Gas Laws

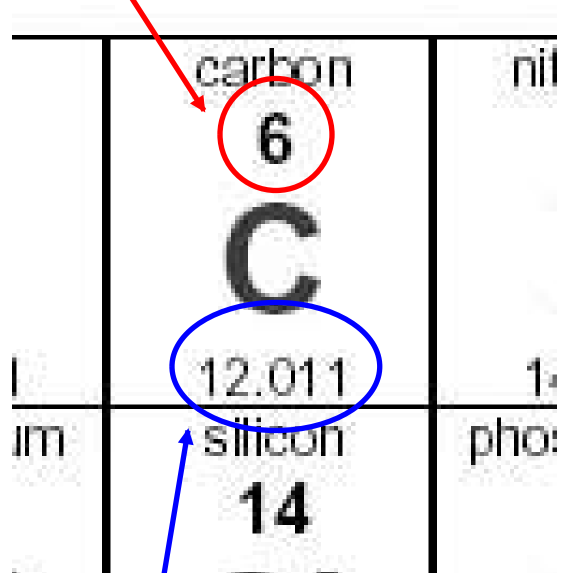
AP Physics B

The Periodic Table

All of the elements on the periodic table are referred to in terms of their atomic mass. The symbol ***u*** is denoted as an atomic mass unit.

1 amu = 1.66 x 10^{-27} kg

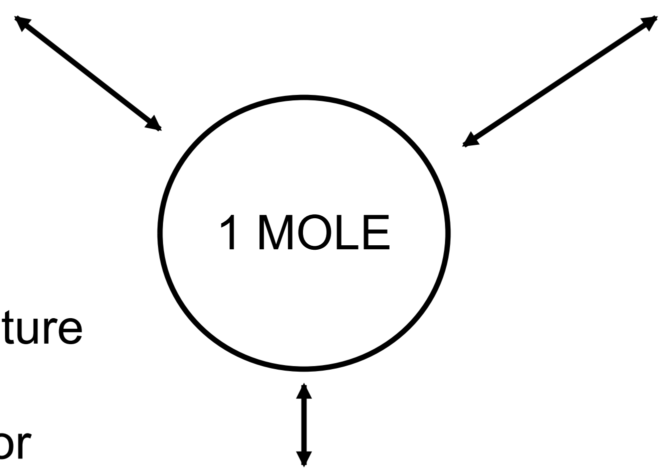
Atomic # - # of protons OR electrons



Atomic Mass - # of protons + Neutrons

The Mole

The word "mole" is derived from Latin to mean "heap" or "pile". It is basically a chemical counting unit. Below, what we have is called the Mole Road Map and it summarizes what a mole equals.



STP = Standard Temperature and Pressure

- ST = 0 degrees Celsius or 273 Kelvin
- SP = atmospheric pressure

Example

A flexible container of Oxygen(O_2) has a volume of 10.0 m^3 at STP. Find the # moles and molecules that exist in the container

$$10m^3\left(\frac{1L}{1x10^{-3}m^3}\right)\left(\frac{1mole}{22.4L}\right)\left(\frac{32.0g}{1mole}\right) =$$ 14,285.71 moles

$$14{,}285.71moles\left(\frac{6.02x10^{23}\ particles}{1mole}\right) =$$ $8.51x10^{29}$ particles

Factors that effect a GAS

1. The **quantity** of a gas, ***n***, in moles
2. The **temperature** of a gas, ***T***, in Kelvin (Celsius degrees + 273)
3. The **pressure** of a gas, ***P***, in pascals
4. The **volume** of a gas, ***V***, in cubic meters

Gas Law #1 – Boyles' Law (complete TREE MAP)

"The pressure of a gas is inverse related to the volume"

- *Moles and Temperature are constant*

$$P \alpha \frac{1}{V} \rightarrow P = \frac{k}{V}$$

$k = \text{constant of proportionality}$

$$P_o V_o = k$$

$$PV = k$$

$$P_o V_o = PV$$

Gas Law #2 – Charles' Law

"The volume of a gas is directly related to the temperature"

- *Pressure and Moles are constant*

$$V_o \alpha\ T_o \rightarrow V_o = kT_o$$

$$k = \frac{V_o}{T_o}$$

$$k = \frac{V}{T}$$

$$\frac{V_o}{T_o} = \frac{V}{T}$$

Gas Law #3 – Gay-Lussac's Law

"The pressure of a gas is directly related to the temperature"

- *Moles and Volume are constant*

$$P_o \alpha\ T_o \rightarrow P_o = kT_o$$

$$k = \frac{P_o}{T_o}$$

$$k = \frac{P}{T}$$

$$\frac{P_o}{T_o} = \frac{P}{T}$$

Gas Law #4 – Avogadro's Law

"The volume of a gas is directly related to the # of moles of a gas"

- *Pressure and Temperature are constant*

$$V_o \alpha\ n_o \rightarrow V_o = kn_o$$

$$k = \frac{V_o}{n_o}$$

$$k = \frac{V}{n}$$

$$\frac{V_o}{n_o} = \frac{V}{n}$$

Gas Law #5 – The Combined Gas Law

You basically take Boyle's Charles' and Gay-Lussac's Law and combine them together.

- *Moles are constant*

$$P_oV_o \alpha\ T_o \rightarrow P_oV_o = kT_o$$

$$k = \frac{P_oV_o}{T_o}$$

$$k = \frac{PV}{T}$$

$$\frac{P_oV_o}{T_o} = \frac{PV}{T}$$

Example

Pure helium gas is admitted into a leak proof cylinder containing a movable piston. The initial volume, pressure, and temperature of the gas are 15 L, 2.0 atm, and 300 K. If the volume is decreased to 12 L and the pressure increased to 3.5 atm, find the final temperature of the gas.

$$\frac{P_o V_o}{T_o} = \frac{PV}{T} \rightarrow T = \frac{T_o PV}{P_o V_o}$$

$$T = \frac{(12)(3.5)(300)}{(15)(2)} =$$ 420 K

Gas Law #6 – The IDEAL Gas Law

All factors contribute! In the previous examples, the constant, k, represented a specific factor(s) that were constant. That is NOT the case here, so we need a NEW constant. This is called, R, the universal gas constant.

$$PV \; \alpha \; nT$$

$$R = \text{constant of proportionality}$$

$$\text{R} = \text{Universal Gas Constant} = 8.31 \frac{\text{J}}{\text{mol} \bullet \text{K}}$$

$$PV = nRT$$

Example

A helium party balloon, assumed to be a perfect sphere, has a radius of 18.0 cm. At room temperature, (20 C), its internal pressure is 1.05 atm. Find the number of moles of helium in the balloon and the mass of helium needed to inflate the balloon to these values.

$$V_{sphere} = \frac{4}{3}\pi r^3 \rightarrow \frac{4}{3}\pi (0.18)^3 =$$ **0.0244 m^3**

$$T = 20 + 273 =$$ **293 K**

$$P = 1.05 atm =$$ **1.05x10^5 Pa**

$$PV = nRT \rightarrow n = \frac{PV}{RT}$$

$$n = \frac{(1.05x10^5)(0.0244)}{(8.31)(293)} =$$ **1.052 moles**

AP Physics: gas law requirements

$$P_oV_o = PV$$

$$\frac{V_o}{T_o} = \frac{V}{T}$$

$$\frac{P_o}{T_o} = \frac{P}{T}$$

$$\frac{P_oV_o}{T_o} = \frac{PV}{T}$$

$$PV = nRT$$

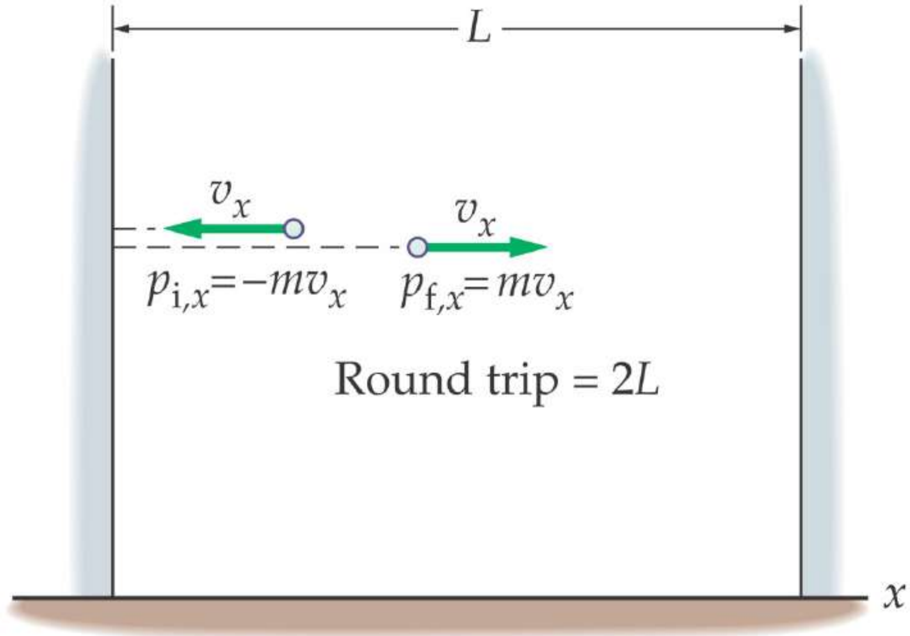
Kinetic Theory

The kinetic theory relates microscopic quantities (position, velocity) to macroscopic ones (pressure, temperature). Assumptions:

- ***N* identical molecules of mass *m* are inside a container of volume *V*; each acts as a point particle.**
- **Molecules move randomly and always obey Newton's laws.**
- **Collisions with other molecules and with the walls are elastic.**

Kinetic Theory

Pressure is the result of collisions between the gas molecules and the walls of the container.

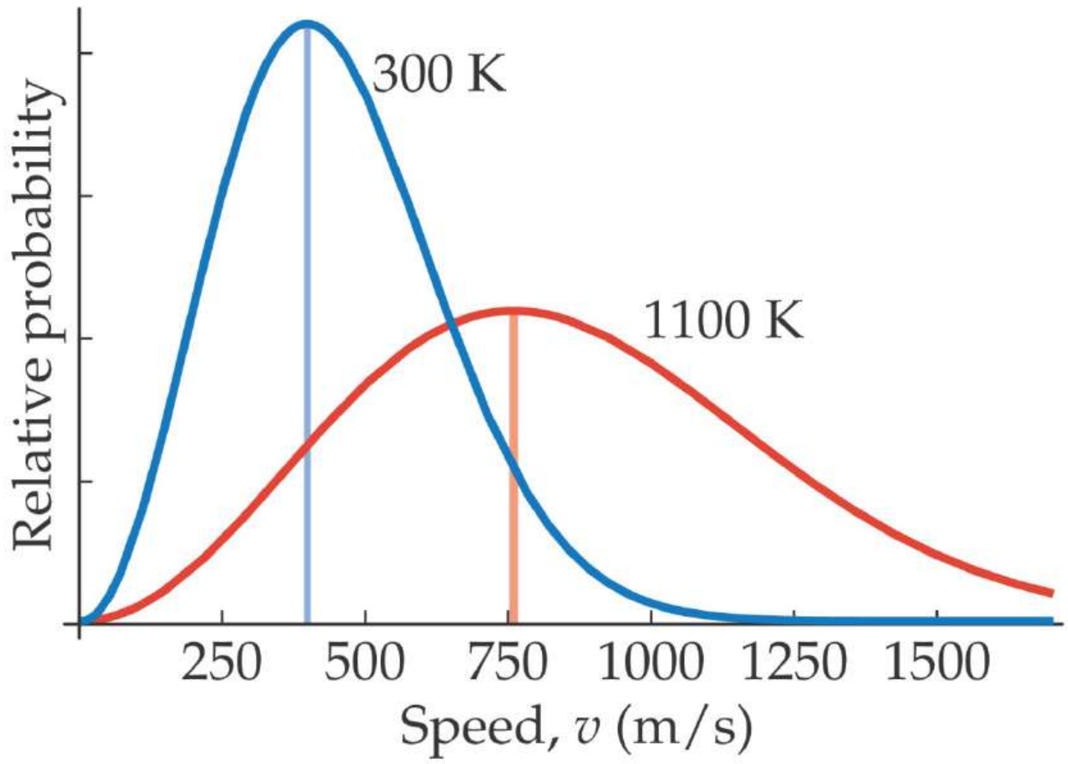


It depends on the mass and speed of the molecules, and on the container size:

$$P = \frac{F}{A} = \frac{(mv_x^2/L)}{L^2} = \frac{mv_x^2}{L^3} = \frac{mv_x^2}{V}$$

Kinetic Theory

Not all molecules in a gas will have the same speed; their speeds are represented by the Maxwell distribution, and depend on the temperature and mass of the molecules.



Kinetic Theory

We replace the speed in the previous expression for pressure with the average speed:

Including the other tw

$$P = \frac{m(v_x^2)_{\text{av}}}{V}$$

$$P = \frac{1}{3}\left(\frac{N}{V}\right)m(v^2)_{\text{av}}$$

Therefore, the pressure in a gas is proportional to the average kinetic energy of its molecules.

17-2 Kinetic Theory

Comparing this expression with the ideal gas law allows us to relate average kinetic energy and temperature:

Kinetic Energy and Temperature

$$\left(\tfrac{1}{2}mv^2\right)_{av} = K_{av} = \tfrac{3}{2}kT$$

The square root of $(v^2)_{av}$ is called the root mean square (rms) speed.

Boltzmann Constant, *k*

$k = 1.38 \times 10^{-23}$ J/K

SI unit: J/K

Kinetic Theory

Solving for the rms speed gives:

RMS Speed of a Gas Molecule

$$v_{\text{rms}} = \sqrt{(v^2)_{\text{av}}} = \boxed{\sqrt{\frac{3kT}{m}}}$$

SI unit: m/s

Boltzmann Constant, *k*

$k = 1.38 \times 10^{-23}$ J/K

SI unit: J/K

17-2 Kinetic Theory

The internal energy of an ideal gas is the sum of the kinetic energies of all its molecules. In the case where each molecule consists of a single atom, this may be written:

Internal Energy of a *Monatomic* Ideal Gas

$$U = \frac{3}{2}NkT$$

SI unit: J

17-5 Latent Heats

- The heat required to convert from one phase to another is called the latent heat.
- The latent heat, *L*, is the heat that must be added to or removed from one kilogram of a substance to convert it from one phase to another. During the conversion process, the temperature of the system remains constant.

Definition of Latent Heat, *L*

$$L = \frac{Q}{m} \qquad \text{17-20}$$

SI unit: J/kg

17-5 Latent Heats

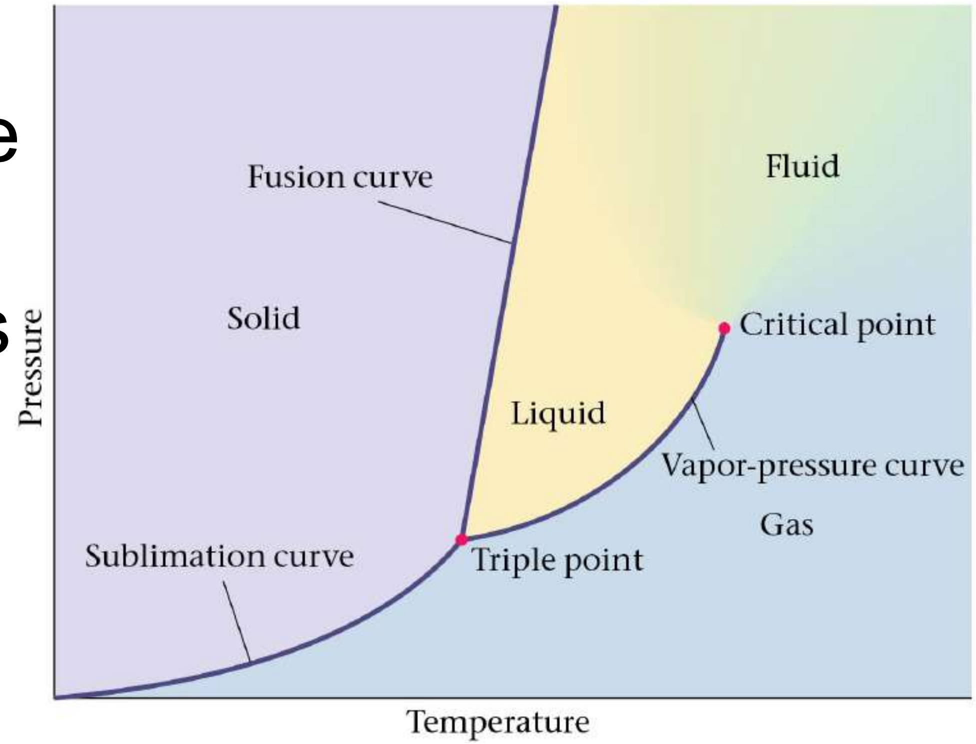
- The latent heat of fusion is the heat needed to go from solid to liquid; the latent heat of vaporization from liquid to gas:

TABLE 17-4 Latent Heats for Various Materials

Material	Latent heat of fusion, L_f (J/kg)	Latent heat of vaporization, L_v (J/kg)
Water	33.5×10^4	22.6×10^5
Ammonia	33.2×10^4	13.7×10^5
Copper	20.7×10^4	47.3×10^5
Benzene	12.6×10^4	3.94×10^5
Ethyl alcohol	10.8×10^4	8.55×10^5
Gold	6.28×10^4	17.2×10^5
Nitrogen	2.57×10^4	2.00×10^5
Lead	2.32×10^4	8.59×10^5
Oxygen	1.39×10^4	2.13×10^5

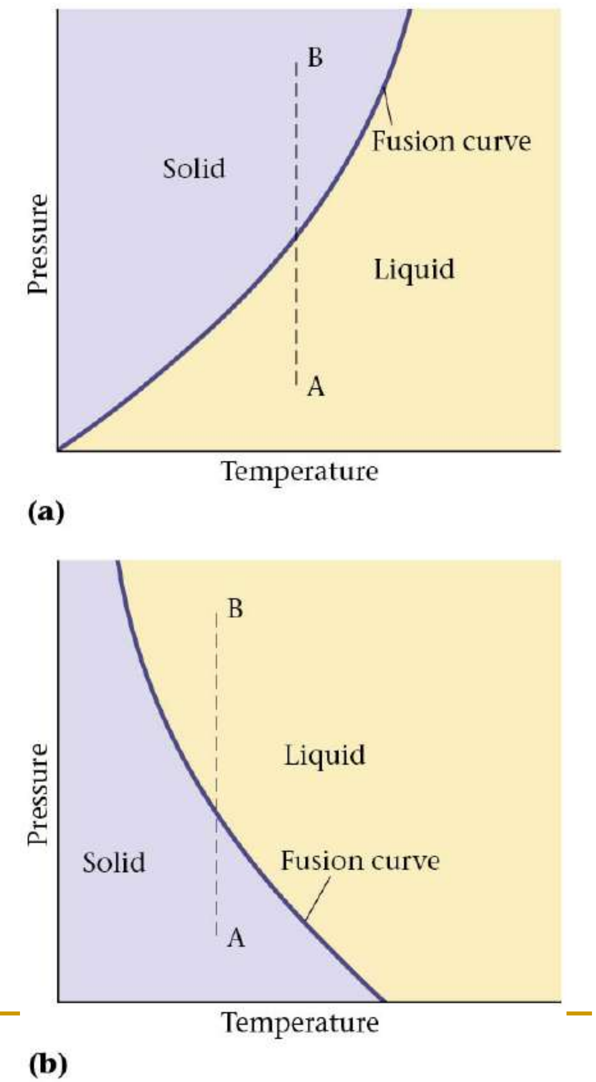
17-4 Phase Equilibrium and Evaporation

- This curve can be expanded. When the liquid reaches the critical point, there is no longer a distinction between liquid and gas; there is only a "fluid" phase.



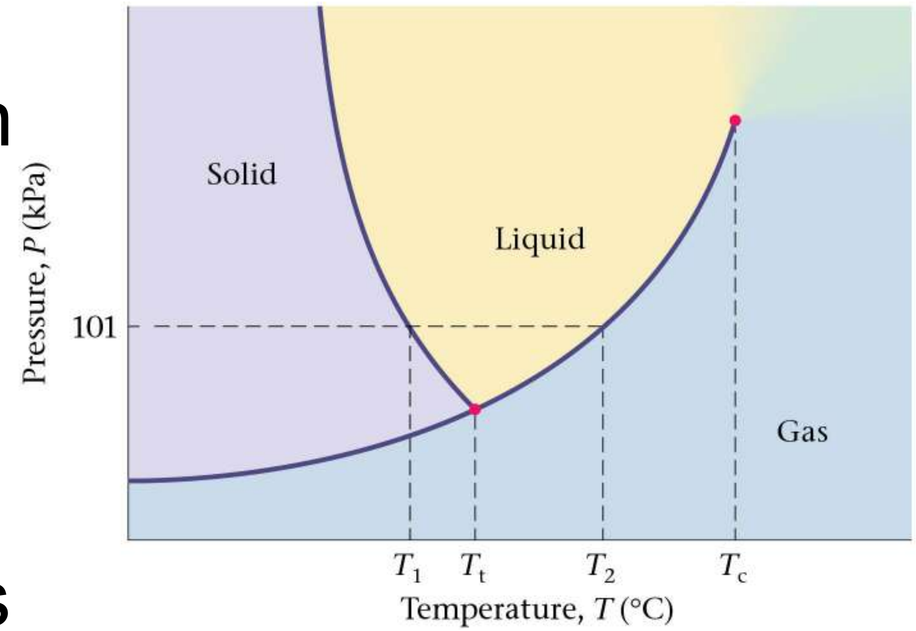
17-4 Phase Equilibrium and Evaporation

- The fusion curve is the boundary between the solid and liquid phases; along that curve they exist in equilibrium with each other. Almost all materials have a fusion curve that resembles (a); water, due to its unusual properties near the freezing point, follows (b).



17-4 Phase Equilibrium and Evaporation

- Finally, the sublimation curve marks the boundary between the solid and gas phases. The triple point, T_t, is where all three phases are in equilibrium. This is shown on the phase diagram for water shown.



Summary of Chapter 17

- An ideal gas is one in which interactions between molecules are ignored.
- Equation of state for an ideal gas: $PV = NkT$
- Boltzmann's constant: $k = 1.38 \times 10^{-23}\ \text{J/K}$
- Universal gas constant: $R = 8.31\ \text{J/(mol} \cdot \text{K)}$
- Equation of state again: $PV = nRT$
- Number of molecules in a mole is Avogadro's number: $N_A = 6.022 \times 10^{23}$

Summary of Chapter 17

- Molecular mass: $M = N_A m$
- Boyle's law: $PV = \text{constant}$
- Charles's law: $\frac{V}{T} = \text{constant}$

- Kinetic theory: gas consists of large number of pointlike molecules.
- Pressure is a result of molecular collisions with container walls.

Summary of Chapter 17

- Molecules have a range of speeds, given by the Maxwell distribution.
- Relation of kinetic energy to temperature:

$$\left(\tfrac{1}{2}mv^2\right)_{\text{av}} = K_{\text{av}} = \tfrac{3}{2}kT$$

- Relation of rms speed to temperature:

$$v_{\text{rms}} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

Summary of Chapter 17

- Internal energy of monatomic gas:

$$U = \frac{3}{2}NkT = \frac{3}{2}nRT$$

- Force required to change the length of a solid:

$$F = Y\left(\frac{\Delta L}{L_0}\right)A$$

- Force required to shear, or deform a solid:

$$F = S\left(\frac{\Delta x}{L_0}\right)A$$

Summary of Chapter 17

- Pressure required to change the volume of a solid:

$$\Delta P = -B\left(\frac{\Delta V}{V_0}\right)$$

- Applied force per area: stress.
- Resulting deformation: strain.
- Deformation is elastic if object returns to its original size and shape when stress is removed.

Summary of Chapter 17

- Most common phases of matter: solid, liquid, gas.
- When phases are in equilibrium, the number of molecules in each is constant.
- Evaporation occurs when molecules in liquid move fast enough to escape into gas phase.
- Latent heat: amount of heat required to transform from one phase to another.
- Latent heat of fusion: melting or freezing.

Summary of Chapter 17

- Latent heat of vaporization: vaporizing or condensing.
- Latent heat of sublimation: sublimation or condensation directly between gas and solid phases.
- When heat is exchanged within a system isolated from its surroundings, the energy of the system is conserved.