Gas Laws

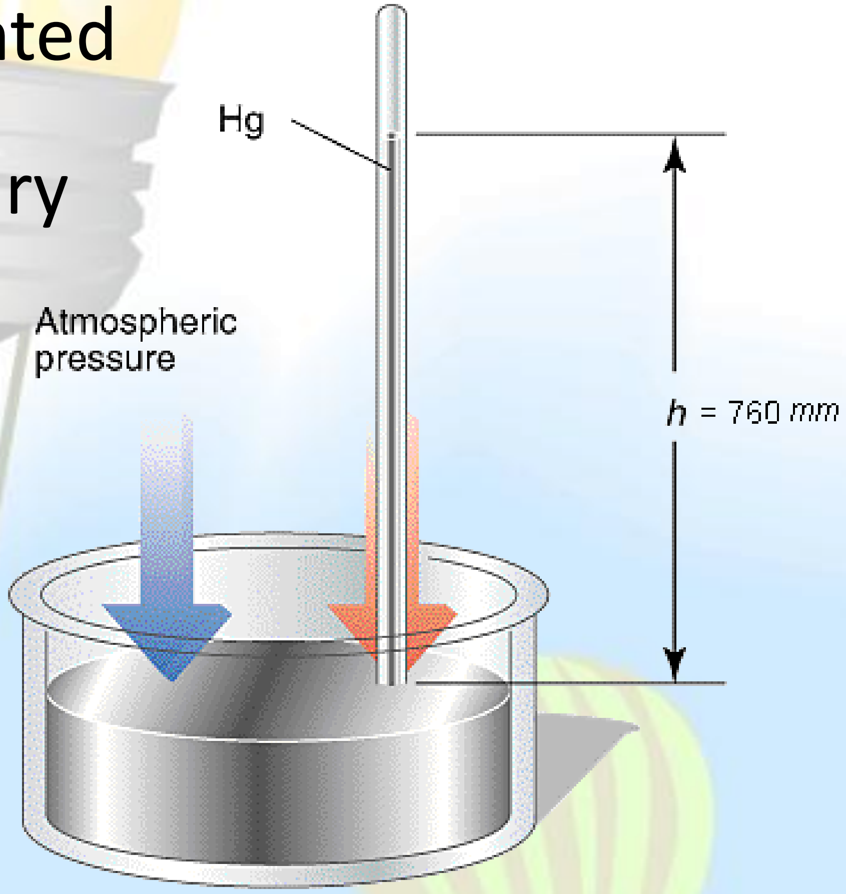
The effect of

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.



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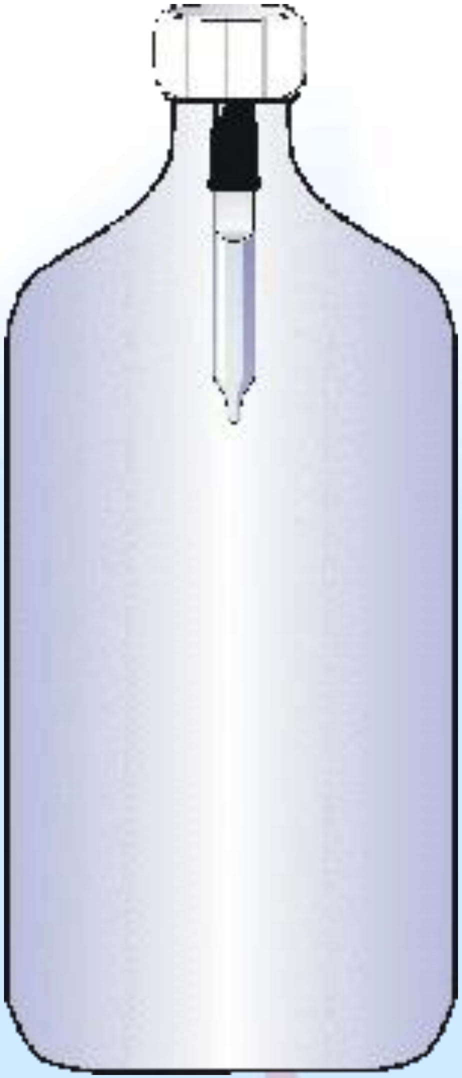
Note: Standard atmospheric pressure is 760 *mm* Hg = 1 atm = 101.3 kPa

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.



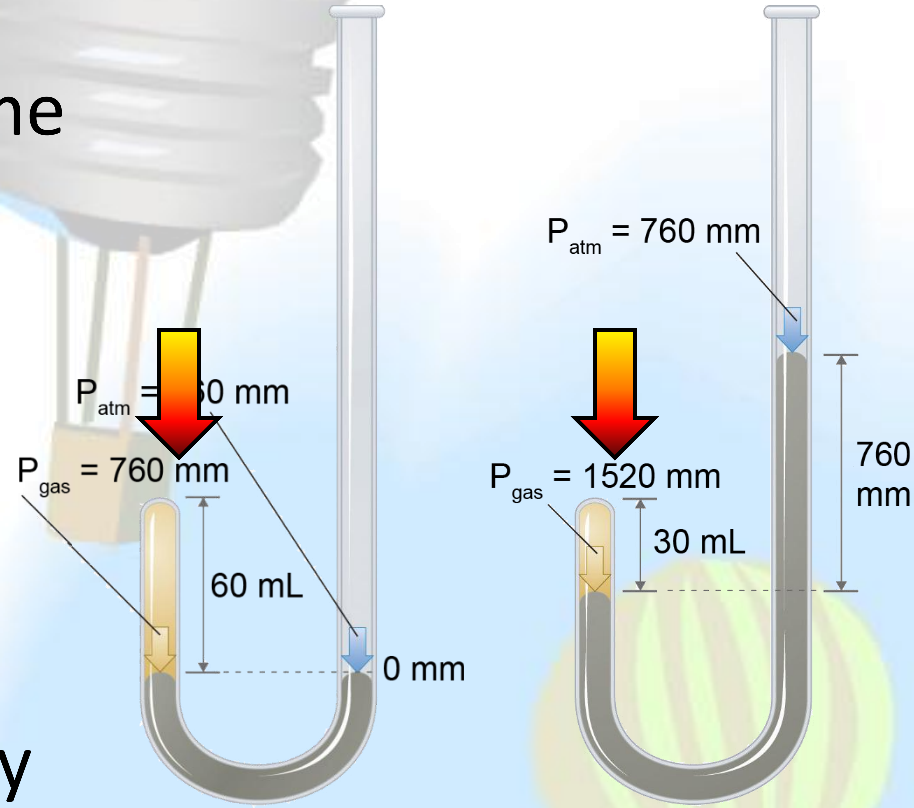
Robert Boyle

- 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

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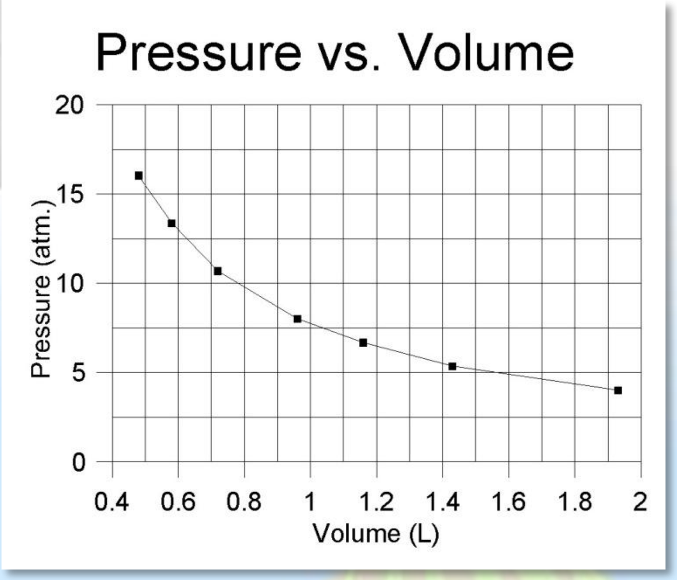
- As the pressure on a gas increases at a constant temperature, the volume decreases.



- In fact if the pressure doubles, the volume is cut in half.
- As a result:

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

$$PV = k$$

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, its volume increases.

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.

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

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 Law

- Up to now, we've considered only what happens when the conditions on a sample of gas change. (This means the number of moles is constant.)
- Avogadro's law tells us that moles are a variable too ($V = kn$).
- When moles are added to the relationship, the equation $PV \propto T$ becomes $PV \propto nT$.
- The universal gas constant "R" is used to get an equality.

$$\mathbf{PV = \mathit{n}RT}$$

Finding "R"

- If $PV = nRT$, it follows that $R = \dfrac{PV}{nT}$.
- We know that 1 *mol* of gas occupies 22.4 *L* at STP.
- Substituting into the equation we get:

$$R = \frac{(1\ atm)(22.4\ L)}{(1\ mol)(273\ \text{K})} = 0.0821\ \frac{L \bullet atm}{mol \bullet \text{K}}$$

An Ideal Gas Law Problem

What is the volume of 6.06 g of hydrogen at 27°C and 1.50 atm?

- If PV = *n*RT, then $V = \frac{nRT}{P}$.
- **Step 1:** Determine the number of moles of the gas.

$$(6.06\ g)\left(\frac{1\ mol}{2.02\ g}\right) = 3.00\ mol$$

- **Step 2:** Substitute into the equation.

$$V = \frac{(3.00\ \text{mol})(0.0821\ \frac{L\bullet atm}{mol\bullet \text{K}})(300.\ \text{K})}{(1.50\ atm)} = 49.3\ L$$