Gases

Characteristics of Gases

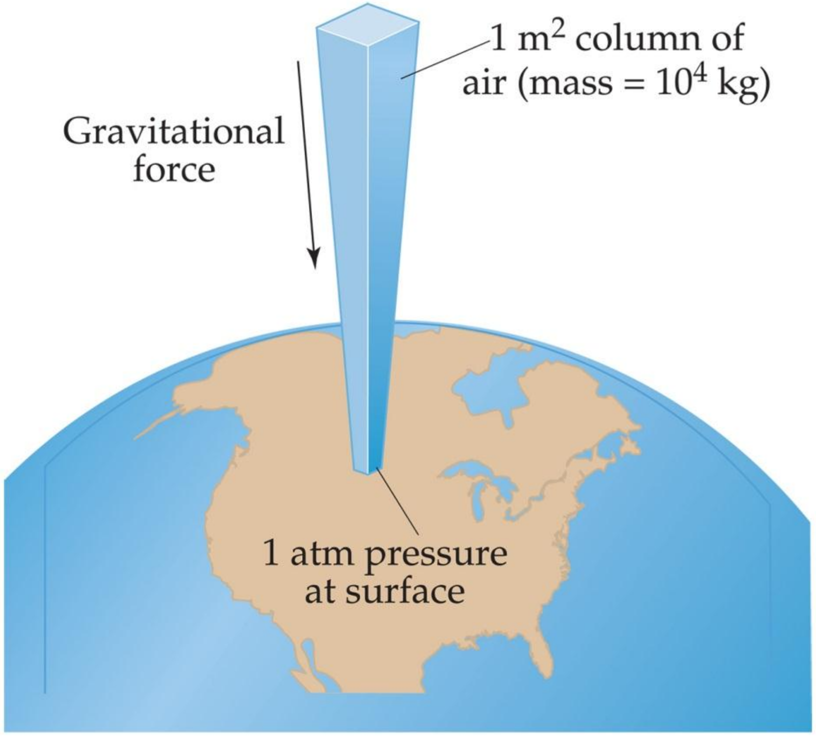
- Unlike liquids and solids, they
  - Expand to fill their containers.
  - Are highly compressible.
  - Have extremely low densities.

Pressure

- Pressure is the amount of force applied to an area.

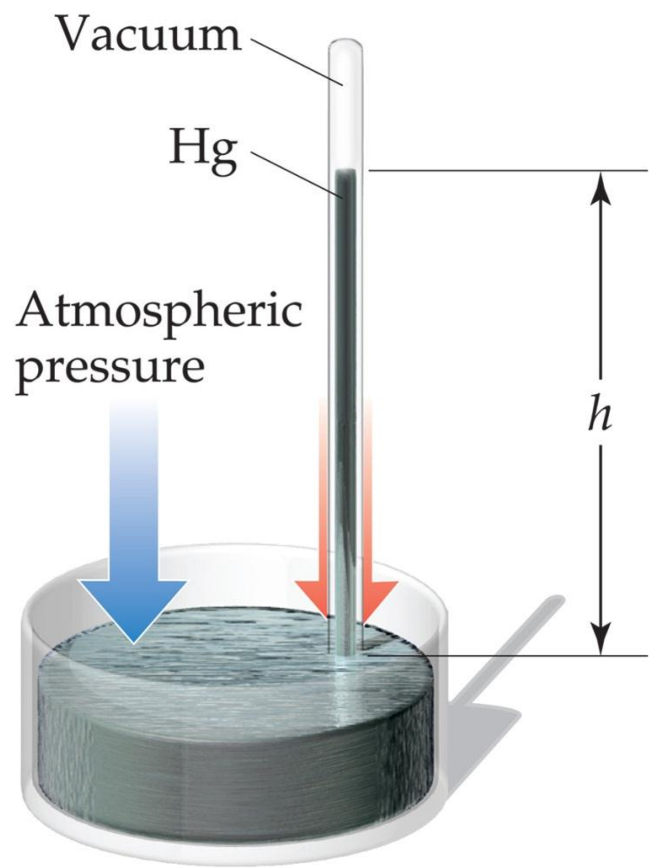
$$P = \frac{F}{A}$$

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



Units of Pressure

- mm Hg 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



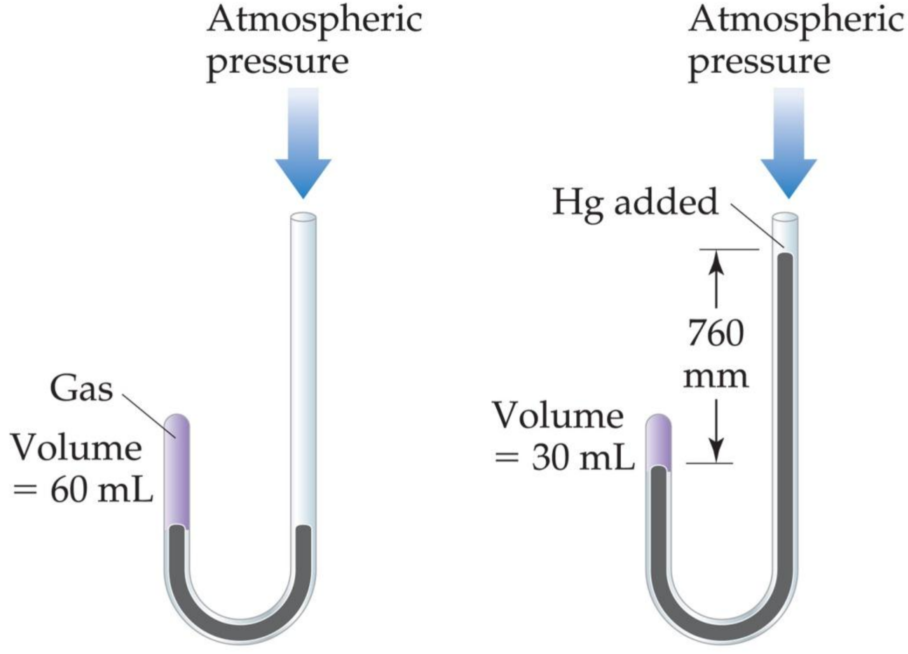
Standard Pressure

- Normal atmospheric pressure at sea level.

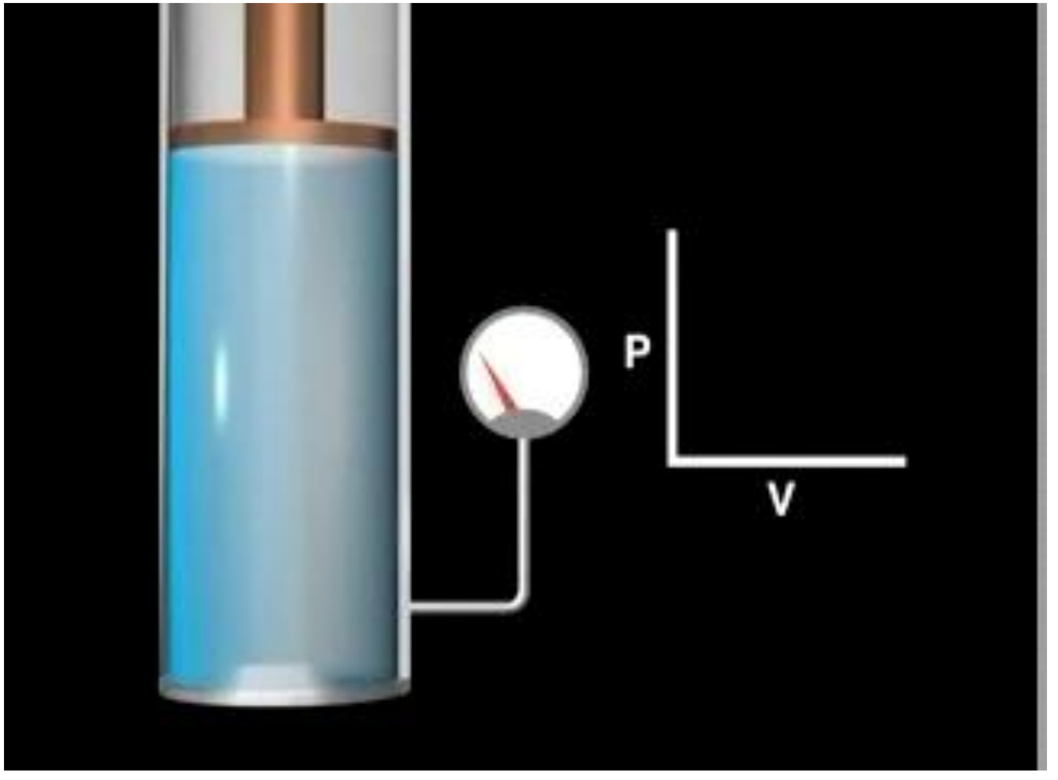
- It is equal to
  - 1.00 atm
  - 760 torr (760 mm Hg)
  - 101.325 kPa

Boyle's Law

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

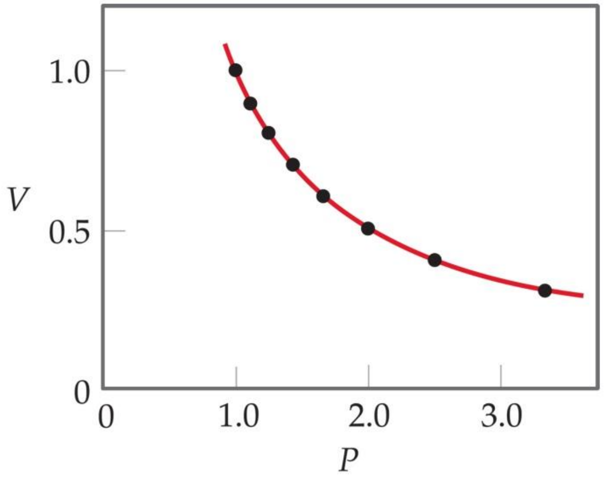


Boyle's Law



As *P* and *V* are inversely proportional

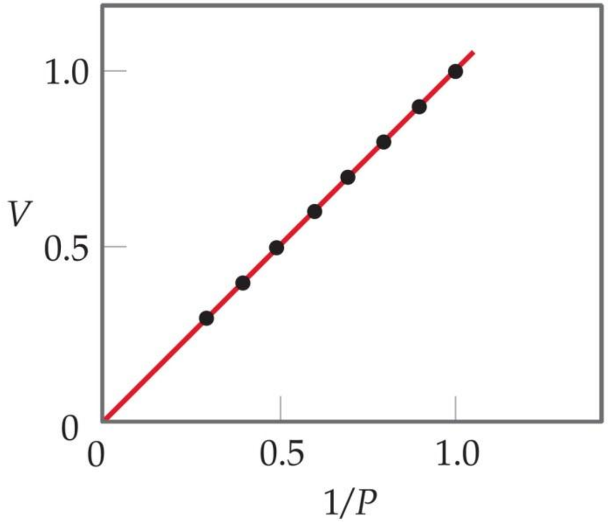
A plot of *V* versus *P* results in a curve.



Since $PV = k$

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

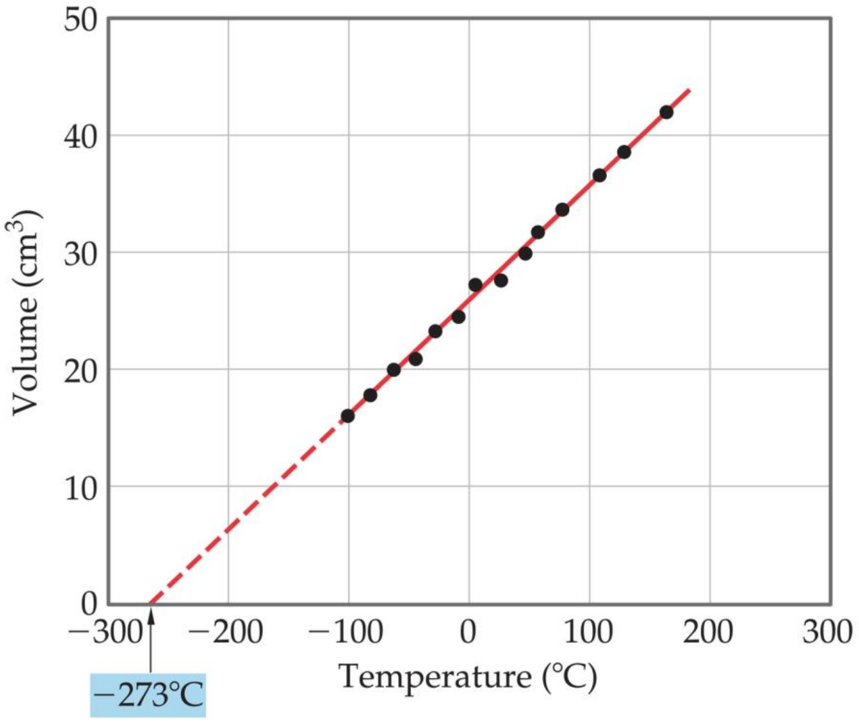
This means a plot of *V* versus 1/*P* will be a straight line.



Charles's Law

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

- i.e., $\frac{V}{T} = k$

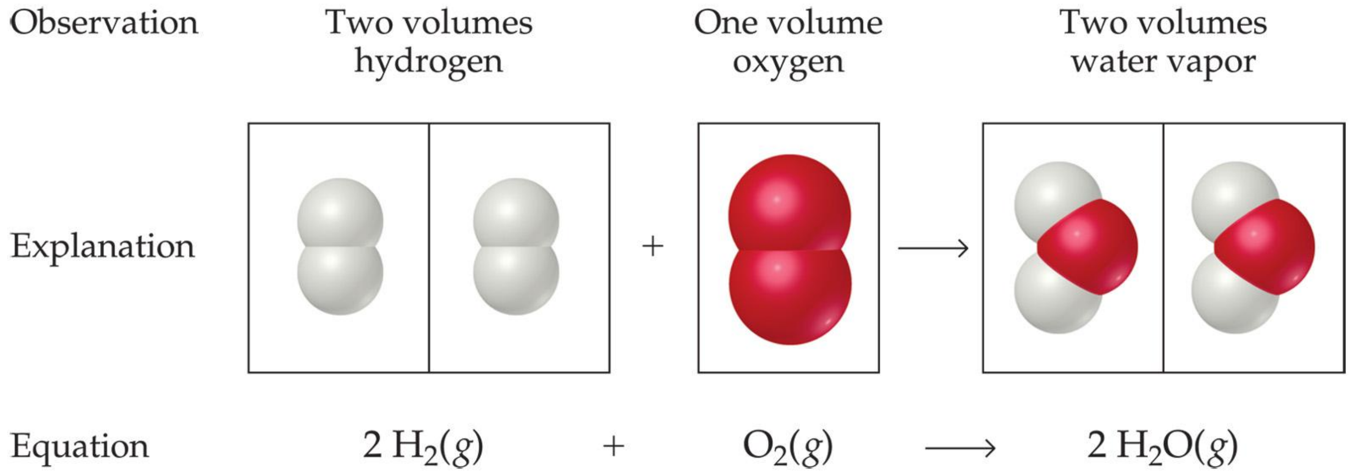


A plot of *V* versus *T* will be a straight line.

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 $V = kn$



Ideal-Gas Equation

- So far we've seen that

$$V \propto 1/P \quad \text{(Boyle's law)}$$

$$V \propto T \quad \text{(Charles's law)}$$

$$V \propto n \quad \text{(Avogadro's law)}$$

- Combining these, we get

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

Ideal-Gas Equation

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

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 $\times$ molecular mass = mass

$$n \times M = m$$

- So multiplying both sides by the molecular mass (M) gives

$$\frac{m}{V} = \frac{PM}{RT}$$

Densities of Gases

- Mass ÷ volume = density
- So,

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

- Note: One only needs to know 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,

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

Main Tenets of Kinetic-Molecular Theory

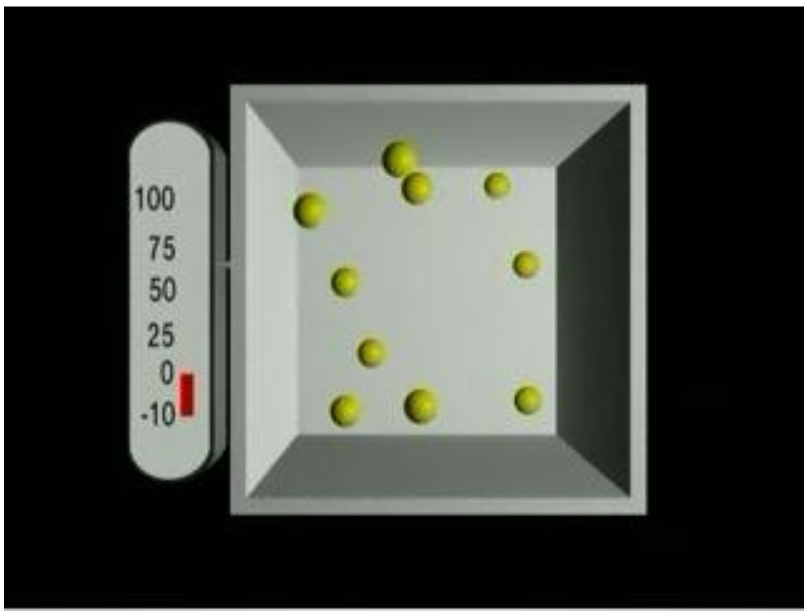
Gases consist of large numbers of molecules that are in continuous, random motion.

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.

- Attractive and repulsive forces between gas molecules are negligible.

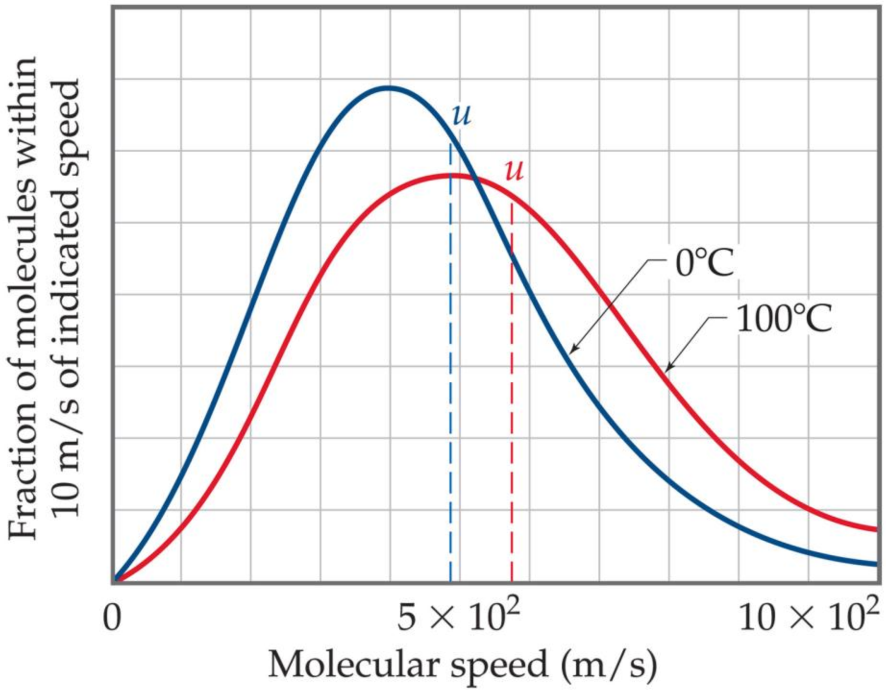
Main Tenets of Kinetic-Molecular Theory



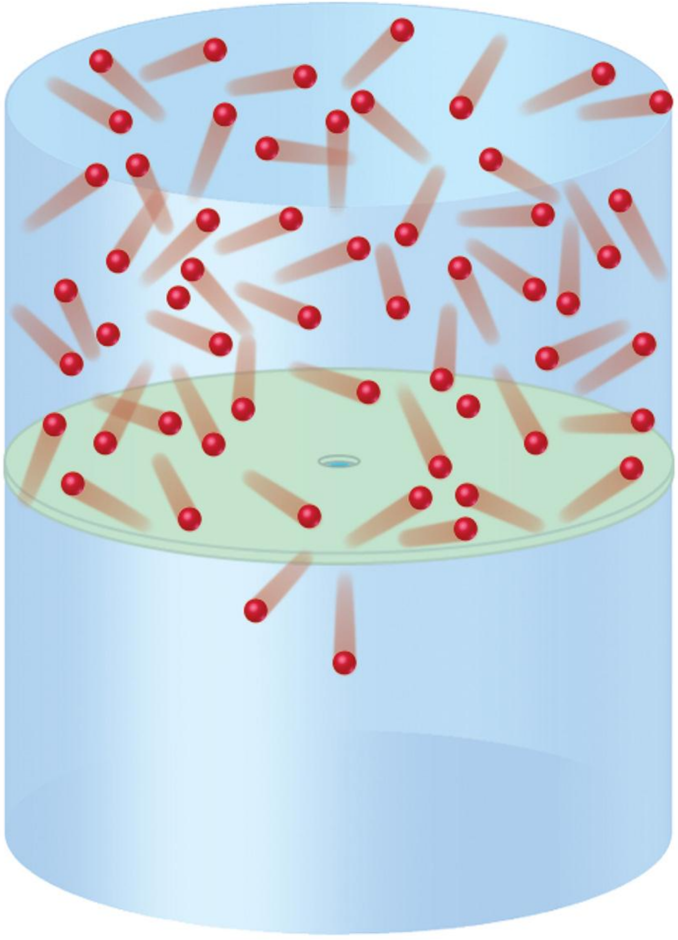
Energy can be transferred between molecules during collisions, but the *average* kinetic energy of the molecules does not change with time, as long as the temperature of the gas remains constant.

Main Tenets of Kinetic-Molecular Theory

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



Effusion

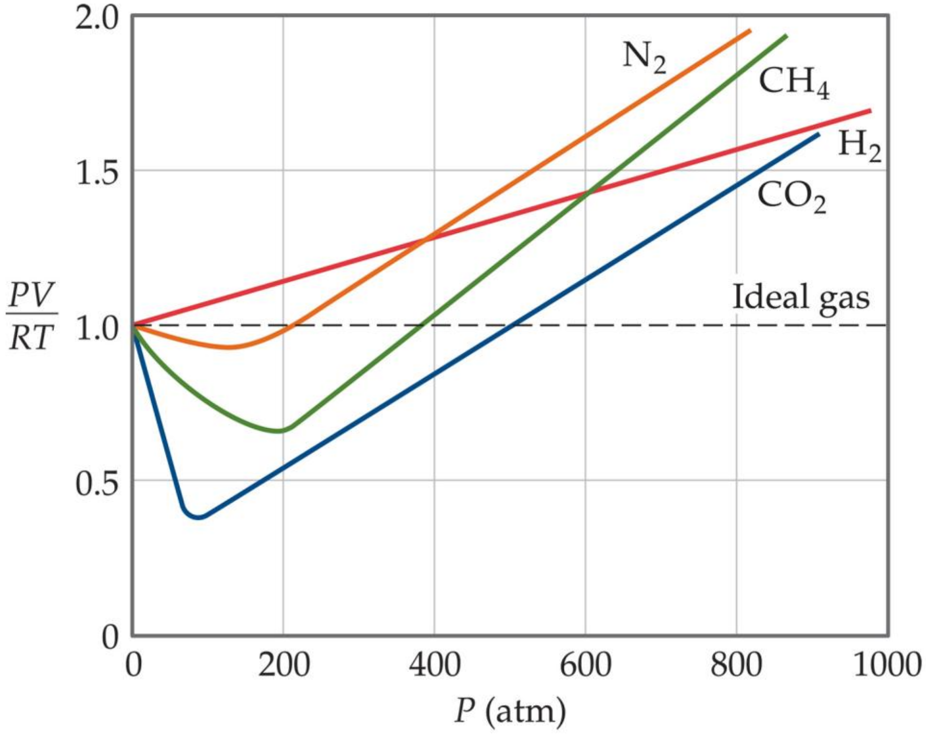


The escape of gas molecules through a tiny hole into an evacuated space.

Diffusion

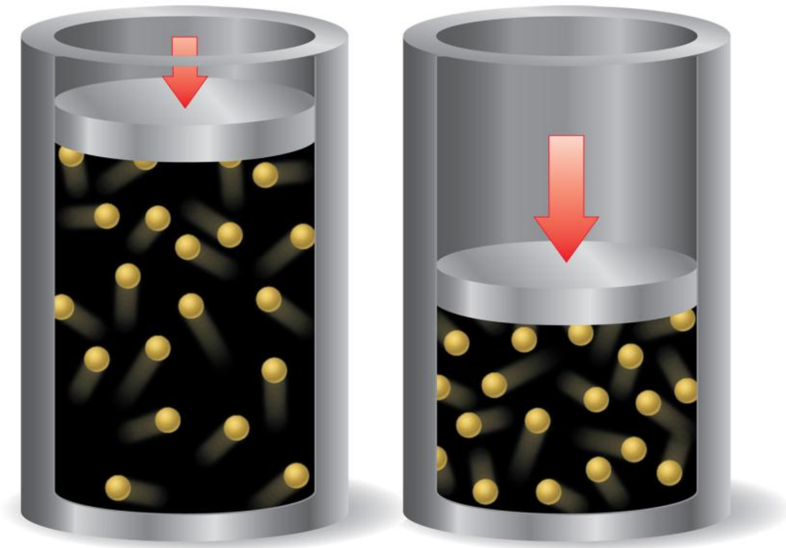
The spread of one substance throughout a space or throughout a second substance.

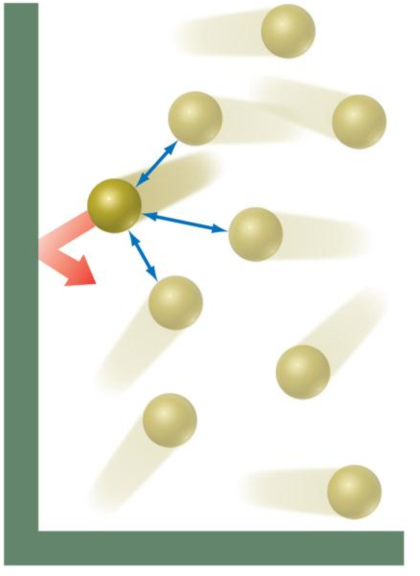
Real Gases



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

Deviations from Ideal Behavior





The assumptions made in the kinetic-molecular model 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

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

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