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# **The Gas, Liquid, and Solid Phase**

**When are interparticle forces important?**

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# Kinetic Theory

## A. Principles

- **Matter is composed of particles in constant, random, motion**
- **Particles collide elastically if they do not react**
- **All particles at a given temp do not have the same KE**

**B. Solids and liquids have particles that are relatively close together - intermolecular forces and shapes of molecules or ions are very important in determining properties**

- C. Gas particles are very far apart -hundreds to thousands of times their own diameters. Thus interactions are usually small and if we neglect them we will not make a large error.**
- D. This allows us to “model” the behavior of gases by defining an ideal gas which is often close to a real gas.**
- 1. Ideal gas particles are point masses so the particles occupy no volume themselves.**
  - 2. Particles have no attraction for each other.**

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# Gas Laws

**A. Measurement- 4 variables specify the state of a gas -**

- **Pressure - many units are used (we shall look at this next)**
- **Volume -  $m^3$ , liters**
- **Number of particles - moles**
- **Temperature - Kelvin (we shall see why soon!)**

**B. Pressure = Force/Area**

- **Units -  $lb/in^2$ ,  $N/m^2$  = Pascal, bar =  $10^5$  Pa, mm Hg=torr, inches of Hg, atm**
- **It is more difficult to measure gas pressure in force/area units. That is why we often measure pressure in terms of what pressure can do - torr, in Hg**

- **It is necessary to convert between these units. A convenient way to do this is to memorize the values for standard pressure**

<b>760. mm Hg</b>	<b>760. torr</b>	<b>30.0 in Hg</b>
<b>1.00 Atm</b>	<b>14.7 lb/in<sup>2</sup></b>	<b>1.013 x 10<sup>5</sup> Pa</b>
<b>101.3 kPa</b>	<b>1.013 bar</b>	

## **C. Temperature**

**The Kelvin scale is used because it is an absolute temperature scale. This means that it begins at absolute zero - the point at which all translational motion would cease. For an ideal gas this means that volume would be zero since it is composed of point masses.**

**Standard temperature is defined at 0°C or 273 K.**

**D. Boyle's Law**  $P \propto 1/V$  when  $n$  and  $T$  are constant

**E. Charles' Law**  $V \propto T$  when  $n$  and  $P$  are constant

**T must be expressed in Kelvin.**

**F. Ideal Gas Law Equation**

$$PV = nRT$$

**The constant  $R$  relates the other variables. From both experimental and theoretical work we know that 1 mole of a gas occupies 22.4 l at 273 K and 1 atm pressure. This gives a value of 0.0821 Atm - liters/mole-K.**

**G.  $PV = nRT$  can also be used to obtain a general use equation for changes in a gas.**

$$\frac{P_1 V_1}{P_2 V_2} = \frac{n_1 T_1}{n_2 T_2}$$

**H. We can also substitute for the (n) in  $PV = nRT$ .**

**$n = m/M$  where  $m$  = mass in grams and  $M$  = molar mass in g/mole. This gives**

$$PV = \frac{m}{M} RT$$

**I. Since Density = mass/volume, an expression for density can also be obtained for a gas**

$$***D = \frac{PM}{RT}***$$

**J. Particle speeds and Graham's Law**

**If different gases have the same temperature, do they have the same average KE? do they have the same speed?**



**Since temperature is a measure of KE they have the same average KE but not the same speed. In fact**

$$\frac{v_1}{v_2} = \sqrt{\frac{M_2}{M_1}}$$

**where v is velocity (speed) and M is molar mass.**

**Since distance = velocity x time we also find that**

$$\frac{D_1}{D_2} = \sqrt{\frac{M_2}{M_1}} \text{ and } \frac{t_2}{t_1} = \sqrt{\frac{M_2}{M_1}}$$

**K. What are the relationships between different gases in a mixture?**

$$\text{total moles} = n_x + n_o + n_z$$

$$\text{total volume} = V_x = V_o = V_z$$

$$\text{Temperature} = T_x = T_o = T_z$$

$$\text{total pressure} = P_x + P_o + P_z$$

**This last statement is called Dalton's Law of Partial Pressures. It means that each gas acts independently in the container and exerts its own pressure.**

$$\text{For each component } P_x = n_x RT/V$$

$$\text{For the total gas } P_{\text{tot}} = n_{\text{tot}} RT/V$$

$$\text{so } P_x = (\text{mole fraction of X}) P_{\text{tot}}$$

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# Stoichiometry

**A. Mass/volume or volume/mass  
(1 reactant or product given)**

**2.02 g of hydrogen react with an excess of oxygen to produce how many liters of water vapor? The water vapor has a pressure of 300. torr and a temperature of 300. K.**

**B. Mass/volume or volume/mass (limiting reactant)  
(more than one reactant or product given) -**

**2.02 g of hydrogen react with 8.00 g of oxygen to produce how many liter of water vapor? The water vapor has a pressure of 300. torr and a temperature of 300. K.**

### **C. Volume/volume under same conditions**

**10.0 liters of hydrogen react with 8.00 liters of oxygen to produce how many liters of water vapor at the same T and P?**

**Use Avogadro's hypothesis - equal volumes of gases at the same T and P contain equal numbers of molecules. This means that a ratio of volumes is the same as a ratio of moles.**

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# The Solid and Liquid Phase

The particle spacings of the solid and liquid phase are such that we must take into account the forces between the particles. In general the properties of solids and liquids are a function of spacing, arrangement and “intermolecular” or “interparticle” forces.

Type of force	Cause for force	Strength (kJ/mole)
covalent bonding between atoms	sharing of electrons	100 - 1000
metallic bonding between atoms	sharing of high energy conduction band electrons	1000
ionic bonding	ion charge attraction	100 - 1000
ion - dipole	ion dipole attraction	40 - 600

**The next types are much weaker and are called Van der Waals forces as a group.**

<b>dipole - dipole</b>	<b>dipole attraction</b>	<b>5-25</b>
<b>dipole - induced dipole</b>	<b>weak dipole attraction</b>	<b>2-10</b>
<b>Instantaneous dipole - induced dipole (also called London force or dispersion force)</b>	<b>very weak dipole attraction</b>	<b>.05 - 40</b>

**The induced dipoles and instantaneous dipoles are due to the polarizability of the molecules. This is a measure of how easily the electric charge distribution of the molecule is distorted. This polarizability usually increases as the size of the molecule increases.**

# Hydrogen bonding

- **special type of dipole-dipole interaction**
- **only occurs between molecules where H is bonded to N, O, and F**
- **High electronegativities of N, F and O give very polar bonds with H and lead to very strong dipole interactions**
- **Simple molecules like H<sub>2</sub>O, NH<sub>3</sub>, and HF hydrogen bond as well as larger molecules and even giant molecules like proteins.**
- **H bonding is responsible for the coiling of protein and nucleic acid chains**

**These forces have effects on the properties of solids and liquids. The structure of solids will be covered in another chapter. Some important properties of liquids are:**

- 1. Vapor pressure - pressure exerted by evaporation of highly energetic particles from a surface**
  - Boiling is defined as the point at which VP of liquid = atmospheric pressure.**
  - Melting is defined as the point at which VP solid = VP liquid.**
  - High BP and MP's indicate strong interparticle forces.**
  - In a series of compounds where there are only very weak dispersion forces, increasing molar mass will decrease the VP and increase the BP.**



- 2. Enthalpy of vaporization - the heat required to convert liquid to gas.**
  - **High  $\Delta H_{\text{vap}}$  indicates strong interparticle forces.**
- 3. Surface tension - an elastic film on a liquid surface due to the unbalanced forces on the surface particles. It measures the work required to expand the surface.**
  - **High surface tensions indicate strong interparticle forces.**

**Specific effects of H-bonding on both the solid and liquid states of water include**

- 1. Water expands when it freezes.**
- 2. Water has a much higher BP and MP than should be expected.**
- 3. Water has a much higher heat capacity than expected**
- 4. Liquid Water has a high surface tension**
- 5. Liquid Water has the ability to dissolve many substances and is called the universal solvent.**