Gas Laws

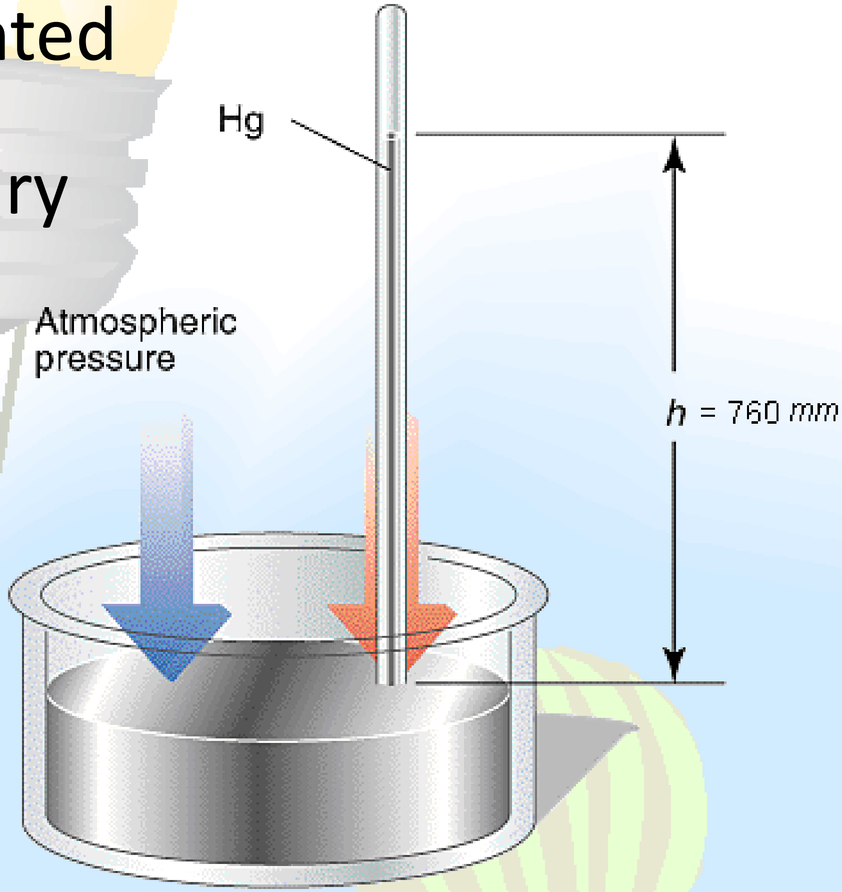
The effect of

Temperature and Pressure

on the volume of a gas

Air Pressure

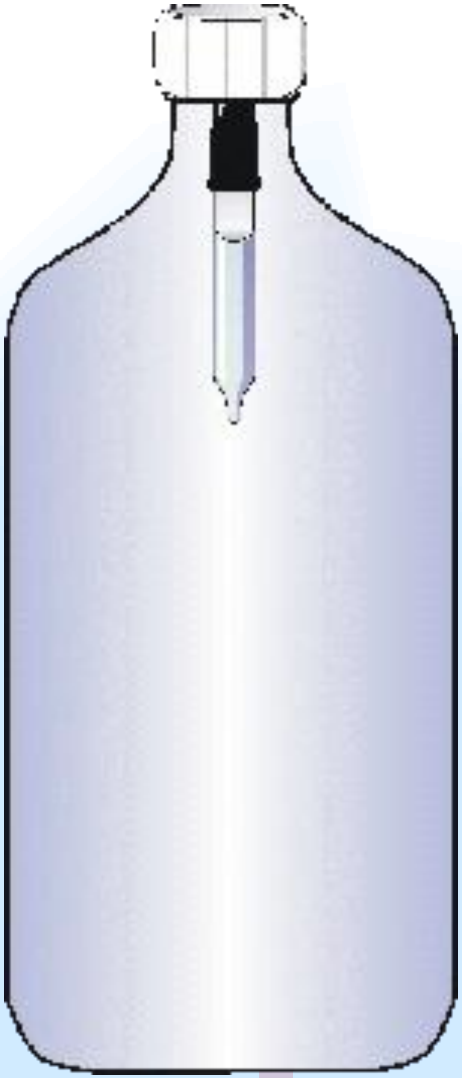
- Evangelista Torricelli invented the mercury barometer in 1643 by inverting a mercury filled glass tube into a dish of mercury.
- He found that air pressure could support a column of mercury 760 *mm* high.
- This knowledge was helpful in quantifying the relationship between the pressure on a gas and its volume.



Note: Standard atmospheric pressure is 760 *mm* Hg = 1 atm = 101.3 kPa

Pressure and Volume

- You can observe the relationship between pressure and the volume of a gas by constructing a Cartesian diver from a soda bottle and a medicine dropper.
- When you squeeze on the soda bottle, the dropper dives.
- This is because as the pressure increases, the volume of the air bubble in the medicine dropper decreases.



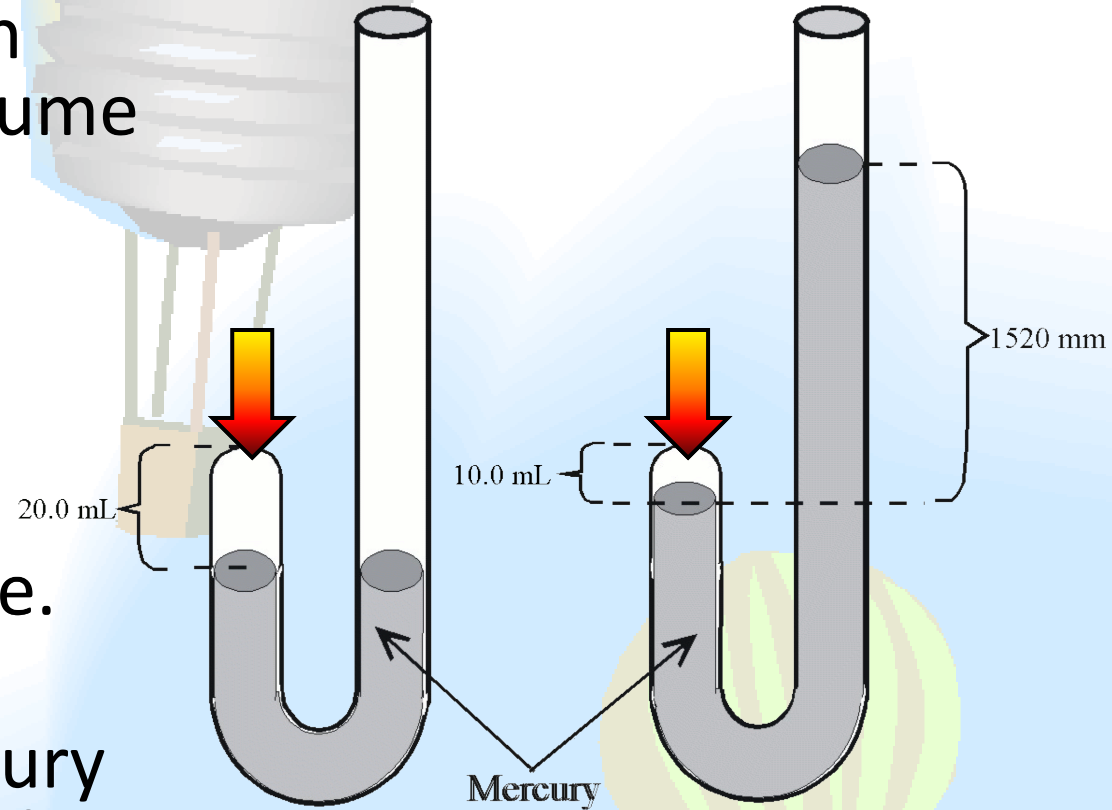
Robert Boyle

- In 1662, Robert Boyle published his study of the volume of gases at different pressures and constant temperature.
- Boyle gathered data by doing experiments using a mercury manometer, a "J" shaped tube sealed at one end, and partially filled with mercury.

ROBERT BOYLE

Boyle's Experiment

- Boyle measured the relationship between the pressure and volume of a gas.
- First he measured the volume of air trapped by mercury in a J-tube at normal atmospheric pressure. (760 *mm* Hg)
- Then he added mercury and measured the volume of air trapped in a J-tube at twice the pressure.



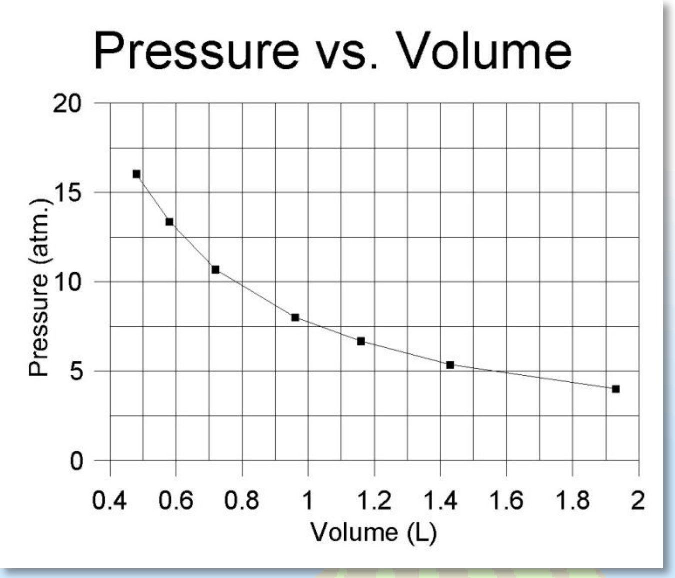
Boyle's Law

WRITE DOWN

- As the pressure on a gas increases at a constant temperature, the volume decreases.
- In fact if the pressure doubles, the volume is cut in half.
- As a result:

  the product of the pressure and the volume is a constant.

  $$PV = k$$



WRITE DOWN

Temperature and Volume

- A balloon is placed over the lip of a flask. Then the flask is placed on a hotplate and heated.
- The balloon blows up.
- As a gas is heated at constant pressure, its volume increases.

WRITE DOWN

Charles' Law

- In 1787 Jacques Charles did experiments on how the volume of gases depended on temperature.
- As the temperature of a gas increases at a constant pressure , the volume increases.

- In fact if the Kelvin temperature doubles, the volume doubles.
- As a result:

  the ratio of the volume and the temperature is a constant.

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

The Combined Gas Law

- If $\mathbf{PV} = k$ and $\dfrac{\mathbf{V}}{\mathbf{T}} = k$ then $\dfrac{\mathbf{PV}}{\mathbf{T}} = k$.
- Let's call the initial pressure, volume, and temperature of a gas $\mathbf{P_1}$, $\mathbf{V_1}$, and $\mathbf{T_1}$.
- After conditions change, let's call the new pressure, volume, and temperature of the gas $\mathbf{P_2}$, $\mathbf{V_2}$, and $\mathbf{T_2}$.
- In that case, since $\dfrac{\mathbf{P_1V_1}}{\mathbf{T_1}} = k$ and $\dfrac{\mathbf{P_2V_2}}{\mathbf{T_2}} = k$,

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

Combined Gas Law Problem

A gas at 27°C and 100. kPa occupies 250. mL. How much space will the gas occupy if the temperature is reduced to 0.0°C and the pressure is increased to 150. kPa?

- **STEP 1**: Identify the variables
  - P_1 = 100. kPa
  - V_1 = 250 mL
  - T_1 = 27°C + 273 = 300. K
  - P_2 = 150. kPa
  - $V_2 = V_2$
  - T_2 = 0°C + 273 = 273 K
- **STEP 2**: Plug the variables into the equation

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \qquad \frac{(100.\ \text{kPa})(250.\ \text{mL})}{(300.\ \text{K})} = \frac{(150.\ \text{kPa})(V_2)}{(273\ \text{K})}$$

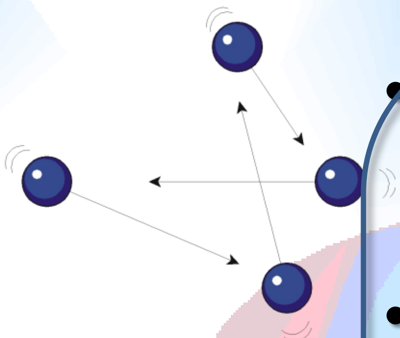
- **STEP 3**: Solve for the unknown

$$\frac{(273\ \text{K})(100.\ \text{kPa})(250.\ \text{mL})}{(150.\ \text{kPa})(300.\ \text{K})} = V_2 = 152\ \text{mL}$$

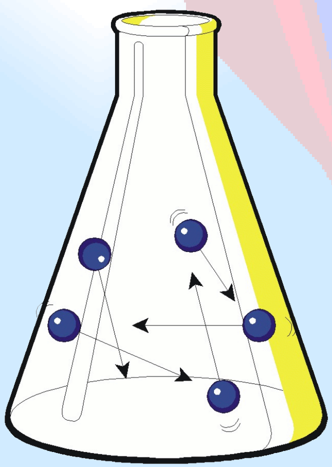
The Ideal Gas

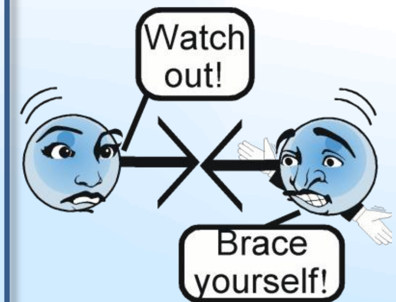
- The gas laws are based on a model known as an *Ideal Gas*.
- The *Ideal Gas* model can only be applied under conditions of **low pressure and high temperature.**
- The *Ideal Gas* model is based on a number of assumptions.

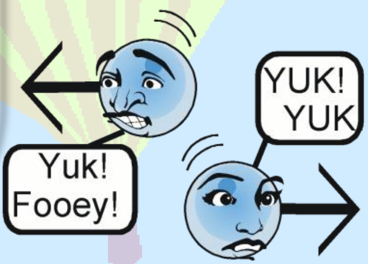
Assumptions of the Ideal Gas Model



- **MOTION** – gas molecules are continuously moving in a random, straight line motion.
- **COLLISION** – when gas molecules collide with each other or with the walls of the container there is no energy lost. Therefore, the total energy of the system never changes.
- **VOLUME** – the actual volume of the molecules is insignificant when compared to the volume of the contained area (the container).
- **ATTRACTION** – no attraction exists between molecules.

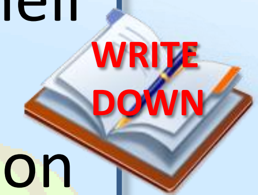






Deviations from the Ideal Gas Model

- Gases deviate from the ideal conditions when conditions of **high pressure and low temperature** exist. These conditions lead to confinement and intermolecular attractions begin to act.
  - VOLUME – gas molecules do have a volume of their own.
  - ATTRACTION – there does exist a force of attraction between gas molecules.



- The above factors (deviations) allow for the existence of gases as either solids or liquids under certain conditions.