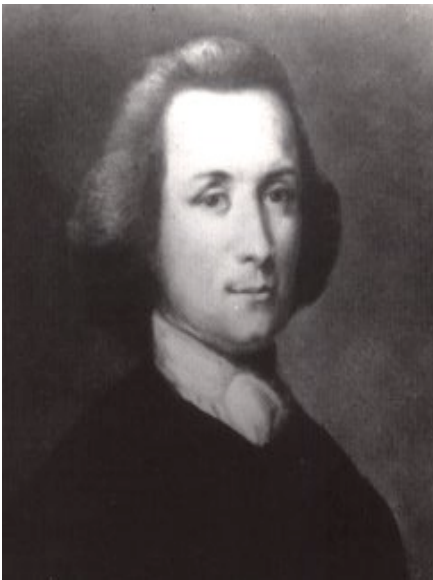


CPC 022

**DAY 7**

*States of  
Matter*

Dr. Olivieri



Joseph Priestly was an English chemist who still influences our lives today. In 1772 he developed soda water, which became the foundation of the soft drink industry. He is also accredited with discovering 8 gasses!

- **States of matter**

### States of Matter

We usually classify matter into 3 states:

- **Gas** - compressible, "tenuous", assumes the shape of whatever contains it.
- **Liquid** - incompressible, relatively dense, assumes shape of its container.
- **Solid** - incompressible, about as dense as a liquid, has its own predetermined shape.

- **Other states of matter**

Less often encountered:

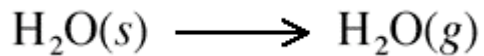
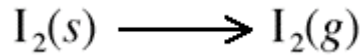
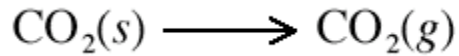
- **Plasma** (not blood plasma)- atoms are so hot that nuclei move independently of electrons.
- **Liquid Crystal** - A liquid that has states in which atoms are arranged in an orderly (as opposed to random) fashion.
- **Amorphous Solid** - glasses are a good example.
  - Contrast SiO<sub>2</sub> crystalline versus SiO<sub>2</sub> amorphous.

- **Transitions between states**

#### Transition Between States

S	→	L	Fusion
S	→	G	Sublimation
L	→	G	Evaporation
L	→	S	Freezing
G	→	L	Condensation
G	→	S	Deposition

Examples of Sublimation:



- **Molecular view of material and phase changes**

### **Molecular View**

What happens when a solid evaporates?

When it melts?

What is happening in the molecular/atomic level?

- **Kinds of solids**

### **Kinds of Solids**

#### **Covalent Network:**

- diamond - superman
- graphite - pencils
- elemental silicon - semiconductors
- silicon dioxide - quartz
- BN - insulator
- SiC - drill bits

### **Ionic:**

- NaCl - pretzels
- CaCO<sub>3</sub> - oysters
- NH<sub>4</sub>NO<sub>3</sub> - cold packs
- CuSO<sub>4</sub> - anti-fungal algacide

### **Molecular:**

- I<sub>2</sub>
- CO<sub>2</sub>(s) - Dry Ice
- C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> - What is this?

### **Metallic:**

- metals & alloys

- **Intermolecular forces**

## **Intermolecular Forces**

Forces **between** molecules

or **between** atoms

or **between** molecules and atoms

or **between** molecules and ions

or **between** atoms and ions.

Types:

- dipole - dipole
- ion - dipole
- dipole - induced dipole
- dispersion
- hydrogen bonding

- **Dipole-dipole**

### **Dipole - Dipole**

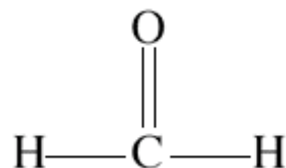
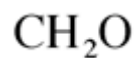
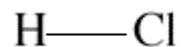
A molecule must be polar for this to happen.

i.e. it must have a permanent dipole moment.

What does this mean?

- A. It must contain polar bonds?
- B. The bonds must be asymmetric?

#### **Examples of polar molecules:**

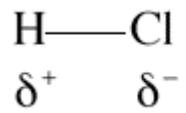


#### **Examples of non-polar molecules:**



Dipoles have separated positive and negative charge.

e.g.



These dipoles attract each other:

- + end to - end
- - end to + end

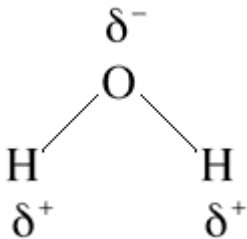
○ **Ion-dipole**

**Ion - Dipole Forces**

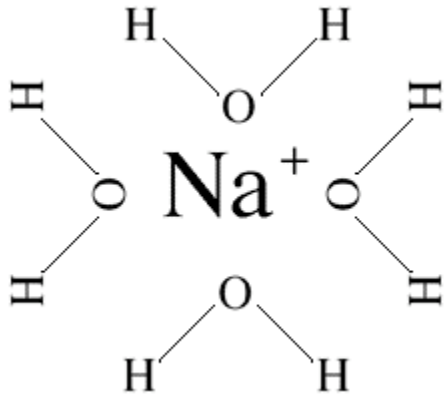
Frequently found in aqueous solutions.

The reason why salts dissolve.

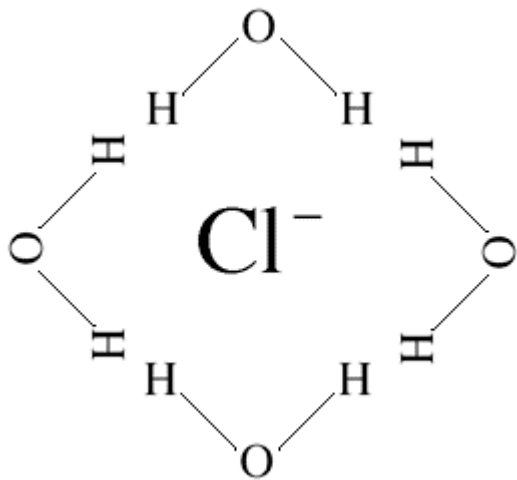
**Water is polar.**



A positive ion is hydrated.



As a negative ion.

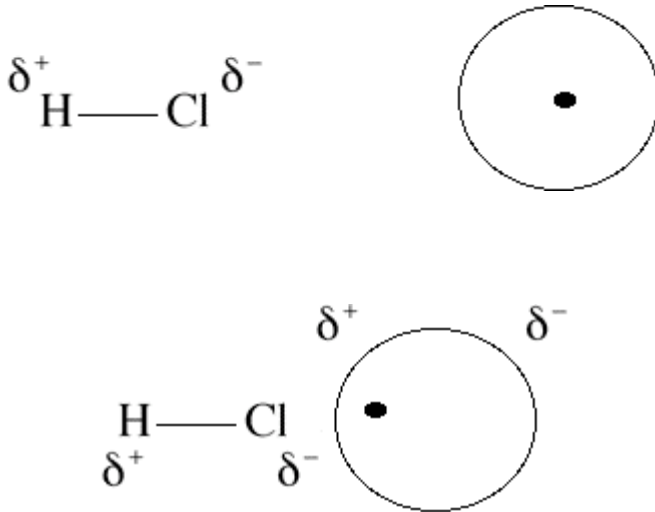


This is how ions are pulled away from crystal lattices.

- **Dipole-induced dipole**

### **Dipole - Induced Dipole**

In a mixture of, say, HCl & Kr, the HCl can distort the electron cloud around Kr.



As the HCl molecule approaches the Kr atom, the negative Cl end of HCl pushes the Kr electron cloud away making the atom asymmetric and conferring upon it a dipole moment.

You then get a weak attraction between HCl and Kr because HCl has induced a dipole moment in Kr.

- **Dispersion Forces**

### **Dispersion Forces**

If molecules (or atoms) have no permanent dipole they can still induce dipoles in each other and attract each other. These attractive forces are called **dispersion forces**.

The squishier the electron cloud the more it can be distorted and the larger the dispersion forces. We call "squishiness of electron cloud", polarizability. We say that the more polarizable a molecule is, the stronger the dispersion forces.

In general,

- the more electrons the more polarizable,
- the more polarizable the larger the dispersion forces.

This is why  $F_2$  has the lowest MP and BP of all halogens while  $I_2$  has the biggest. Iodine has more electrons. Iodine is more polarizable. Iodine molecules exert larger dispersion forces on each other than do fluorine molecules. Thus at room temperature  $I_2$  is a solid and  $F_2$  is a gas.

The same reasoning applies to why  $CH_4$  and  $C_2H_4$  are gases,  $C_3H_8$  and  $C_4H_{10}$  can be liquefied under moderate pressure,  $C_5H_{12}$  & up are liquids at room temperature, until approximately  $C_{20}H_{42}$  at which point you get solids (AKA paraffin waxes).

### ○ Hydrogen bonding

## Hydrogen Bonding

First...**Hydrogen bonding is not bonding**...it is really a very strong dipole-dipole interaction between molecules containing O, N, or F bonded to a hydrogen.

### Examples

1.)  $C_2H_5OH$

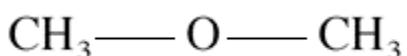
2.)  $H_2O$

3.)  $NH_3$

4.)  $HF$

- All of the above exhibit hydrogen bonding

### But



does not...why not?

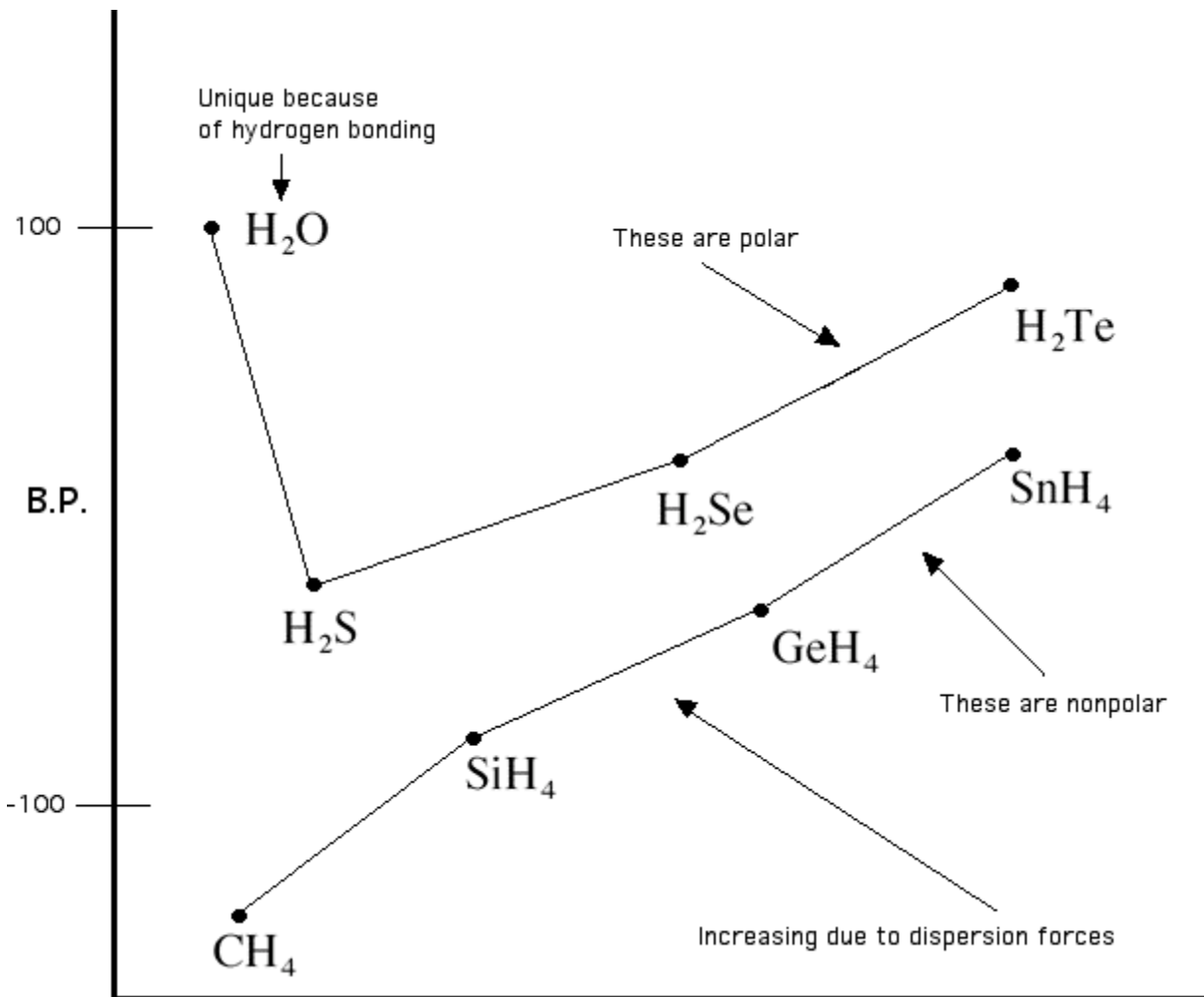
▪ Trends in halogens

**Trends**

**Halogens:**

As noted above, there is a systematic increase in melting point and boiling point of halogens as you go down the periodic table due to dispersion forces.

**Some systematic trends in small molecules in the oxygen and carbon families:**



Note how graph illustrates:

- Importance + strength of hydrogen bonding.
- Polar compounds boil higher than do nonpolar compounds, *all else being equal*.
- More electrons means, more polarizability, means stronger dispersion forces.

### **Question**

Are there dispersion forces in action between water molecules?  
See the next page for discussion.

## **Dispersion Forces and Water?**

Every molecule and every ion contains electrons and an electron cloud is what causes dispersion forces. Therefore, water molecules exert dispersion forces on each other. The hydrogen bonding forces between water molecules are so strong, however, that we usually concentrate on them when we are talking about the properties of water.

In the above paragraph, we said one untrue thing. Do you know what it is? See next page.

## **Do all ions contain electrons?**

Hydrogen ions do not contain electrons. Thus they cannot be attracted through dispersion forces because a dipole cannot be induced in them. So the statement that we find dispersion forces in all ions and molecules is not exactly true. In general, statements about all things, all people, all whatever, are to be mistrusted.

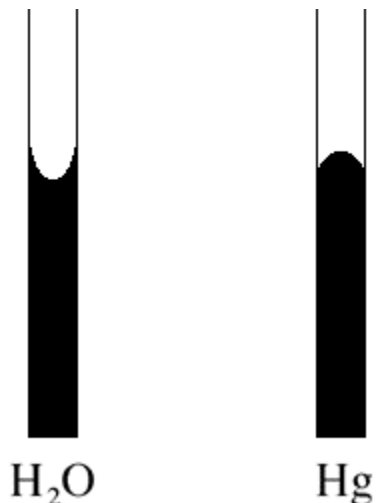
### ○ **Properties**

## **Properties of Liquids**

### **Properties:**

- **Viscosity:** internal friction of liquid.
- **Surface Tension:** skin on a liquid's surface.
- **Meniscus formation:** can be rationalized by contrasting adhesive forces with cohesive forces.

## Meniscus Formation



These can be rationalized by contrasting adhesive forces with cohesive forces. The hydroxyl groups on the surface of glass engage in hydrogen bonding with water molecules. These adhesive forces drag the water up the sides of the glass tube. Metallic bonds act between mercury atoms but not between mercury and glass. The metallic bonds between the mercury atoms (cohesive forces) make the mercury "ball up" into a dome shaped meniscus.

### Question

In terms of intermolecular forces why does water "bead up" on a newly waxed car?

## Waxing Your Car

Waxes are composed of non-polar molecules (long chained hydrocarbons and such) and the overwhelmingly predominant intermolecular forces are dispersion forces. Water, as we know, is dominated by hydrogen bonding. The cohesive forces drawing the water molecules together are therefore much stronger than the adhesive forces (weak dispersion forces) attracting the water to the wax. This is why water beads up when you wax your car.

- **Pressure**

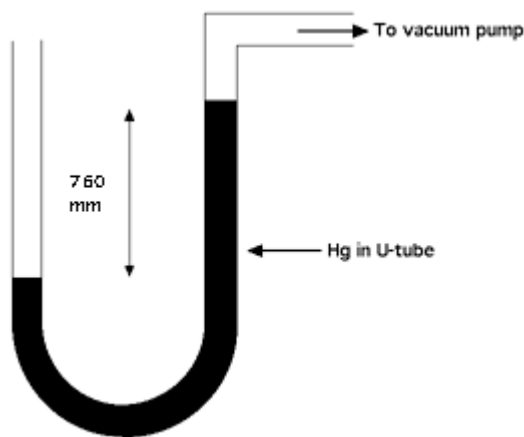
### **Gases: Pressure**

Here's the equation:

$$P = \frac{F}{A}$$

But, what *is* pressure? And how do we measure it?

#### **The u-tube manometer**



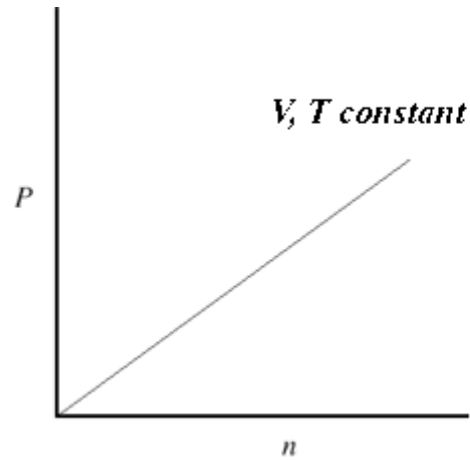
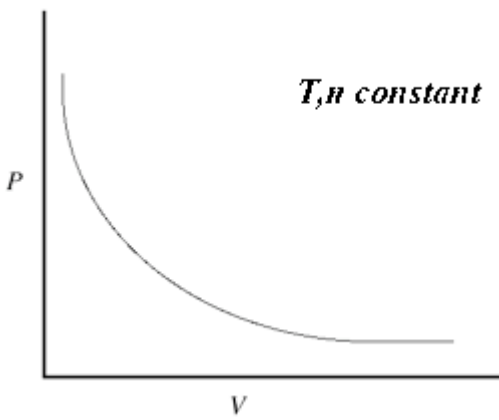
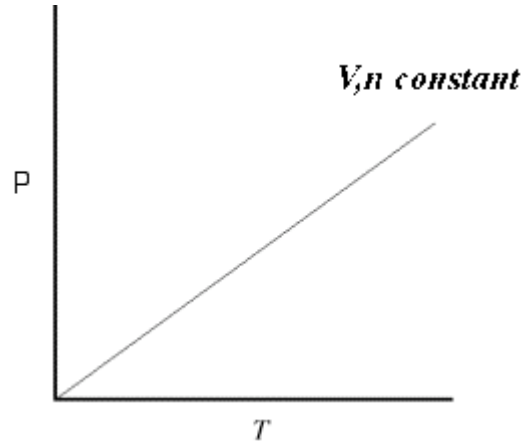
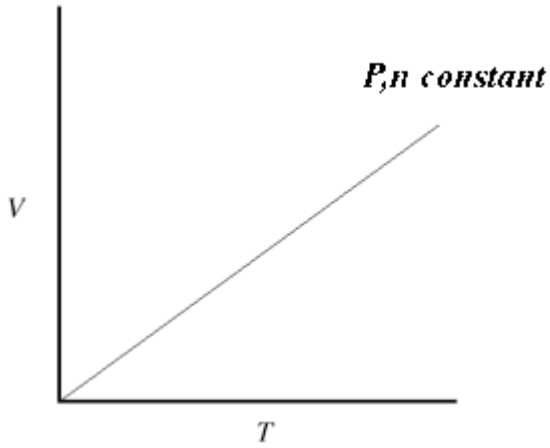
1 mm of Hg  
= 1 torr

1  
atmosphere  
= 760 torr

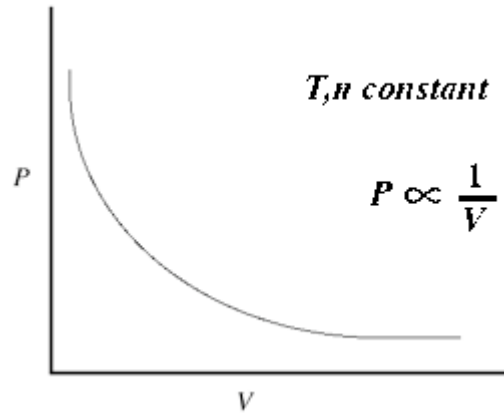
The u-tube manometer defines the most commonly used unit of pressure. If one side of the manometer is pumped out, we find that the atmosphere can support a column of mercury of approximately 760 millimeters, if the measurement is made at sea level. Thus the unit of pressure called mm of Hg is completely tied to this instrument. An atmosphere is the amount of pressure exerted by the "typical" sea level atmosphere. Obviously, this can change as the weather or the level of the sea changes. For this reason, scientists have standardized on one atmosphere equaling 760 torr.

- **State variables**

### Relationships Between Variables of State of Gases

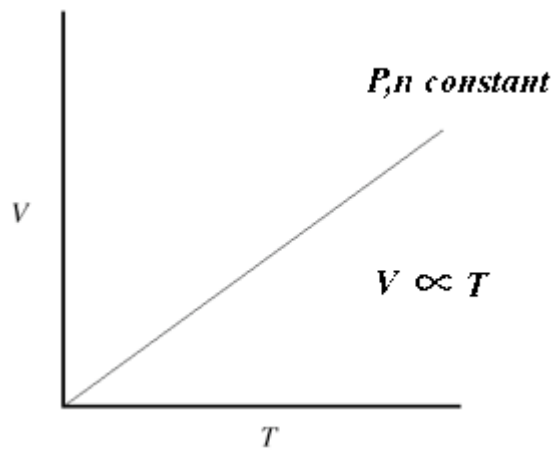


### Relationship between Pressure and Volume



This graph says that, if you double  $V$ , you reduce  $P$  by a factor of 2.

### **Relationship between $V$ and $T$**

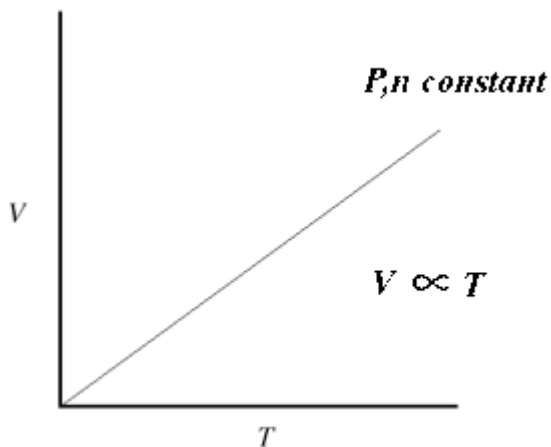


This means that if you double  $T$  you double  $V$ .

- **Idea of absolute zero**

### **Absolute Zero**

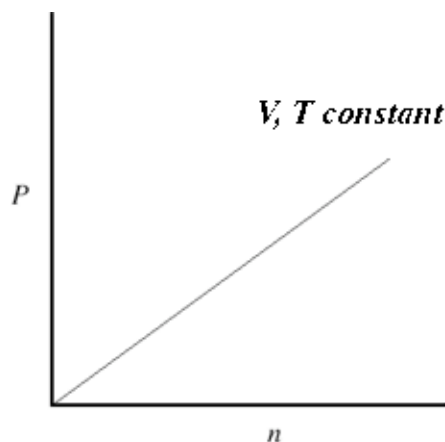
We just saw this graph but something seems to be wrong. It says that, as we make the temperature smaller and smaller, the volume gets smaller and smaller.



But what happens if  $T < 0$ ??!! If you continue with the line, you would conclude that you get a negative volume, an idea so counterintuitive that it has not even made it into science fiction. The only reasonable conclusion you can draw is that there must be some lowest temperature, which we call absolute zero.

- **Number of moles**

### **Relationship between $P$ and $n$**



This says that if you put more air (i.e. more moles of air) into a tire, the pressure will go up.

Notice that  $n$  doesn't specify what gas you use...this means that a collection of gases will each exert a pressure proportional to the total number of moles---each gas exerting a part of that pressure, proportional to its particular value of  $n$ .

This is Dalton's Law of Partial Pressures.

### **Ideal Gas Law**

The Ideal Gas Law sums up the previous graphs in a single equation linking all the state variables of a gas.

$$PV = nRT$$

- **$P$  is the pressure**
- **$V$  is the volume**
- **$n$  is the number of moles**
- **$T$  is the absolute temperature**
- **$R$  is the universal gas constant, as shown below**

$$R = 0.08205 \frac{\text{liter} \cdot \text{atm}}{\text{mole} \cdot \text{K}}$$

### **Here's an easy problem**

If  $P = 6$  atm and  $T = 27$  degrees Celsius, what is the volume of 3 moles of helium?

$$V = \frac{nRT}{P}$$

$$= \frac{3 \text{ moles} \left( \frac{.08205 \text{ l} \cdot \text{atm}}{\text{mole} \cdot \text{K}} \right) (300 \text{ K})}{6 \text{ atm}}$$

$$= 12.3 \text{ l}$$

- Note how dimensional analysis verifies our algebra

### STP

One useful point of reference is referred to as STP: **S**tandard **T**emperature & **P**ressure.

- 0 degrees Celsius (273 Kelvin)
- 1 atm

The volume of 1 mole of an ideal gas at STP can easily be calculated.

$$V = \frac{(1 \text{ mole}) \left( \frac{.08205 \text{ l} \cdot \text{atm}}{\text{mole} \cdot \text{K}} \right) (273 \text{ K})}{1 \text{ atm}}$$

$$= 22.4 \text{ liters}$$

- a useful factoid to remember

▪ **What is an ideal gas**

**What is an Ideal Gas Anyway?**

Well...it doesn't exist because it's only an ideal.

Assumption:

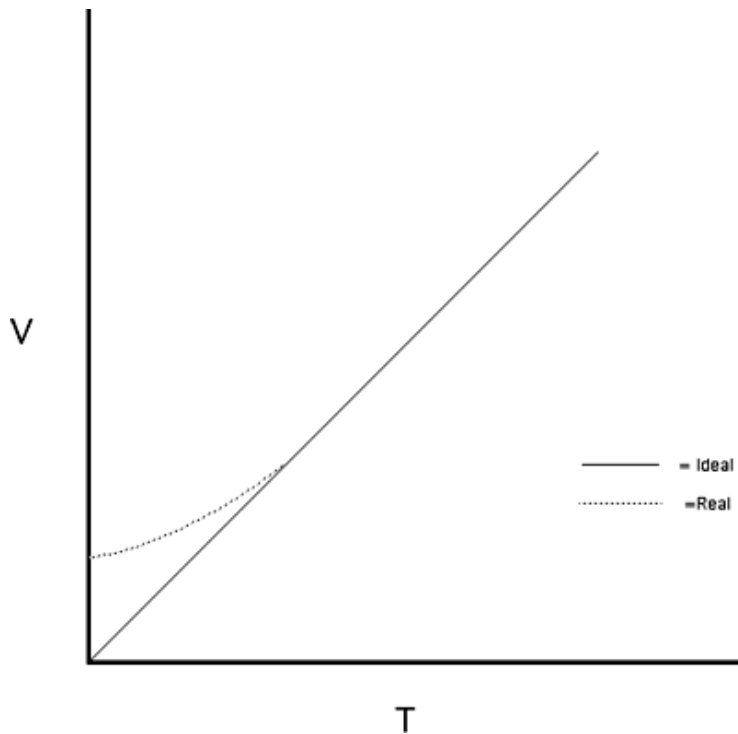
- Atoms occupy no space
- No forces between molecules of gas, except when they collide.

Are these true?

Are these almost true?

Do you see why we call this an ideal gas?

**Real Gases**



In real gases the atoms and molecules have some residual volume. The volume never goes to zero, but approaches some positive, minimum value, corresponding roughly to the volume of a liquid.

## **Kinetic theory of gases**

Kinetic theory views gases as a collection of infinitely small spheres (much like Ideal Gas Law except on a microscopic level).

### **Three important results:**

1. Energy depends only on temperature:

$$E = \frac{3}{2}nkT$$

where "n" equals the number of molecules

---

2. The temperature tells you the average speed:

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

---

3. A gas does not have a single molecular velocity, but there is a probabilistic distribution of molecular velocities.

## Explanations of Equations

**Meaning of energy equation:**

$$E = \frac{3}{2}nkT$$

$$T = \frac{2E}{3nk}$$

$$T \propto \frac{E}{n}$$

i.e., Temperature is proportional to internal energy per molecule.

---

Meaning of velocity equation:

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

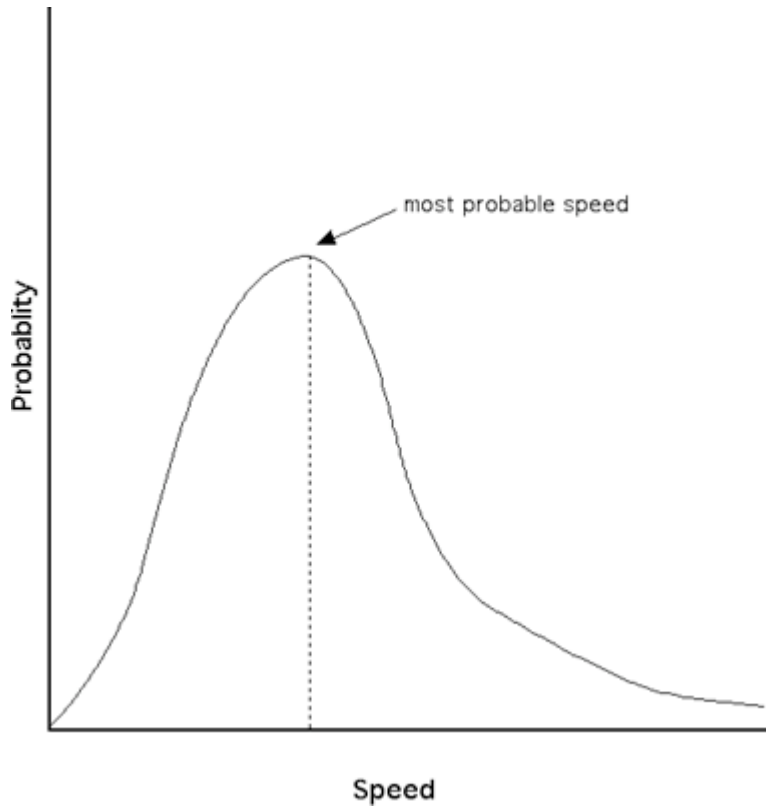
v<sub>rms</sub>= root mean square. It is a kind of average.

This says that, as you raise the temperature, the molecules go faster, and, at a given temperature, heavier molecules travel more slowly than do light ones.

- **Velocity distribution**

### Velocity Distribution

The molecules of gas in this or any room do not all travel at the same speed...they have a **distribution** of velocities...much like a distribution of grades.



If you raise the temperature of a gas, the velocity distribution shifts to higher velocities.

