
\[ F(r) = -\frac{dU}{dr} \]

- \( r > r_o, \quad F < 0, \quad U \) increases w/ increasing \( r \)
- \( r < r_o, \quad F > 0, \quad U \) increases w/ decreasing \( r \)

At \( r_o \), \( F = 0 \), \( U \) at minumum

Temperature rises:
- Solid → liquid → gas
- Intermolecular distance
- Molecular kinetic energy
18-3. Kinetic-Molecular Model of an Ideal Gas

Average translational kinetic energy for $N$ molecules

$$K_{tr} = \frac{1}{2} m (v^2)_{av} \times N$$

$$p = \frac{F}{A} = \frac{Nm (v^2)_{av}}{3V}$$

$$pV = \frac{2}{3} N \left[ \frac{1}{2} m (v^2)_{av} \right] = \frac{2}{3} K_{tr}$$

$$K_{tr} = \frac{3}{2} nRT$$

$$\frac{1}{2} m (v^2)_{av} = \frac{3}{2} kT$$ — Average translational kinetic energy of a gas molecule
18-4. Heat Capacity

Consider a gas at constant volume

Define molar heat capacity at const. Volume: \( C_V \)

Adding heat \( dQ \) into the system:

\[
dQ = nC_V dT
\]

\[
dK_{tr} = \frac{3}{2} nRdT
\]

Thus

\[
nC_V dT = \frac{3}{2} nRdT
\]

\[
C_V = \frac{3}{2} R
\]

Ideal gas of point particles

\[
= 12.47 \text{ J/mol} \cdot \text{K}
\]

Applies to monatomic gases, way off for diatomic & polyatomic gases
Equipartition of Energy

Equipartition of Energy:
Each velocity component (linear or angular) is associated with a kinetic energy per molecule of $kT/2$.

Degrees of freedom:
# of velocity components needed to describe the motion of a molecule completely.

Monatomic gas (He, Ar, etc):
3 degrees of freedom
av. kinetic energy/molecule $3 \left( kT/2 \right)$
$C_V = 3R/2 = 12.47 \text{ J/mol K}$

Diatomic molecules
3 translational + 2 rotational degrees of freedom = 5
av. kinetic energy/molecule $5 \left( kT/2 \right)$
$C_V = 5R/2 = 20.79 \text{ J/mol K}$

Vibrational motion:
Also contribute, at higher energy (temperature)
Heat Capacity of Solids

Monatomic Solid:

Crystal with \( N \) identical atoms

Each atom has \( 3kT \) energy

kinetic + potential

\[ E_{\text{total}} = 3NkT = 3nRT \]

Rule of Dulong & Petit

\[ C_V = 3R - \text{ideal monatomic solid} \]

= 24.9 J/mol K
18-6. Phases of Matter

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