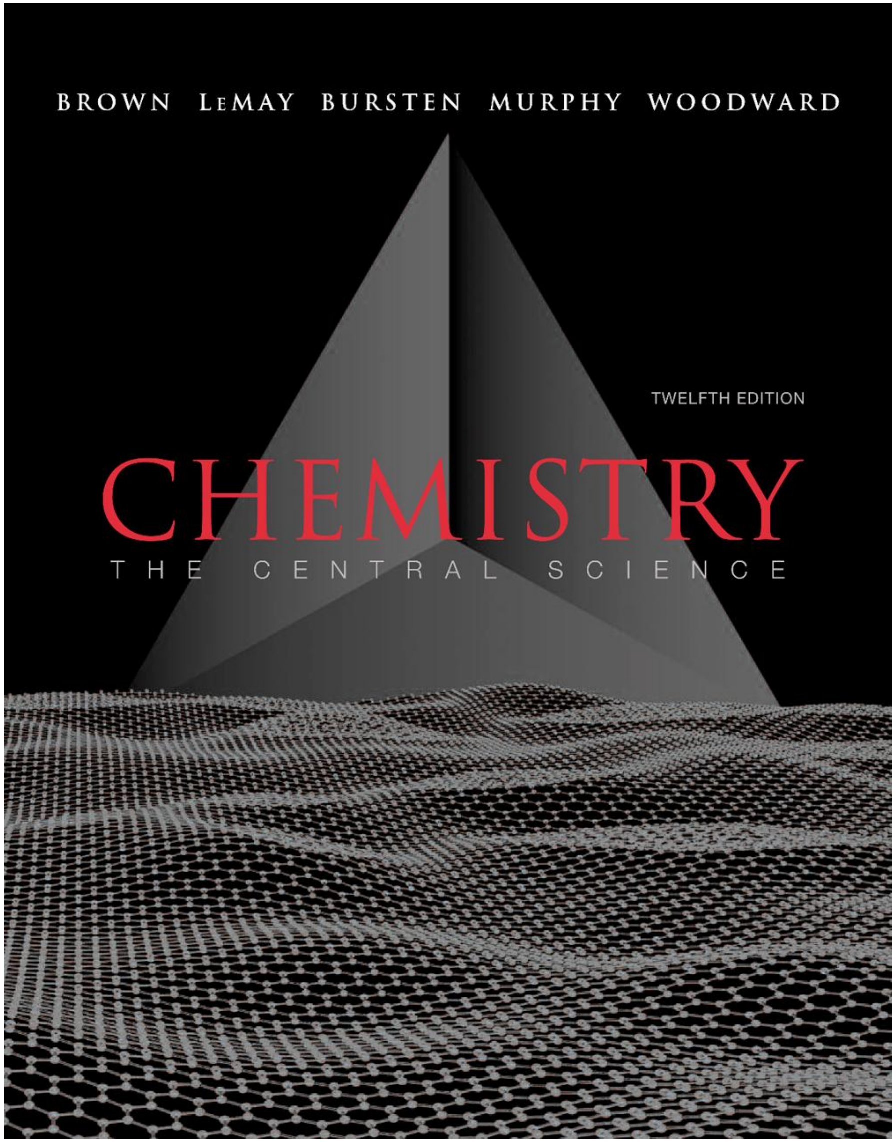

Lecture Presentation

Chapter 10

Gases

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Characteristics of Gases

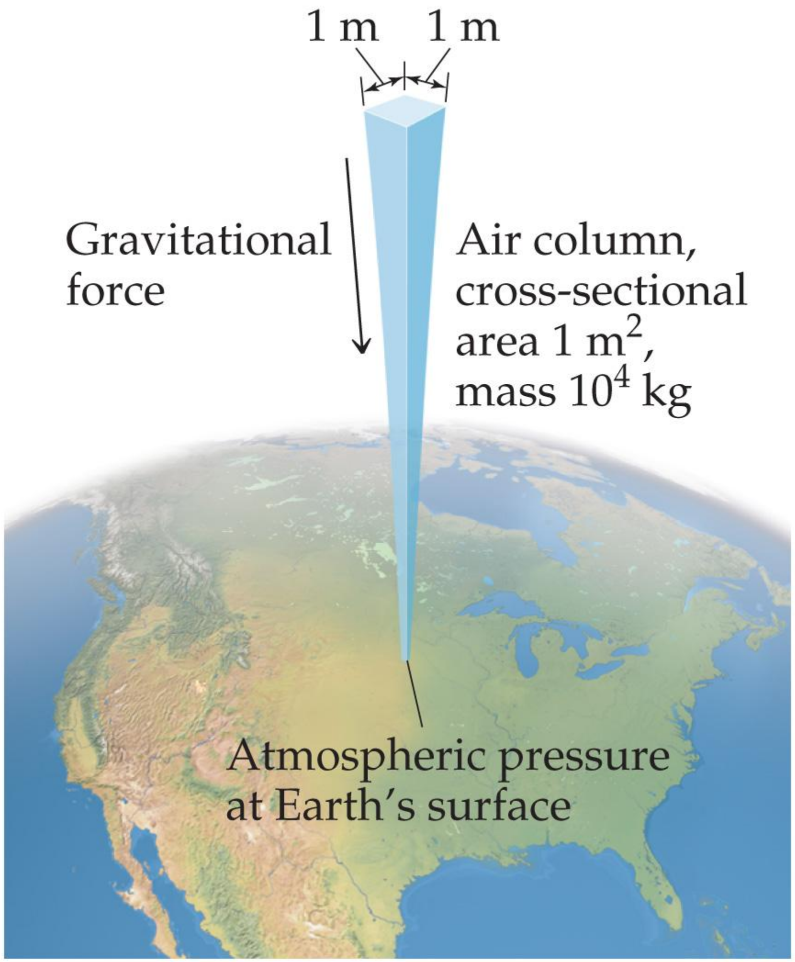
- Unlike liquids and solids, gases
  - Expand to fill their containers.
  - Are highly compressible.
  - Have extremely low densities.

Pressure

- **Pressure** is the amount of force applied to an area:

$$P = \frac{F}{A}$$

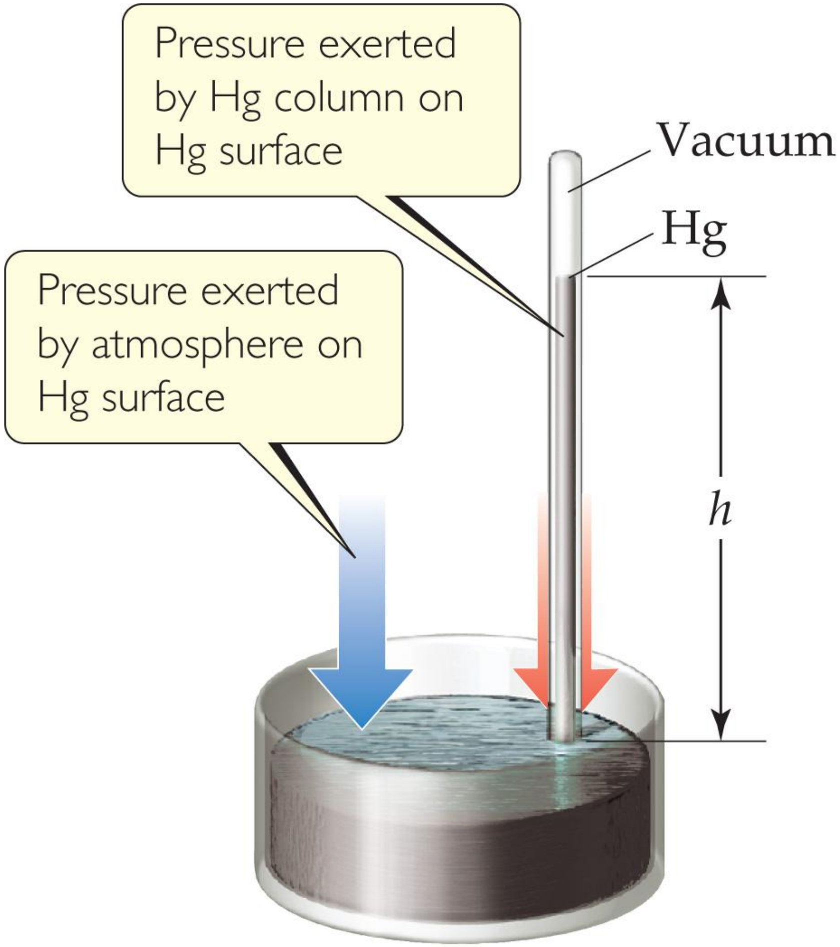
- **Atmospheric pressure** is the weight of air per unit of area.



Units of Pressure

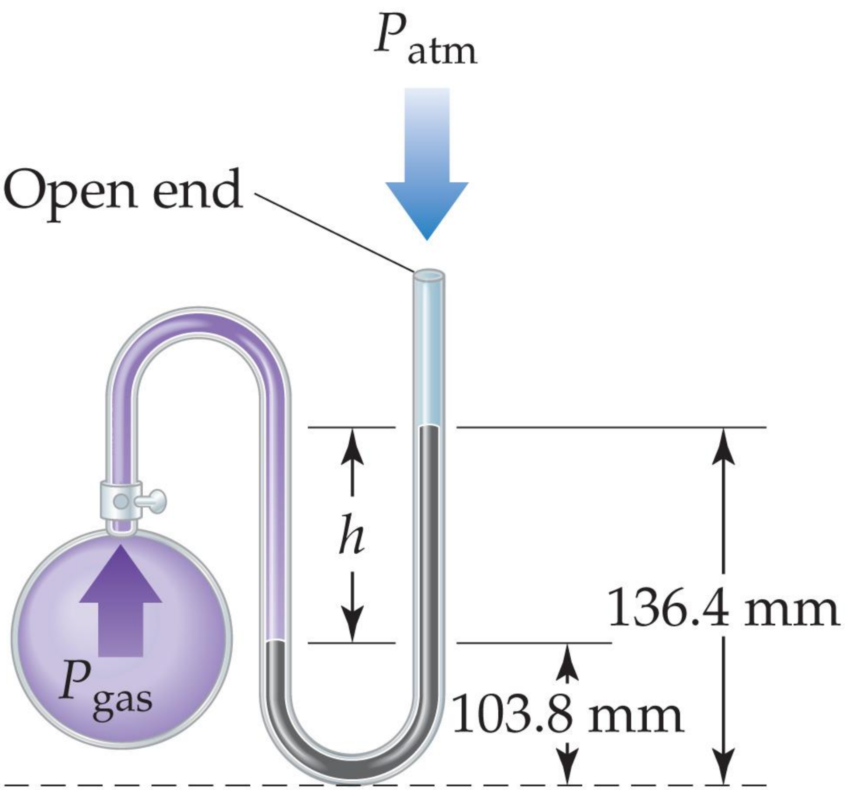
- Pascals
  - $1\ \text{Pa} = 1\ \text{N/m}^2$
- Bar
  - $1\ \text{bar} = 10^5\ \text{Pa} = 100\ \text{kPa}$

Units of Pressure



- mmHg or torr
  - These units are literally the difference in the heights measured in mm (h) of two connected columns of mercury.
- Atmosphere
  - 1.00 atm = 760 torr

Manometer



$$P_{gas} = P_{atm} + P_h$$

The manometer is used to measure the difference in pressure between atmospheric pressure and that of a gas in a vessel.

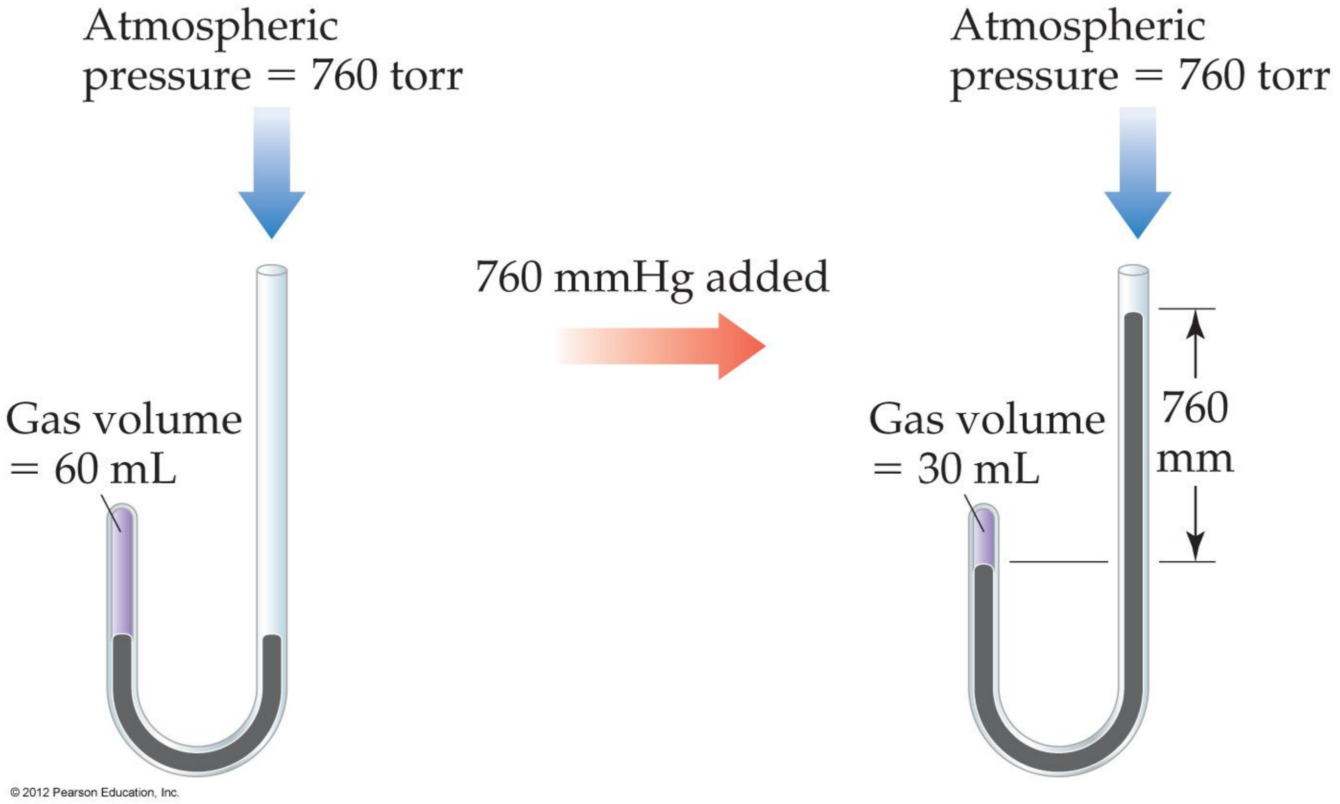
Standard Pressure

- Normal atmospheric pressure at sea level is referred to as **standard pressure**.

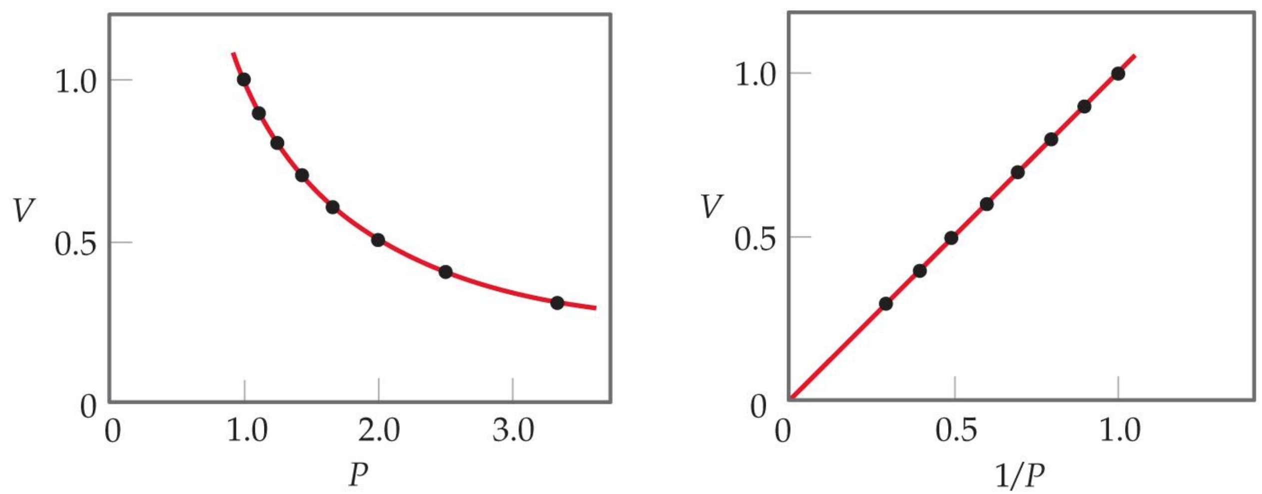
- It is equal to
  - 1.00 atm
  - 760 torr (760 mmHg)
  - 101.325 kPa

Boyle's Law

The volume of a fixed quantity of gas at constant temperature is inversely proportional to the pressure.



P and *V* are Inversely Proportional



Since

$$PV = k$$

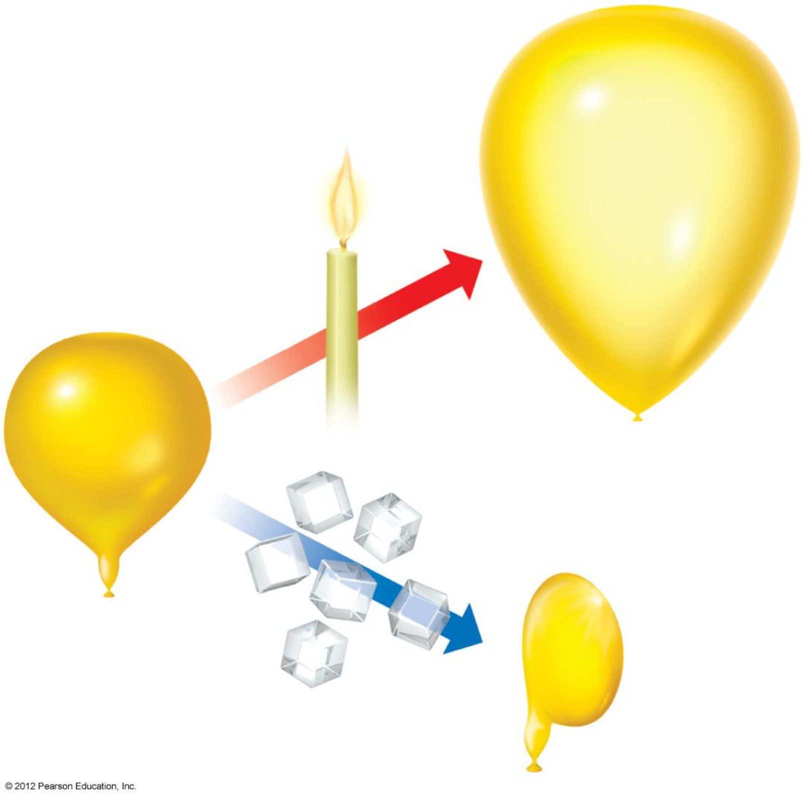
A plot of *V* versus *P* results in a curve.

$$V = k\,(1/P)$$

This means a plot of *V* versus 1/*P* will be a straight line.

Charles's Law

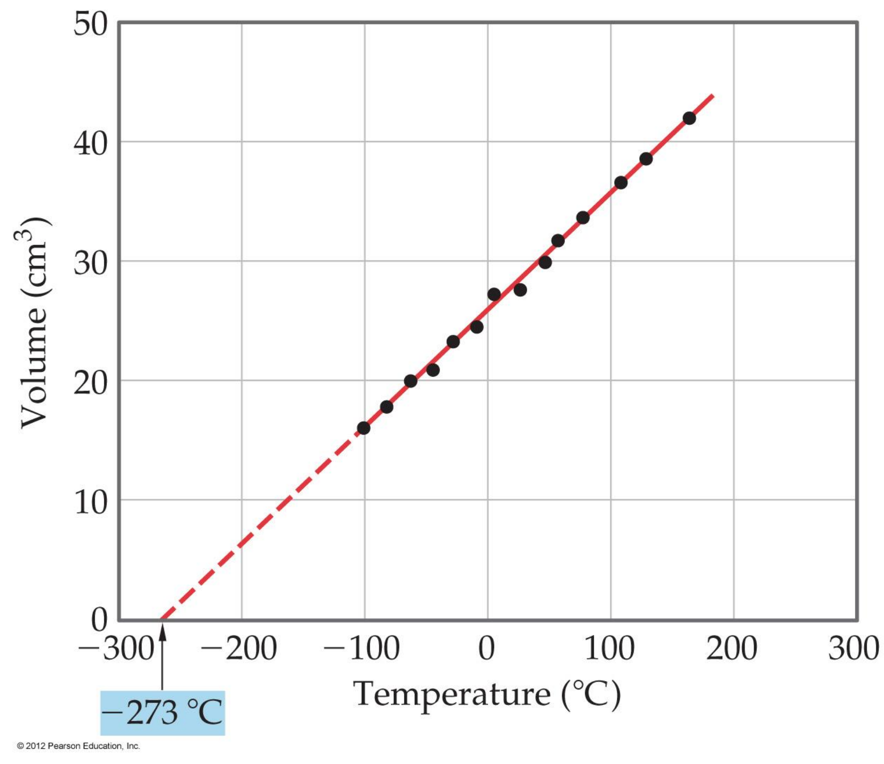
- The volume of a fixed amount of gas at constant pressure is directly proportional to its absolute temperature.



Charles's Law

- So, $$\frac{V}{T} = k$$

- A plot of *V* versus *T* will be a straight line.



Avogadro's Law

- The volume of a gas at constant temperature and pressure is directly proportional to the number of moles of the gas.
- Mathematically, this means $V = kn$

Volume	22.4 L	22.4 L	22.4 L
Pressure	1 atm	1 atm	1 atm
Temperature	0 °C	0 °C	0 °C
Mass of gas	4.00 g	28.0 g	16.0 g
Number of gas molecules	6.02×10^{23}	6.02×10^{23}	6.02×10^{23}

Ideal-Gas Equation

- So far we've seen that

$V \propto 1/P$ (Boyle's law)

$V \propto T$ (Charles's law)

$V \propto n$ (Avogadro's law)

- Combining these, we get

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

Ideal-Gas Equation

The constant of proportionality is known as *R*, the gas constant.

TABLE 10.2 • Numerical Values of the Gas Constant *R* in Various Units

Units	Numerical Value
L-atm/mol-K	0.08206
J/mol-K*	8.314
cal/mol-K	1.987
m^3-Pa/mol-K*	8.314
L-torr/mol-K	62.36

*SI unit

Ideal-Gas Equation

The relationship

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

then becomes

$$V = R\,\frac{nT}{P}$$

or

$$PV = nRT$$

Densities of Gases

If we divide both sides of the ideal-gas equation by *V* and by *RT*, we get

$$\frac{n}{V} = \frac{P}{RT}$$

Densities of Gases

- We know that
  - Moles × molecular mass = mass

$$n \times \mathcal{M} = m$$

- So multiplying both sides by the molecular mass ($\mathcal{M}$) gives

$$\frac{m}{V} = \frac{P\mathcal{M}}{RT}$$

Densities of Gases

- Mass ÷ volume = density
- So, $$d = \frac{m}{V} = \frac{P\mathcal{M}}{RT}$$

Note: One needs to know only the molecular mass, the pressure, and the temperature to calculate the density of a gas.

Molecular Mass

We can manipulate the density equation to enable us to find the molecular mass of a gas:

$$d = \frac{PM}{RT}$$

becomes

$$M = \frac{dRT}{P}$$

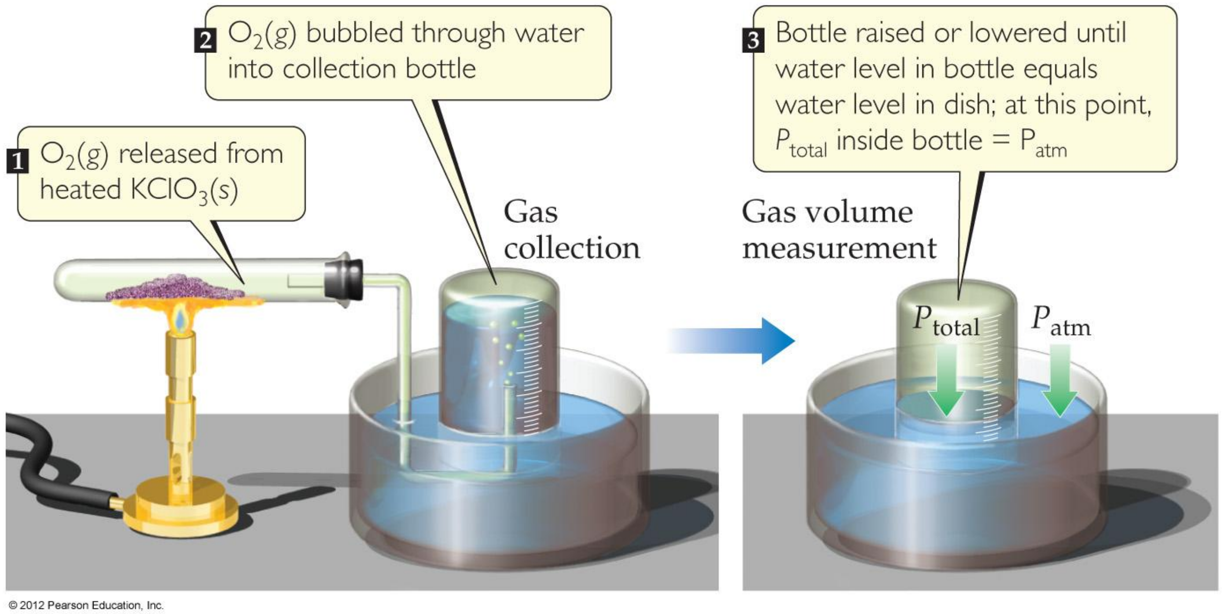
Dalton's Law of Partial Pressures

- The total pressure of a mixture of gases equals the sum of the pressures that each would exert if it were present alone.

- In other words,

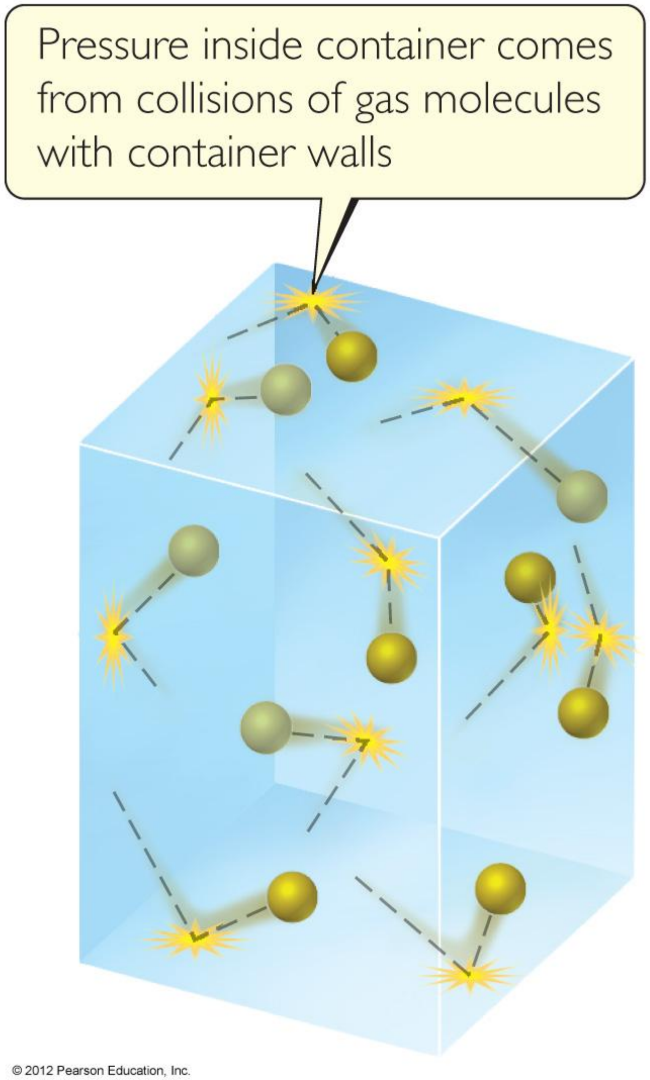
$$P_{\text{total}} = P_1 + P_2 + P_3 + \ldots$$

Partial Pressures



- When one collects a gas over water, there is water vapor mixed in with the gas.
- To find only the pressure of the desired gas, one must subtract the vapor pressure of water from the total pressure.

Kinetic-Molecular Theory



This is a model that aids in our understanding of what happens to gas particles as environmental conditions change.

Main Tenets of Kinetic-Molecular Theory

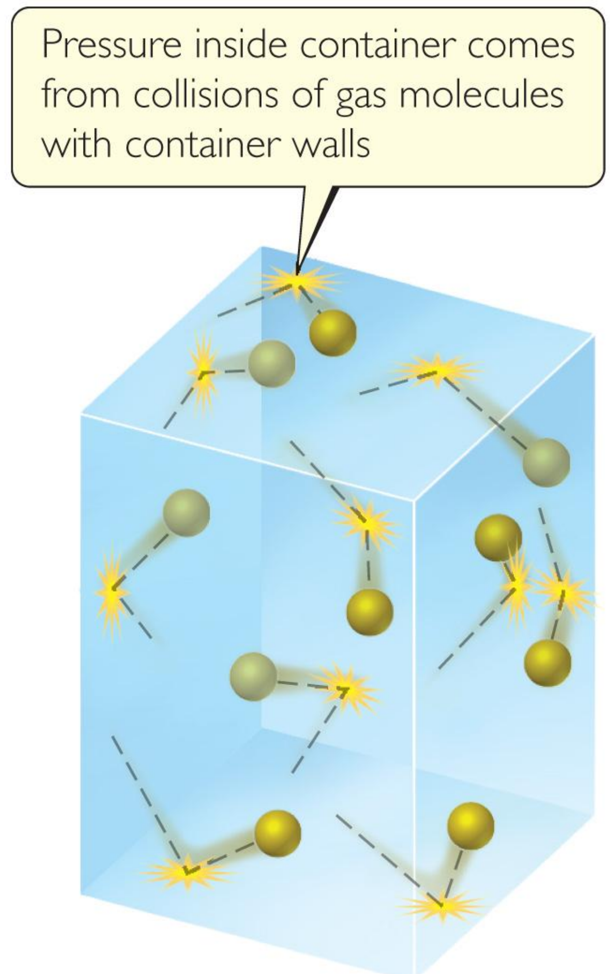
Gases consist of large numbers of molecules that are in continuous, random motion.

Main Tenets of Kinetic-Molecular Theory

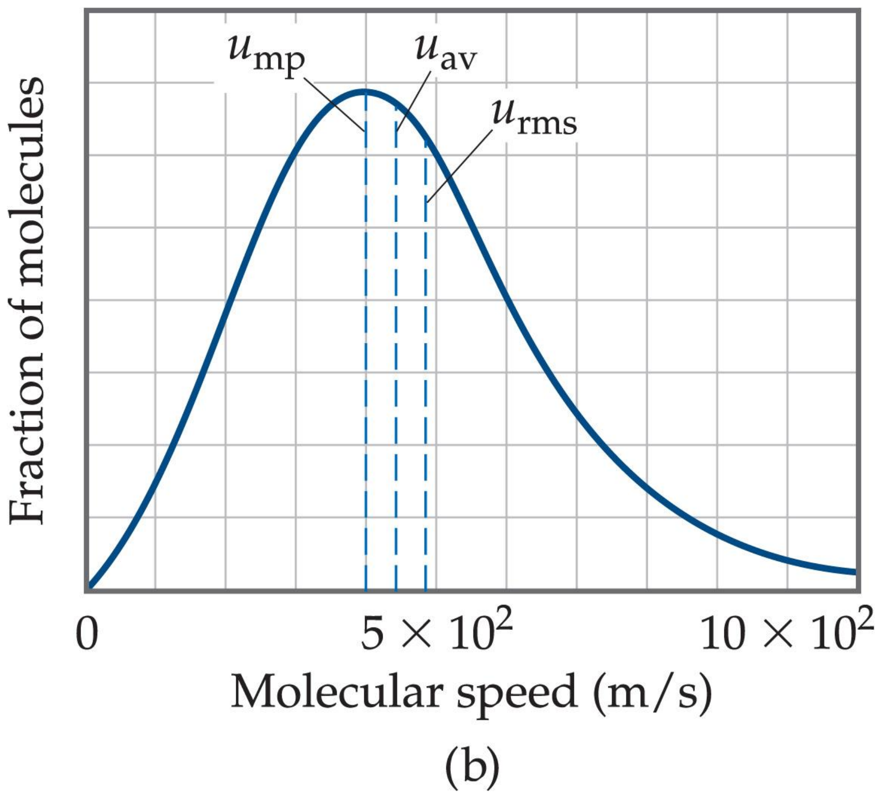
The combined volume of all the molecules of the gas is negligible relative to the total volume in which the gas is contained.

Main Tenets of Kinetic-Molecular Theory

Attractive and repulsive forces between gas molecules are negligible.



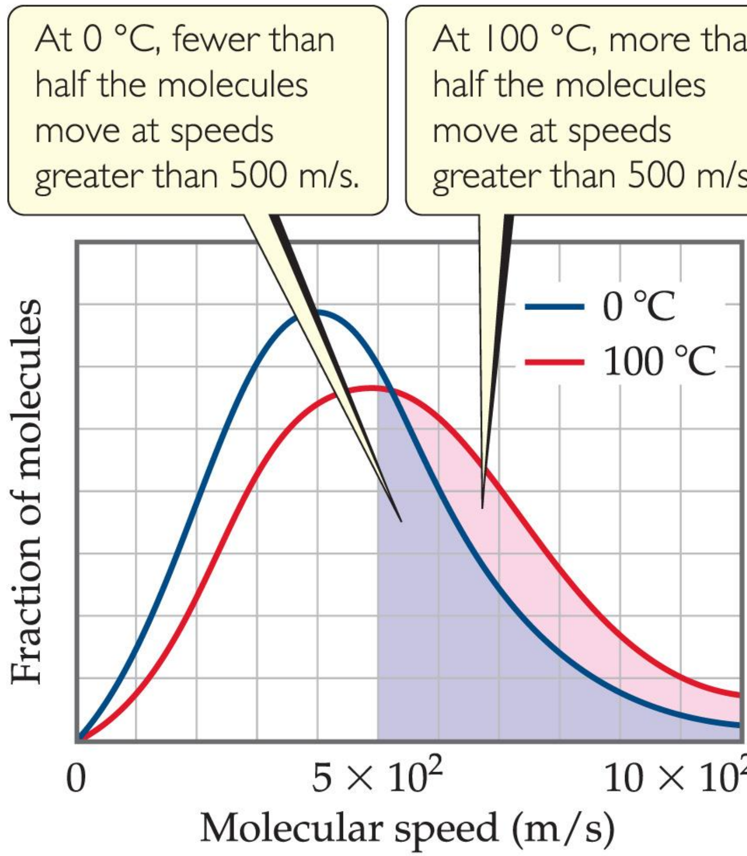
Main Tenets of Kinetic-Molecular Theory



Energy can be transferred between molecules during collisions, but the *average* kinetic energy of the molecules does not change with time, as long as the temperature of the gas remains constant.

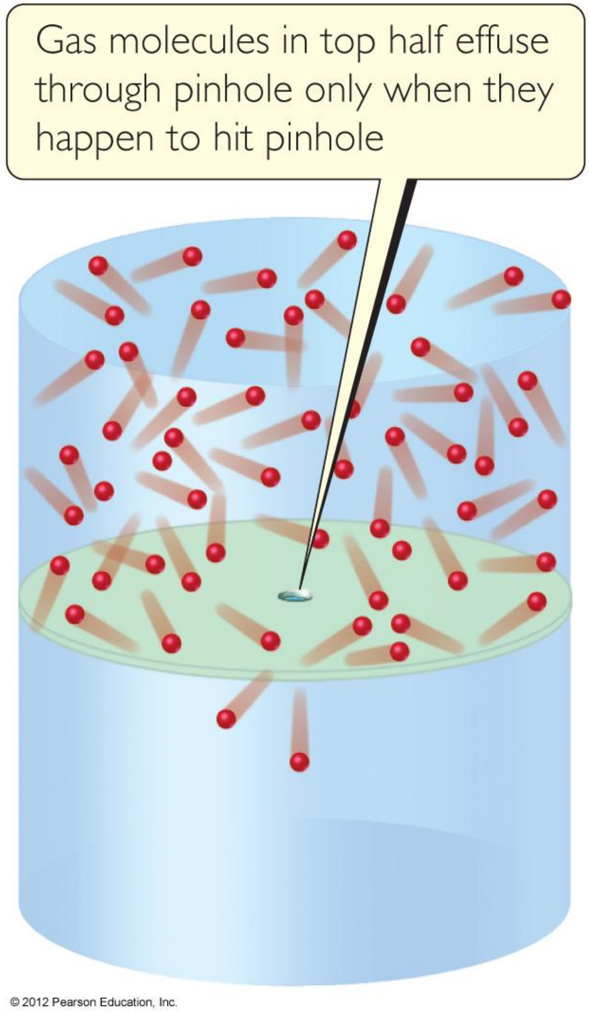
Main Tenets of Kinetic-Molecular Theory

The average kinetic energy of the molecules is proportional to the absolute temperature.



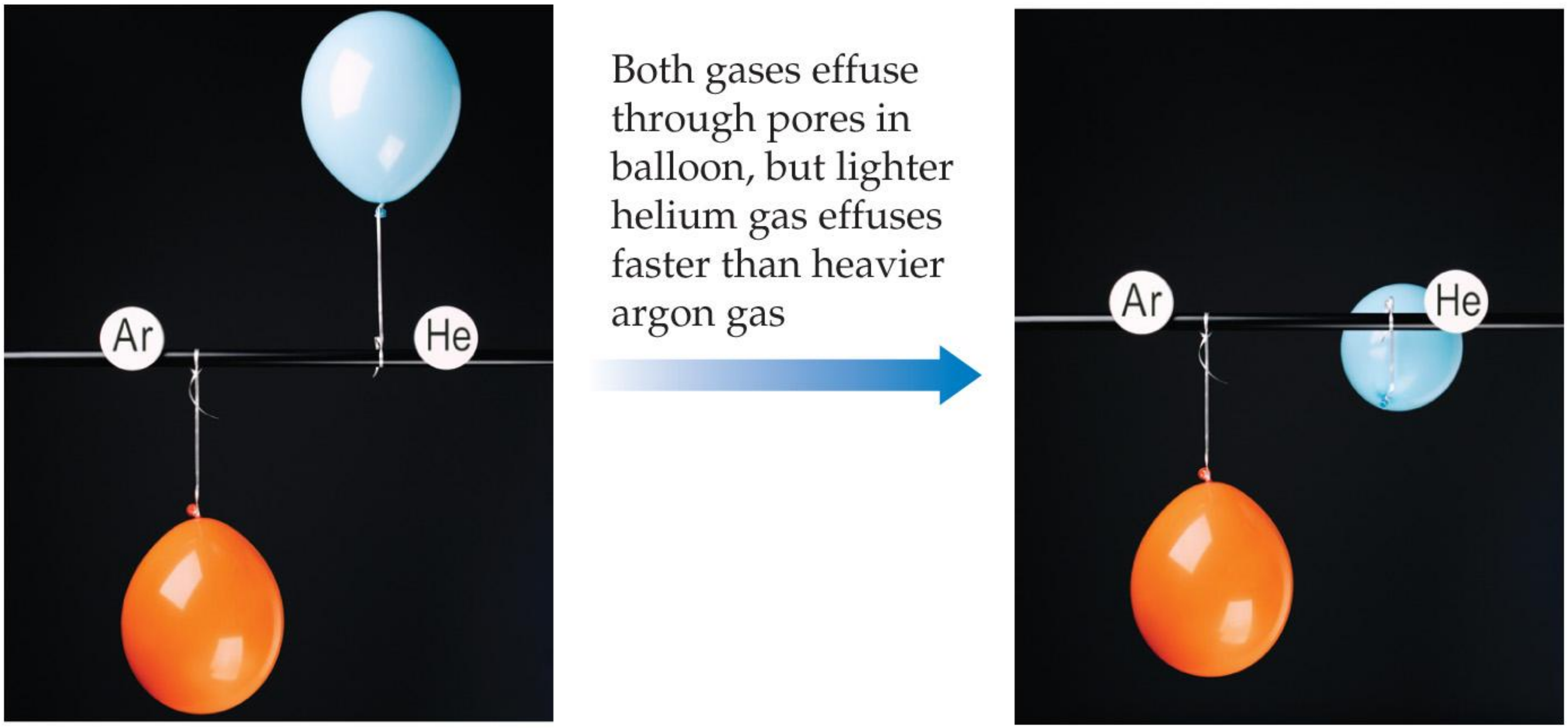
(a)

Effusion



Effusion is the escape of gas molecules through a tiny hole into an evacuated space.

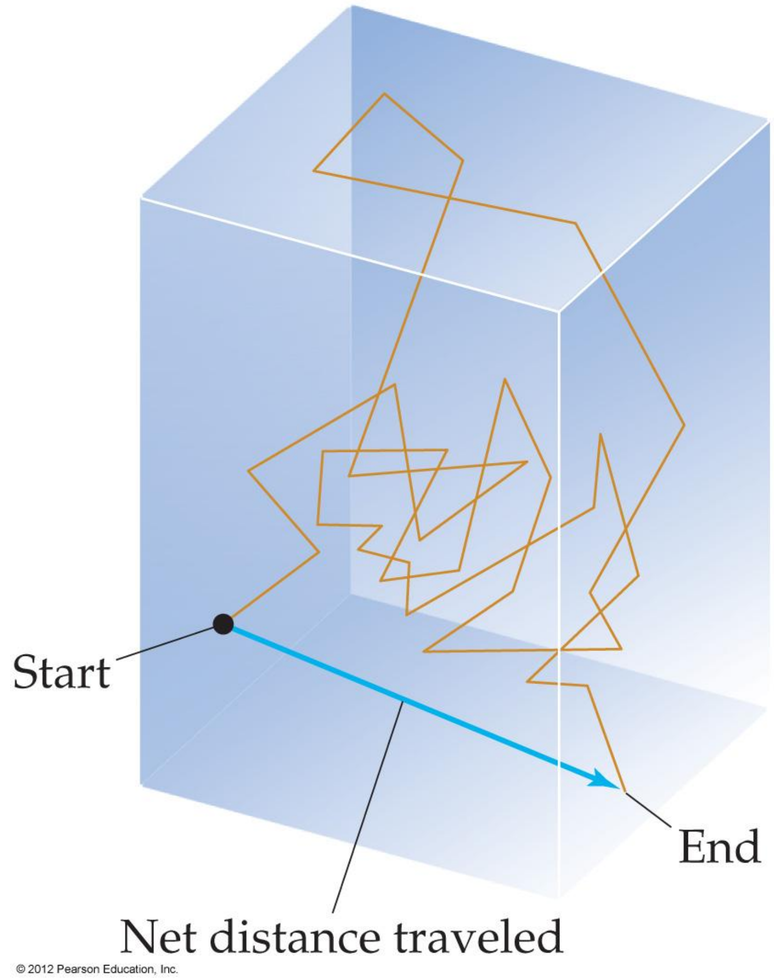
Effusion



The difference in the rates of effusion for helium and nitrogen, for example, explains why a helium balloon would deflate faster.

Diffusion

Diffusion is the spread of one substance throughout a space or throughout a second substance.



Graham's Law

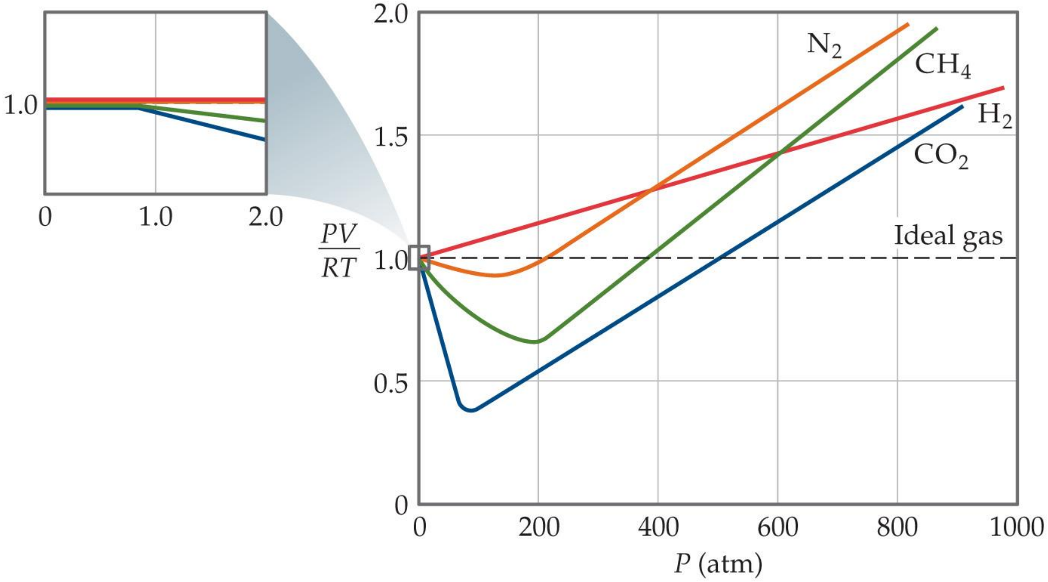
$$KE_1 = KE_2$$

$$1/2\, m_1 v_1^2 = 1/2\, m_2 v_2^2$$

$$\frac{m_1}{m_2} = \frac{v_2^2}{v_1^2}$$

$$\frac{\sqrt{m_1}}{\sqrt{m_2}} = \frac{\sqrt{v_2^2}}{\sqrt{v_1^2}} = \frac{v_2}{v_1}$$

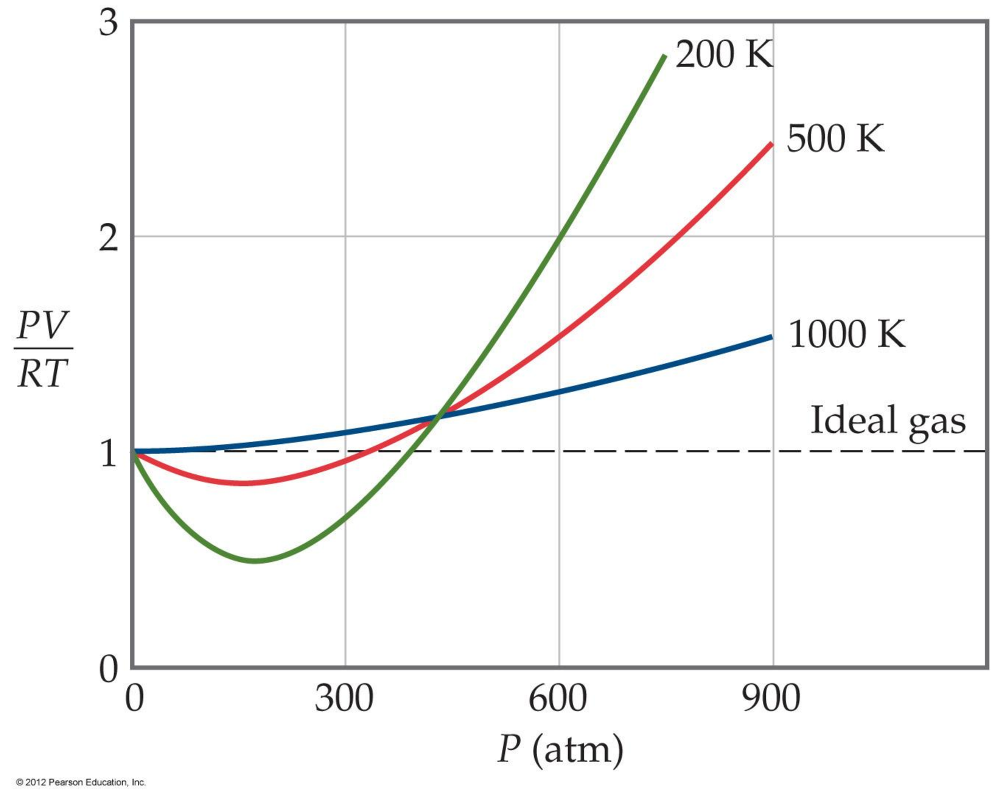
Real Gases



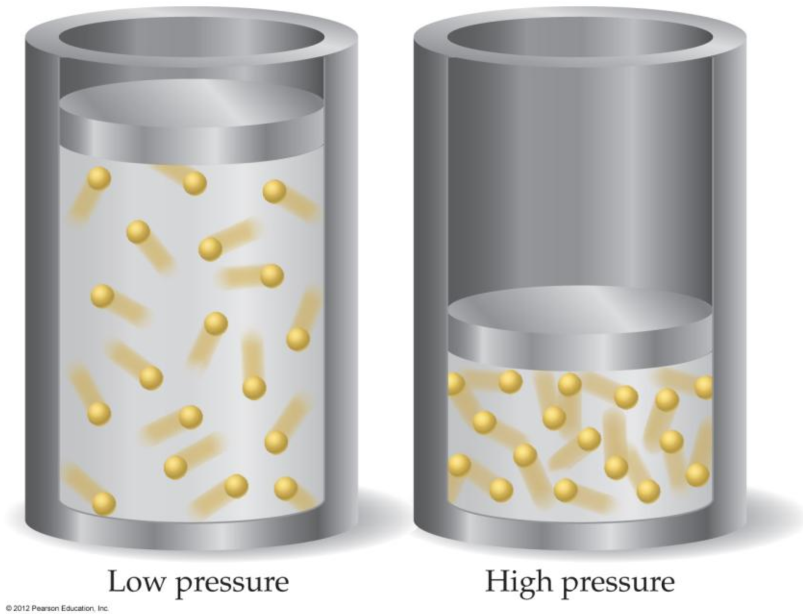
In the real world, the behavior of gases only conforms to the ideal-gas equation at relatively high temperature and low pressure.

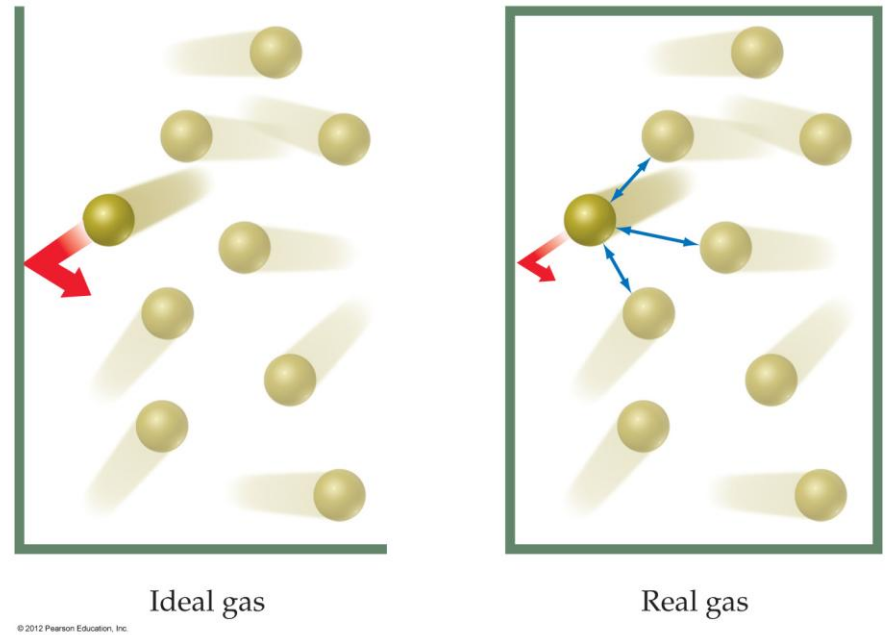
Real Gases

Even the same gas will show wildly different behavior under high pressure at different temperatures.



Deviations from Ideal Behavior





The assumptions made in the kinetic-molecular model (negligible volume of gas molecules themselves, no attractive forces between gas molecules, etc.) break down at high pressure and/or low temperature.

Corrections for Nonideal Behavior

- The ideal-gas equation can be adjusted to take these deviations from ideal behavior into account.
- The corrected ideal-gas equation is known as the **van der Waals equation**.

The van der Waals Equation

$$\left(P + \frac{n^2a}{V^2}\right)(V - nb) = nRT$$

TABLE 10.3 • Van der Waals Constants for Gas Molecules

Substance	a (L^2-atm/mol^2)	b (L/mol)
He	0.0341	0.02370
Ne	0.211	0.0171
Ar	1.34	0.0322
Kr	2.32	0.0398
Xe	4.19	0.0510
H_2	0.244	0.0266
N_2	1.39	0.0391
O_2	1.36	0.0318
Cl_2	6.49	0.0562
H_2O	5.46	0.0305
CH_4	2.25	0.0428
CO_2	3.59	0.0427
CCl_4	20.4	0.1383