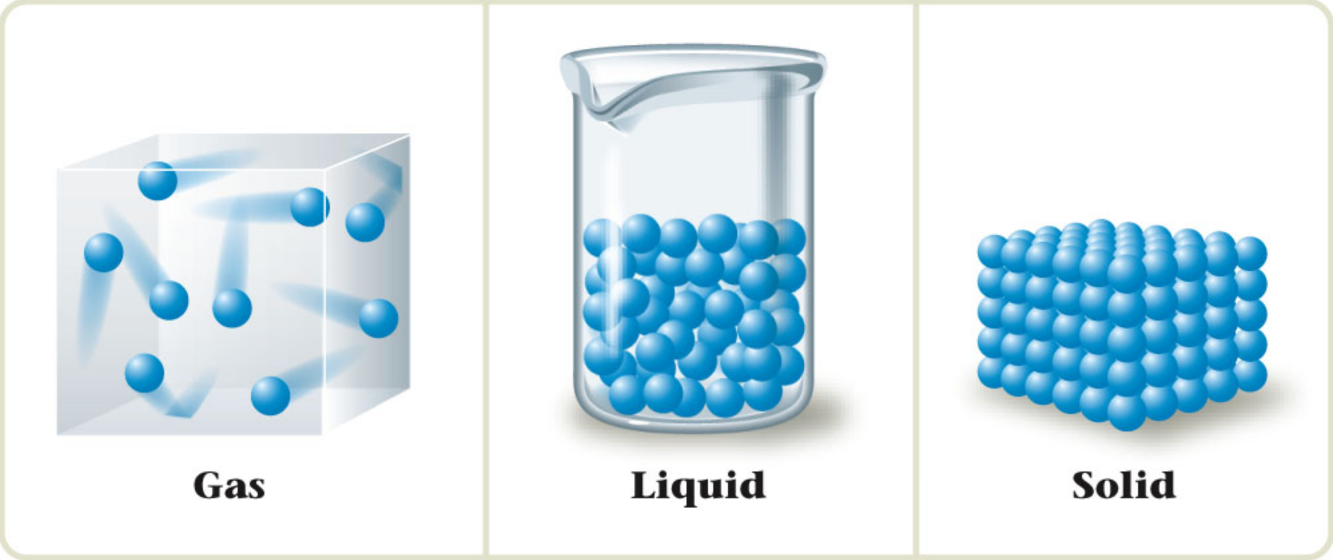
Ch 11. Gases

Introduction

Gases, Liquids, and Solids

- Gas: widely spaced, rapid random motion, low density
- Liquid: closer together, randomly arranged
- Solid: Closely packed, fixed position, rigid, high density



Gases

- Have lower densities than liquid, solid.
- Easily compressed when placed under pressure.
- Assume shape and volume of their container.

Kinetic Molecular Theory

Explains *why* gases behave as they do

1. Particle Motion: Gas particles (atoms or molecules) are in constant, random motion.
2. Particle Volume: There is a lot of space between particles compared to the size of the particles, so the volume of each particle can be assumed to be negligible (point masses).
3. Particle Collisions: Gas particles do not attract or repel each other, so collisions are perfectly elastic.
4. Particle Energy: The average kinetic energy (energy of motion) of a collection of gas particles is directly proportional to the Kelvin temperature.

$$KE_{avg} \propto T \text{ (in K)}$$

Ideal Gas

- **Ideal Gas:** a gas that obeys all the assumptions of the kinetic-molecular theory

- Most gases display nearly ideal behavior under normal conditions.

Pressure

Pressure: the result of collisions of particles with the walls of the container

$$\text{Pressure} = \frac{\text{force}}{\text{area}} = \frac{\text{ma}}{\text{area}}$$

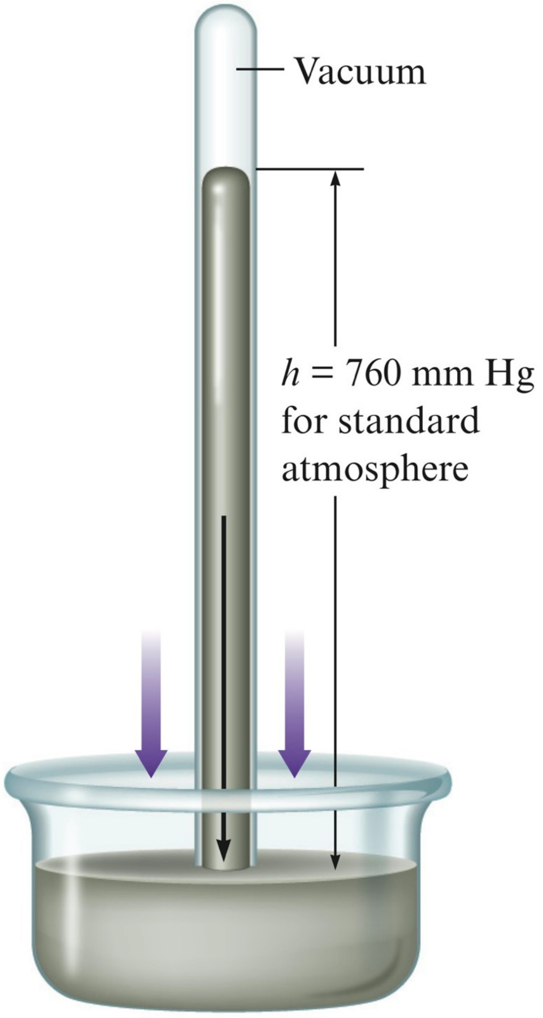
On Earth, atmospheric gases exert a force on all surfaces.

Barometer

Barometer: A device to measure atmospheric pressure

(invented by Torricelli in 1643)

- At sea level and 0°C, atmospheric pressure = 760 mmHg



Standard Atmospheric Pressure and Pressure Units

Standard atmospheric pressure: typical atmospheric pressure at sea level and 0°C

1 atm = 760 mmHg = 760 Torr Memorize

= 101,325 Pa (SI unit: Pascal = Newton/m^2)

= 14.7 psi

Common Units of Pressure

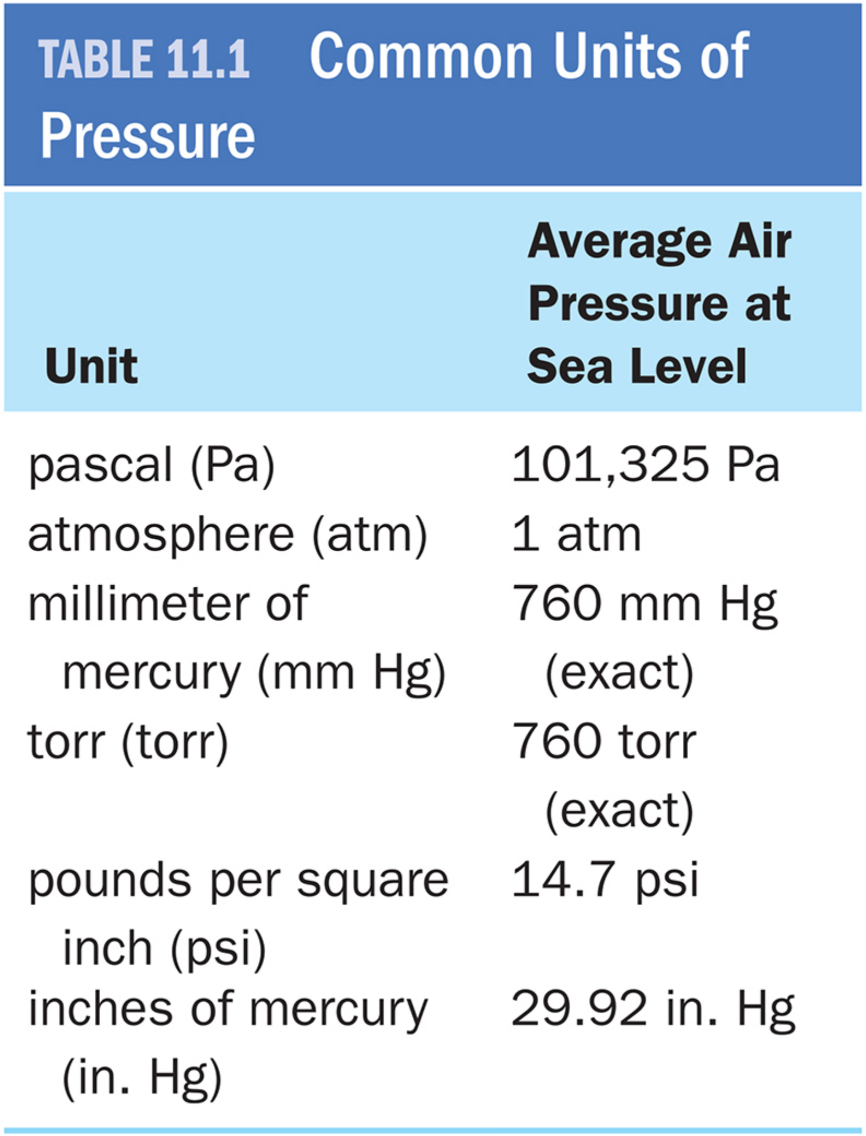


TABLE 11.1 Common Units of Pressure

Unit	Average Air Pressure at Sea Level
pascal (Pa)	101,325 Pa
atmosphere (atm)	1 atm
millimeter of mercury (mm Hg)	760 mm Hg (exact)
torr (torr)	760 torr (exact)
pounds per square inch (psi)	14.7 psi
inches of mercury (in. Hg)	29.92 in. Hg

Sea level: 14.7 psi

Mt. Everest summit: 4.7 psi

Ex Probs

Gas Laws

Four Properties of Gas

Four properties completely describe the state of a gas (the condition of a gas at a given time):

- P = pressure
- V = volume
- T = temperature
- n = number of moles

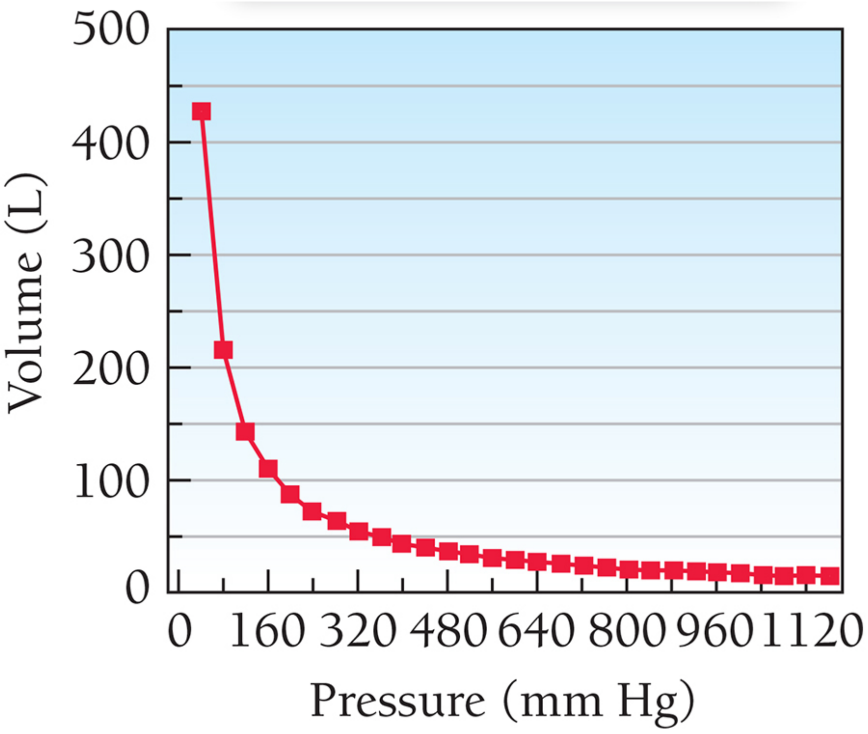
Gas Laws

1. Boyle's Law: $V \propto \frac{1}{P}$ (at fixed V, n)
2. Charles's Law: $V \propto T$ (at fixed P, n)
3. Avogadro's Law: $V \propto n$ (at fixed P, T)
4. Combined Gas Law : $\frac{PV}{T} = k$ (at fixed n)
5. Ideal Gas Law: $PV = nRT$

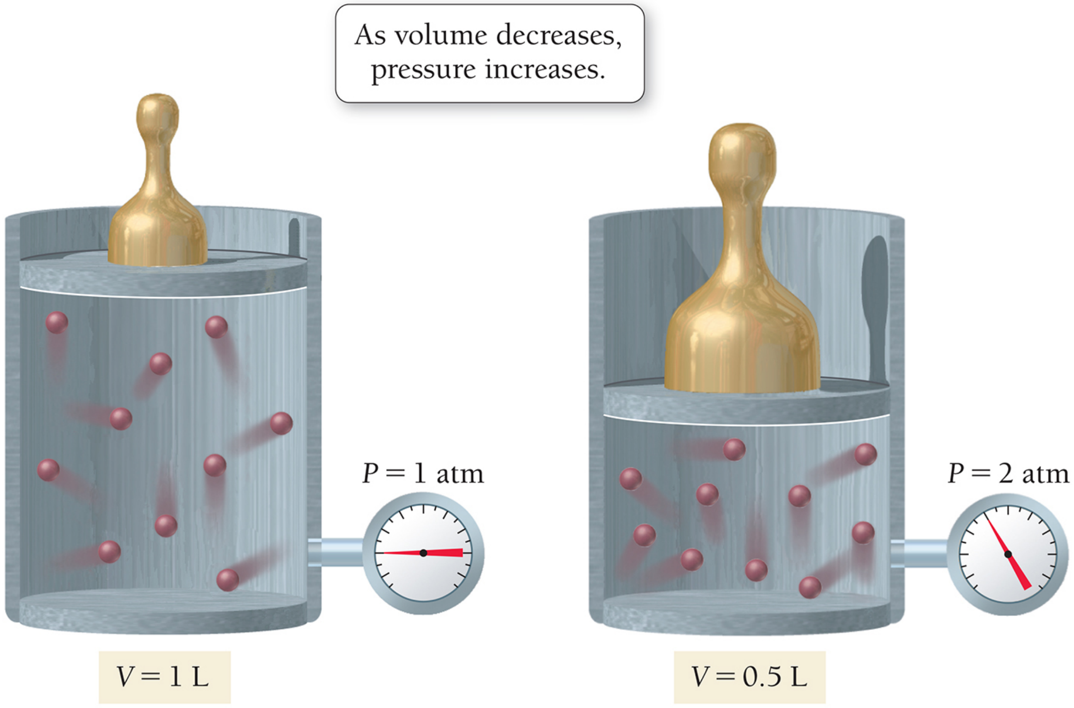
Boyle’s Law: Pressure and Volume

“V and P are inversely related, at fixed n and T.”

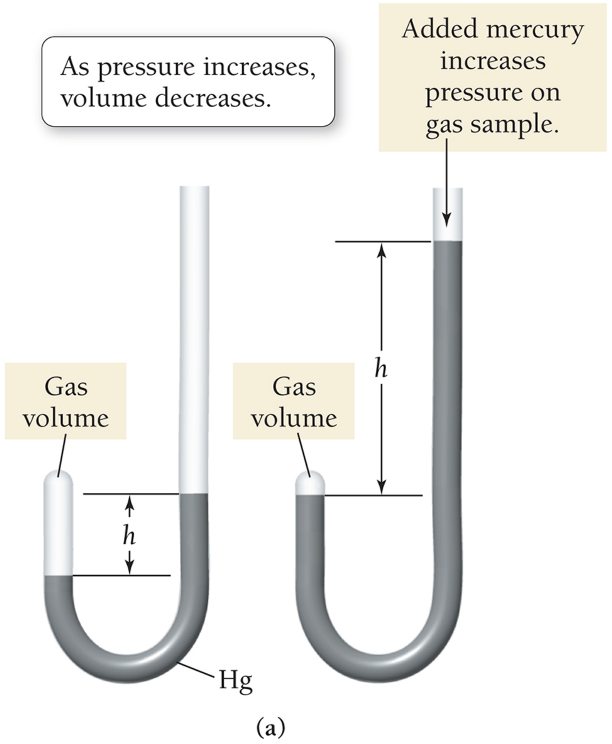
$$V \propto \frac{1}{P}$$ *(at fixed n, T)*



Boyle’s Law: Pressure and Volume



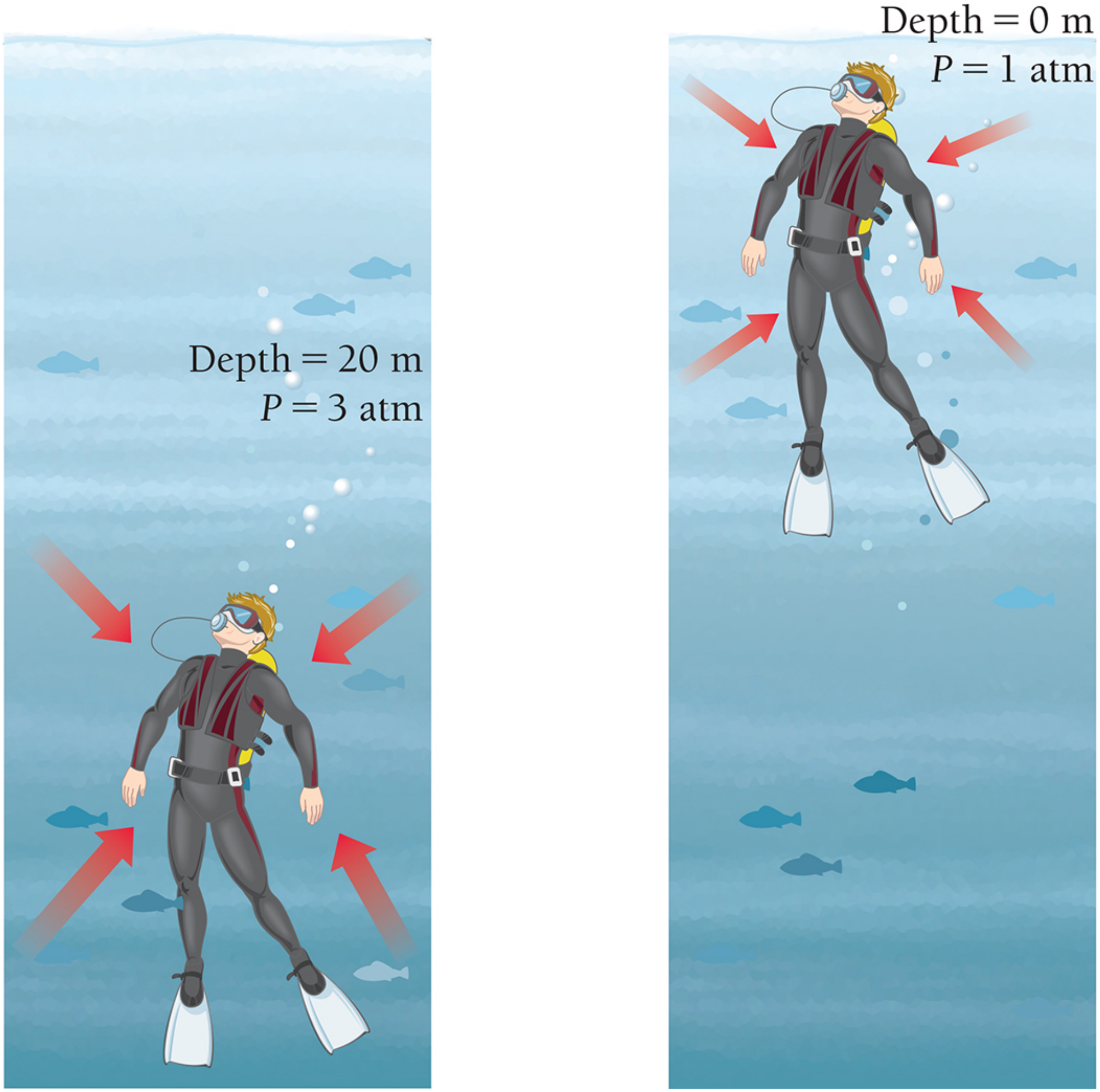
As volume decreases, pressure increases.



As pressure increases, volume decreases.

Added mercury increases pressure on gas sample.

Diver and Air Pressure



Pressure decreases → Volume of air increases.

Useful Form of Boyle's Law

$$V \propto \frac{1}{P}$$ (*at fixed n, T*)

$$V = b \times \frac{1}{P}$$ (b = a constant)

$$PV = b$$

Useful Form of Boyle's Law

$PV = b$ (at fixed n, T)

Gas changes from state 1 → state 2, at fixed n and T.

- $P_1V_1 = b$ for gas in state 1
- $P_2V_2 = b$ for gas in state 2

$$\boxed{P_1V_1 = P_2V_2}$$

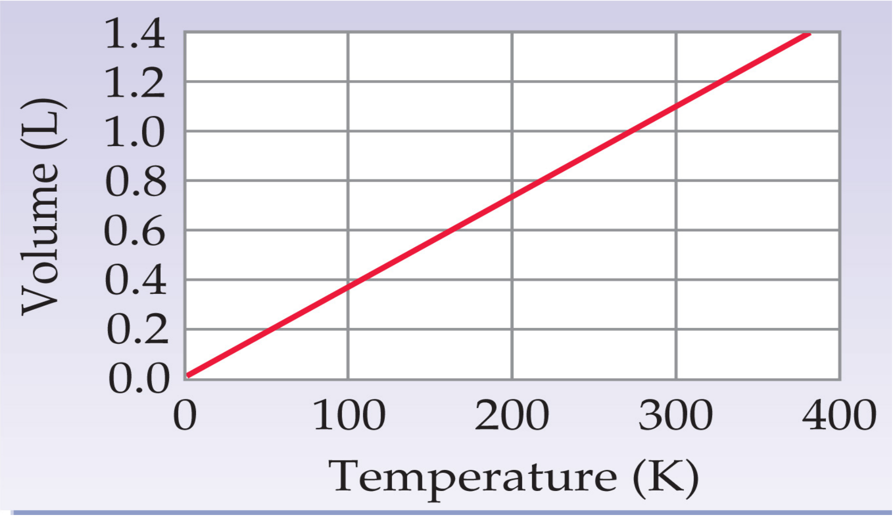
Useful form of Boyle's Law for predicting P or V after a state change

Ex Probs

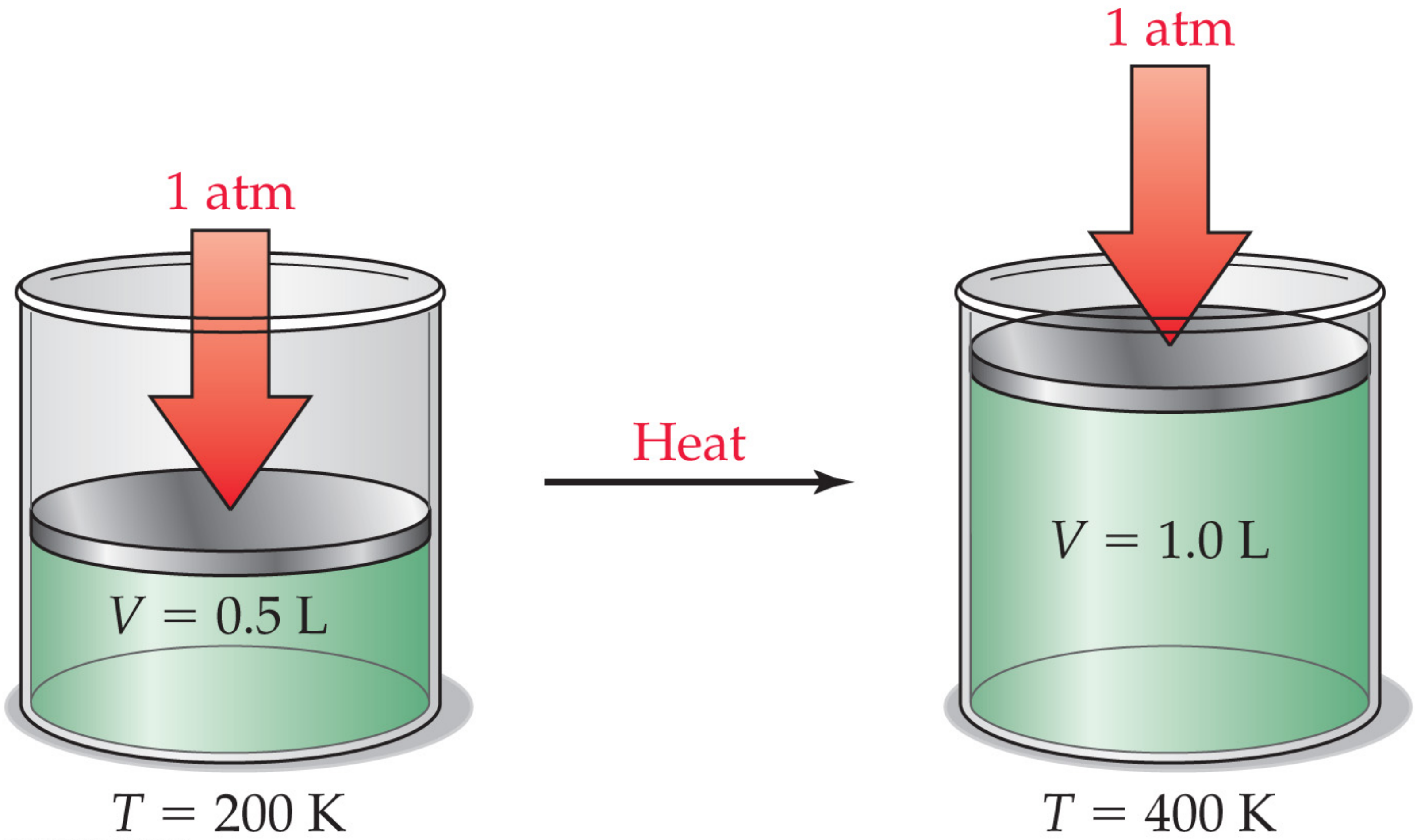
Charles's Law: Volume and Temperature

“Volume of a gas is directly proportional to Kelvin temp, at fixed n and P. ”

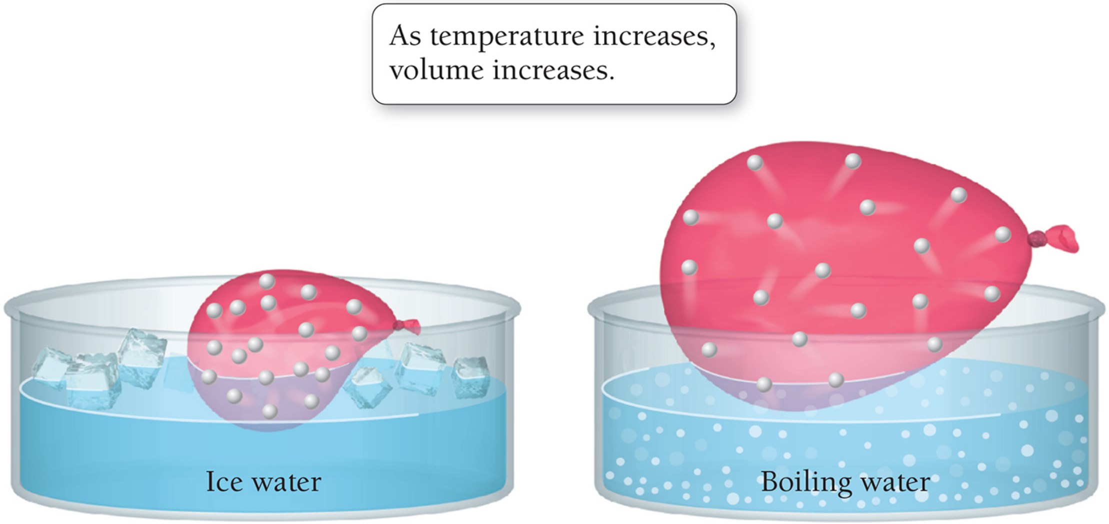
$V \propto T$ *(at fixed n, P)*



Charles's Law: Volume and Temperature



Charles's Law: Volume and Temperature



As temperature increases, volume increases.

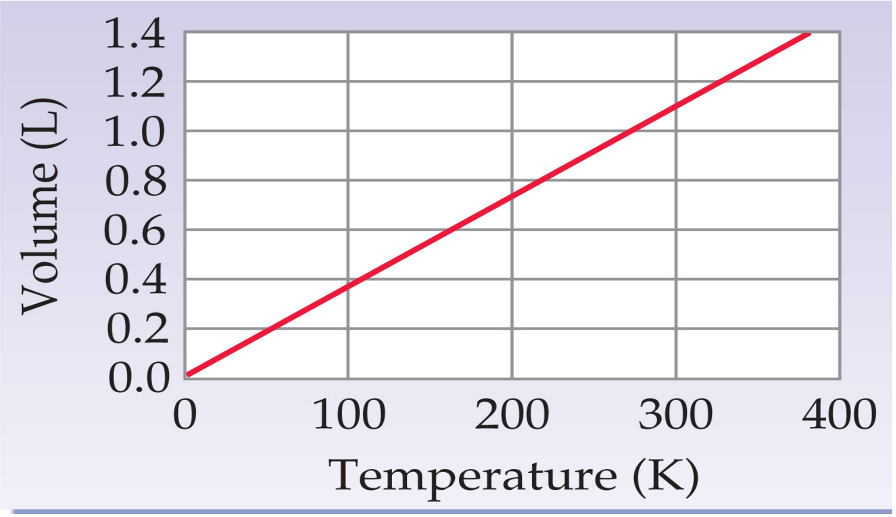
Useful Form of Charle's Law

$V \propto T$ (*at fixed n, P*)

$V = c \times T$ (c = a constant)

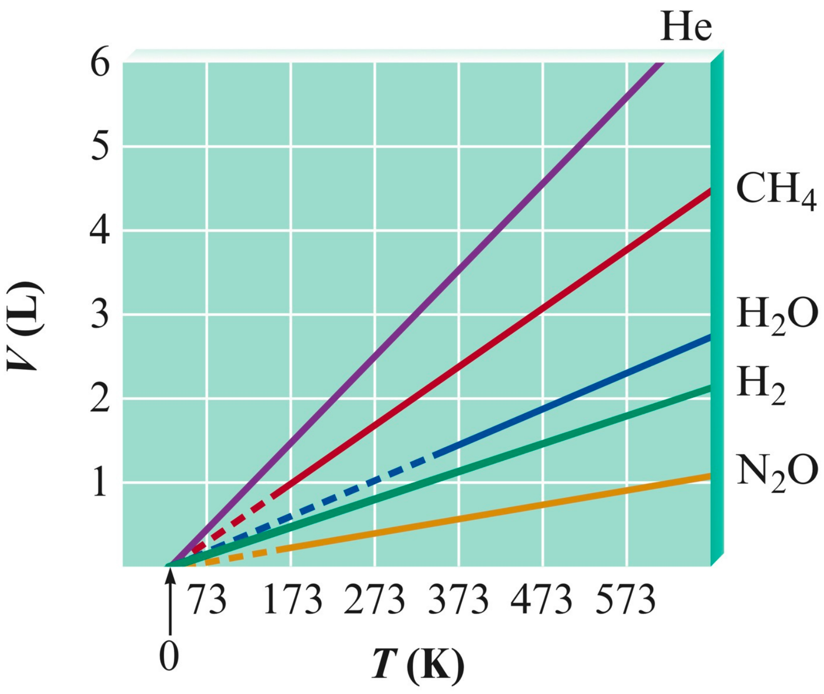
$$\frac{V}{T} = c$$

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



Ex Probs

Absolute Zero (0 K) from Charles's Law



$V = c \times T$

- V extrapolates to 0 when T = 0 K.
- Since gas cannot have neg. volume, suggests temps lower than 0 K cannot be reached.
- 0 K = absolute zero

Combined Gas Law

Combine

Boyle's Law: $V \propto \frac{1}{P}$ (at fixed V, n)

Charles's Law: $V \propto T$ (at fixed P, n)

$$V \propto \frac{T}{P}$$

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

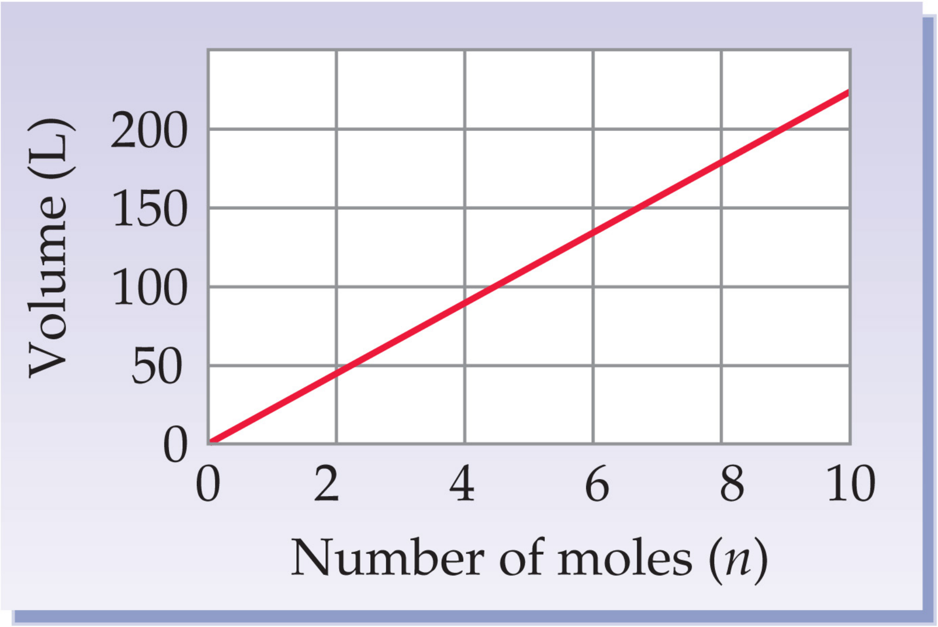
$$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$$

Ex Probs

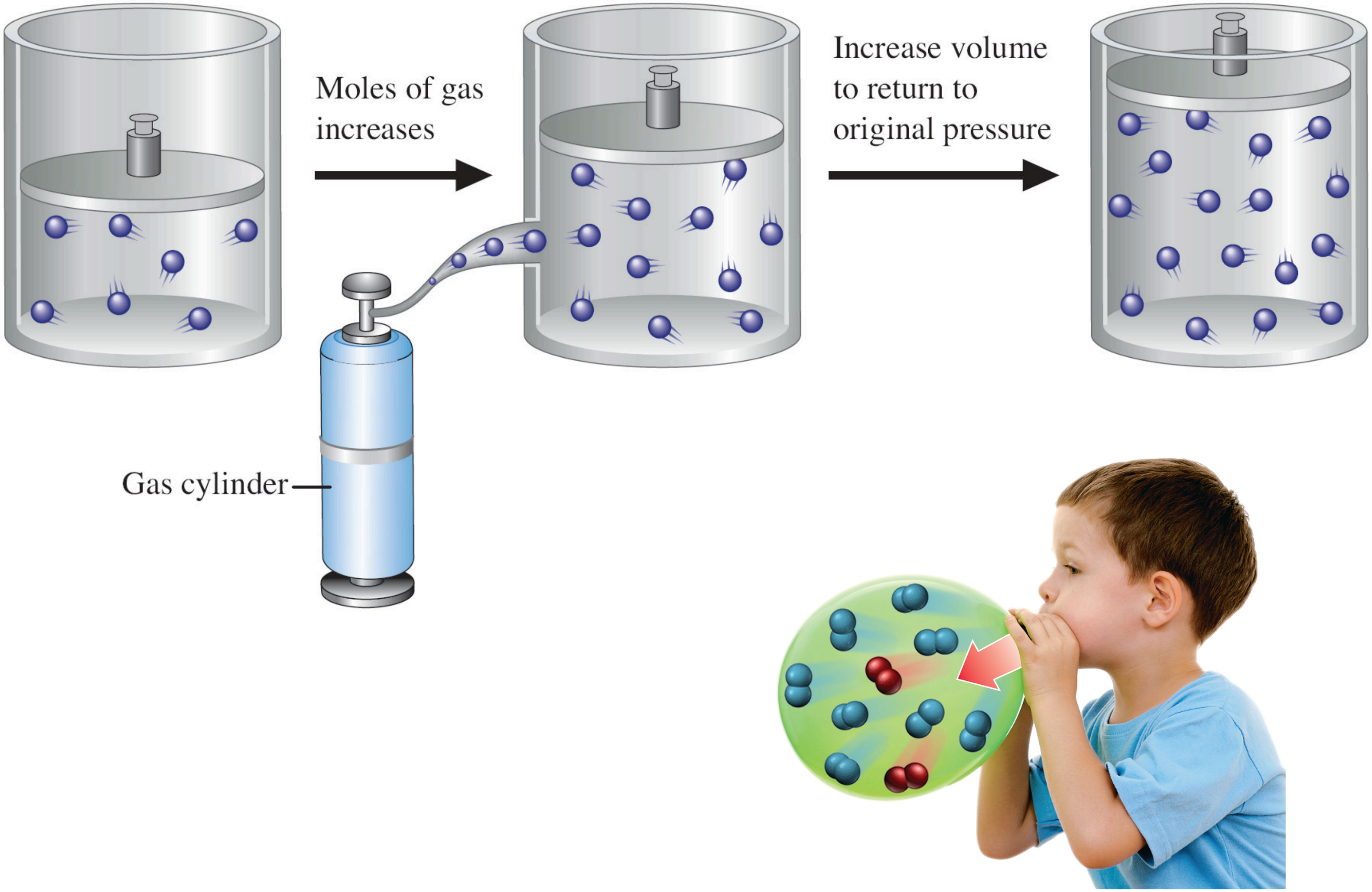
Avogadro's Law: Volume and Moles

"Volume is directly proportional to moles of gas, at fixed T and P. "

$V \propto n$ *(fixed T, P)*



Avogadro’s Law: Volume and Moles



Useful Form of Avogadro's Law

$V \propto n$ *(fixed T, P)*

$V = a \times n$ (a is a constant)

$$\frac{V}{n} = a$$

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

Ideal Gas Law

Boyle's Law: $V \propto 1/P$ (at fixed V, n)

Charles's Law: $V \propto T$ (at fixed P, n)

Avogadro's Law: $V \propto n$ (at fixed P, T)

$$\boxed{V \propto \frac{Tn}{P}}$$

$$V = \frac{R(Tn)}{P}$$

R = universal gas constant

= 0.0821 $\frac{\text{L-atm}}{\text{mol-K}}$)

$$\boxed{PV = nRT}$$

Ideal Gas Law

Ex Probs

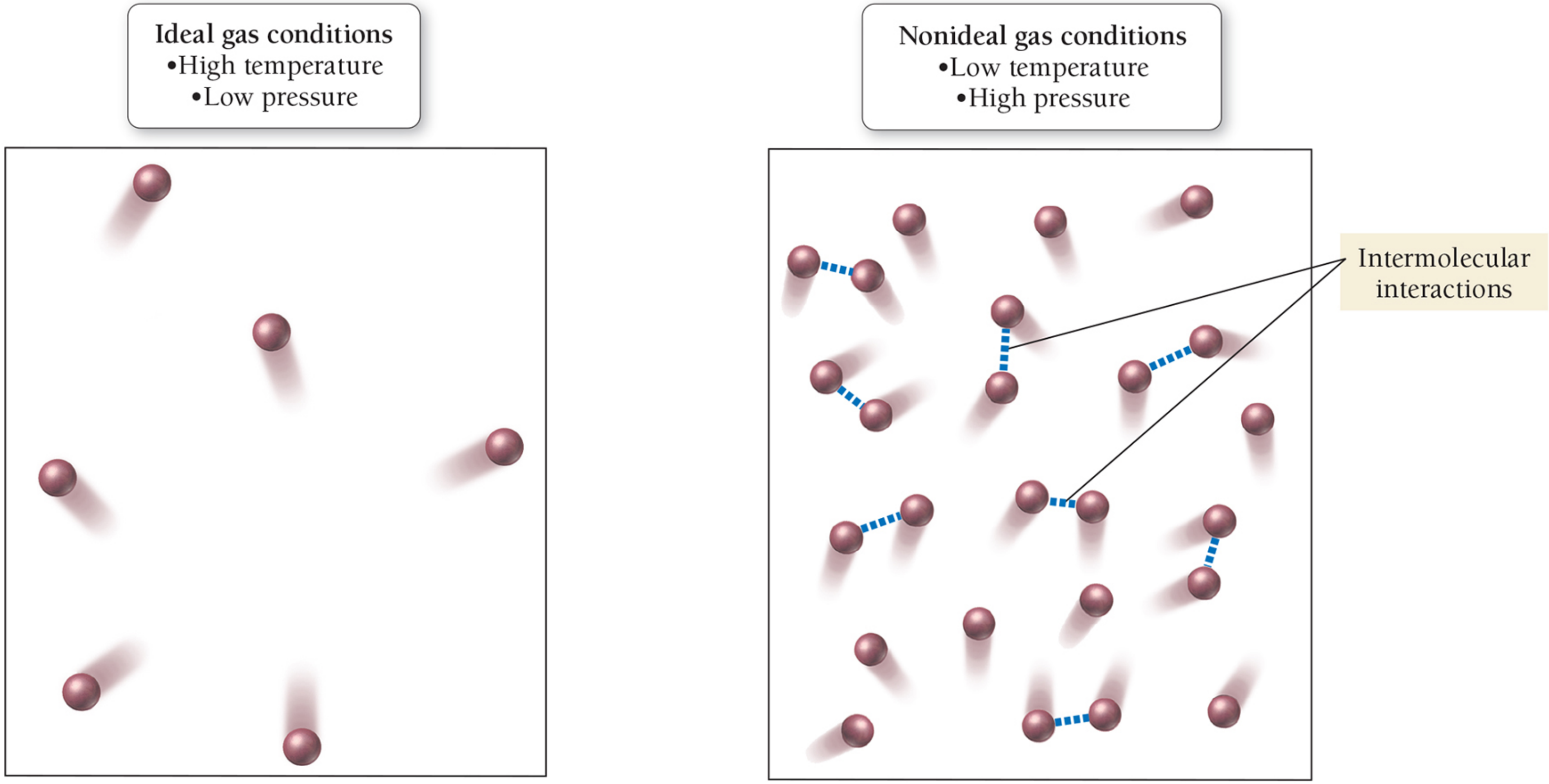
Finding Molar Mass of Gas from Ideal Gas Law

1. Find moles of gas from PV = nRT
2. Use molar mass = mass/moles

Ex Probs

Real Gas Behavior

- Real gases deviate from ideal behavior under very high pressures and very low temperatures.



Gases in Mixtures

Dalton's Law of Partial Pressures

Dalton's Law:

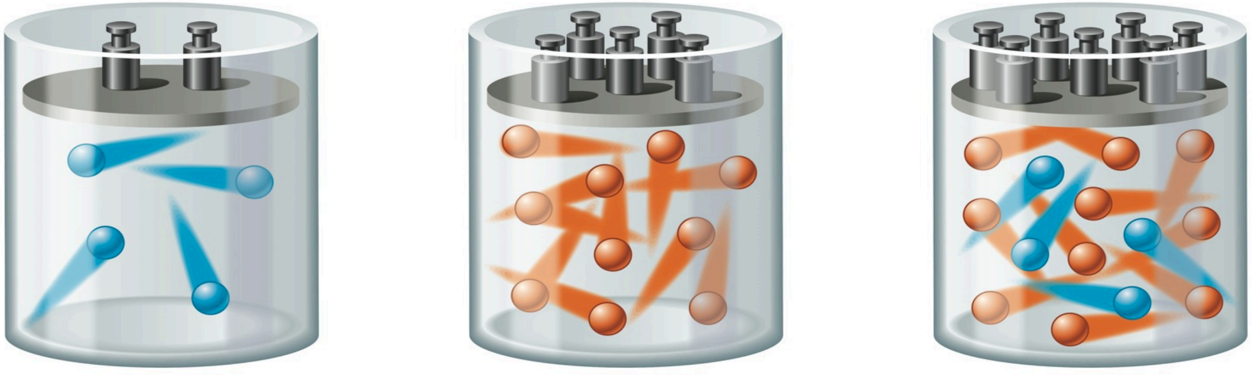
For a mixture of gases in a container:

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

(P_1, P_2, P_3, etc. = Partial pressure: the pressure contributed by a given gas in a mixture to the total pressure)

Dalton’s Law of Partial Pressures

Dalton’s Law: “The total pressure exerted is the sum of the partial pressures of the component gases.”



© Cengage Learning. All Rights Reserved.

$$P_1 \quad + \quad P_2 \quad = \quad P_{Tot}$$

Partial Pressures

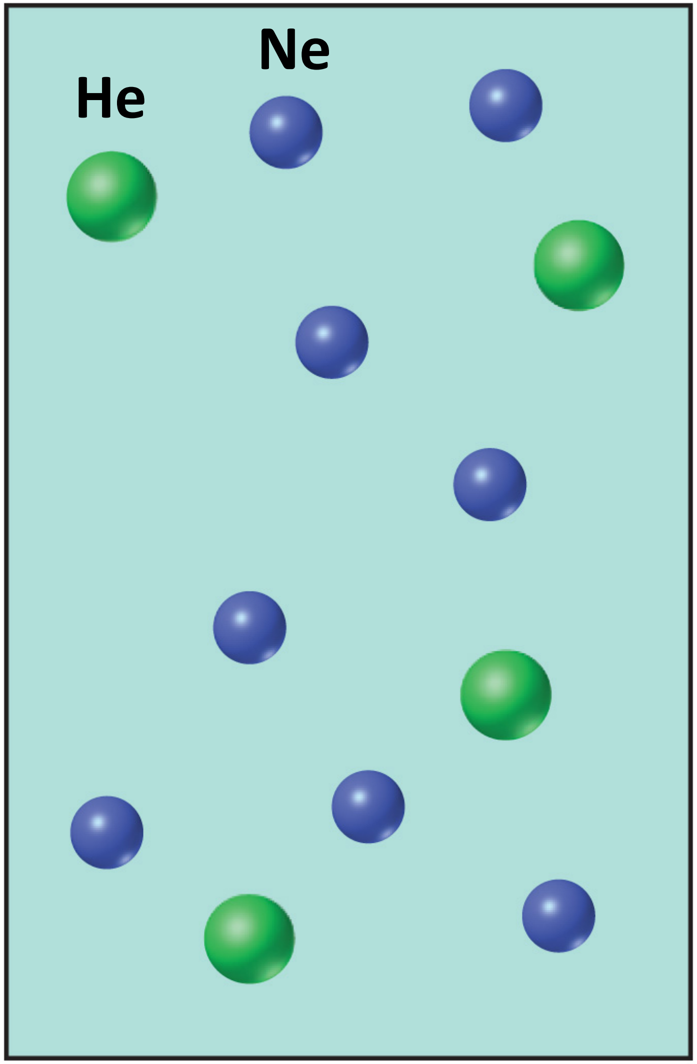
- The partial pressure of each gas in a mixture is dependent only on the moles of each gas.

- So $P_1 = X_1 P_{Tot}$ where X_1 = mole fraction of gas 1 = n_1/n_{Tot}

- And, according to Dalton's Law:

$$P_{Tot} = X_1 P_{Tot} + X_2 P_{Tot} + X_3 P_{Tot} \ldots$$

Q: Partial Pressures



© 2013 Pearson Education, Inc.

At 300K, the total pressure of the mix is 750 mmHg.

What are the partial pressures of each of the gases?

Ex Probs