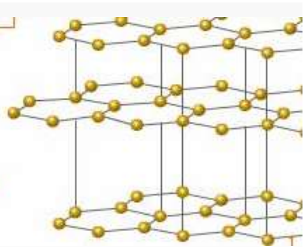
V. **Solids**—*matter with fixed shape and fixed volume*
A. **freezing**—*conversion of a liquid to a solid*
B. **sublimation**—*conversion of a solid directly to a gas or vapor*
C. **melting**—*conversion of a solid to a liquid at the* **melting point** *(m.p.)*
D. types of solids
1) **crystalline**
   a) **crystal lattice**—*organized repeating pattern in 3-D*
   b) **unit cell**—*smallest repeating unit in a crystal*
   c) **allotropes**—two or more different arrangements for the same element in the same state (C: graphite, diamond, "buckyballs")



Buckminsterfullerene (buckyball, C_{60})



diamond

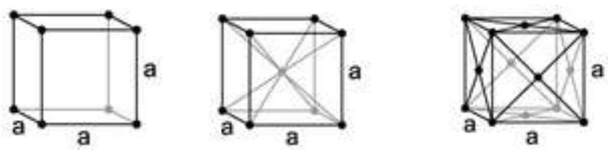


graphite

(Source: tutorvista.com)

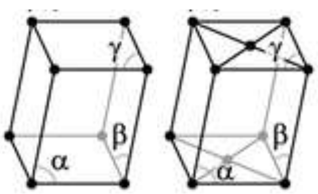
d) *categories and examples of crystalline solids*
- *atomic (solids of Group 18 or VIIIA)*
- *molecular (sugars)*
- *covalent network (quartz)*
- *ionic (BI,TI, other)*
- *metallic (iron)*

e) common shapes of crystals (www.nationmaster.com)



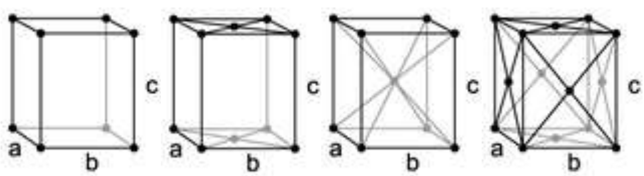
simple body-centered face-centered

CUBIC (3)



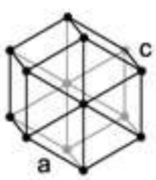
simple centered

MONOCLINIC (2)

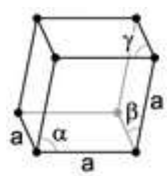


simple base-centered body-centered face-centered

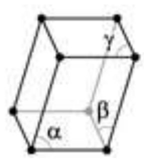
ORTHORHOMBIC (4)



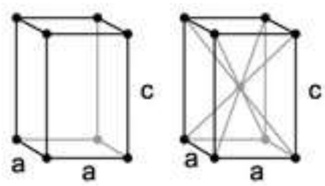
HEXAGONAL



RHOMBOHEDRAL



TRICLINIC



simple body-centered

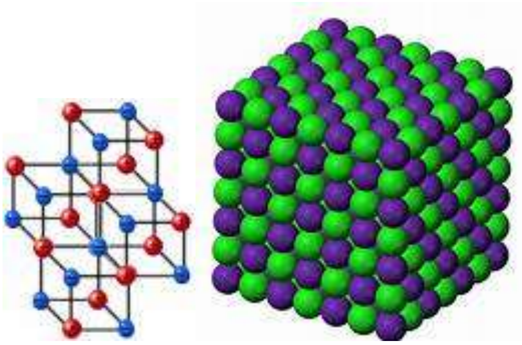
TETRAGONAL (2)

2) **amorphous**—solids without a set structure

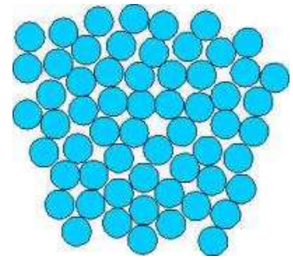
a) incomplete crystal lattice formed

b) rubber, plastics, glass (new research on glass ongoing)

c) glass can be called a *supercooled liquid*



CRYSTAL LATTICES



AMORPHOUS SOLID

VI. Other Forms of Matter

A. **amorphous solids** (amorphous materials)

B. *liquid crystals*—an intermediate phase formed when solids partially melt in only one or two dimensions (LCD = liquid crystal display)

C. **plasmas**

1) *gaseous mixture of cations and electrons*
2) most common form of matter in the universe but least common on Earth itself
3) exists at high temperatures

VII. Phase Changes and Kinetic Energy (K.E.)

A. Temperature and particle motion

1) temperature—the measure of the *average K.E.* of particles in a sample
2) **Kelvin** *(K) – SI base unit of temperature; measures average K.E.*
   a) Kelvin temp α K.E. (*Kelvin temp is directly proportional to K.E.*)
   b) When temp increases, particle motion increases. When temp decreases, particle motion decreases. (A temp of 300 K has twice the kinetic energy as 150 K.)
   c) *0 Kelvin* = **absolute zero** = *no molecular motion*
   d) Absolute zero is theoretical. 0.006 K is the lowest achieved Kelvin temperature.
   e) no degrees sign (°) is used with Kelvin numbers
   f) there will never be negative numbers for Kelvin temperatures
3) Kelvin-Celsius conversion equation **K = C + 273.15**

EXAMPLE 5) Express 366.13 K in degrees Celsius.

K = C + 273.15   366.13 = C + 273.15   C = 92.98 °C

EXAMPLE 6) Convert a temperature of 45 °C to Kelvin.

K = C + 273.15   K = 45 + 273.15 = 318 K

B. Changing state; **phase changes**

IMPORTANT: Temperature does not change during a phase change.
Increasing the temperature will only make the change happen faster.

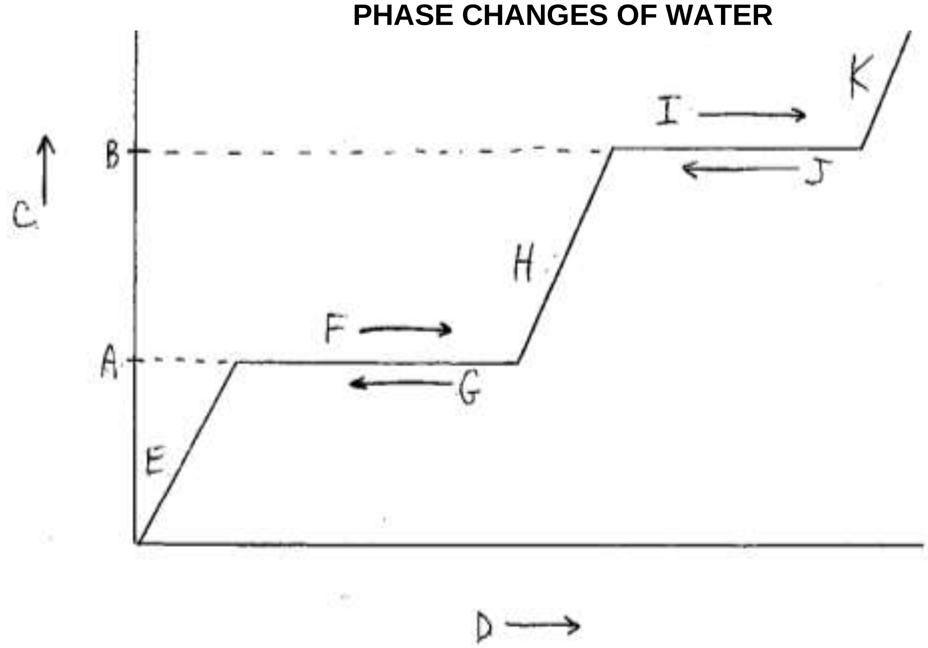
1) evaporation and condensation
   a) **evaporation** *(vaporization)—conversion of a liquid to a gas or vapor below the boiling point (b.p.)*
   b) **condensation**—*conversion from a gas or vapor to a liquid*
   c) **dynamic equilibrium** *(equilibrium = balance)— when evaporation rate equals the condensation rate*

2) **boiling**—*conversion from a liquid to a gas or vapor at the boiling point*
   a) **vapor pressure**—pressure of evaporated particles in a partially filled, sealed container
   b) **boiling point** *(***b.p.***)*—temperature at which the vapor pressure equals the external atmospheric pressure
   c) **normal boiling point**—b.p. of liquids at standard pressure
   d) **heat of vaporization**—the amount of heat necessary to boil or condense 1 mole of a substance at its boiling point

3) sublimation and deposition
   a) **sublimation**—*changing from a solid directly to a vapor*
   b) **deposition**—changing from a vapor/gas directly to a solid

4) melting and freezing
   a) **melting**—changing from a solid to a liquid
   b) **freezing**—changing from a liquid to a solid
   c) **heat of fusion**—the amount of heat absorbed or given off to melt or freeze 1 mole of substance at its freezing point

PHASE CHANGES OF WATER



A = freezing point, (melting point, 0 ºC)
B = boiling point (100 ºC)
C = temperature (ºC)
D = time
E = solid
F = melting
G = freezing
H = liquid
I = boiling
J = condensing
K = gas

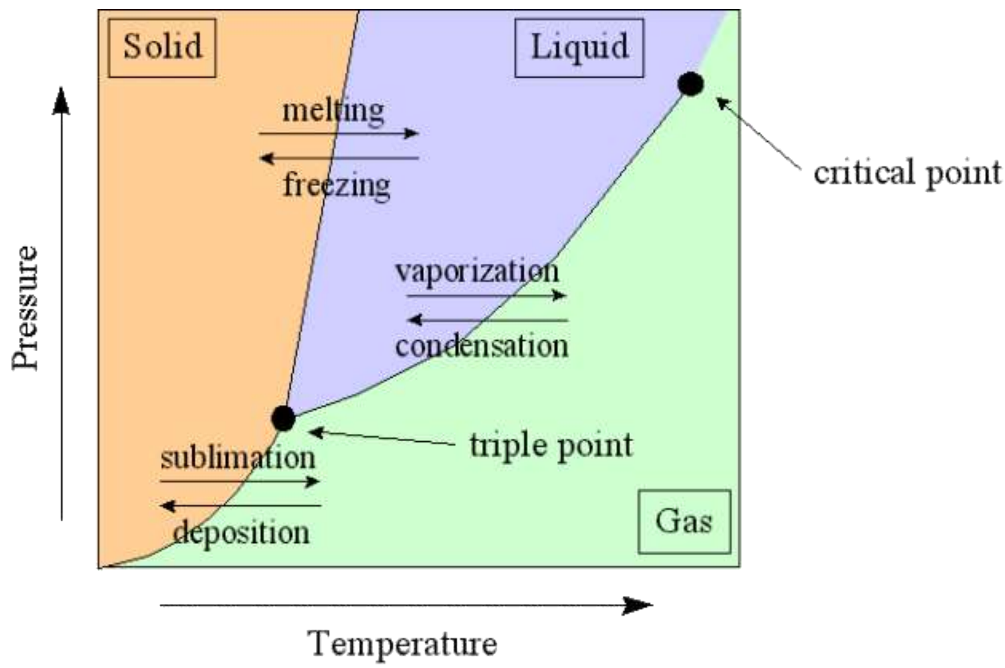
VIII. **<u>Phase Diagrams</u>**

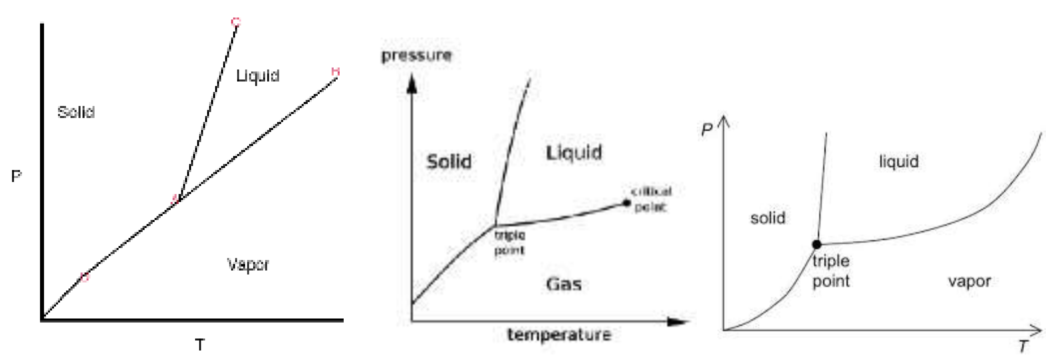
A. *graph of the relationships between all phases of a substance*

B. consists of three curves and a **<u>triple point</u>**, which is the point where all three meet

C. *critical point*—the point at which the physical properties of the liquid and gaseous states are identical

PHASE DIAGRAM (Source: FSU)





(Sources: scramling, ccuart, csun.edu)