Gases

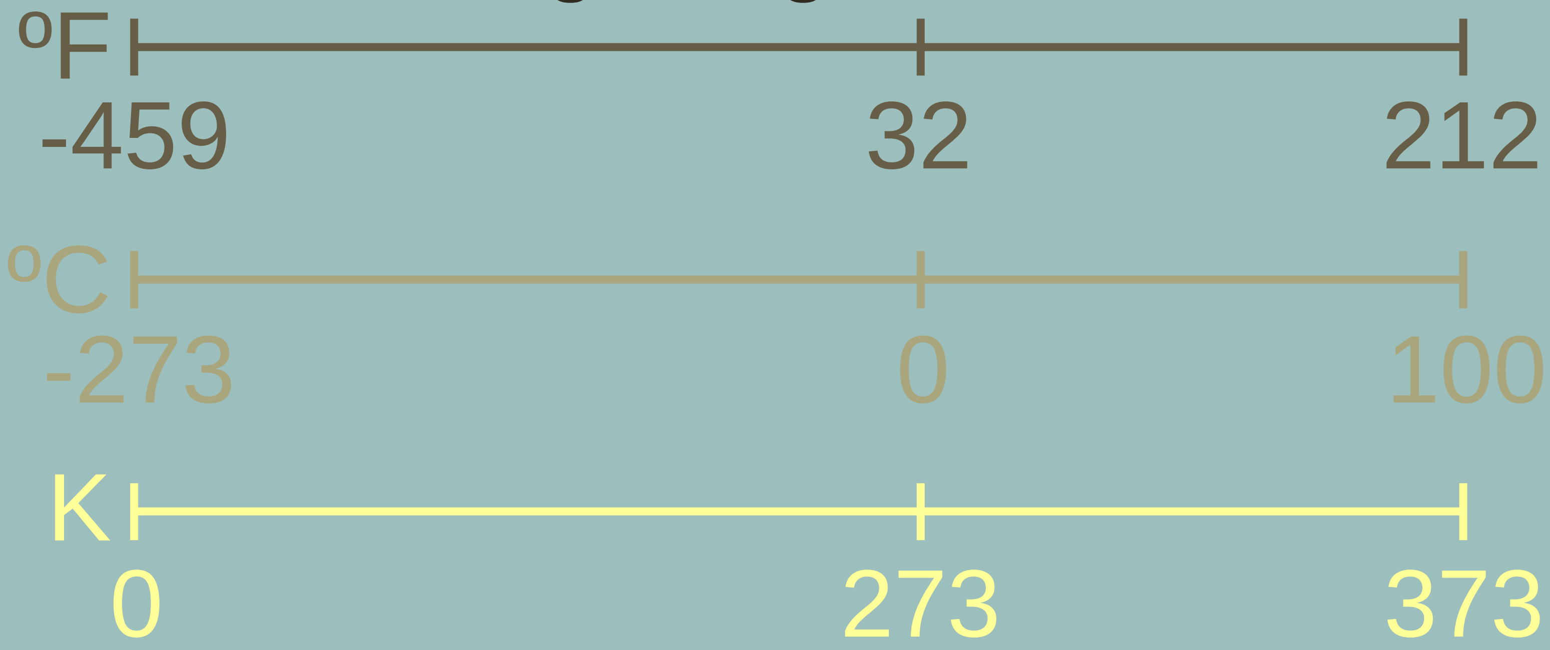
Physical Properties

Objectives

1. To learn about atmospheric pressure and how barometers work
2. To learn the units of pressure
3. To understand how the pressure and volume of a gas are related
4. To do calculations involving Boyle's Law
5. To learn about absolute zero
6. To understand how the volume and temperature of a gas are related
7. To do calculations involving Charles's Law
8. To understand how the volume and number of moles of a gas are related
9. To do calculations involving Avogadro's Law

Temperature

- ***Always*** use absolute temperature (Kelvin) when working with gases.



$$°C = \frac{5}{9}\left(°F - 32\right) \qquad K = °C + 273$$

STP

STP

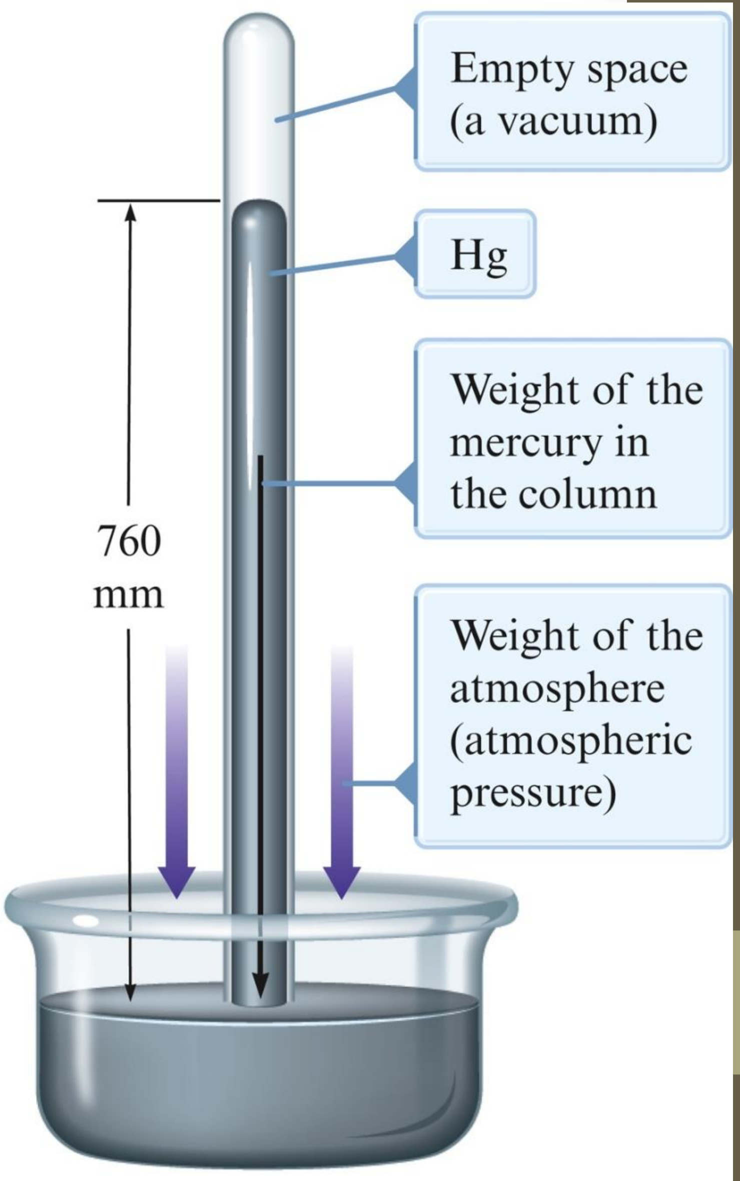
Standard Temperature & Pressure

0°C		273 K
	-OR-	
1 atm		101.325 kPa

Pressure

Measuring Pressure

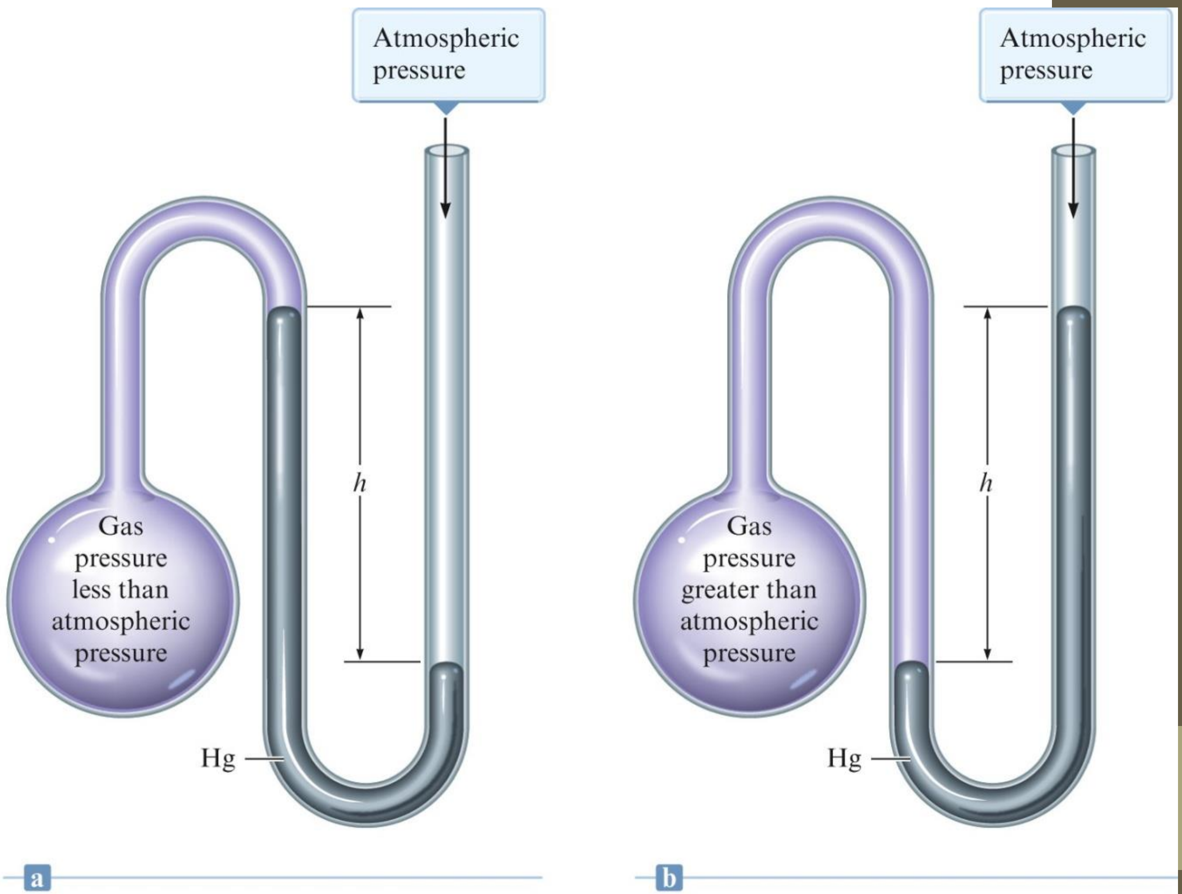
- Barometer – device that measures atmospheric pressure
  - Invented by Evangelisti Torricelli in 1643



Pressure

Units of Pressure

- A manometer measures the pressur[e] of a gas in a container



Gas pressure = atmospheric pressure – *h*.

Gas pressure = atmospheric pressure + *h*.

Pressure

- **KEY UNITS AT SEA LEVEL**

101.325 kPa (kilopascal)

1 atm

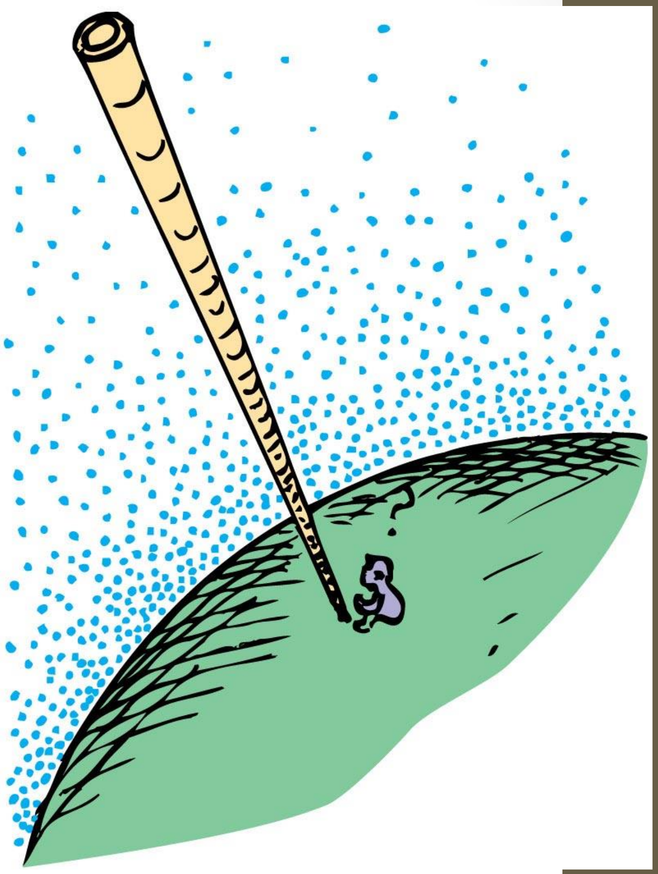
760 mm Hg

760 torr

14.7 psi

$$pressure = \frac{force}{area}$$

$$kPa = \frac{N}{m^2}$$



You carry the weight of a column of air all the way to space

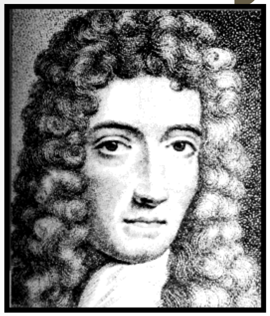
Pressure Conversions: An Example

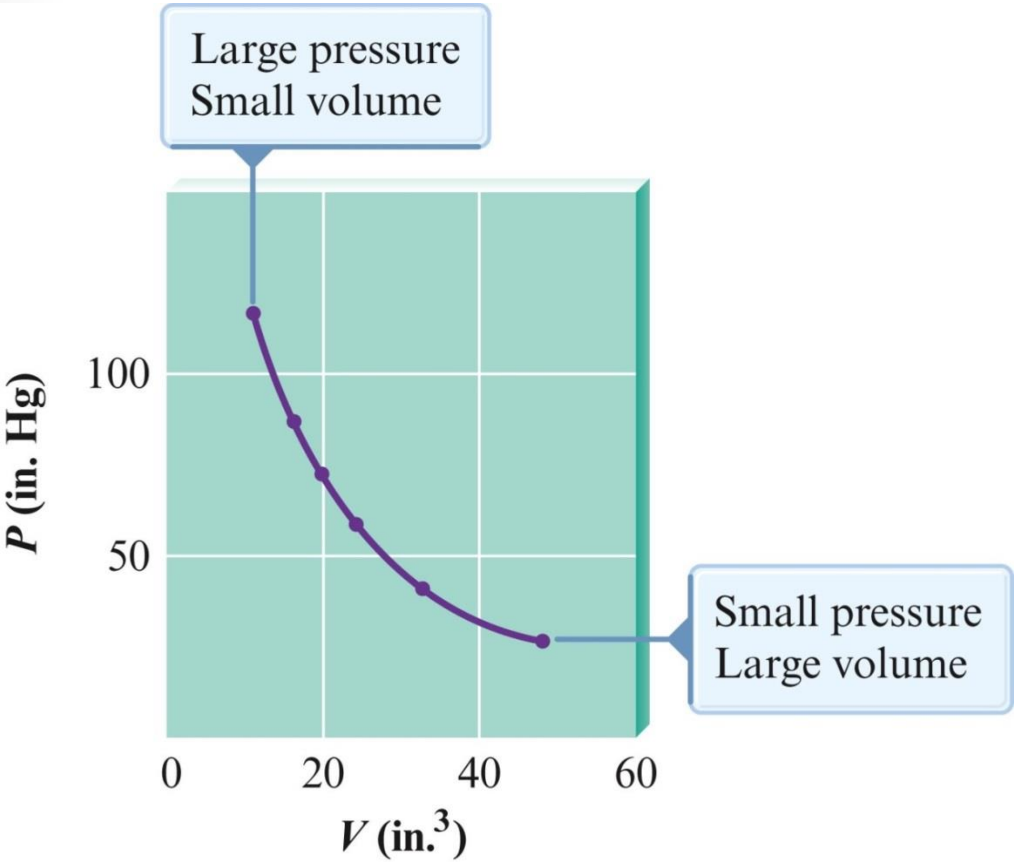
The pressure of a gas is measured as 2.5 atm. Represent this pressure in both torr and pascals.

$$(2.5\ \text{atm}) \times \left(\frac{760\ \text{torr}}{1\ \text{atm}}\right) = 1.9 \times 10^{3}\ \text{torr}$$

$$(2.5\ \text{atm}) \times \left(\frac{101{,}325\ \text{Pa}}{1\ \text{atm}}\right) = 2.5 \times 10^{5}\ \text{Pa}$$

Boyle's Law (Pressure and Volume)





In 1662, Robert Boyle discovered that the *volume* of a gas is inversely proportional to its *pressure* (at constant temperature).

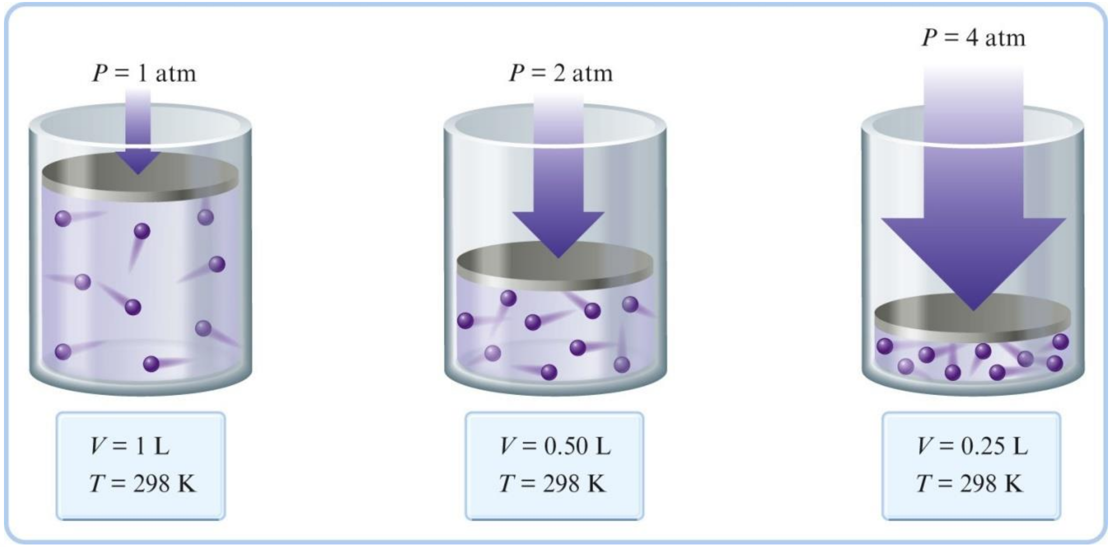
$$P_1V_1 = k$$

k is a constant

Boyle's Law (Pressure and Volume)

If $P_1V_1 = k$ and $P_2V_2 = k$ then $P_1V_1 = P_2V_2$

- Volume and pressure are inversely proportional.
  - If one increases the other decreases.



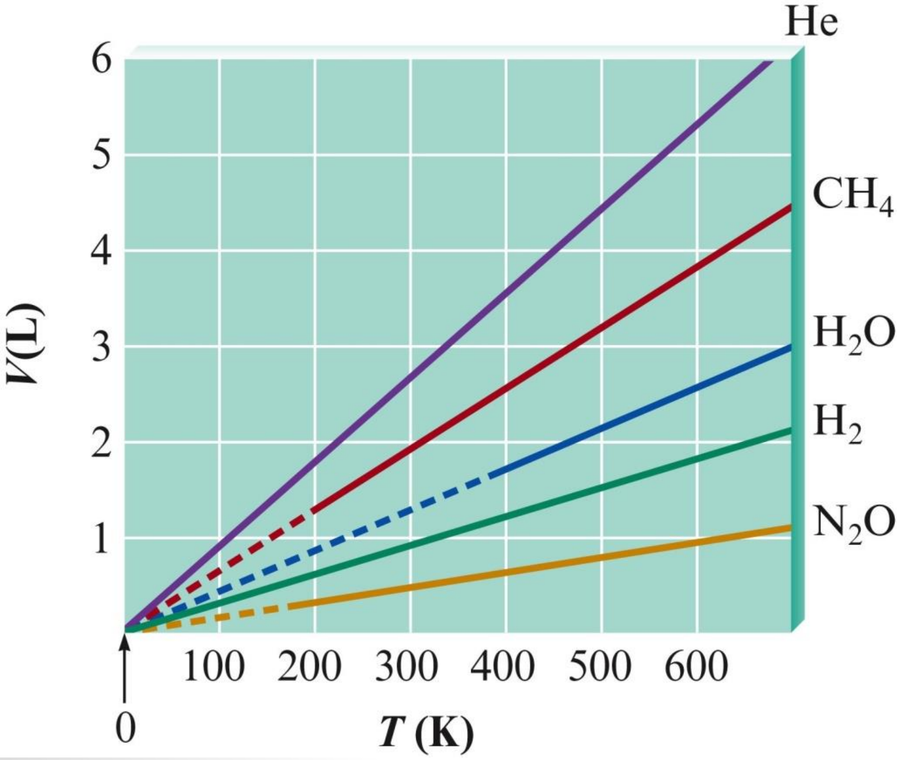
Exercise (Boyle's Law)

A sample of helium gas occupies 12.4 L at 23°C and 0.956 atm. What volume will it occupy at 1.20 atm assuming that the temperature stays constant?

9.88 L

Charles' Law

In 1787 Charles discovered that the *volume* and absolute *temperature* (K) of a gas were related (at constant pressure).



$$V_1 = bT_1$$

b is a constant

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

Exercise (Charles's Law)

Suppose a balloon containing 1.30 L of air at 24.7°C is placed into a beaker containing liquid nitrogen at –78.5°C. What will the volume of the sample of air become (at constant pressure)?

0.849 L

Combined Gas Law

Pressure and *Temperature* are also proportional (at constant volume).

By putting all relationships together, it forms the **Combined Gas Law**.

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

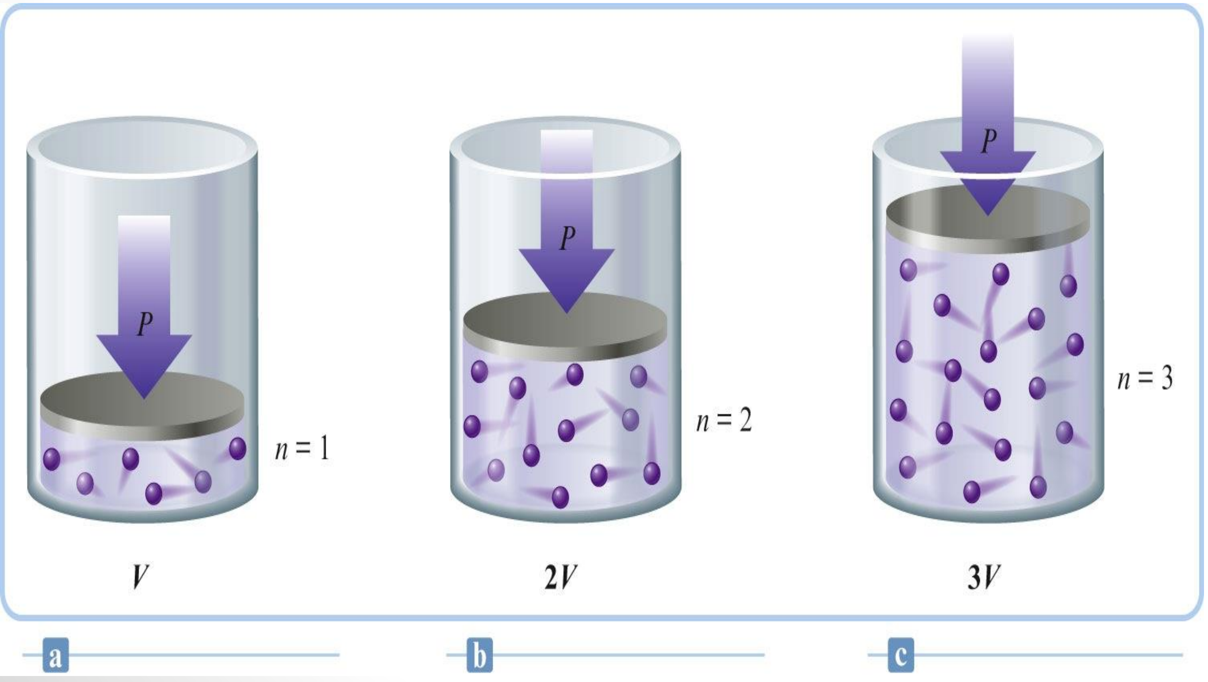
Exercise (Combined Gas Law)

A tire at sea level (1.0 atm) is inflated with 32.5 L of air at a temperature of 33.0 C. The car its in travels to the top of a mountain where the temperature is now 22.5 C and the pressure reads 0.6 atm. What is the new volume of the tire?

52.3 L

Avogadro's Law

In 1811, Avogadro proposed that *equal volumes of gases contain equal numbers of particles (at same T, P)*
It followed that the *volume* of a gas is proportional to the number of *moles*.



$$V = na$$

a is a constant

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

Gas Laws Experiment

- You will have two class periods to perform and complete the write up for this activity
- You will be working in groups of four and will hand in one group report. Lab groups will be assigned. Each group
- The directions for this experiment will be given orally, <u>once</u>.
- Take notes so you will remember all directions given.
- Please ask any questions before starting your work.
- This activity will allow you to make predictions based on your understanding of the gas laws and your previous knowledge.
- Think carefully about your claims. Try to anticipate the outcomes based on everything you have learned and/or experienced.
- Make connections between your observations and scientific concepts we have discussed.

Gas Laws Experiment

Alka-Seltzer

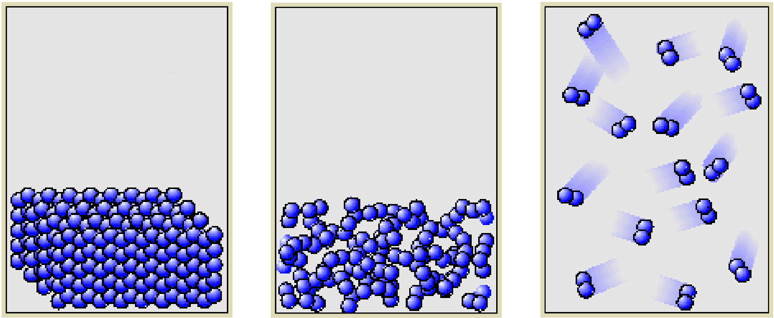
- **Set up your equipment** as demonstrated.
- **Write a clear and precise claim** that predicts what you will observe when you add the alka-seltzer to the water in the flask
- **Add 1 alka-seltzer** tablet to the Erlenmeyer flask, when you have completed your claim,
- **Carefully record all observations** on your lab sheet.
- **Diagram a model** which shows a particle representation of the changes you observed and provides a detailed explanation. Remember labels, titles, and arrows

Steel Wool

- **Set up your equipment** as demonstrated.
- **Write a clear and precise claim** that predicts what you will observe when you come back on Monday
- **Carefully record all observations** on your lab sheet. (Monday)
- **Diagram a model** which shows the changes you observed and provides a detailed explanation. Remember labels, titles, and arrows. (Monday)
- **Support or refute your claim** using observational evidence along with your understanding of gas laws.
- **Turn in your completed lab sheet**

Characteristics of Gases

- Gases expand to fill any container.
  - random motion, no attraction
- Gases are fluids (like liquids).
  - no attraction
- Gases have very low densities.
  - no volume = lots of empty space



Real Gases

- Particles in a REAL gas…
  - have their own volume
  - attract each other
- Gas behavior is most ideal…
  - at low pressures
  - at high temperatures
  - in nonpolar atoms/molecules

Ideal gas Law

Boyle's law	$PV = k$	At constant T and n
Charles's law	$V = bT$	At constant P and n
Avogrado's law	$V = na$	At constant T and P

Can be combined to form:

$$PV = nRT$$

R = 0.08206 L-atm/K-mol

Gas Stoichiometry

Molar Volume

- Standard temperature and pressure (STP)
  - 0^oC and 1 atm
- For one mole of a gas at STP

$$V = \frac{nRT}{P} = \frac{(1.00\ \cancel{\text{mol}})(0.08206\ \text{L}\ \cancel{\text{atm}}/\cancel{\text{K}}\ \cancel{\text{mol}})(273\ \cancel{\text{K}})}{1.00\ \cancel{\text{atm}}} = 22.4\ \text{L}$$

- Molar volume of an ideal gas at STP

  22.4 L

Exercise

An automobile tire at 23°C with an internal volume of 25.0 L is filled with air to a total pressure of 3.18 atm. Determine the number of moles of air in the tire.

3.27 mol

Exercise

What is the pressure in a 304.0 L tank that contains 5.670 kg of helium at 25°C?

114 atm

Exercise

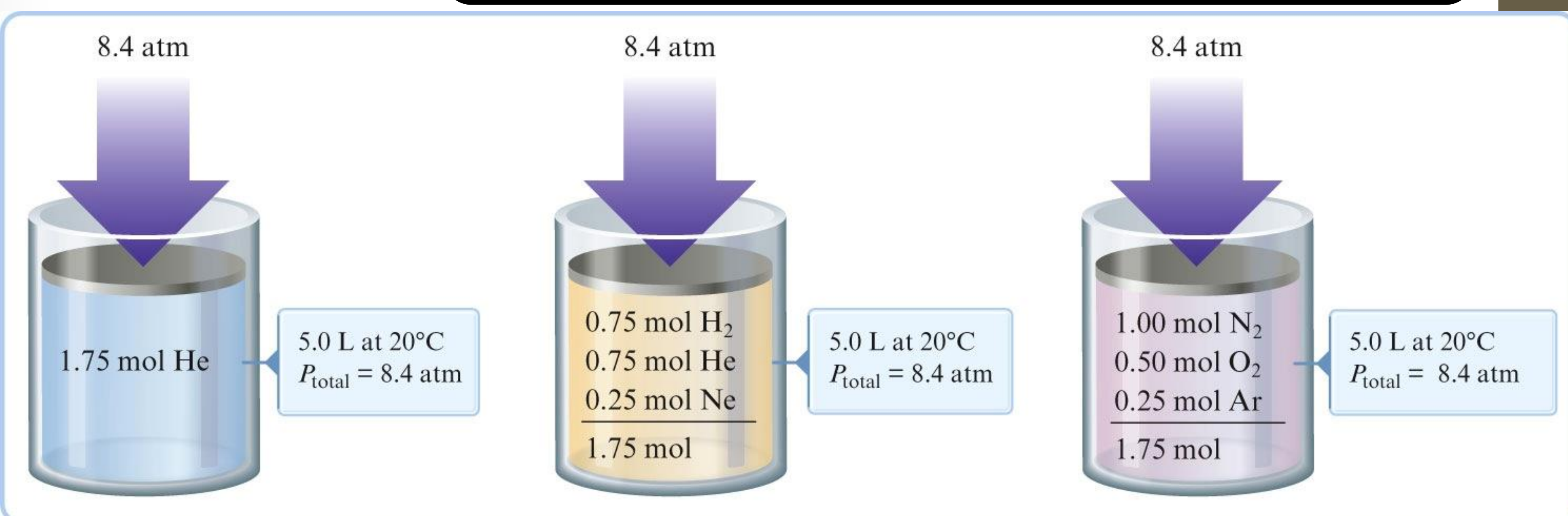
At what temperature (in °C) does 121 mL of CO_2 at 27°C and 1.05 atm occupy a volume of 293 mL at a pressure of 1.40 atm?

696°C

Dalton's Law of Partial Pressures

The total pressure of a mixture of gases equals the sum of the partial pressures of the individual gases.

$$P_{total} = P_1 + P_2 + \ldots$$



Exercise

27.4 L of oxygen gas at 25.0°C and 1.30 atm, and 8.50 L of helium gas at 25.0°C and 2.00 atm were pumped into a tank with a volume of 5.81 L at 25°C.

- Calculate the new partial pressure of oxygen.

  6.13 atm

- Calculate the new partial pressure of helium.

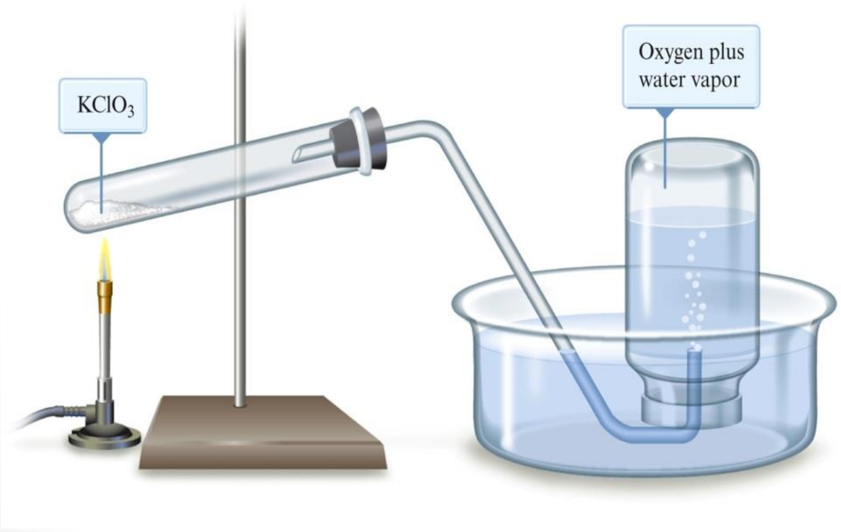
  2.93 atm

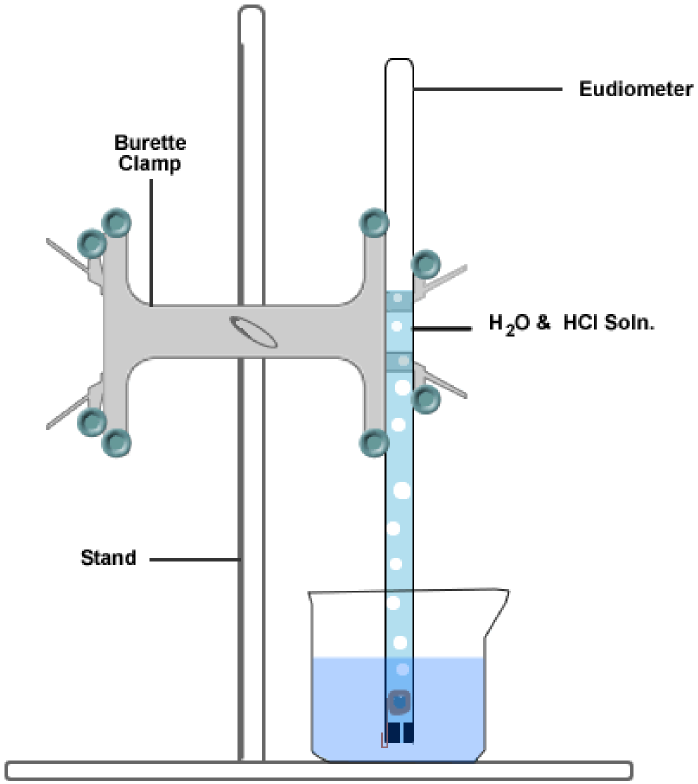
- Calculate the new total pressure of both gases.

  9.06 atm

Dalton's Law of Partial Pressures

Collecting a gas over water





- Total pressure is the pressure of the gas + the vapor pressure of the water.

The Kinetic Molecular Theory of Gases (KMT)

Assumptions of the Kinetic Molecular Theory of Gases

1. Gases consist of tiny particles (atoms or molecules).
2. These particles are so small, compared with the distances between them, that the volume (size) of the individual particles can be assumed to be negligible (zero).
3. 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.
4. The particles are assumed not to attract or to repel each other.
5. The average kinetic energy of the gas particles is directly proportional to the Kelvin temperature of the gas.

The Implications of the KMT

- Meaning of temperature – Kelvin temperature is directly proportional to the average kinetic energy of the gas particles
- Relationship between Pressure and Temperature – gas pressure increases as the temperature increases because the particles speed up
- Relationship between Volume and Temperature – volume of a gas increases with temperature because the particles speed up

Kinetic Molecular Theory

- Particles in an ideal gas (KMT)…
  - have no volume *(the particles are so small compared to the distance between them)*
  - have elastic collisions.
  - are in constant, random, straight-line motion *(collisions with the container cause pressure)*
  - don't attract or repel each other *(exert no forces on each other)*
  - have an avg. KE directly related to Kelvin temperature.