Gas Laws

The complexities involved in measuring properties of gases are related to:

1.) Complications in weighing due to the buoyancy of air;

2.) Problems in pressure measurements over water; and,

3.) Non-ideality of Gases.

Physical Characteristics of Gases

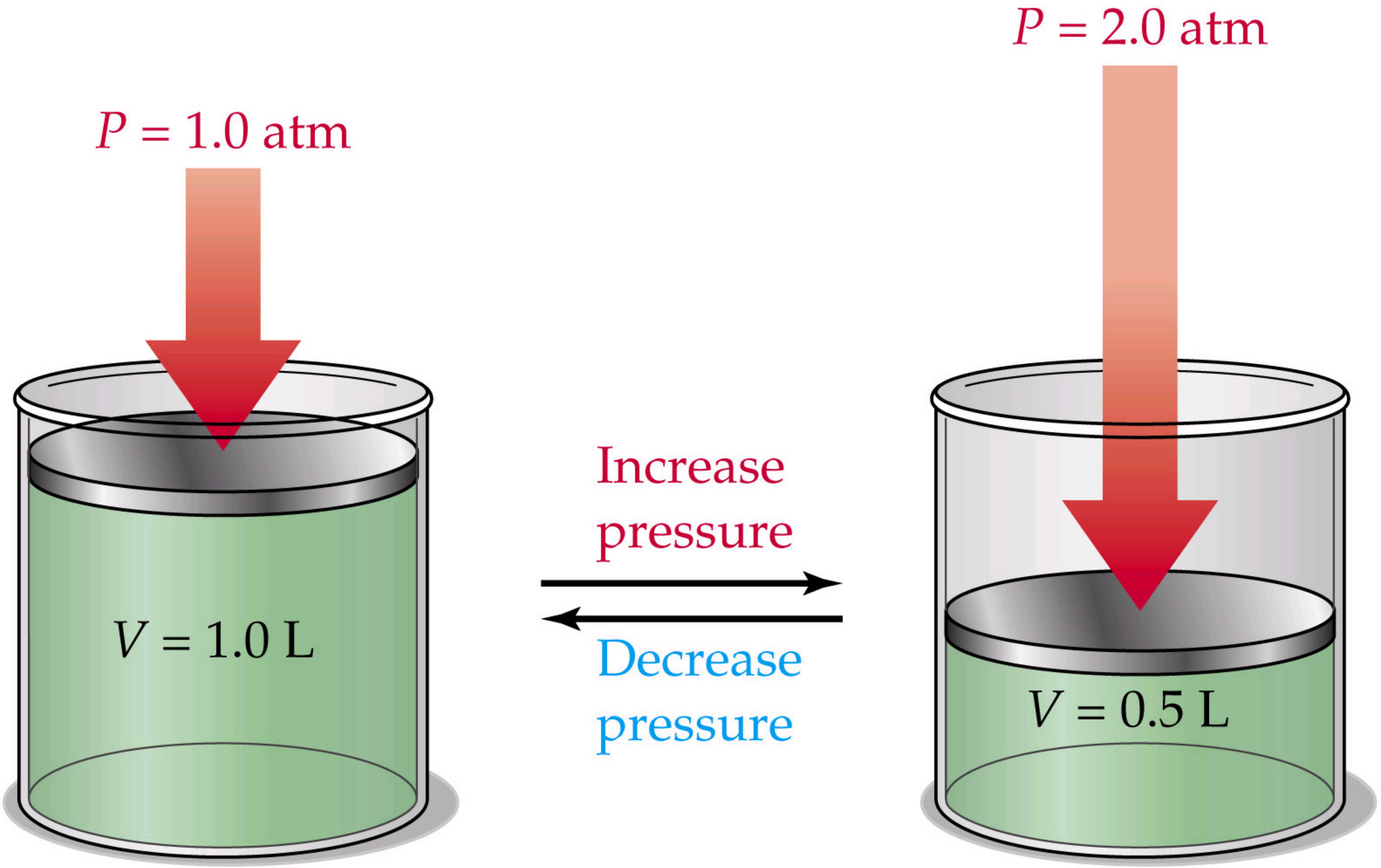
Physical Characteristics	Typical Units
Volume, **V**	liters (**L**)
Pressure, **P**	atmosphere (1 **atm** = 1.015×10^5 N/m^2)
Temperature, **T**	Kelvin (**K**)
Number of atoms or molecules, **n**	**mole** (1 mol = 6.022×10^{23} atoms or molecules)

“Father of Modern Chemistry”
Robert Boyle
Chemist & Natural Philosopher
Listmore, Ireland
January 25, 1627 – December 30, 1690

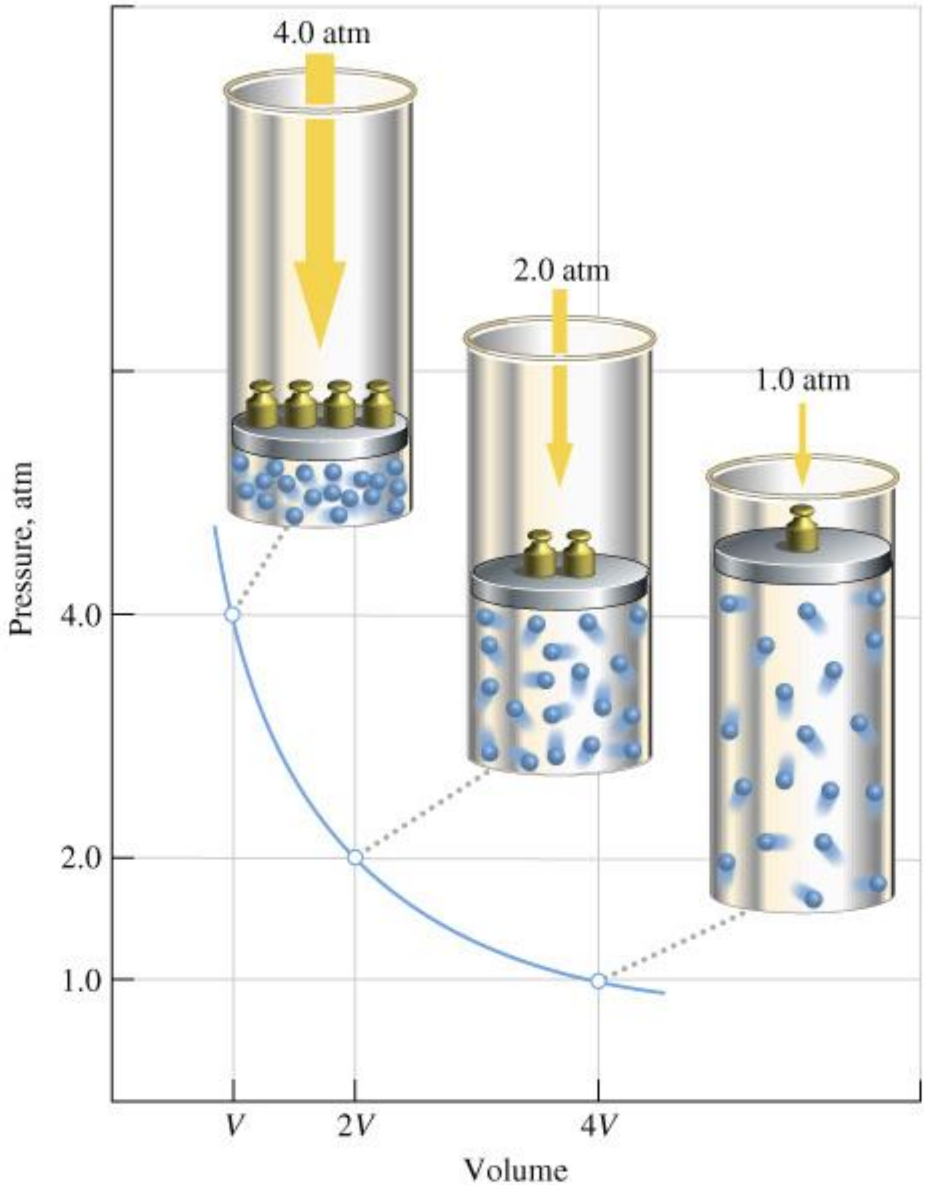
Boyle’s Law

- **Pressure and volume are inversely related** at **constant temperature**.
- **$PV = K$**
- As one goes up, the other goes down.
- **$P_1V_1 = P_2V_2$**

Boyle's Law: $P_1V_1 = P_2V_2$



Boyle's Law: $P_1V_1 = P_2V_2$

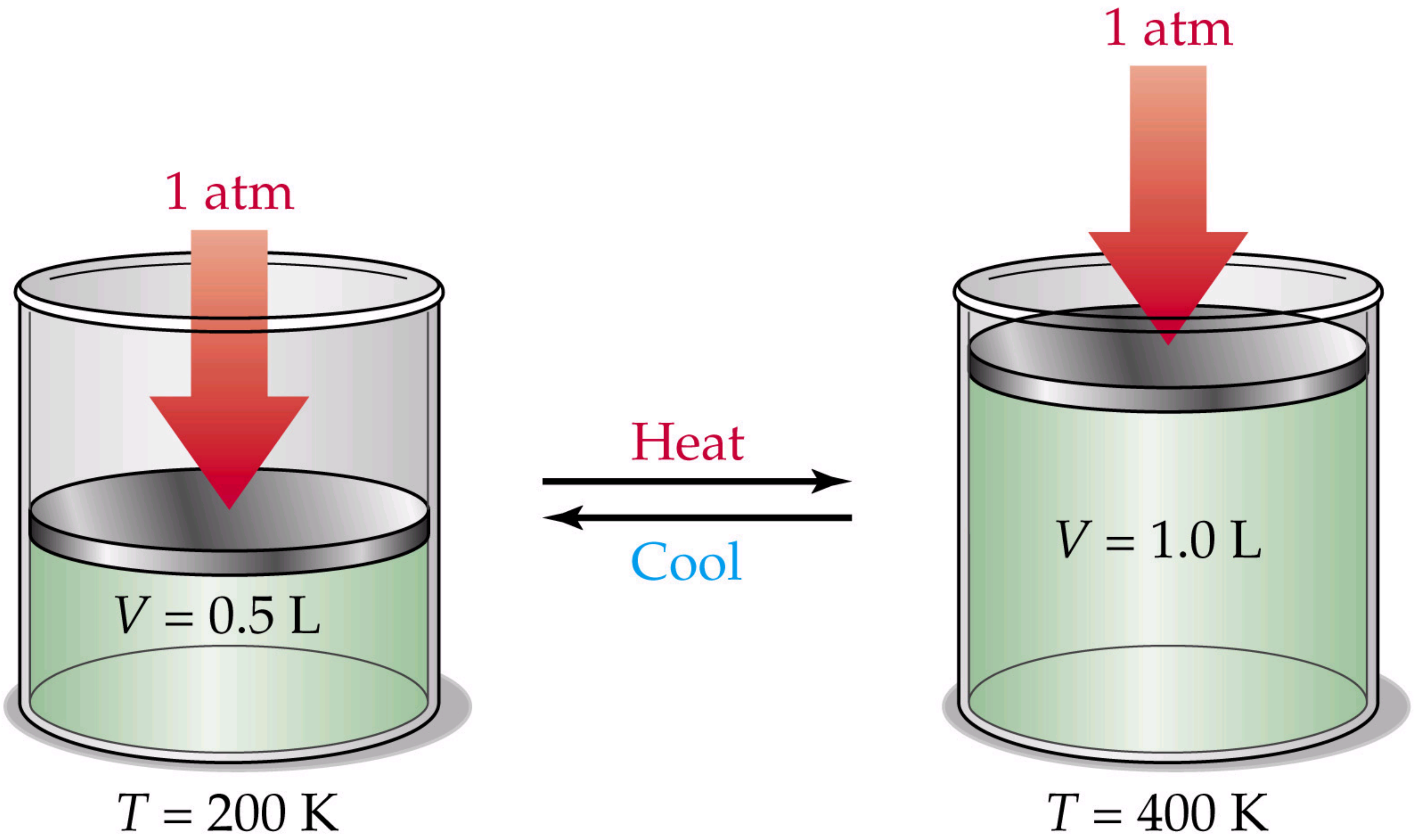


Charles' Law

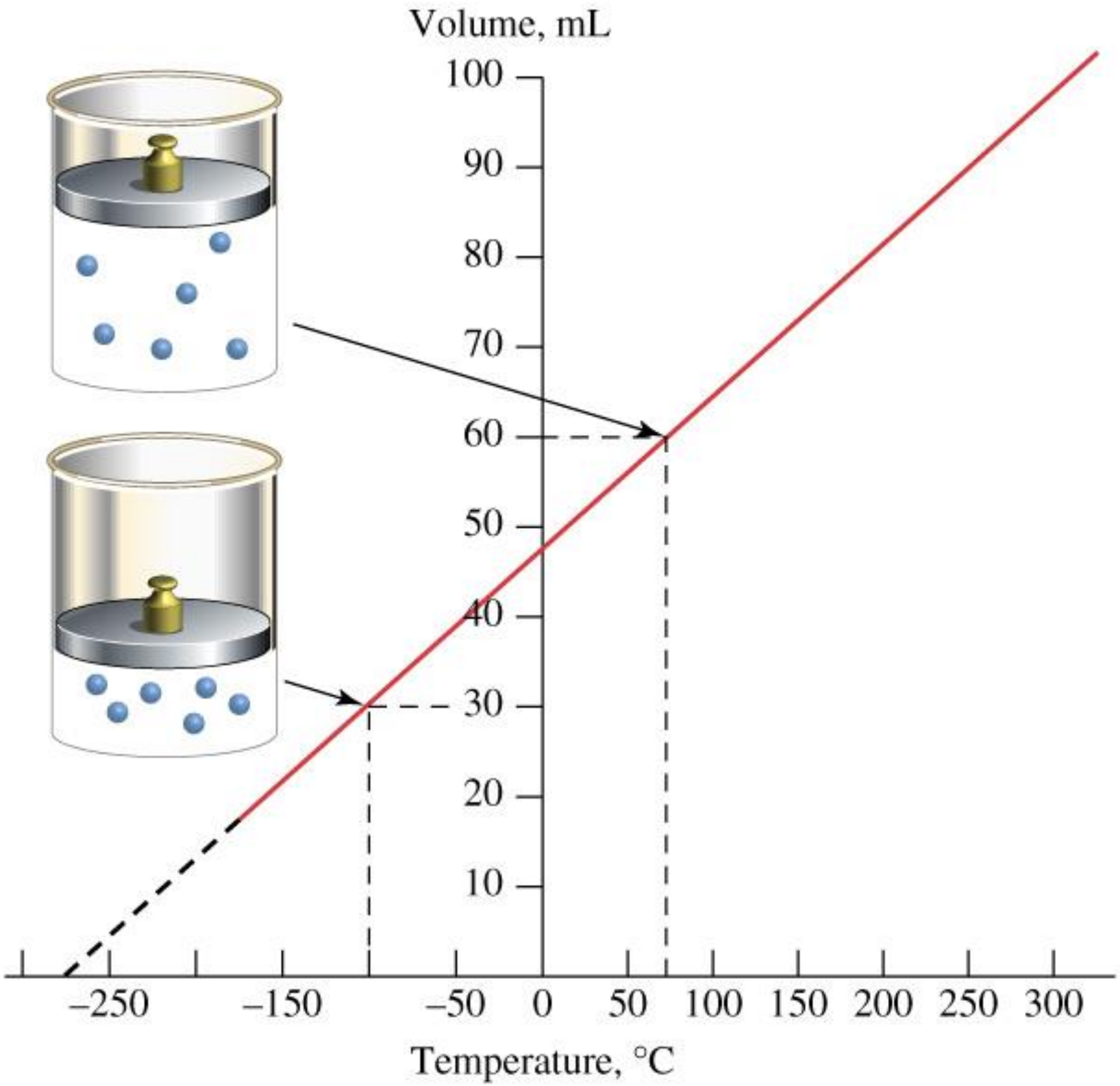
- **Volume** of a gas **varies directly with** the absolute **temperature** at **constant pressure.**
- **V = KT**
- $V_1 / T_1 = V_2 / T_2$

Jacques-Alexandre Charles
Mathematician, Physicist, Inventor
Beaugency, France
November 12, 1746 – April 7, 1823

Charles' Law: $V_1/T_1 = V_2/T_2$



Charles' Law: $V_1/T_1 = V_2/T_2$

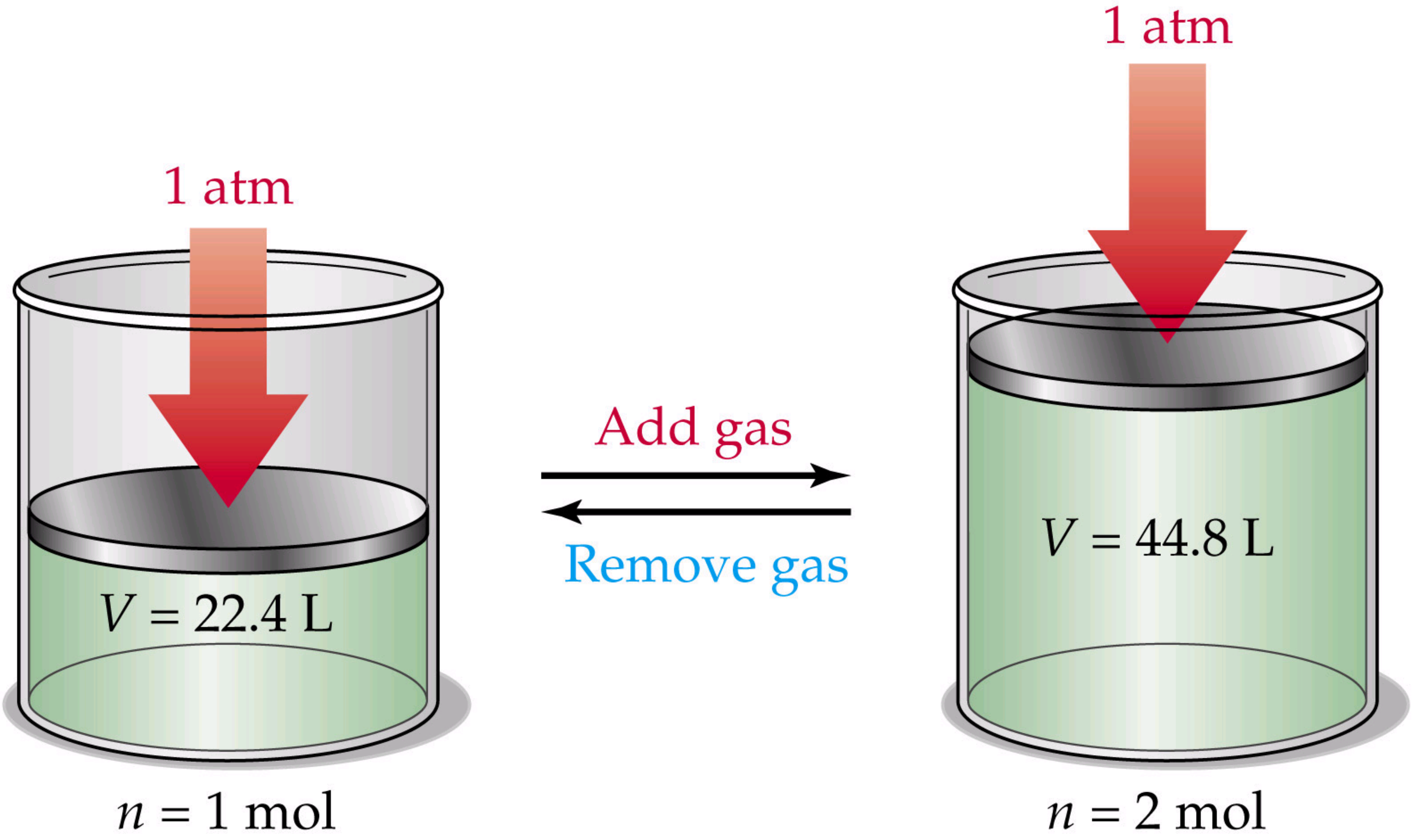


Avogadro's Law

Amedeo Avogadro
Physicist
Turin, Italy
August 9, 1776 – July 9, 1856

- At **constant temperature and pressure**, the **volume** of a gas is **directly related to the number of moles**.
- **$V = K n$**
- **$V_1 / n_1 = V_2 / n_2$**

Avogadro's Law: $V_1/n_1=V_2/n_2$



Lussac Law

- At **constant volume**, **pressure** and **absolute temperature** are **directly related**.
- **P = k T**
- $P_1 / T_1 = P_2 / T_2$

Joseph-Louis Lussac
Experimentalist
Limoges, France
December 6, 1778 – May 9, 1850

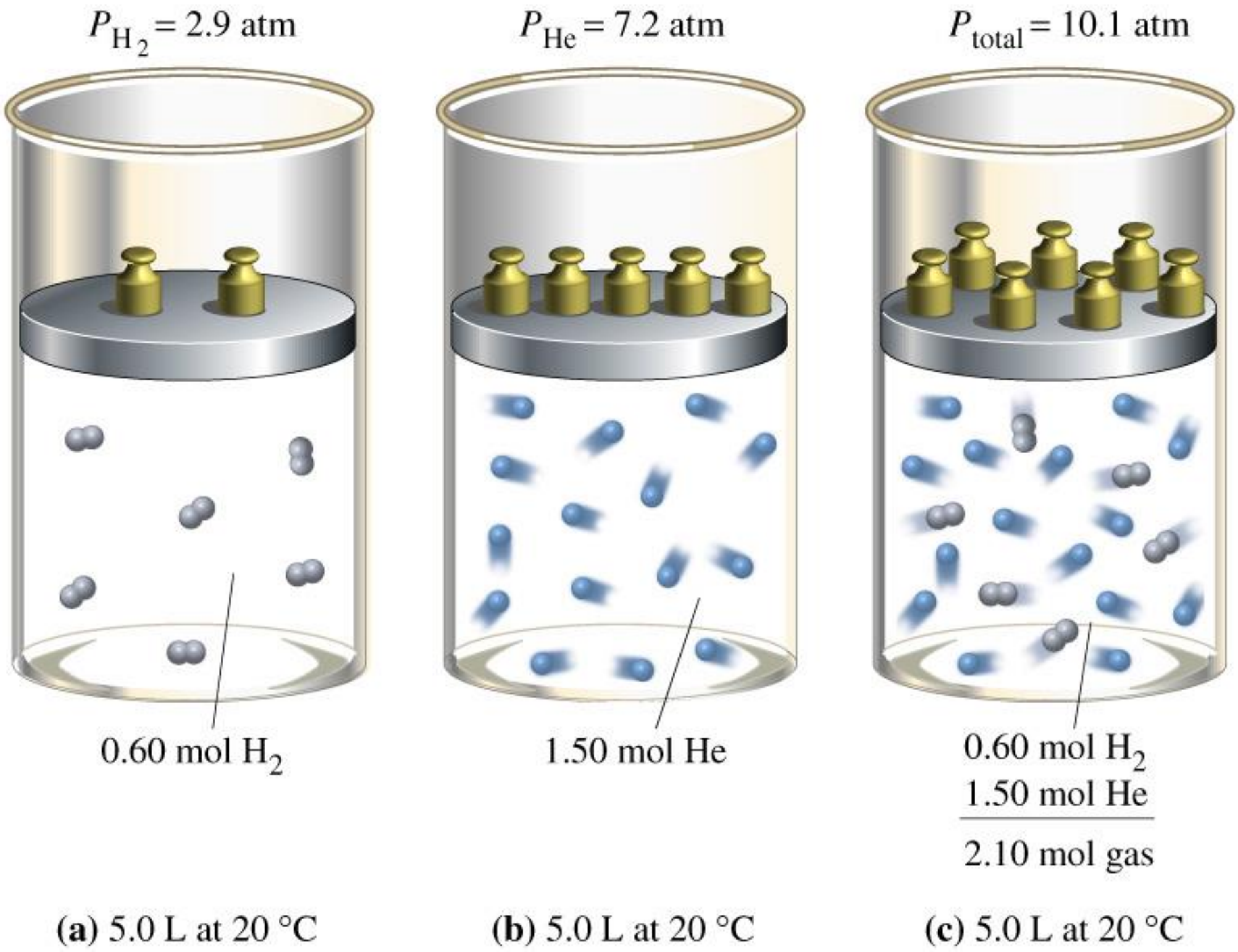
Dalton's Law

- The **total pressure** in a container is the **sum of the pressure each gas** would exert if it were alone in the container.
- The total pressure is the sum of the partial pressures.
- $P_{Total} = P_1 + P_2 + P_3 + P_4 + P_5 \ldots$

(For each gas $P = n\,RT/V$)

John Dalton
Chemist & Physicist
Eaglesfield, Cumberland, England
September 6, 1766 – July 27, 1844

Dalton's Law



P_{H_2} = 2.9 atm
P_{He} = 7.2 atm
P_{total} = 10.1 atm
0.60 mol H_2
1.50 mol He
0.60 mol H_2
1.50 mol He
2.10 mol gas
(a) 5.0 L at 20 °C
(b) 5.0 L at 20 °C
(c) 5.0 L at 20 °C

Vapor Pressure

- ***Water evaporates!***
- When that water evaporates, the **vapor has a pressure**.
- Gases are often collected over water so the **vapor pressure of water** must be **subtracted from the total pressure**.

Kinetic Molecular Theory- ideal gas

Particles in an ideal gas…

1. have no volume.
2. have elastic collisions.
3. are in constant, random, straight-line motion.
4. don’t attract or repel each other.
5. have an avg. KE directly related to Kelvin temperature.

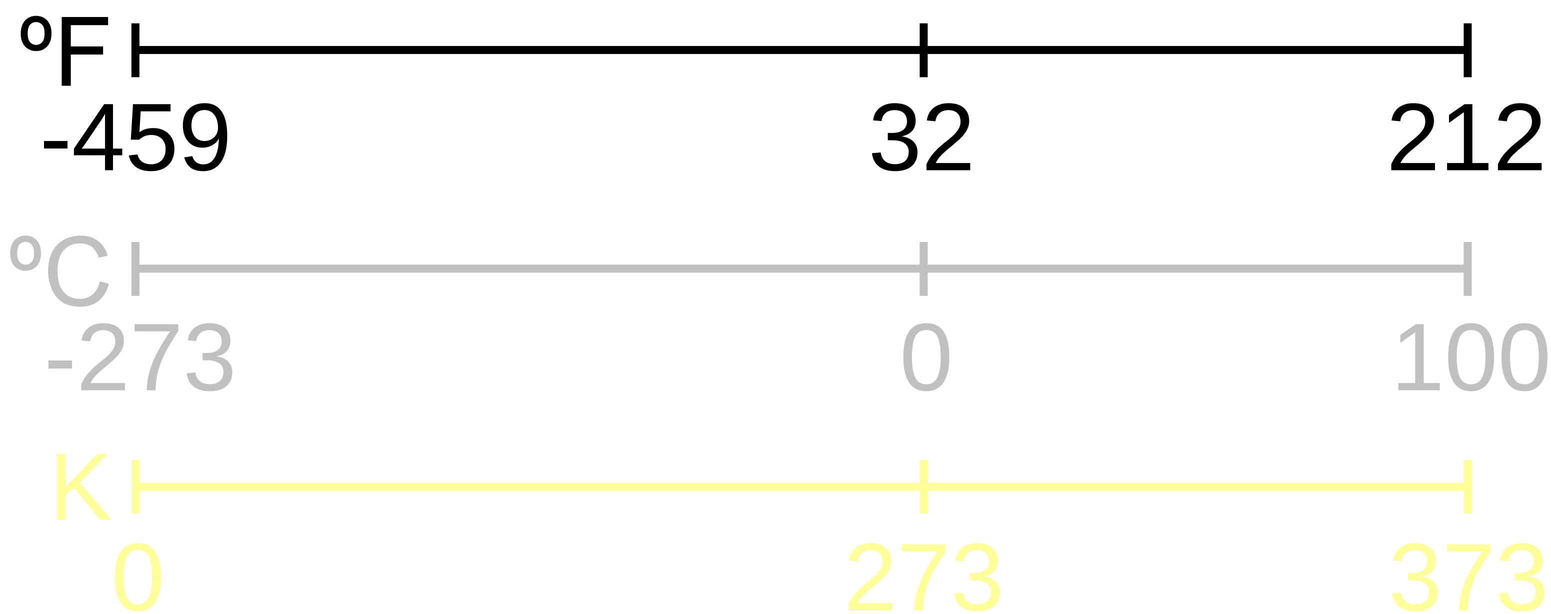
Real Gases

1. Particles in a REAL gas…
   - have their own volume
   - attract each other

2. Gas behavior is most ideal…
   - at low pressures
   - at high temperatures
   - in nonpolar atoms/molecules

Temperature

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



$$°C = \frac{5}{9}(°F - 32)$$

$$K = °C + 273$$

Differences Between Ideal and Real Gases

	Ideal Gas	Real Gas
Obey PV=nRT	Always	Only at very low P and high T
Molecular volume	Zero	Small but nonzero
Molecular attractions	Zero	Small
Molecular repulsions	Zero	Small

Real Gases

- **Real molecules** **do take up space** and **do interact** with each other (especially polar molecules).
- Need to **add correction factors** to the ideal gas law to account for these.

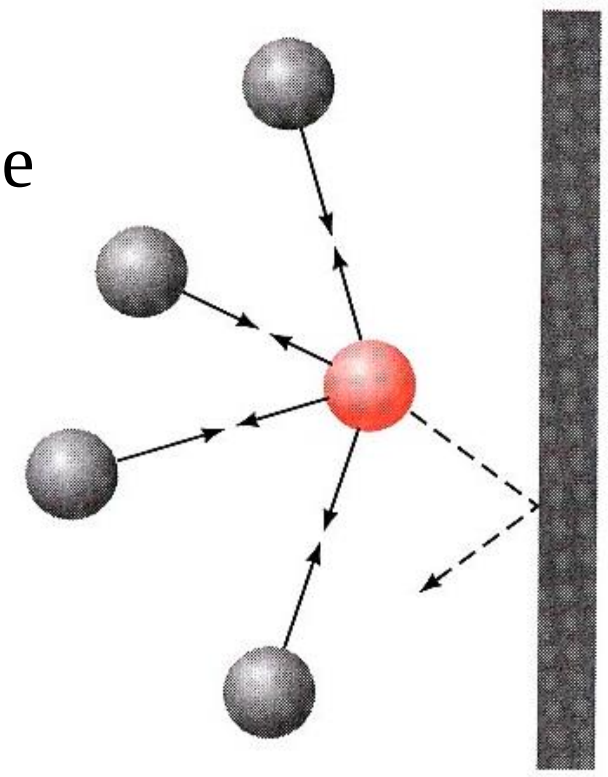
But since real gases do have volume, we need:

Volume Correction

- The **actual volume** free to move in is **less** because of particle size.
- **More molecules** will have **more effect**.
- Corrected volume **$V' = V - nb$**
- "**b**" is a constant that **differs for each gas**.

Pressure Correction

- Because the **molecules are attracted** to each other, the **pressure** on the container will be **less than ideal**.
- Pressure **depends on** the **number of molecules per liter**.
- Since **two molecules interact**, the **effect must be squared**.



$$P_{observed} = P - a\left(\frac{n}{V}\right)^2$$

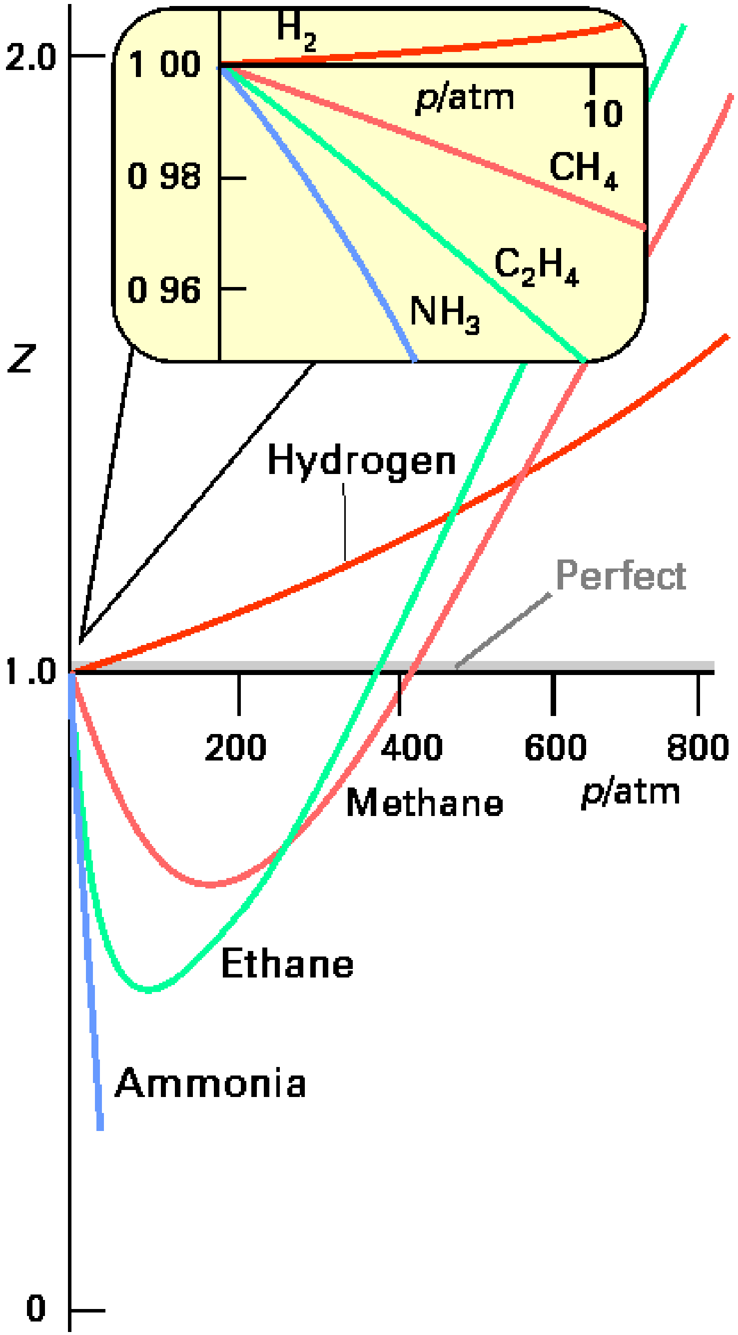
Van der Waal's equation

$$[P_{obs} + a\left(\frac{n}{V}\right)^2](V - nb) = nRT$$

Corrected Pressure **Corrected Volume**

- "**a**" and "**b**" are **determined by experiment**
- "**a**" and "**b**" are **different for each gas**
- **bigger molecules** have **larger** "**b**"
- "**a**" depends on both **size** **and** **polarity**

Johannes Diderik van der Waals
Mathematician & Physicist
Leyden, The Netherlands
November 23, 1837 – March 8, 1923



Compressibility Factor

The most useful way of displaying this new law for real molecules is to plot the compressibility factor, **Z** :

For **n = 1**

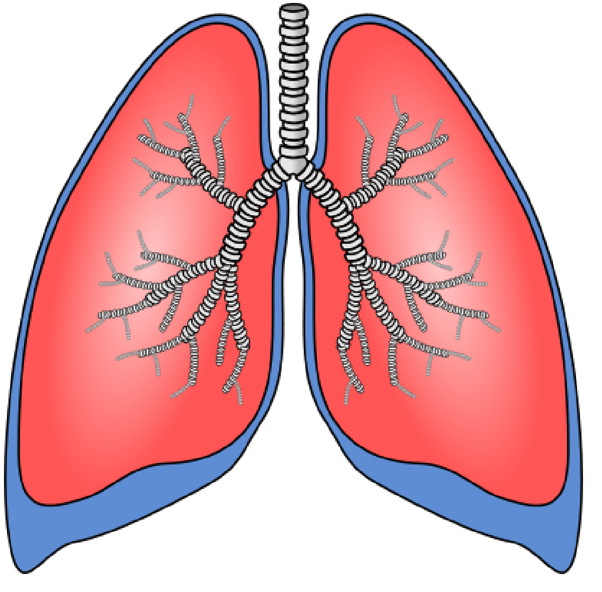
$$Z = PV / RT$$

Ideal Gases have **Z = 1**

Real-life Examples of Boyle's Law

- **Human lungs**

The lungs are an important organ of the body. They play a vital role in the respiratory system. As the lungs expand, there is a momentary reduction in the pressure. Thus, the pressure inside the body is lower than the outside. Consequently, the surrounding air slips in the body. This process is called inhalation



Problem

- #1: If a gas at 25 °C occupies 3.6 liters at a pressure of 1 atm, what will be its volume at a pressure of 2.5 atm?

- (1 atm) (3.6 liters) = (2.5 atm) (x)
- x = 1.44 L

Problem

- #2: Calculate the decrease in temperature when 6 L at 20 °C is compressed to 4 L.
- Charles' Law

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

$$\frac{6.00\,L}{293\,K} = \frac{4.00\,L}{T_2}$$

$$T_2 = 4.00\,\cancel{L}\left(\frac{293\,K}{6.00\,\cancel{L}}\right)$$

$$\boxed{T_2 = 195.3\,K}$$

Problem

- #3: The gases in a hair spray can are at a temperature of 27^{o}C and a pressure of 30 lbs/in^2. If the gases in the can reach a pressure of 90 lbs/in^2, the can will explode. To what temperature must the gases be raised in order for the can to explode? Assume constant volume. (630 ^{o}C).
- Lussac's Law

$$\frac{P_1}{T_1} = \frac{P_2}{V_2}$$

$$\frac{30\ lb/in^2}{300\ K} = \frac{90\ lb/in^2}{T_2}$$

$$T_2 = 90\ lb/in^2 \left(\frac{300\ K}{30\ lb/in^2}\right)$$

$$\boxed{T_2 = 900\ K}$$

HW

- 1) A container holds 500. mL of CO_2 at 20.° C and 742 torr. What will be the volume of the CO_2 if the pressure is increased to 795 torr?
- 2) A gas tank holds 2785 L of propane, C_3H_8, at 830. mm Hg. What is the volume of the propane at standard pressure?
- 3) A balloon contains 7.2 L of He. The pressure is reduced to 2.00 atm and the balloon expands to occupy a volume of 25.1 L. What was the initial pressure exerted on the balloon?
- 4) A sample of neon occupies a volume of 461 mL at STP. What will be the volume of the neon when the pressure is reduced to 93.3 kPa?
- 5) 352 mL of chlorine under a pressure of 680. mm Hg are placed in a container under a pressure of 1210 mm Hg. The temperature remains constant at 296 K. What is the volume of the container in liters?