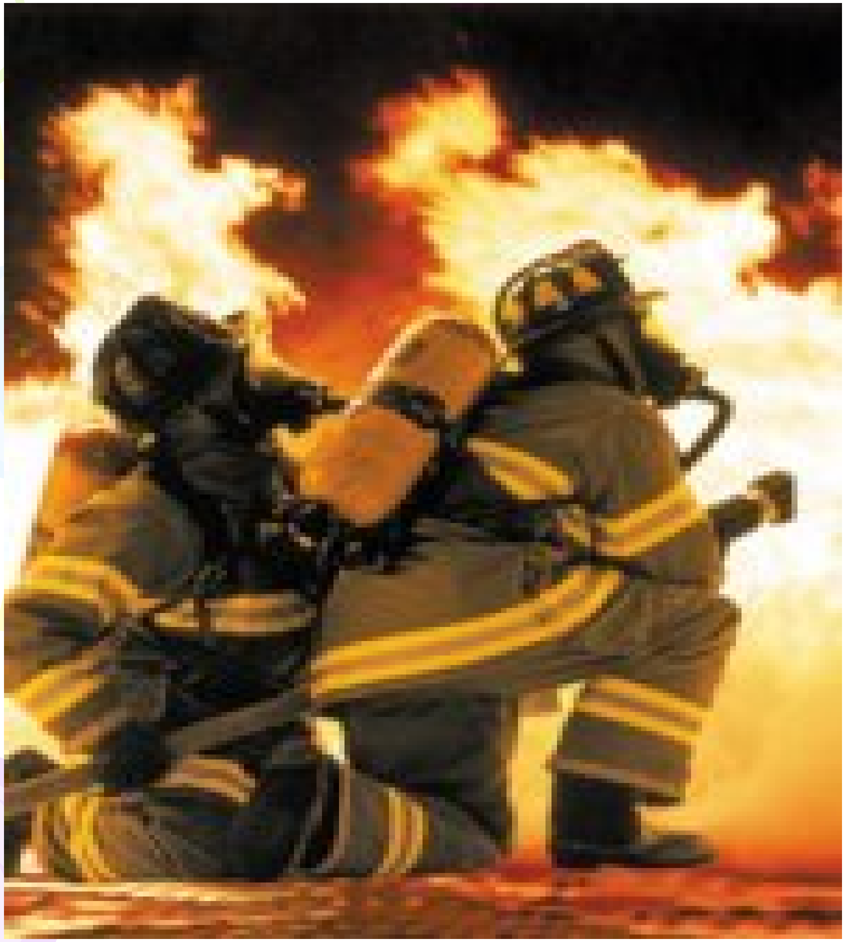
40S Chemistry

Behavior of Gases

Introduction



- Why do the fire fighters in this photo need to use air tanks?
- A fire raises the temperature of all gases in the immediate area.
- This reduces the amount of O_2 available for breathing.

Introduction

- From gas BBQ's to hot air balloons, many activities involve gases.
- It is important to be able to predict what effect changes in pressure, temperature, volume or amount will have on the properties of a gas.

Outcomes

- Research Canadian and global initiatives to improve air quality.
- Examine the historical development of the measurement of pressure.
- Describe the various units used to measure pressure.
- Include: atmospheres (atm), kilopascals (kPa), mm of mercury (mmHg)

- Experiment to develop the relationship between pressure and volume of a gas using visual, numerical and graphical representations.
- Include: historical contributions of Robert Boyle

- Experiment to develop the relationship between volume and temperature of a gas using visual, numerical and graphical representations.
- Include: historical contributions of Charles, the determination of absolute zero, and the Kelvin temperature scale.

- Experiment to develop the relationship between pressure and temperature of a gas using visual, numerical and graphical representations.
- Include: historical contribution of Gay-Lussac.
- Solve quantitative problems involving the relationships among pressure, temperature and volume of a gas using dimensional analysis.

- Identify various industrial, environmental, and recreational applications of gases.
- *Examples: SCUBA, anaesthetics, air bags, acetylene welding, propane appliances, hyperbaric chambers…*

Topics

- Properties of Gases
- The Gas Laws
- Ideal Gases
- Real Gases
- Gas Stoichiometry

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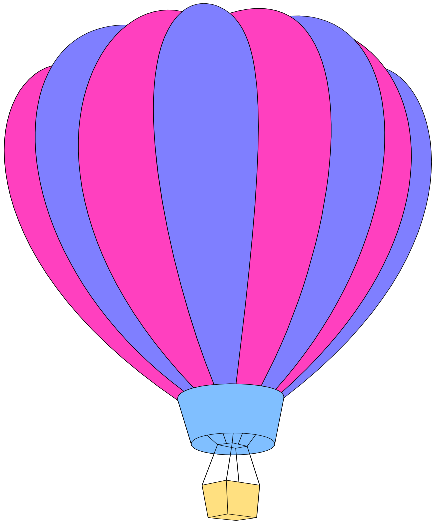
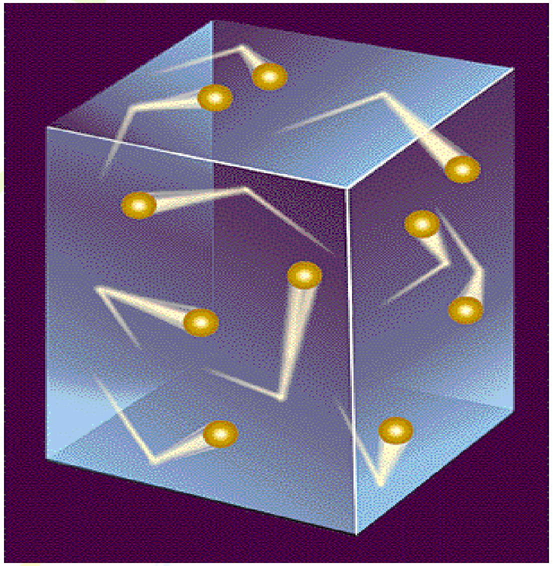
Properties of Gases

Properties of Gases

- Some physical properties of gases include:
  - They diffuse and mix in all proportions
  - They expand to fill their containers
  - They are compressible
- The properties of a gas are explained by Kinetic Molecular Theory of gases (KMT)



Kinetic Molecular Theory of Gases



1. Gases are composed of large numbers of particles in constant, random motion.
2. Gas particles are separated by relatively large distances (~10 particle diameters).
3. Gas particles collide elastically with each other and with the walls of their container – there is no loss of energy in the collisions.
4. Gas particles are assumed to be points in space – their volumes are negligible.
5. Gas particles experience no intermolecular forces

Variables that describe a Gas

- **The four variables and their common units:**
  1. **pressure** (P) in kilopascals
  2. **volume** (V) in Liters
  3. **temperature** (T) in Kelvin
  4. **number of moles** (n)

Pressure

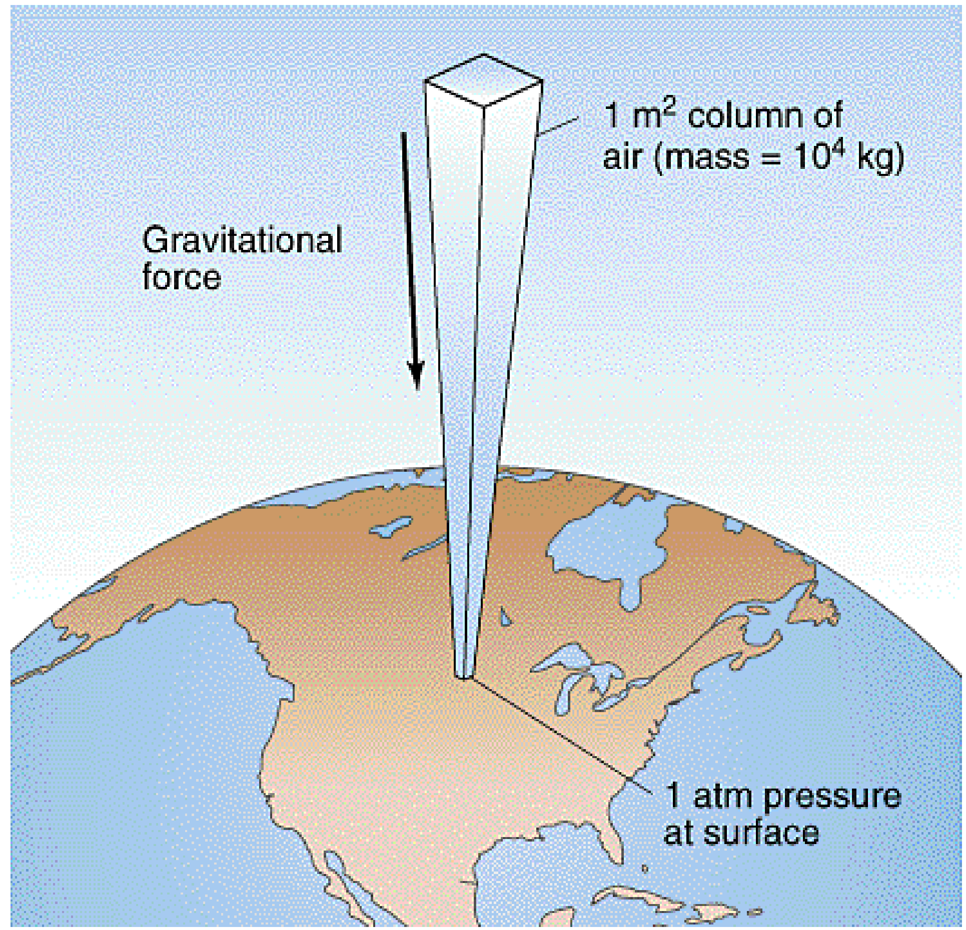
- Pressure is defined as a FORCE acting over an AREA

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

- Each time a gas particle collides with its container, it exerts a tiny force over a tiny area
- The sum of all these forces, over the area of the container walls, produces a measurable pressure within the container

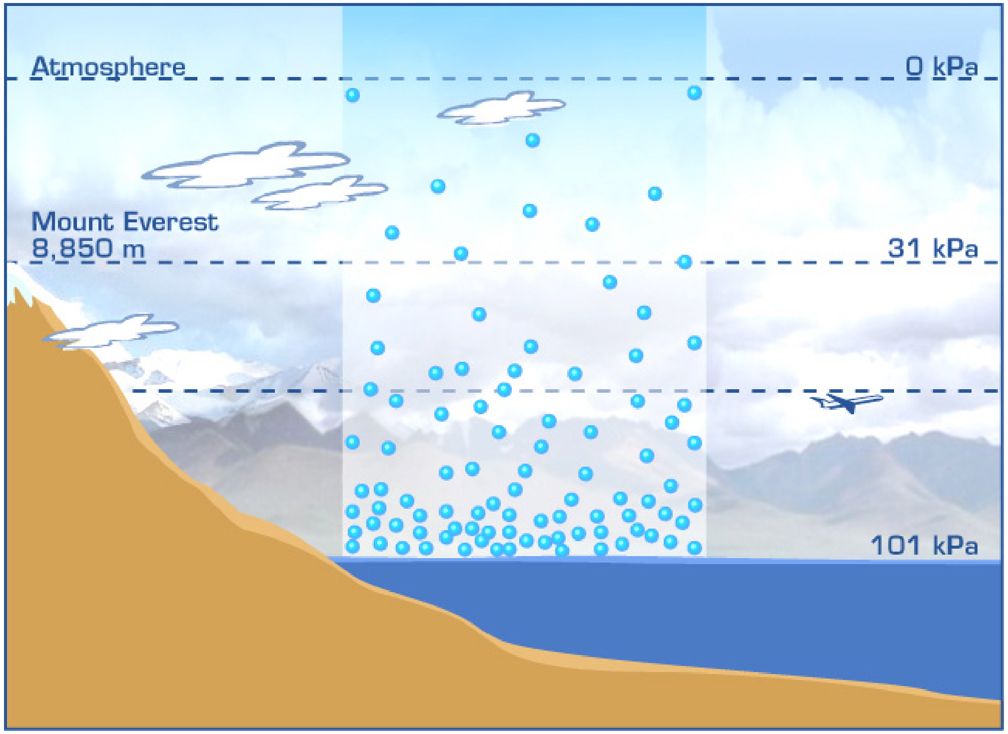
Air Pressure is Huge!

- The mass of the atmosphere above 1 m^2 of earth is 10 000 kg!
- This pressure can support 76 cm of mercury – or about 30 ft of water!
- We aren't crushed because the pressure inside our bodies is equal to the pressure outside – recall the aluminum can demo!

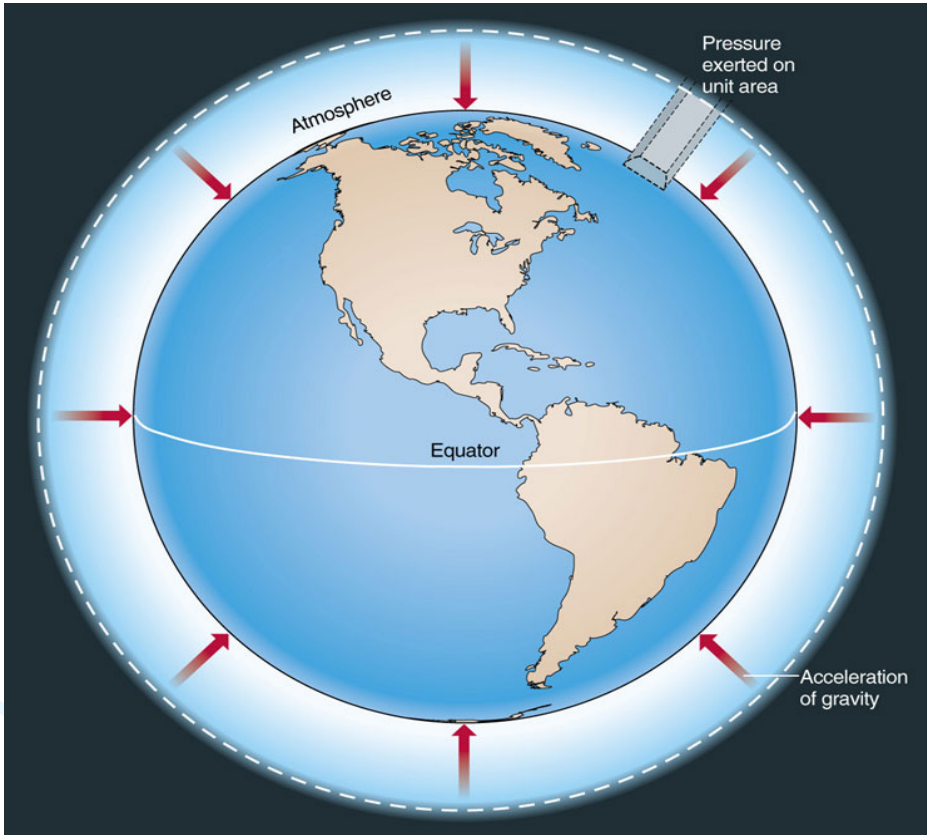


Altitude and Atmospheric Pressure

- The density of the atmosphere changes as altitude increases.
- Air pressure is less at higher elevations as a result.



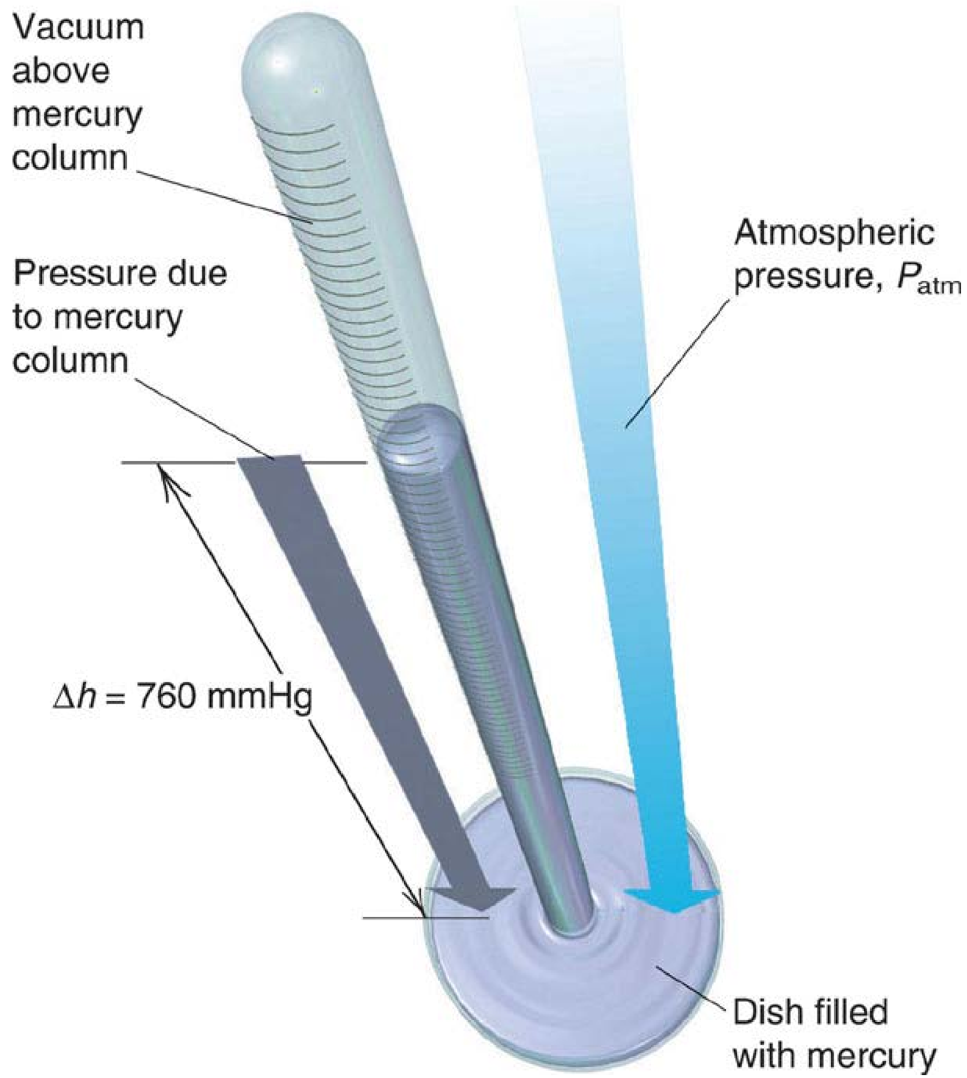
Atmospheric Pressure Video



http://fany.savina.net/2011/10/atmospheric-pressure/

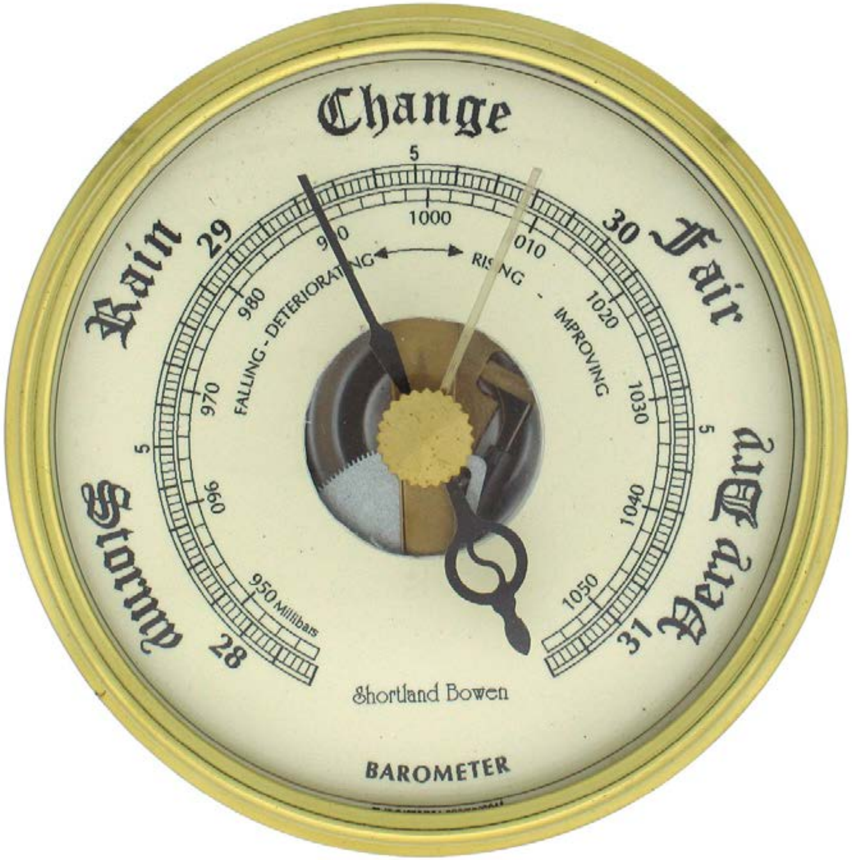
Mercury Barometer

- The BAROMETER was invented by Torricelli and is used to measure atmospheric pressure
- The weight of the air pushes down on the mercury in the dish (P_{atm})
- Inside the glass tube, the weight of the mercury is pulling down (P_{Hg})
- Here, the air pressure can support 760 mm Hg



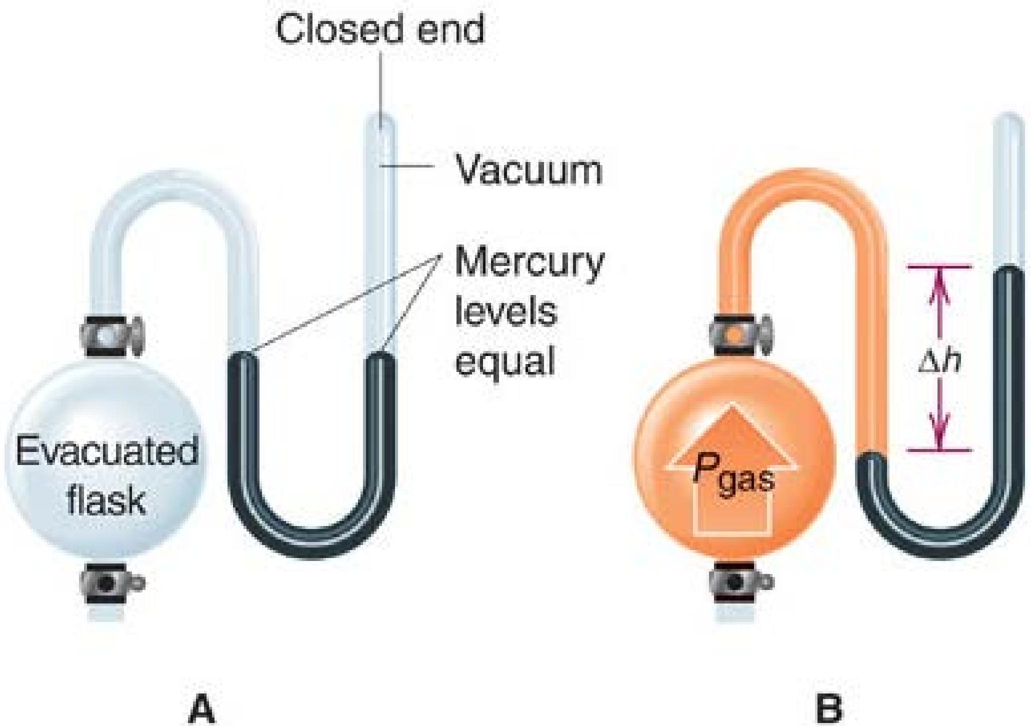
Modern Barometers

- Useful on predicting changes in weather.
- Increases or decreases in atmospheric pressure indicated changes in weather systems.
- May be analogue or digital….



http://wawangresort.wordpress.com/tag/barometer/

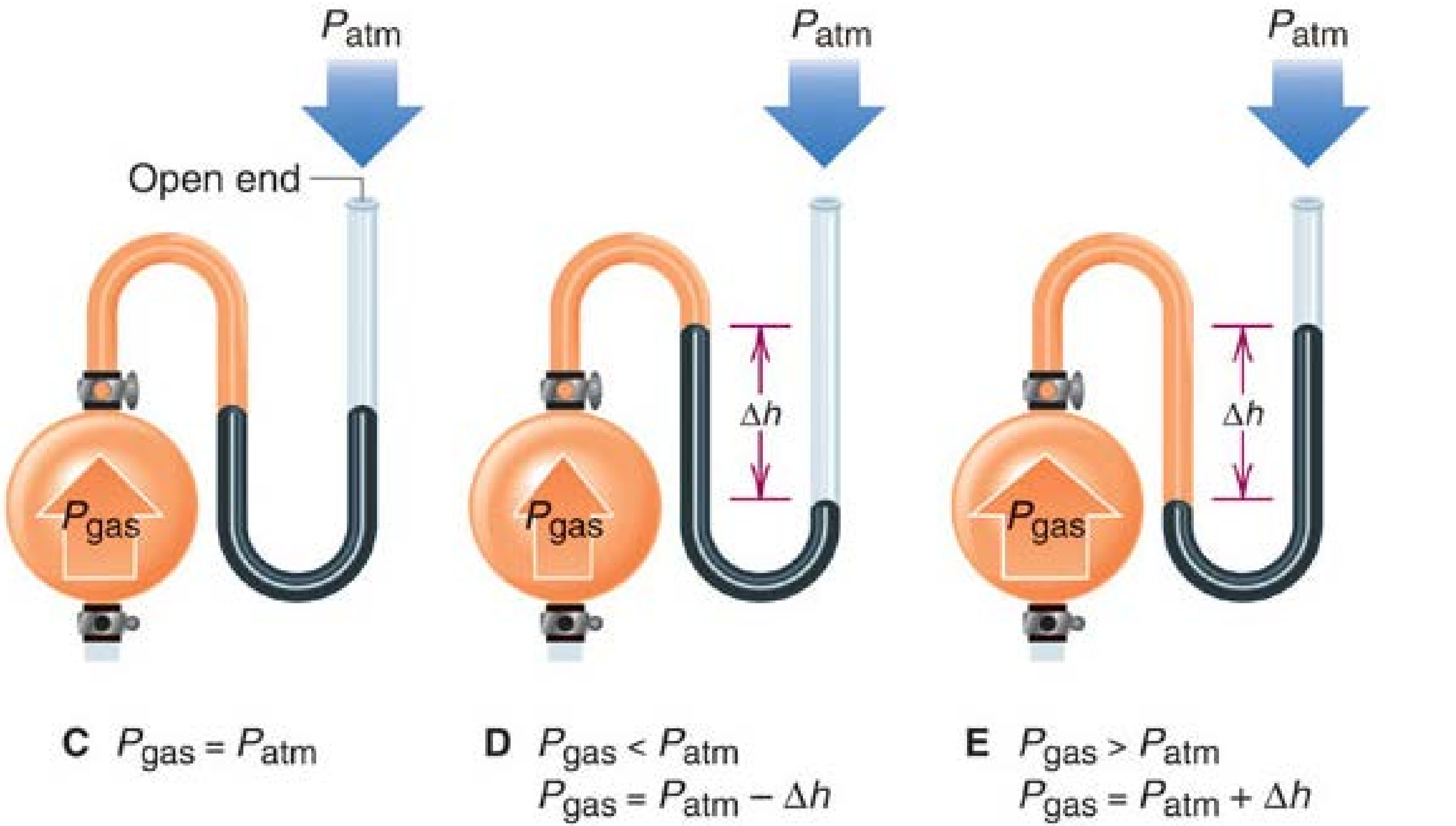
Measuring Gas Pressure: Closed Manometers



- A gas is placed into the flask attached to a closed manometer
- The gas pressure pushes the mercury in the tube
- The gas pressure is equal to Δh, the difference in height between the two sides of the U-tube

Measuring Gas Pressure: Open Manometers

- In an open manometer, air pressure and gas pressure "compete" to push the mercury column



Standard Units of Pressure

- The S.I. unit for pressure is the Pascal, Pa
- 1 Pa = 1 Nm^{-2}
- Because of its small size, we normally use the kPa in chemistry (1 kPa = 1000 Pa)

- Standard Pressure is 101.3 kPa
- Other common units for pressure:

101.3 kPa = 1.00 atm = 760 mm Hg = 760 torr

Amount of Gas

- When we inflate a balloon, we are <u>adding</u> gas molecules.
- Increasing the number of gas particles increases the number of collisions
  - thus, the pressure increases
- If temp. is constant- doubling the number of particles doubles pressure

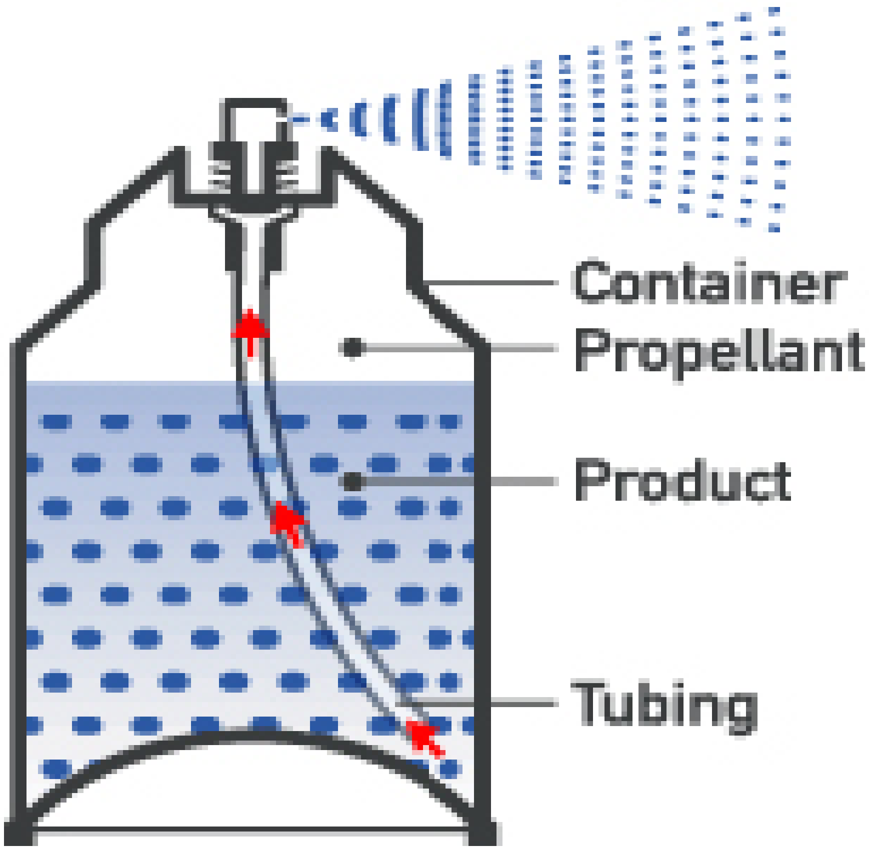
Pressure and the number of molecules are <u>directly related</u>

- More molecules means more collisions.
- Fewer molecules means fewer collisions.
- Gases naturally move from areas of <u>high pressure to low pressure</u> because there is empty space to move in - spray can is example.

Common use?

- Aerosol (spray) cans
  - gas moves from higher pressure to lower pressure
  - a propellant forces the product out
  - whipped cream, hair spray, paint

Inside an Aerosol Can



Volume of Gas

- In a smaller container, molecules have less room to move.
- Hit the sides of the container more often.
- As volume decreases, pressure increases. (think of a syringe)

Temperature of Gas

- Raising the temperature of a gas increases the pressure, if the volume is held constant.
- The molecules hit the walls harder, and more frequently!
- The only way to increase the temperature at constant pressure is to increase the volume.

If a balloon is moved from an ice water bath into a boiling water bath, its volume increases because as the molecules move faster (due to increased temperature) they collectively occupy more volume.

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The Gas Laws

The Gas Laws

- Three common laws were developed to see the effects of Pressure, Temperature and Moles on the Volume of a gas. A fourth law describes the effect of temperature on pressure of a gas.

a) Boyle's Law,

b) Charles's Law,

c) Gay-Lussac's Law, and

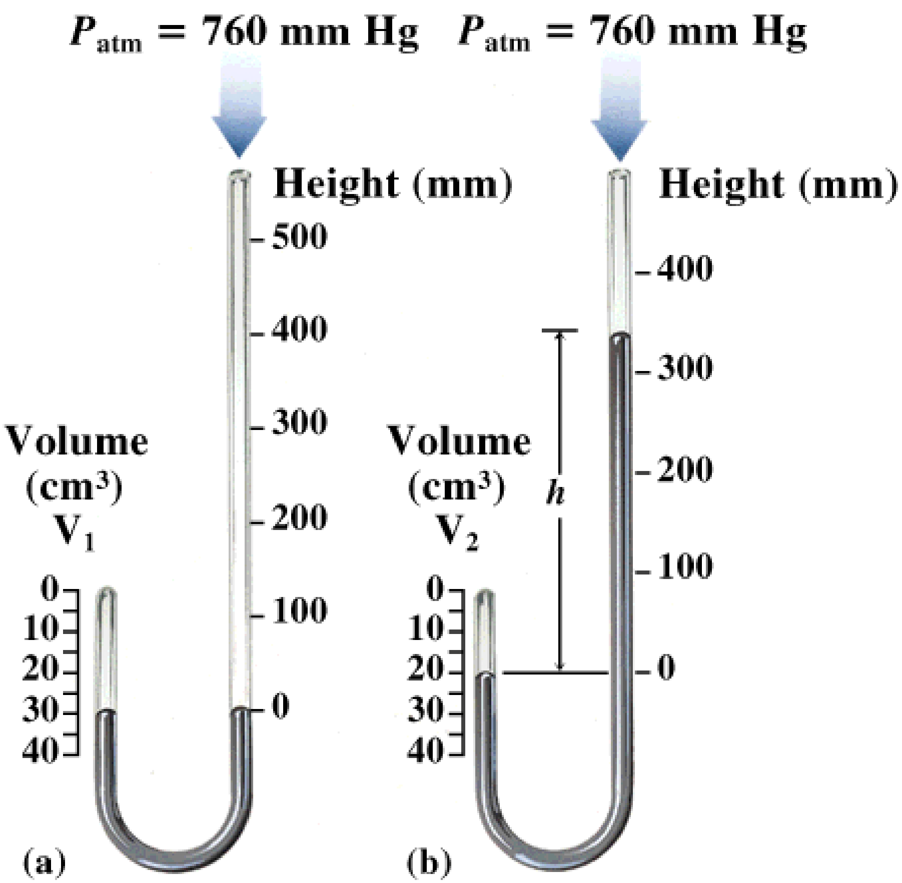
d) the Combined Gas Law.

Boyle's Law (P,V)

- Robert Boyle (1662) discovered that the **volume** of a gas varies **inversely** with **pressure**
- That is, when gas pressure INCREASES, its volume DECREASES proportionally

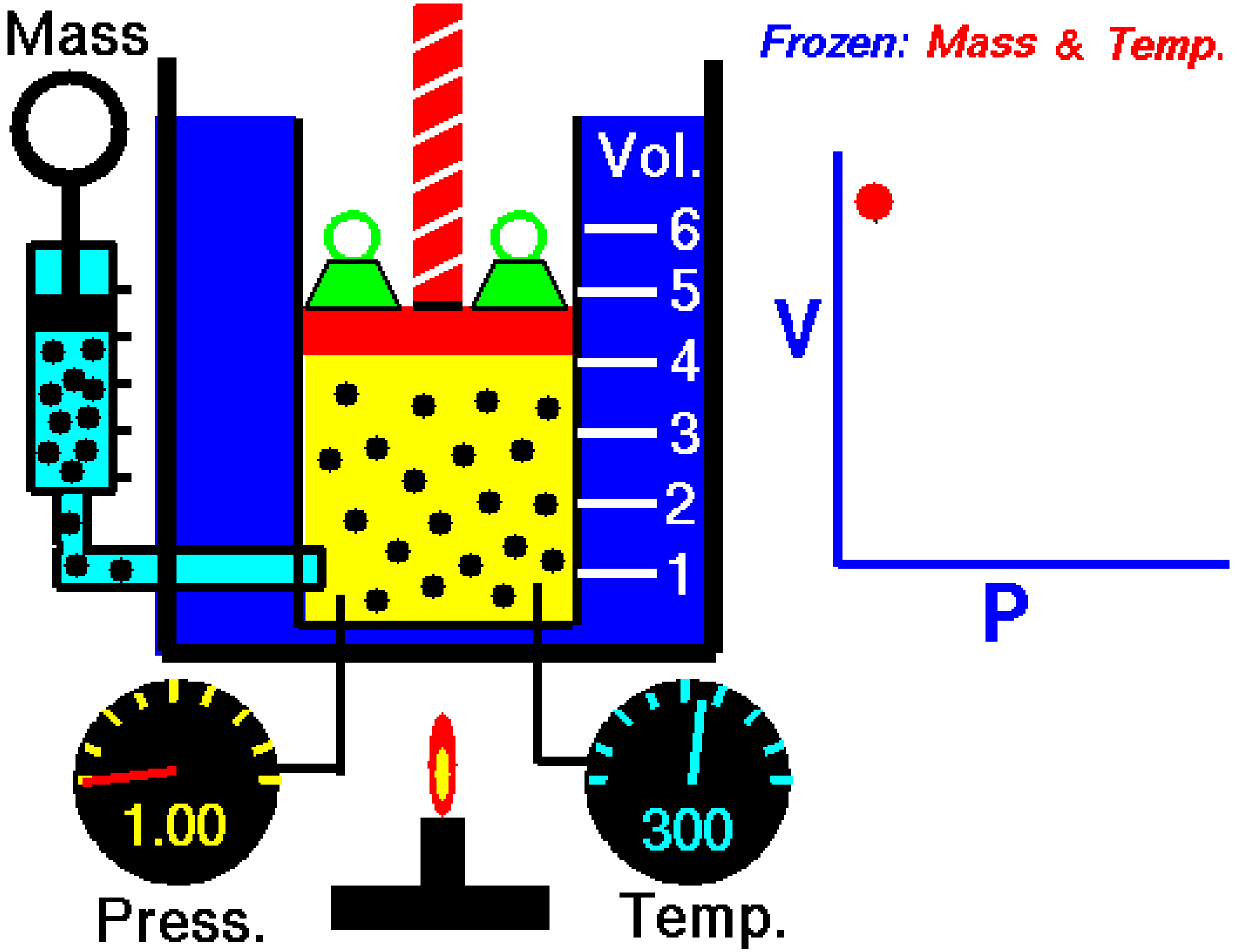
$$V \sim \frac{1}{P} \quad \text{or} \quad V = \frac{k}{P}$$

$$\boxed{PV = k \quad \text{or} \quad P_1V_1 = P_2V_2}$$

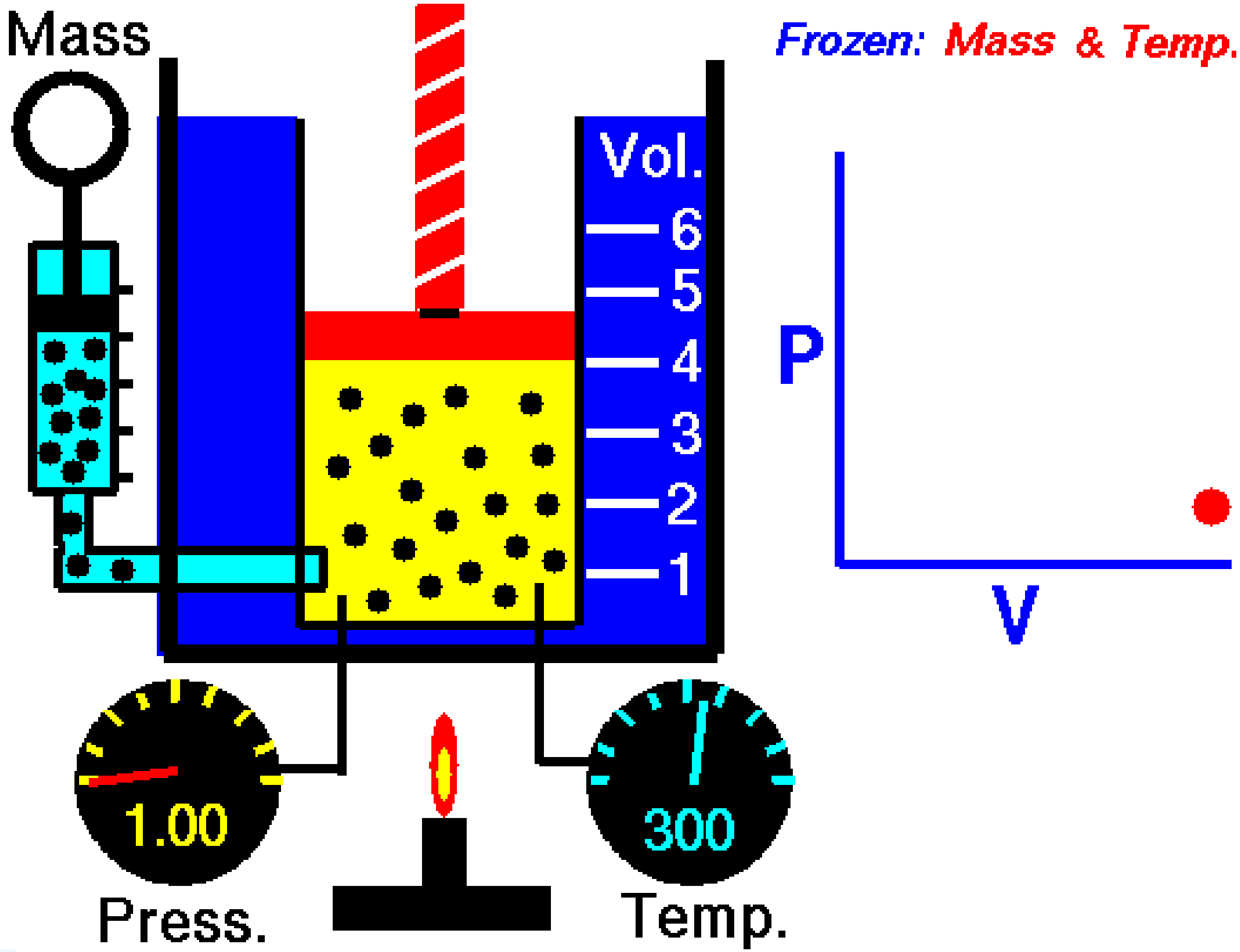


Note that Temperature and Moles are held constant here!

Boyle's Law Video



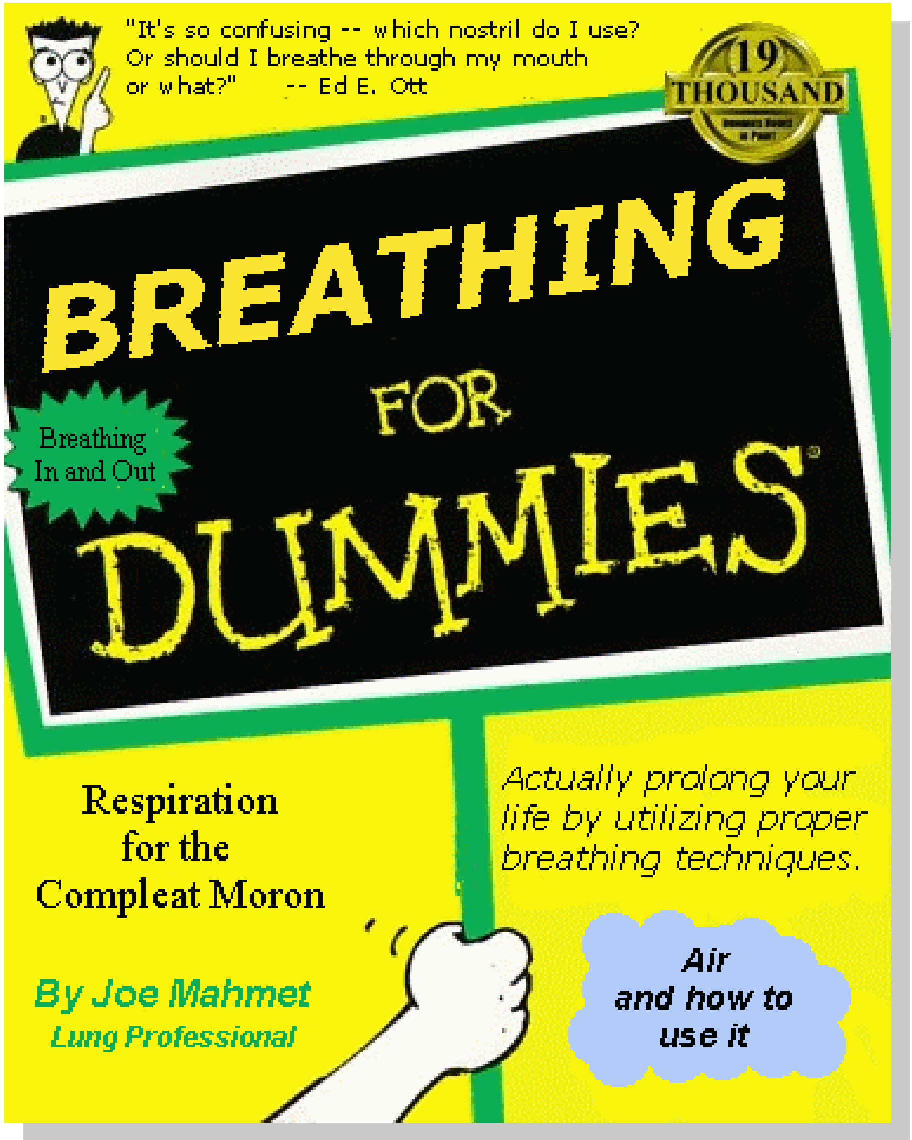
The pressure can be changed by adding or removing green weights from the top of the red piston.



The volume is changed by adjusting the position of the piston using the red screw.

Applications:

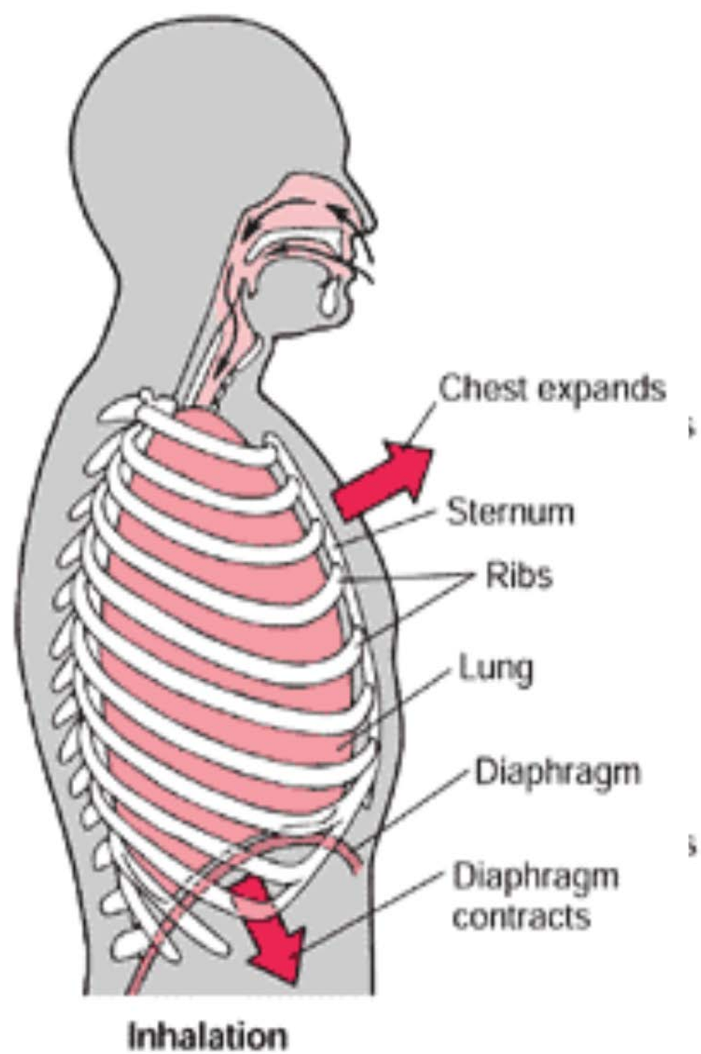
- Many people do not understand the process of breathing, even though they do it thousands of times per day, everyday of their lives!
- Fortunately, there are publications available to assist them with this important procedure!



Breathe Deeply!

It's Boyle's Law!

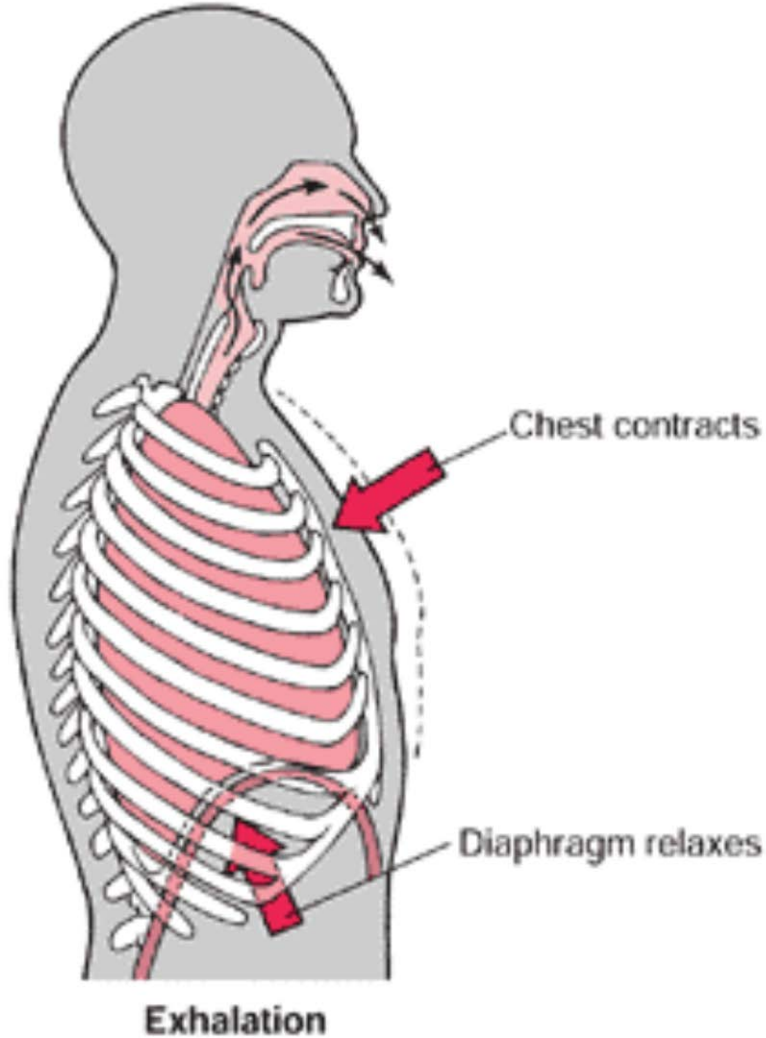
- When the diaphragm contracts, the volume of the thoracic cavity increases
- The lungs expand and pressure decreases. Since $P_{air} > P_{lungs}$, air enters.



Breathe Deeply!

It's Boyle's Law!

- When the diaphragm relaxes, the volume of the thoracic cavity decreases.
- The lungs contract and the pressure in the lungs increases. $P_{lungs} > P_{air}$, so air is exhaled.



Assignment

40S Behavior of Gases Study Guide:

- Sections 14-1 and 14-2

40S Science Notebook:

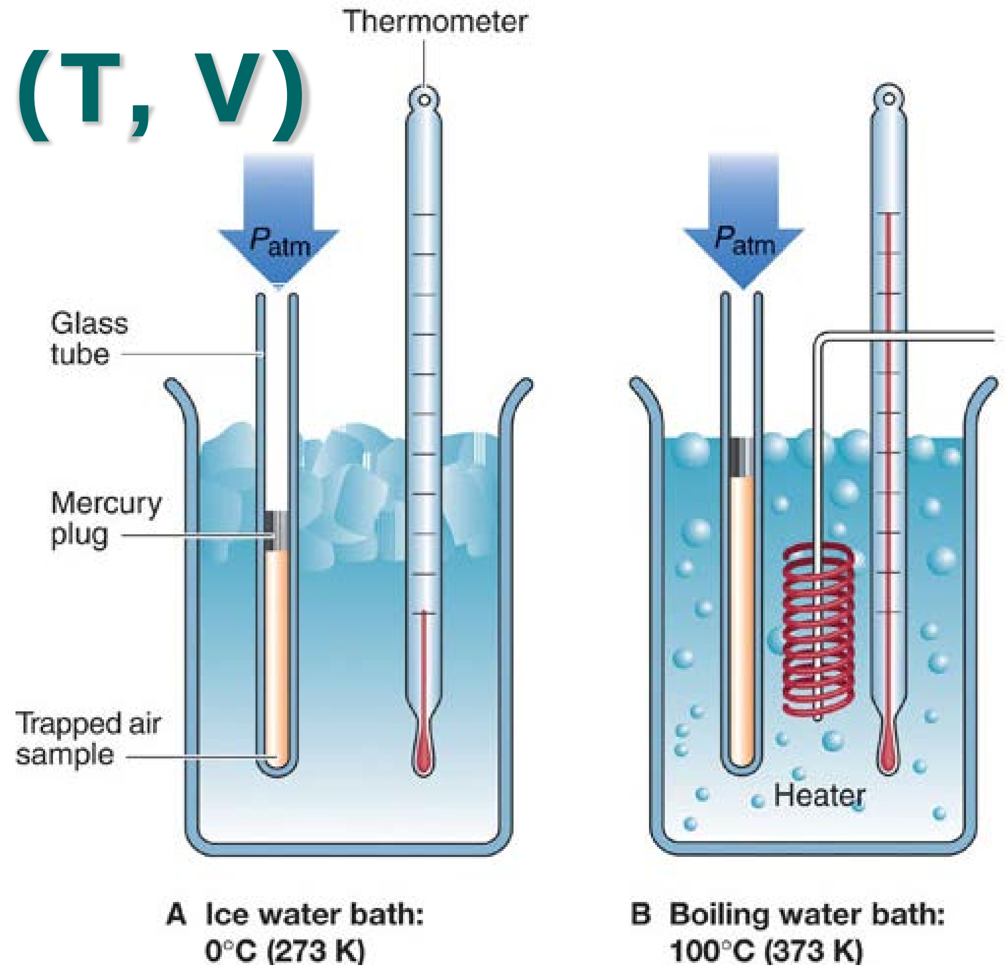
- pages 1-6 (odd numbered questions only)

Charles's Law (T, V)

- Jacques Charles (1787) discovered that the **volume** of a gas varies **directly** with **absolute temperature**
- The Kelvin temperature scale is used when applying Charles's Law.

$$V \sim T \quad \text{or} \quad V = kT$$

$$\boxed{\frac{V}{T} = k \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}}$$



Note that Pressure and Moles are held constant here!

The Absolute Temperature Scale

- Temperature measures *average* Kinetic Energy of particles:
- When motion stops, particles have no kinetic energy.
- This means there must be an absolute “zero” temperature!
- The Kelvin temperature scale starts at Absolute Zero:

$$\boxed{K = {}^{\circ}C + 273.15}$$

Avogadro's Law (n, V)
Gay-Lussac's Law (T, P)

- Avogadro showed that the **volume** of a gas varies **directly** with the **amount** of gas (# of moles)
- Thus, a similar relationship exists as in Charles's Law:

$$\frac{V}{n} = k \quad \text{or} \quad \frac{V_1}{n_1} = \frac{V_2}{n_2}$$

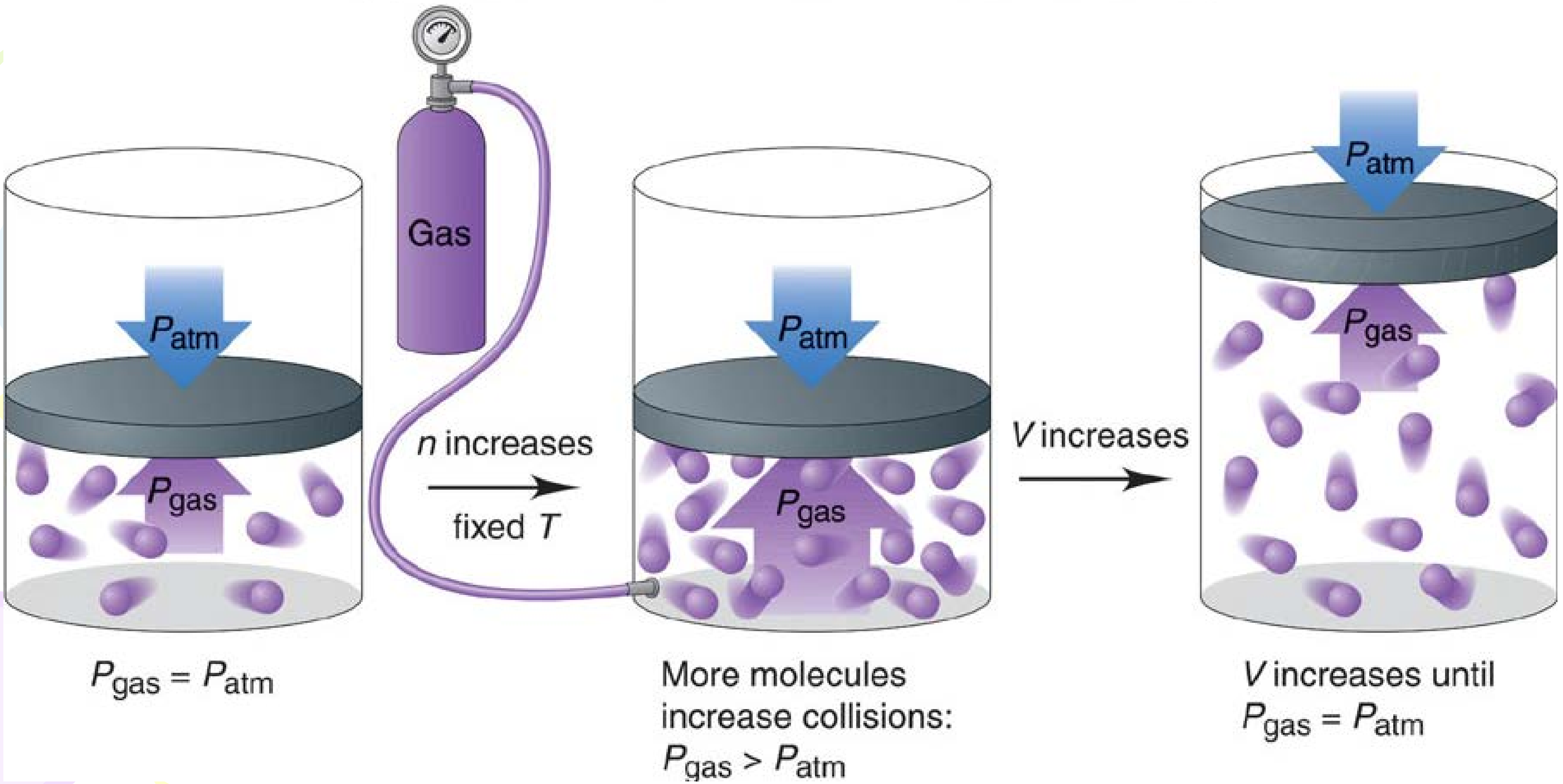
Pressure & Temperature are held constant here!

- Gay-Lussac studied how **temperature** affects the **pressure** of a gas.
- He discovered a **direct** relationship!

$$\frac{P}{T} = k \quad \text{or} \quad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Moles & Volume are held constant here!

Avogadro's Law Illustrated



Assignment

40S Chemistry Study Guide:

- 14-3 and 14-4

Continue with 40S Science Notebook:

- pages 1-6 (odd numbered questions only)

The Combined Gas Law

- The gas laws can be combined into one equation.
- Volume and pressure vary inversely, while volume varies directly with temperature.
- The moles of particles, n, remains constant.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

- When variables are held constant, they can be deleted from the combined law – this produces all four gas laws we studied earlier.

- The combined gas law contains all the other gas laws!
- If the temperature remains constant...

$$P_1 \times V_1 = P_2 \times V_2$$

Boyle's Law

- The combined gas law contains all the other gas laws!
- If the pressure remains constant…

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Charles's Law

- The combined gas law contains all the other gas laws!
- If the volume remains constant…

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Gay-Lussac’s Law

Assignment

40S Science Notebook:

- pages 7-12 (odd numbered questions only)

Ideal Gases

- We are going to assume the gases behave “ideally”- obeys the Gas Laws under all temp. and pres.
- An ideal gas does not really exist, but it makes the math easier and is a close approximation.
- Particles have no volume.
- No attractive forces.

Ideal Gases

- There are no gases for which this is true; however,
- Real gases behave this way at high temperature and low pressure.

The Ideal Gas Law

- The combined gas law can be re-written: $$\frac{PV}{nT} = R$$
- Here, we use the symbol "R" to represent the combined proportionality constants from the different gas laws. It is known as the **Ideal Gas Constant**
- Gas problems are solved using Kelvin temperatures, moles and Litres for volume.
- The value of R will depend on the units for pressure:

$$R = 8.314 \text{ kPa L mol}^{-1}\text{K}^{-1} \text{ or } 0.0821 \text{ atm L mol}^{-1}\text{K}^{-1}$$

$$\text{or } 62.4 \text{ mmHg L mol}^{-1}\text{K}^{-1}$$

- Choose the value of R that matches the units for pressure in the problem you are solving.

Ideal Gas Law, cont'd

- We can rewrite the combined law in a form that is known as the Ideal Gas Law:

$$PV = nRT$$

- The value of the Ideal Gas Law over the previous laws is that only ONE set of conditions is required – if 3 of the variables are known, the 4th can be calculated.
- Use substitution and some algebra to *derive* the related equations from the Ideal Gas Law:

Ideal Gas Law, cont'd

- To find the molar mass of a gas sample, the mass, temperature, pressure and volume must be known.
- To calculate the number of moles of a gas, use the formula . . .

$$n = \frac{m}{M}$$

Where:

n = number of moles

m = mass of sample

M = molar mass

Ideal Gas Law, cont'd

- Because of this, n in the equation can be substituted with $\frac{n}{M}$ to obtain the formula . . .

$$PV = \frac{mRT}{M}$$

- Or, to solve for molar mass, M . . .

$$M = \frac{mRT}{PV}$$

Ideal Gas Law, cont'd

- Density, D, is defined as mass per unit volume and is found using the formula . . .

$$D = \frac{m}{V}$$

Where:

D = density

m = mass

V = volume

Ideal Gas Law, cont'd

- After rearranging the ideal gas equation to solve for molar mass, D can be substituted for $\frac{m}{V}$ . . .

$$M = \frac{mRT}{PV} = \frac{DRT}{P}$$

- Or, to solve for density, D . . .

$$D = \frac{MP}{RT}$$

Assignment

Continue with 40S Science Notebook:

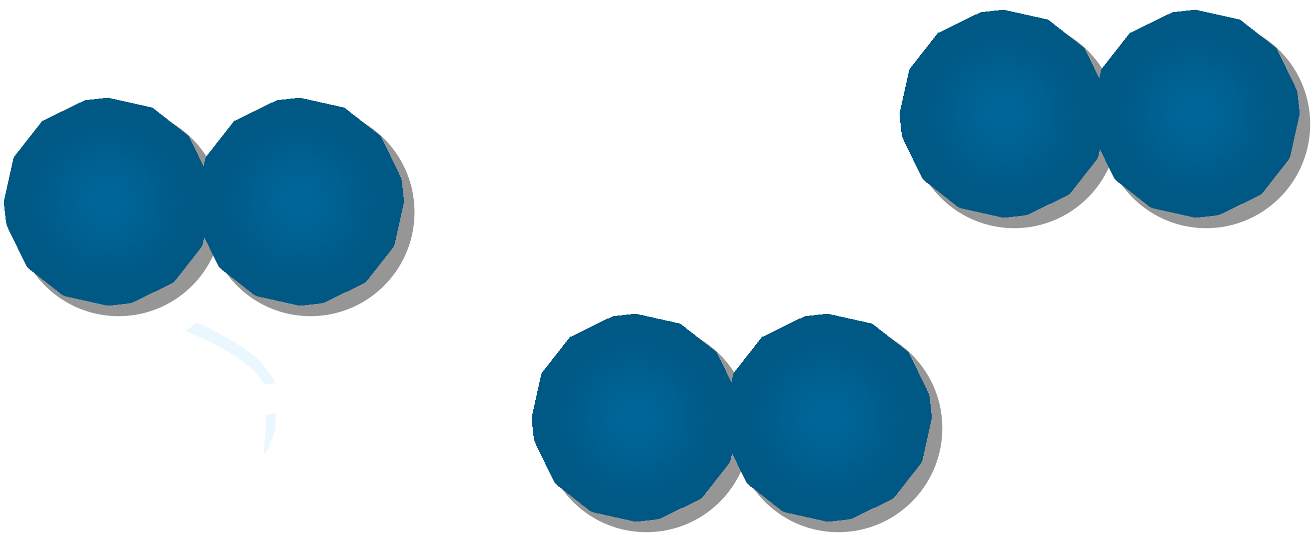
- pages 7-12 (odd numbered questions only)

40S Chemistry

Real Gases

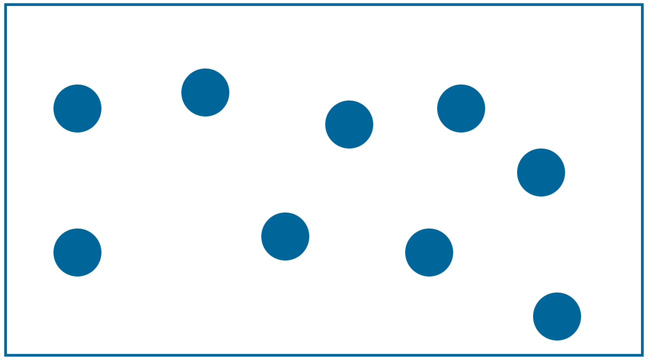
Ideal Gases don't exist

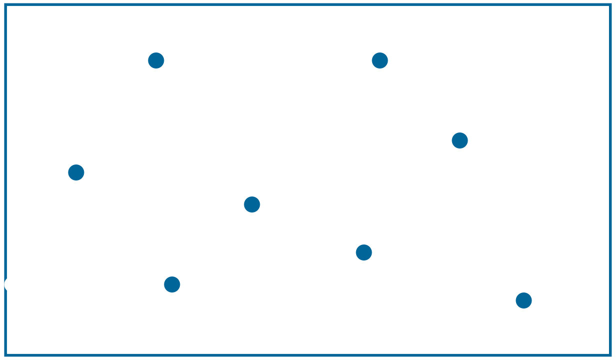
- Molecules do take up space
- There are attractive forces
- otherwise there would be no liquids formed



Real Gases behave like Ideal Gases…

- When molecules are far apart
- Molecules do not take up as big a % of the space
- We can ignore their volume.
- This is at low pressure





Real Gases behave like Ideal gases when…

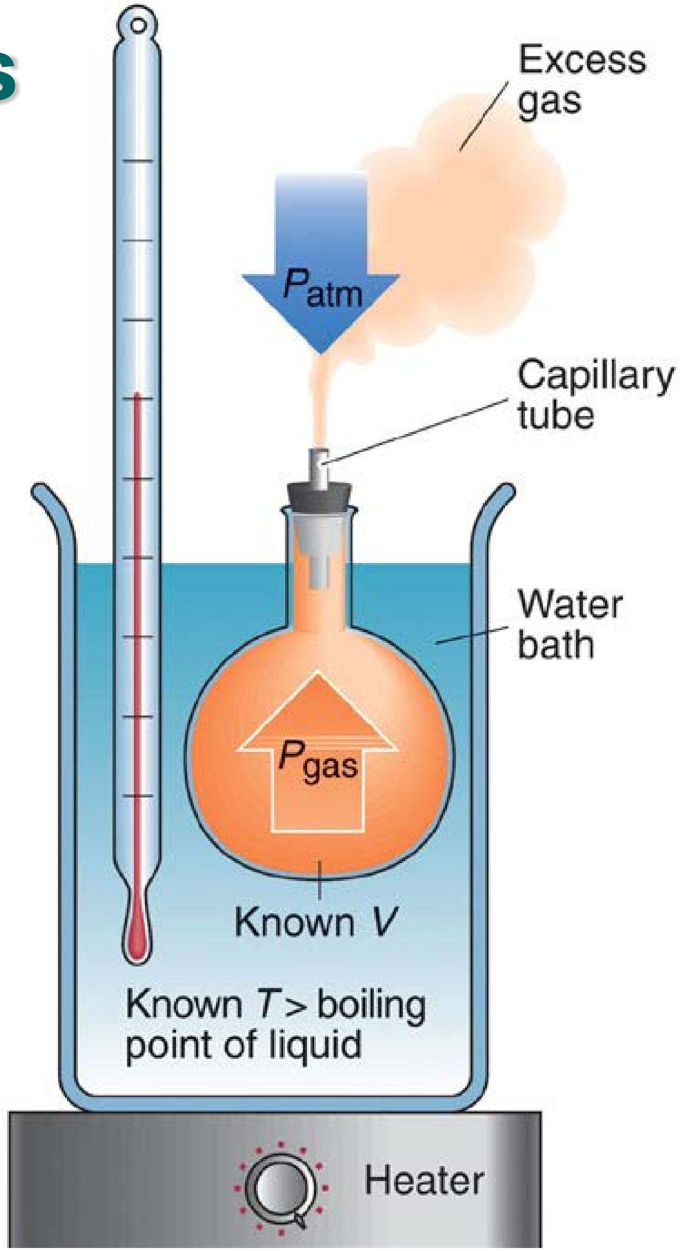
- When molecules are moving fast
  = high temperature
- Collisions are harder and faster.
- Molecules are not next to each other very long.
- Attractive forces can’t play a role.

Standard Molar Volume: 22.4 L @ STP

$n = 1$ mol	$n = 1$ mol	$n = 1$ mol
$P = 1$ atm (760 torr)	$P = 1$ atm (760 torr)	$P = 1$ atm (760 torr)
$T = 0°C$ (273 K)	$T = 0°C$ (273 K)	$T = 0°C$ (273 K)
$V = 22.4$ L	$V = 22.4$ L	$V = 22.4$ L
Number of gas particles $= 6.022 \times 10^{23}$	Number of gas particles $= 6.022 \times 10^{23}$	Number of gas particles $= 6.022 \times 10^{23}$
Mass = 4.003 g	Mass = 28.02 g	Mass = 32.00 g
$d = 0.179$ g/L	$d = 1.25$ g/L	$d = 1.43$ g/L

Determining Molar Mass of a Volatile Liquid

- A "volatile" liquid is one that evaporates easily
- The liquid in the flask evaporates, filling the flask with vapor
- Since the flask is open to the air, eventually the P_{gas} will equal P_{air}
- Measure the temperature of the water, the volume of the flask and the mass of the flask before and after heating
- Calculate the Molar Mass of the gas (same as the volatile liquid)



Dalton's Law of Partial Pressures

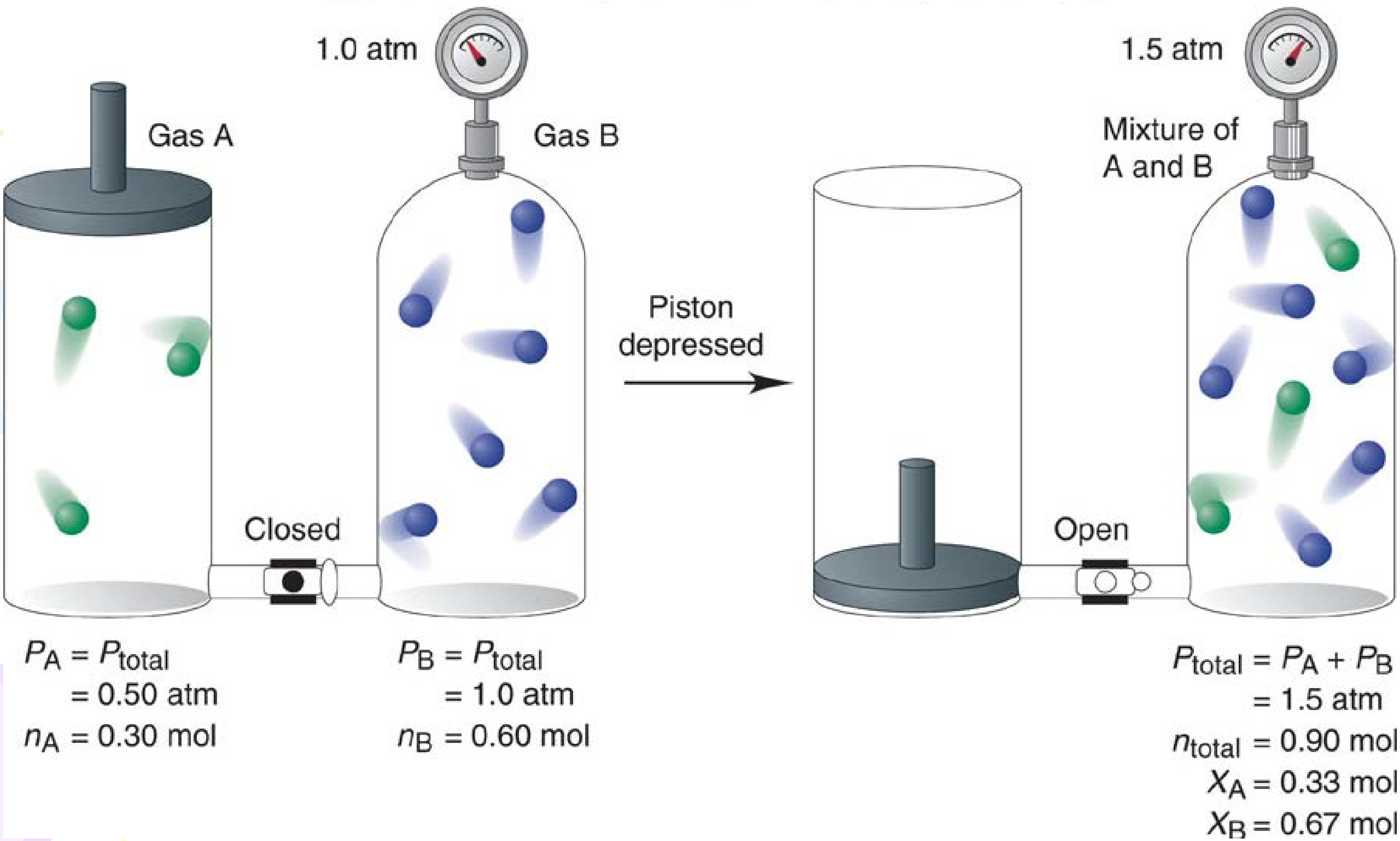
- In a mixture of gases, the TOTAL pressure of gas is the sum of the pressures caused by each gas (the partial pressures):

$$P_{Total} = P_1 + P_2 + P_3 + \ldots$$

P_{Total} = total pressue

P_1, P_2, and so on . . . = partial pressure of each gas in the mixture.

Dalton's Law Illustrated



Assignment

Complete the worksheet:

- *Dalton's Law of Partial Pressure*

Behavior of Gases Topic Test