Thermal & Statistical Physics
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PHYS 343
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LECTURE 4

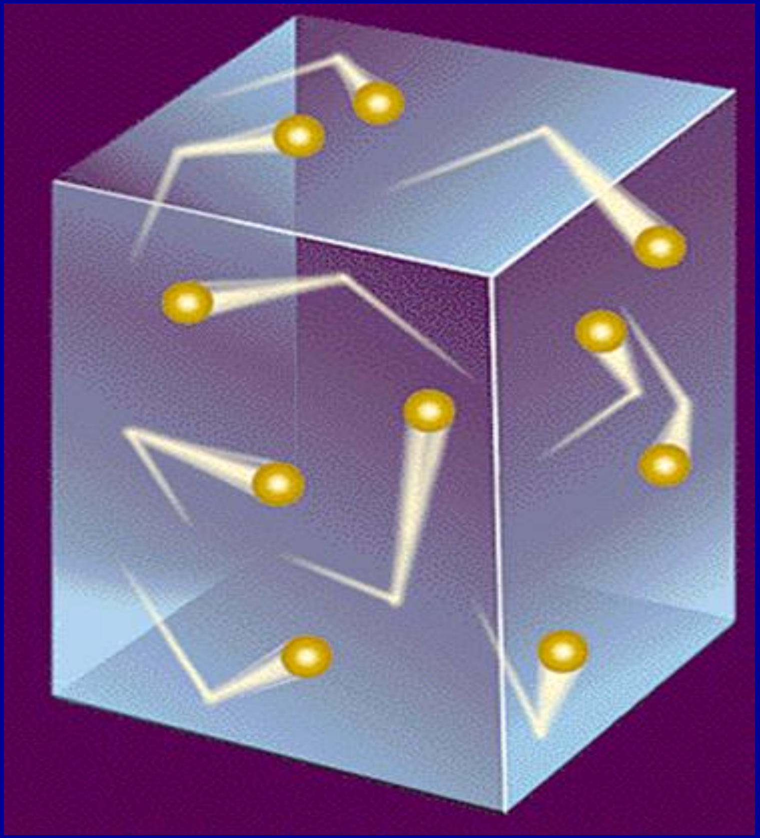
Kinetic Theory of Gases

Ideal Gas Model

Ideal Gas Model

Ideal Gas Model

States of Matter
and
Kinetic Theory of Gases

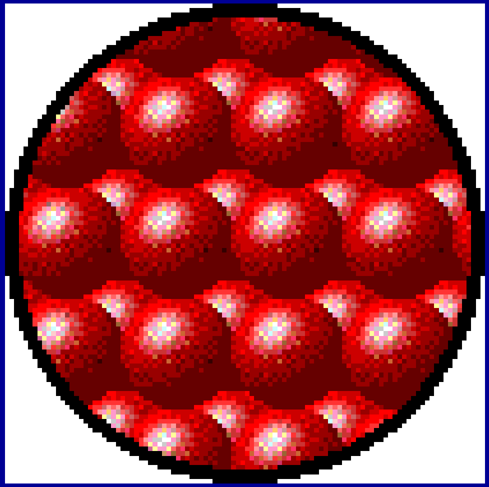


States of Matter

- Solid
- Liquid
- Gas
- Plasma

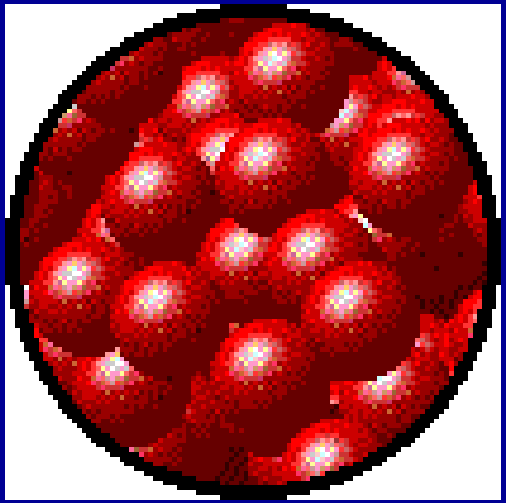
Solid

- Solids have fixed (definite) shape and volume at a given temperature.
- Solids are incompressible.



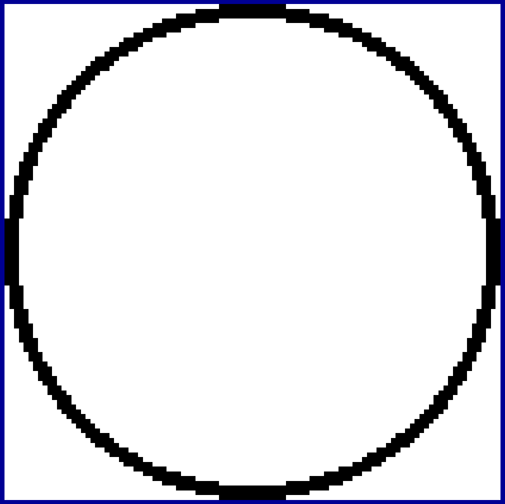
Liquids

- Liquids have fixed (definite) volume.
- They take the shape of its container , they do not have a definite shape.



Gases

- Gases take the volume and shape of their container.
- Gases do not have a definite shape or definite volume.



States of Matter

Glenn
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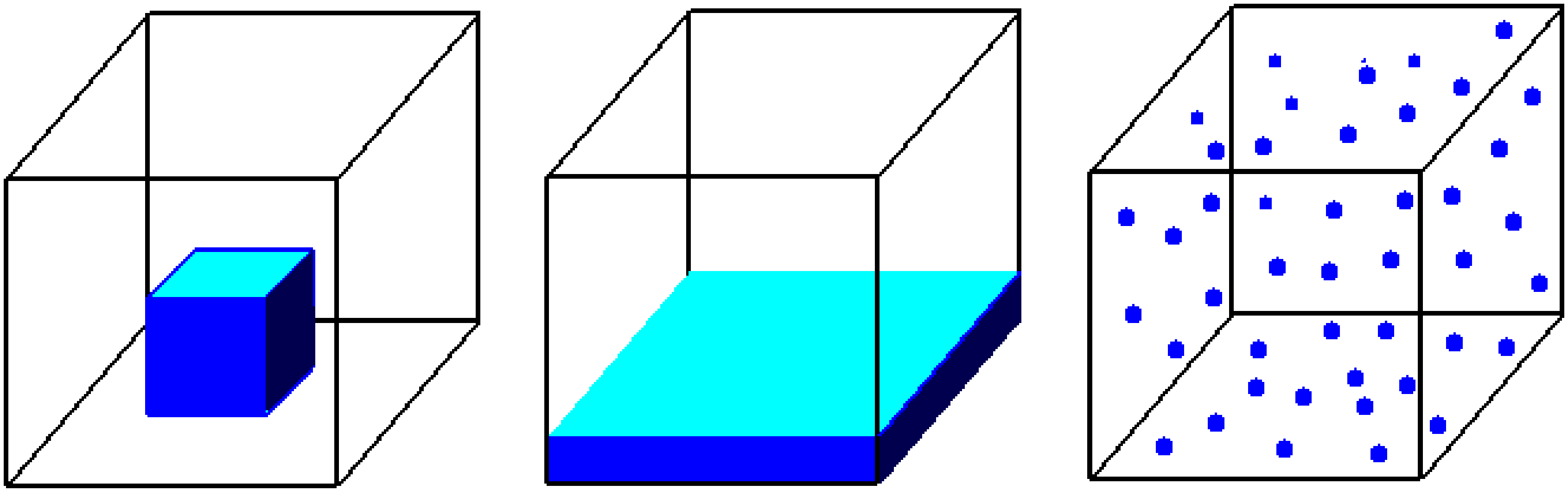
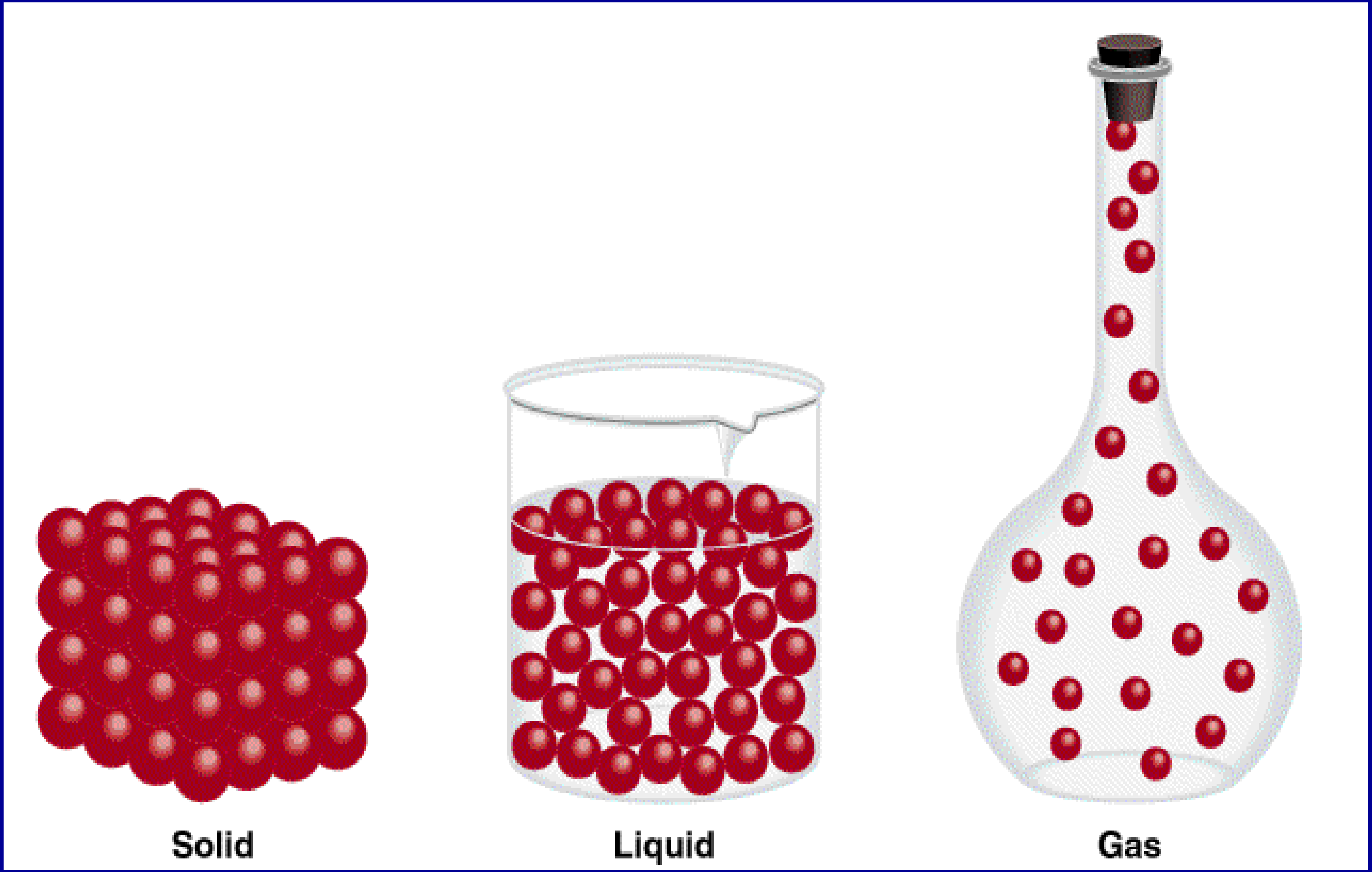
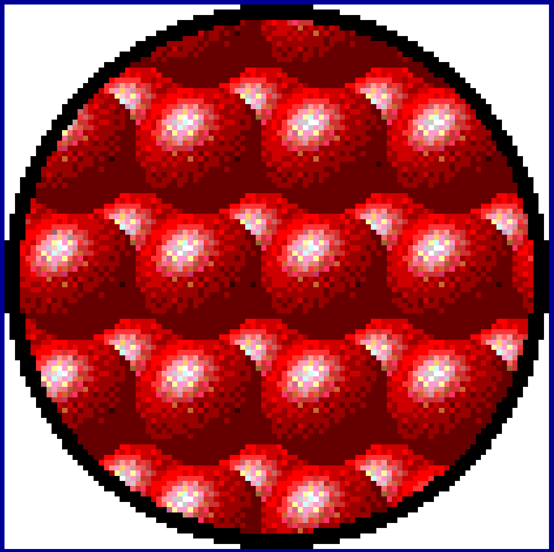


Solid	Liquid	Gas
Holds Shape	Shape of Container Free Surface	Shape of Container
Fixed Volume	Fixed Volume	Volume of Container

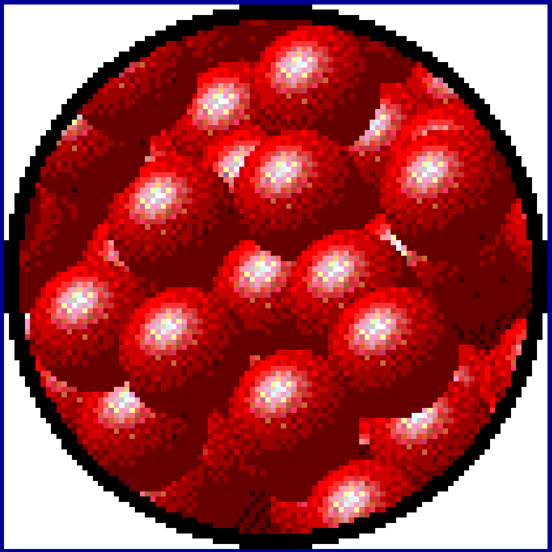


Solid
Liquid
Gas

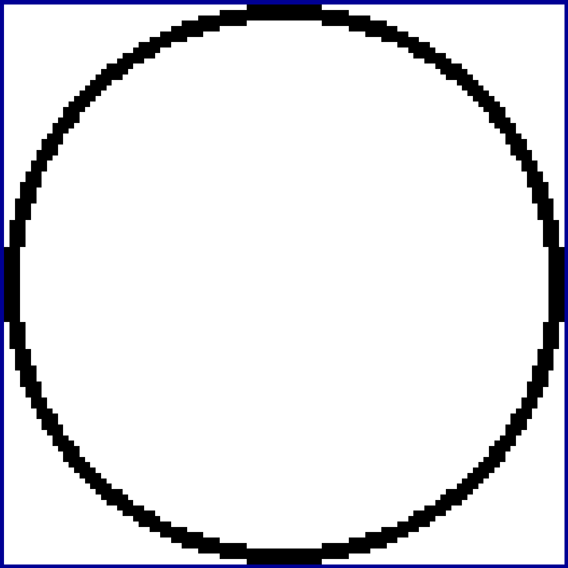
Solid



Liquid



Gas



Plasma

- Ionized gases and free electrons

GASES

A windy day or a still day is a result of the difference in pressure of gases in two different locations. A fresh breeze on a mountain peak is a study in basic gas laws.

Important Characteristics of Gases

- **Gases are highly compressible**

  An external force compresses the gas sample and decreases its volume, removing the external force allows the gas volume to increase.

- **Gases are thermally expandable**

  When a gas sample is heated, its volume increases, and when it is cooled its volume decreases.

- **Gases have high viscosity**

  Gases flow much easier than liquids or solids.

- **Most Gases have low densities**

  Gas densities are on the order of grams per liter whereas liquids and solids are grams per cubic cm, 1000 times greater.

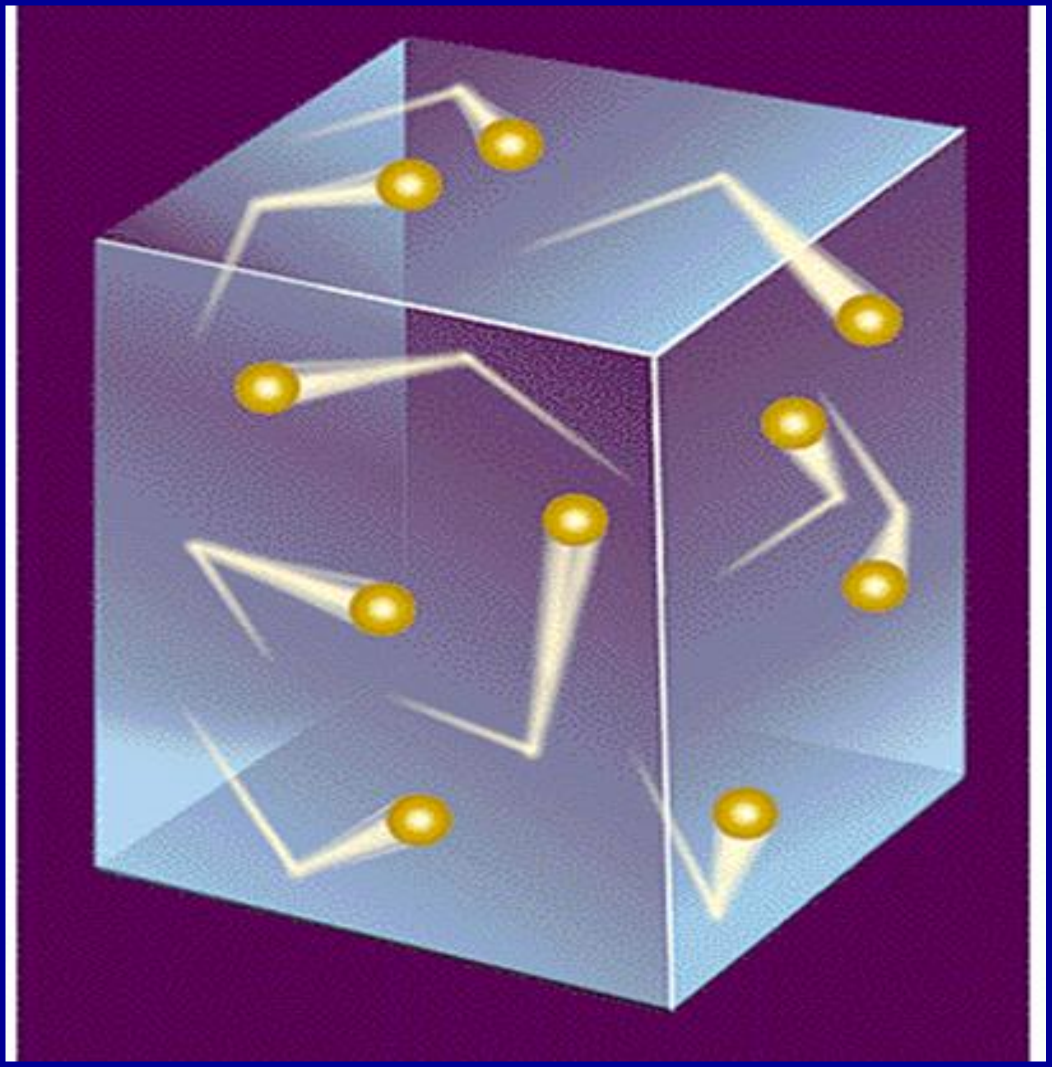
- **Gases are infinitely miscible**

  Gases mix in any proportion such as in air, a mixture of many gases.

Kinetic Energy

- The energy of **motion.**
- Any moving particle has kinetic energy.

Kinetic Theory of Gases



Kinetic M. Theory of Gases

- A theory that attempts to explain the behavior of an **ideal gas.**

- **An ideal gas** is a gas that obeys the assumptions of the KMT.

Kinetic Molecular Theory

Submicroscopic particles of matter are in constant, random motion.

Kinetic Molecular Theory

- To fully understand the world around us requires that we have a good understanding of the behavior of gases. The description of gases and their behavior can be approached from several perspectives.

- The *Gas Laws* are a mathematical interpretation of the behavior of gases.

- However, before understanding the mathematics of gases, a physicist must have an understanding of the conceptual description of gases. That is the purpose of the *Kinetic Molecular Theory*.

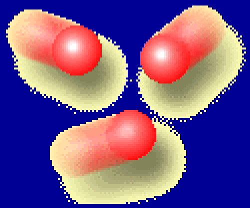
Kinetic Molecular Theory

- **The Kinetic Molecular Theory** is a single set of descriptive characteristics of a substance known as **the Ideal Gas.**

- **All real gases** require their own unique sets of descriptive characteristics. Considering the large number of known gases in the World, the task of trying to describe each one of them individually would be an awesome task.

- In order to simplify this task, the scientific community has decided **to create an *imaginary gas* that approximates the behavior of all real gases.** In other words, the Ideal Gas is a substance that does not exist.

- **The Kinetic Molecular Theory** describes that gas. While the use of the Ideal Gas in describing **all real gases** means that the descriptions of all real gases will be wrong, the reality is that the descriptions of real gases will be close enough to correct that any errors can be overlooked.

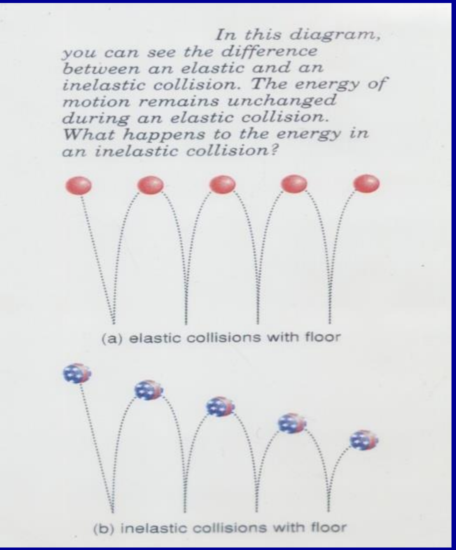


The assumptions Kinetic Theory

- Gas consists of large number of particles (atoms or molecules)
- Particles make elastic collisions with each other and with walls of container
- There exist no external forces (density constant)
- Particles, on average, separated by distances large compared to their diameters
- No forces between particles except when they collide

How does the bouncing ball lose energy?

- Through friction with the air (air resistance)
- Through sound when it hits the floor
- Through deformation of the ball
- Through heat energy in the bounce

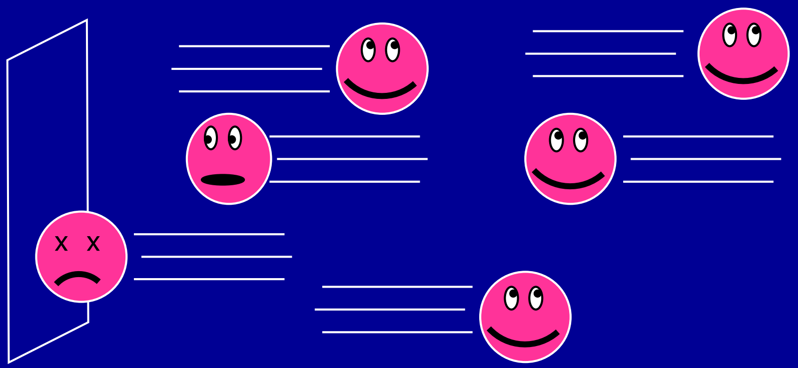


Remember ...

Kinetic Molecular Theory (KMT) for an ideal gas states that all gas particles:

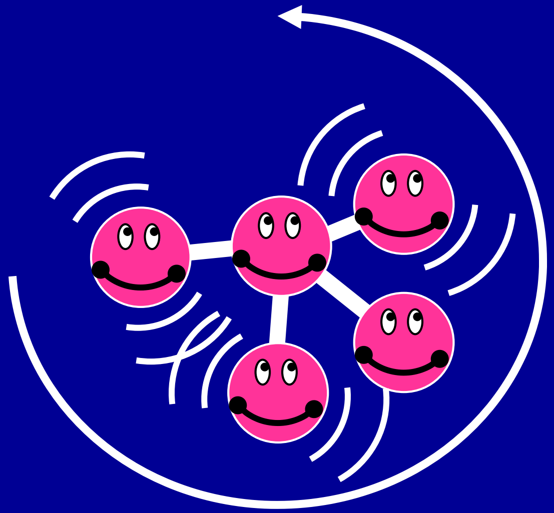
- **are in random, constant, straight-line motion.**
- **are separated by great distances relative to their size; the volume of the gas particles is considered negligible.**
- **have no attractive forces between them.**
- **have collisions that may result in the transfer of energy between gas particles, but the total energy of the system remains constant.**

Ideal vs. Non-Ideal Gases



- Kinetic Theory Assumptions
  - Point Mass
  - No Forces Between Molecules
  - Molecules Exert Pressure Via Elastic Collisions With Walls

Ideal vs. Non-Ideal Gases



- Non-Ideal Gas
  - Violates Assumptions
    - Volume of molecules
    - Attractive forces of molecules

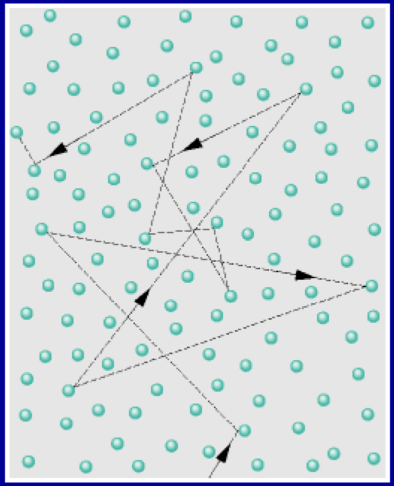
(courtesy F. Remer)

Kinetic Molecular Theory of Gases…

- Gases consist of tiny particles.
- These particles are so small compared to the distances between them, that the volume (size) of the individual particles can be assumed to be negligible (zero).

Kinetic Molecular Theory of Gases …

- The particles are in constant random motion, colliding with the walls of the container. **These collisions** with the walls cause **the pressure** exerted by the gas.



- The particles are assumed not to attract or repel each other.

Kinetic Molecular Theory of Gases …

- The **average kinetic energy** of the gas particles is directly proportional to the **Kelvin temperature** of the gas
- the fact that gases fill up the volume of the container they're in , is due to the **freedom of the molecules to move around**

An Equation of state

- ***An equation of state exists*** ***$p = f(V,T,N)$*** relating pressure, molar or specific volume, and temperature for any pure homogeneous fluid in equilibrium states.
- An equation of state may be solved for any one of the three quantities P, V, or T as a function of the other two.
- Example:

$$dV = \left(\frac{\partial V}{\partial T}\right)_P dT + \left(\frac{\partial V}{\partial P}\right)_T dP$$

Volume expansivity: $\beta \equiv \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$

Isothermal compressibility: $\kappa \equiv -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$

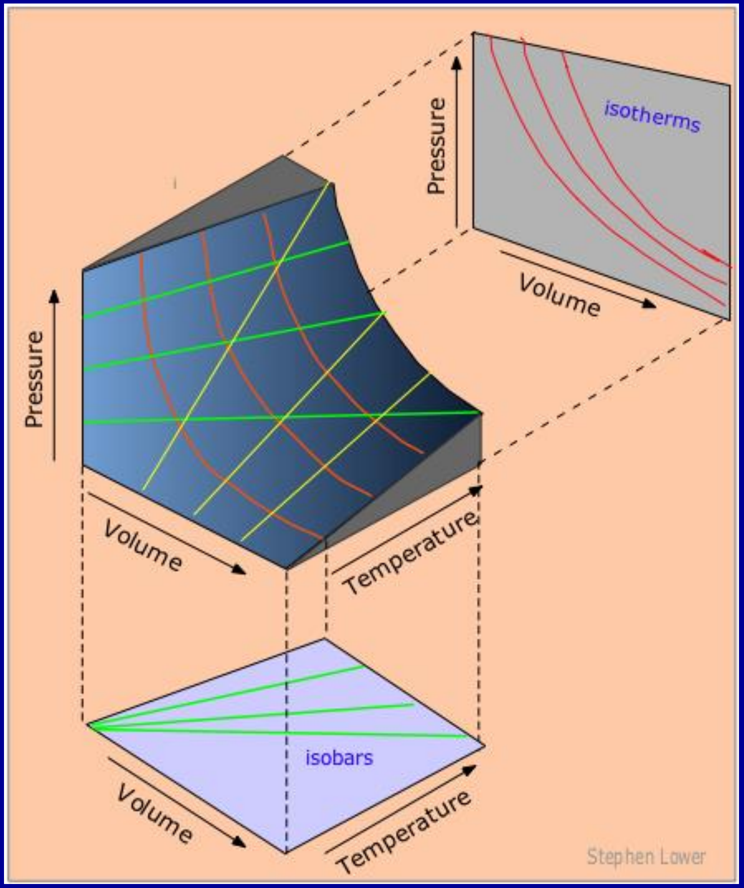
$$\frac{dV}{V} = \beta dT - \kappa dP$$

EQUATION OF STATE....

p = f(V,T,N)

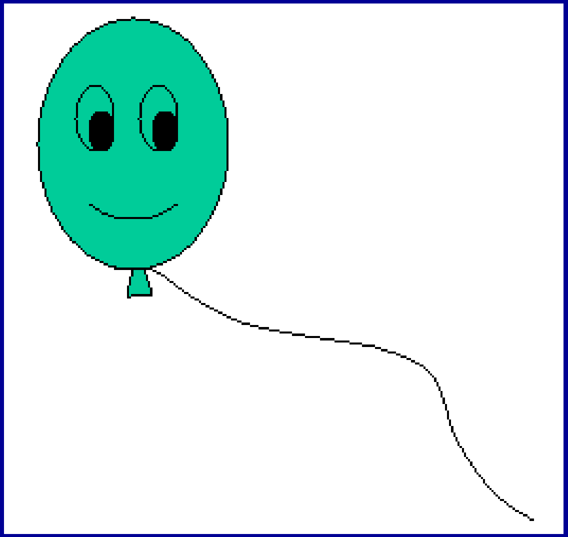
- For incompressible fluid, both β an dκ are zero.
- For liquids β is almost positive (liquid water between 0°C and 4°C is an exception), and κ is necessarily positive.
- At conditions not close to the critical point, β and κ can be assumed constant

$$\ln \frac{V_2}{V_1} = \beta(T_2 - T_1) - \kappa(P_2 - P_1)$$



The Gas Laws

- What would Polly Parcel look like if she had no gas molecules inside?



zero molecules = zero pressure inside

zero pressure inside = zero force on the inside

Gas Law Variables

- In order to describe gases, mathematically, it is essential to be familiar with the **variables** that are used. There are four commonly accepted gas law variables

- **Temperature**
- **Pressure**
- **Volume**
- **Moles**

Temperature

- The temperature variable is always symbolized as T.
- It is critical to remember that all temperature values used for describing gases must be in terms of absolute kinetic energy content for the system.
- Consequently, T values must be converted to the Kelvin Scale. To do so when having temperatures given in the Celsius Scale remember the conversion factor

  Kelvin = Celsius + 273
- According to the Kinetic Molecular Theory, every particle in a gas phase system can have its own kinetic energy. Therefore, when measuring the temperature of the system, the average kinetic energy of all the particles in the system is used.
- The temperature variable is representing the position of the average kinetic energy as expressed on the Boltzmann Distribution.

Pressure

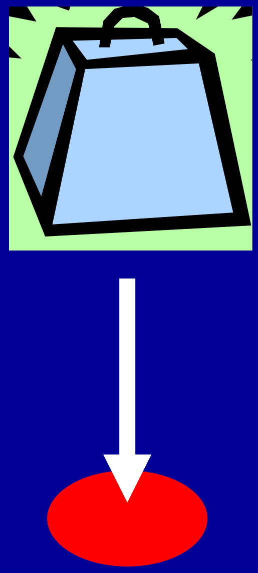
- The pressure variable is represented by the symbol P.
- The pressure variable refers to the pressure that the gas phase system produces on the walls of the container that it occupies.
- If the gas is not in a container, then the pressure variable refers to the pressure it could produce on the walls of a container if it were in one.
- The phenomenon of pressure is really a force applied over a surface area. It can best be expressed by the equation

$$\text{Pressure} = \frac{\text{Force}}{\text{Surface Area}}$$

Pressure

Macroscopic Viewpoint

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$



- $\uparrow$ Temp, $\uparrow$KE, $\uparrow$ Force, $\uparrow$ P
- $\downarrow$Volume, $\downarrow$ Area, $\uparrow$ P

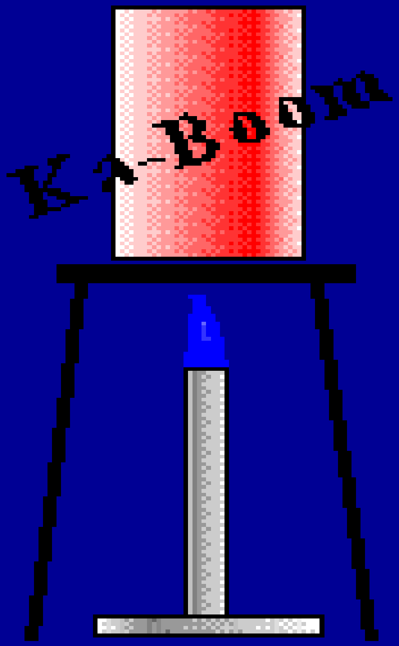
<u>Units of Pressure</u>

1 pascal (Pa) = 1 N/m^2

1 atm = 760 mmHg = 760 torr

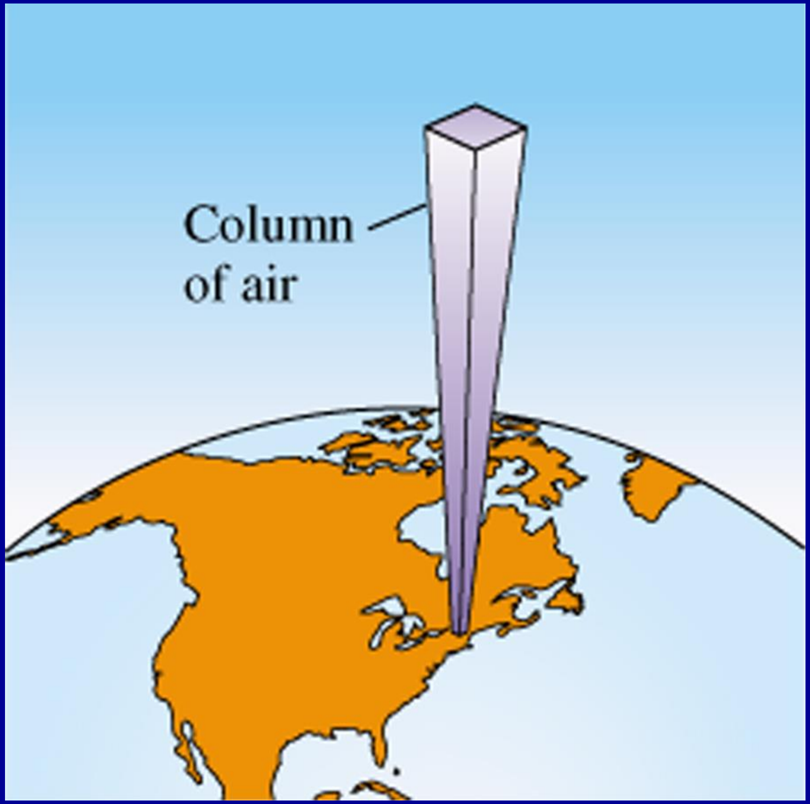
1 atm = 101,325 Pa

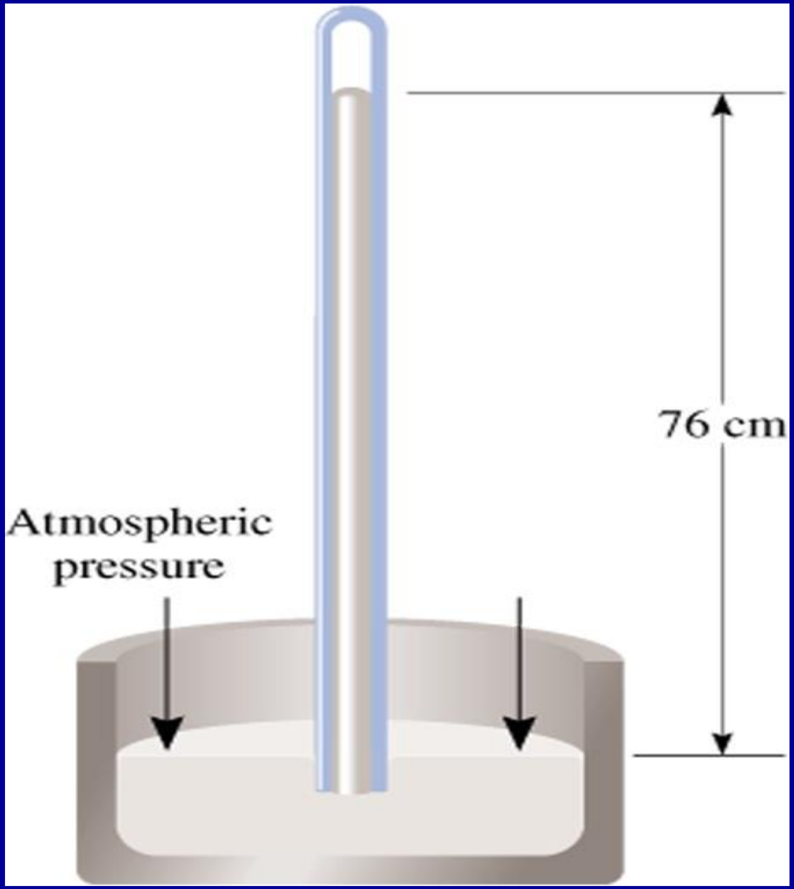
Pressure



- As this container of gas is heated, the temperature increases. As a result, the average kinetic energy of the particles in the system increases.
- With the increase in kinetic energy, the force on the available amount of surface area increases. As a result, the pressure of the system increases.
- Eventually,.............................
- ....Ka-Boom

Atmospheric Pressure





Barometer

Volume

- The Volume variable is represented by **the symbol V**. It seems like this variable should either be very easy to work with or nonexistent.
- Remember, according to the Kinetic Molecular Theory, the volume of the gas particles is set at zero. Therefore, the volume term V seems like it should be zero.
- In this case, that is not true. **The volume being referred to here is the volume of the container, not the volume of the gas particles.**
- The actual variable used to describe a gas should be the amount of **volume available for the particles to move around in. In other words**

$$\text{Volume}_{(\text{Available})} = \text{Volume}_{(\text{Container})} - \text{Volume}_{(\text{Particles})}$$

Volume

- Since the Kinetic Molecular Theory states that the volume of the gas particles is zero, then the equation simplifies.
- As a result, the amount of available space for the gas particles to move around in is approximately equal to the size of the container.
- Thus, as stated before, the variable V is the volume of the container.

Moles

- The final gas law variable is the quantity of gas. This is always expressed in terms of moles. The symbol that represents the moles of gas is n. Notice that, unlike the other variables, it is in lower case.

- Under most circumstances , the quantity of a substance is usually expressed in grams or some other unit of mass. The mass units will not work in gas law mathematics. Experience has shown that the number of objects in a system is more descriptive than the mass of the objects.

- Since each different gas will have its own unique mass for the gas particles, this would create major difficulties when working with gas law mathematics.

- The whole concept of the Ideal Gas says that all gases can be approximated has being the same. Considering the large difference in mass of the many different gases available, using mass as a measurement of quantity would cause major errors in the Kinetic Molecular Theory.

- Therefore, the mole will standardize the mathematics for all gases and minimize the chances for errors.

Conclusions

There are four variables used mathematically for describing a gas phase system. While the units used for the variables may differ from problem to problem, the conceptual aspects of the variables remain unchanged.

- **T, or Temperature**, is a measure of the average kinetic energy of the particles in the system and MUST be expressed in the Kelvin Scale.
- **P, or Pressure**, is the measure of the amount of force per unit of surface area. If the gas is not in a container, then P represents the pressure it could exert if it were in a container.
- **V, or Volume**, is a measure of the volume of the container that the gas could occupy. It represents the amount of space available for the gas particles to move around in.
- **n, or Moles**, is the measure of the quantity of gas. This expresses the number of objects in the system and does not directly indicate their masses.