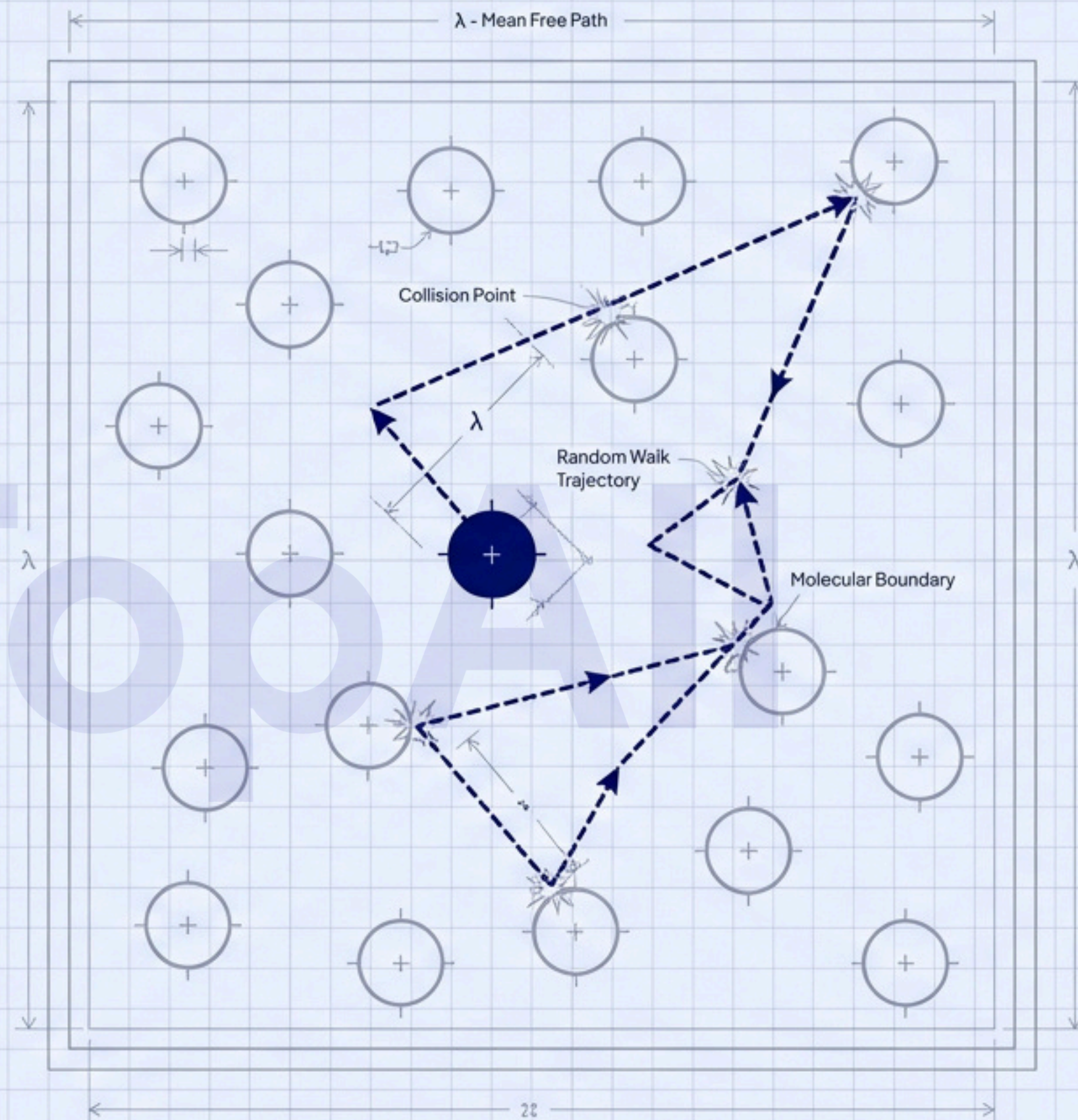


12.7 Mean Free Path

The invisible geometry of molecular collisions



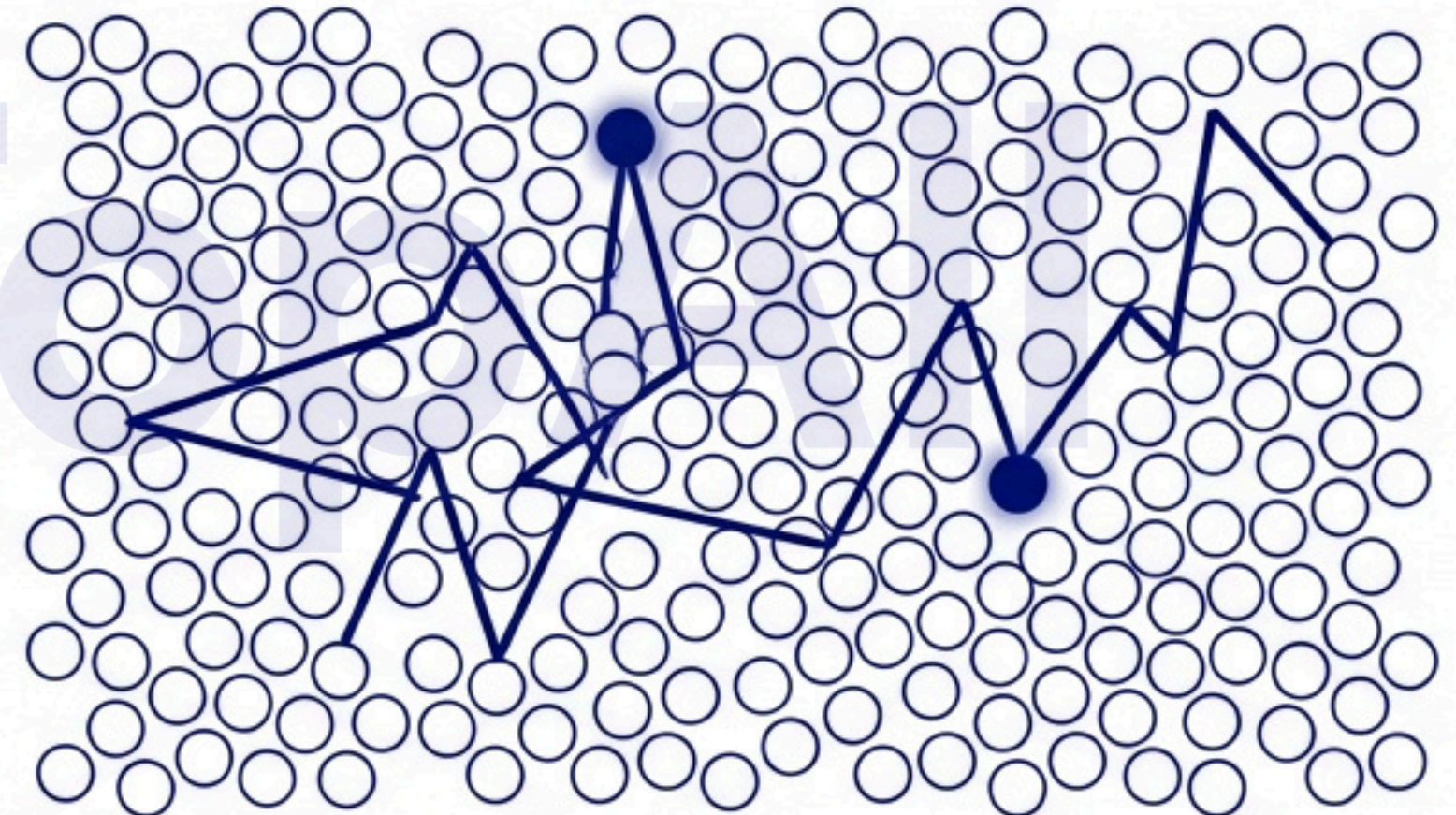
H2: Molecules Move Fast, But Diffuse Slowly

- **The Speed:** Gas molecules travel at the speed of sound (e.g., ~485 m/s).
- **The Problem:** Finite molecular size ensures they cannot move in straight lines unhindered.
- **The Result:** Incessant deflections create a random walk.

Ideal Point Mass



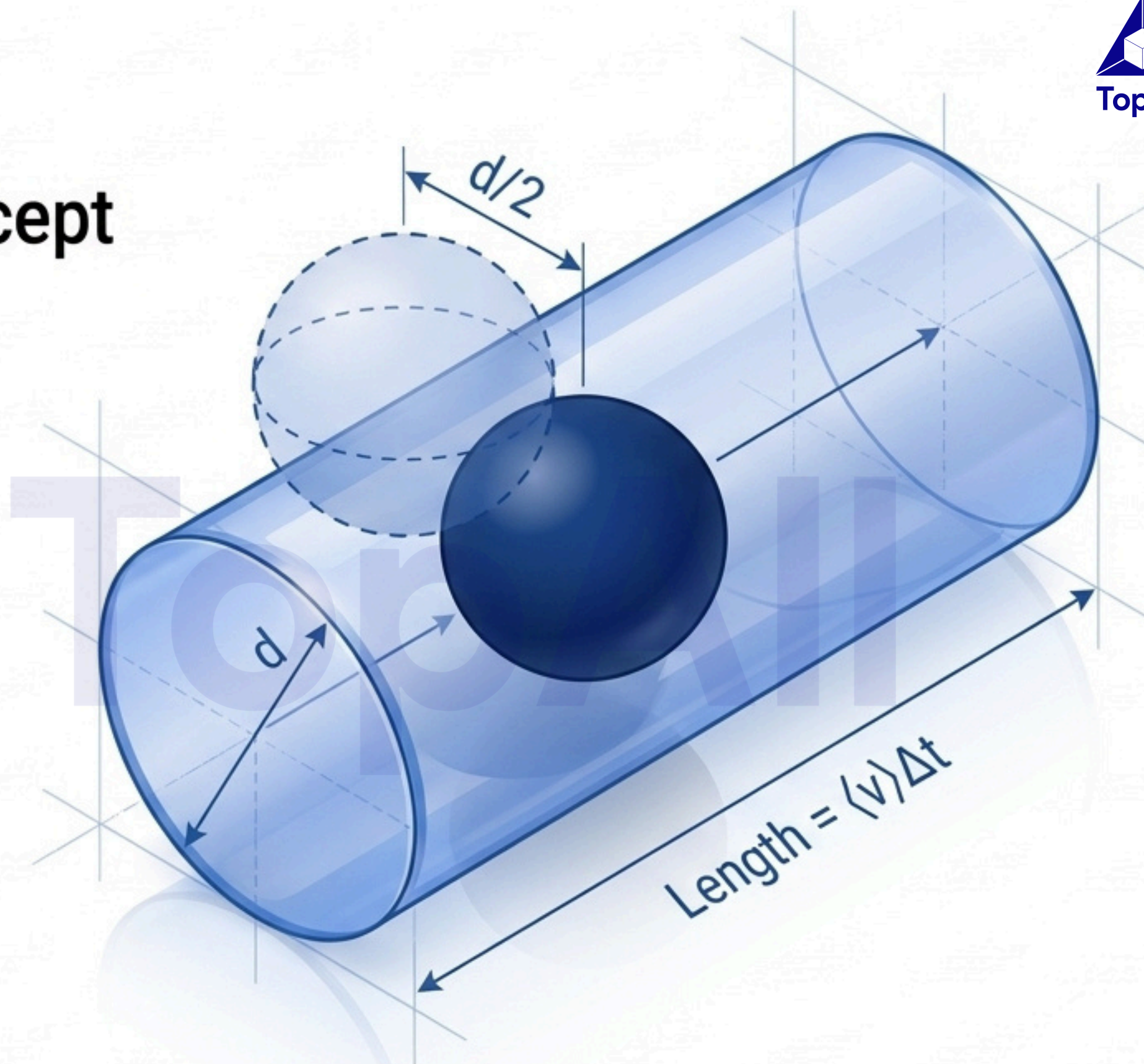
Real Finite Molecule



Mean Free Path (l) = The average distance a molecule travels between two successive collisions.

H2: The Swept Volume Concept

- Assume molecules are spheres of diameter d .
- A collision occurs if another molecule's center comes within distance d .
- In time Δt , the moving molecule sweeps a collision cylinder:
- Volume = Base Area $\times$ Length
 $= (\pi d^2) \times (\langle v \rangle \Delta t)$





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$$E=mc^2$$



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H2: How Often Do Collisions Happen?

Let n = number density
(molecules per unit volume).

Total collisions in $\Delta t = n \times (\text{Swept Volume})$

Total collisions = $n \pi d^2 \langle v \rangle \Delta t$

Collision Rate = $n \pi d^2 \langle v \rangle$

Eq. (12.38)

Relaxation Time (τ)

$$\tau = \frac{1}{n \pi \langle v \rangle d^2}$$

*Represents the average time
between two successive collisions.*

H2: From Time to Distance

Eq. (12.39)

Basic Mean Free Path

$$l = \langle v \rangle \tau = \frac{1}{n \pi d^2}$$

Eq. (12.40)

More Exact Mean Free Path

$$l = \frac{1}{\sqrt{2} n \pi d^2}$$

(Accounts for the relative velocity of all moving molecules)

Dependency Matrix

$$l \propto \frac{1}{n} \text{ (Number Density)}$$

$$l \propto \frac{1}{d^2} \text{ (Molecular Size)}$$

H2: Scale and Magnitude at STP



Speed

$$\langle v \rangle \approx 485 \text{ m/s}$$

Density

$$n \approx 2.7 \times 10^{25} \text{ m}^{-3}$$

Diameter

$$d \approx 2 \times 10^{-10} \text{ m}$$

Eq 12.41

$$\tau = 6.1 \times 10^{-10} \text{ s}$$

(Billions of collisions per second!)

$$l = 2.9 \times 10^{-7} \text{ m}$$



The Insight: Gases are mostly empty space!

Chapter 12.7 Summary

- **The Paradox:** High molecular speeds ($\sim$ sound) result in slow diffusion due to incessant collisions.
- **The Collision Volume:** Modeled as a swept cylinder of volume $\pi d^2 \langle v \rangle \Delta t$.
- **The Master Formula:** $l = \frac{1}{\sqrt{2}n\pi d^2}$ (Eq. 12.40).
- **Dependencies:** Mean free path depends inversely on number density (n) and the square of molecular diameter (d^2).



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