

Diatomic Gases & Specific Heat

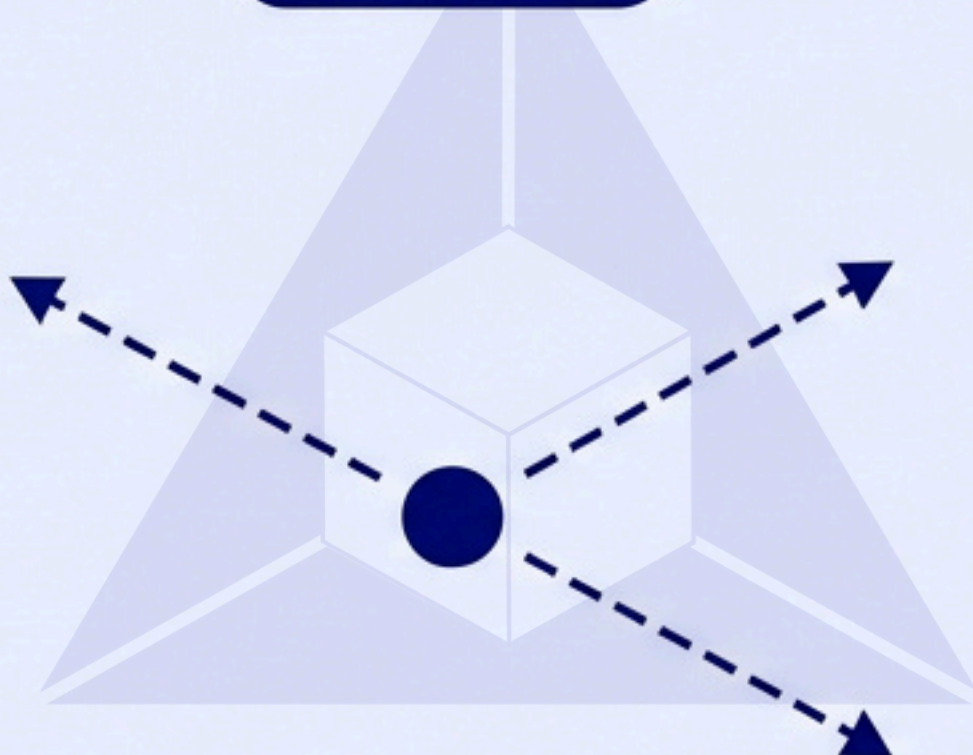
Understanding the Rigid Rotator Model and its Degrees of Freedom



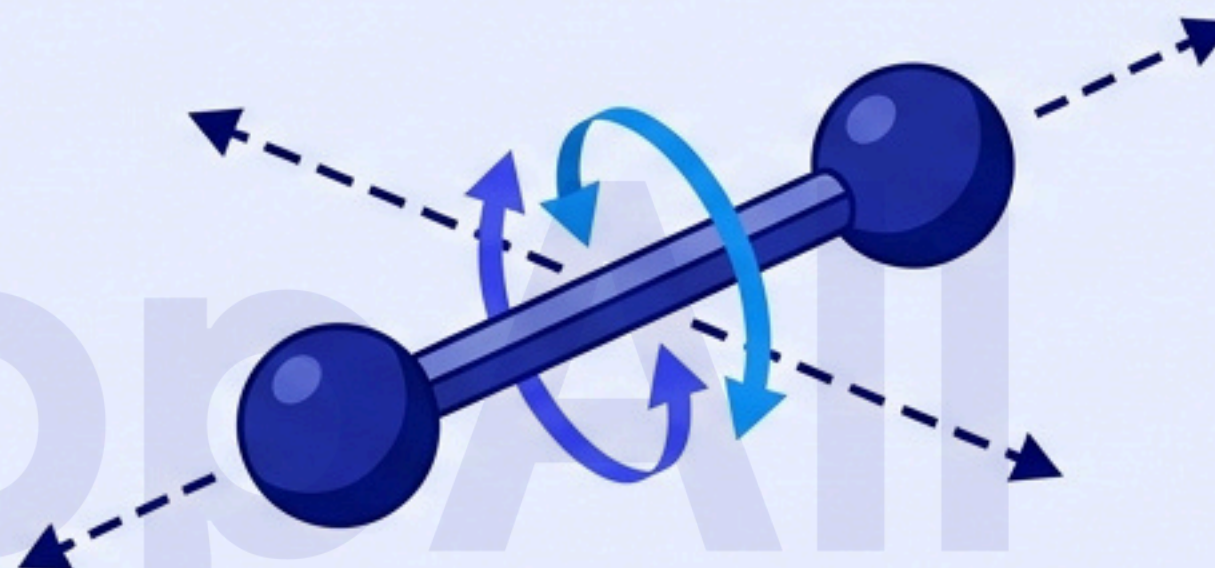
From Point Mass to Rigid Rotator

Unlike single atoms, a diatomic molecule (like O_2 or N_2) has a **physical structure**: two atoms connected by an interatomic axis.

Monatomic



Diatomic



- We model it as a dumbbell or rigid rotator.
- It can move through space just like a single atom.
- **Crucial Difference:** It can also rotate around its center of mass.

CONCEPT ALERT: At moderate temperatures, we ignore vibration (assume rigid bonds).

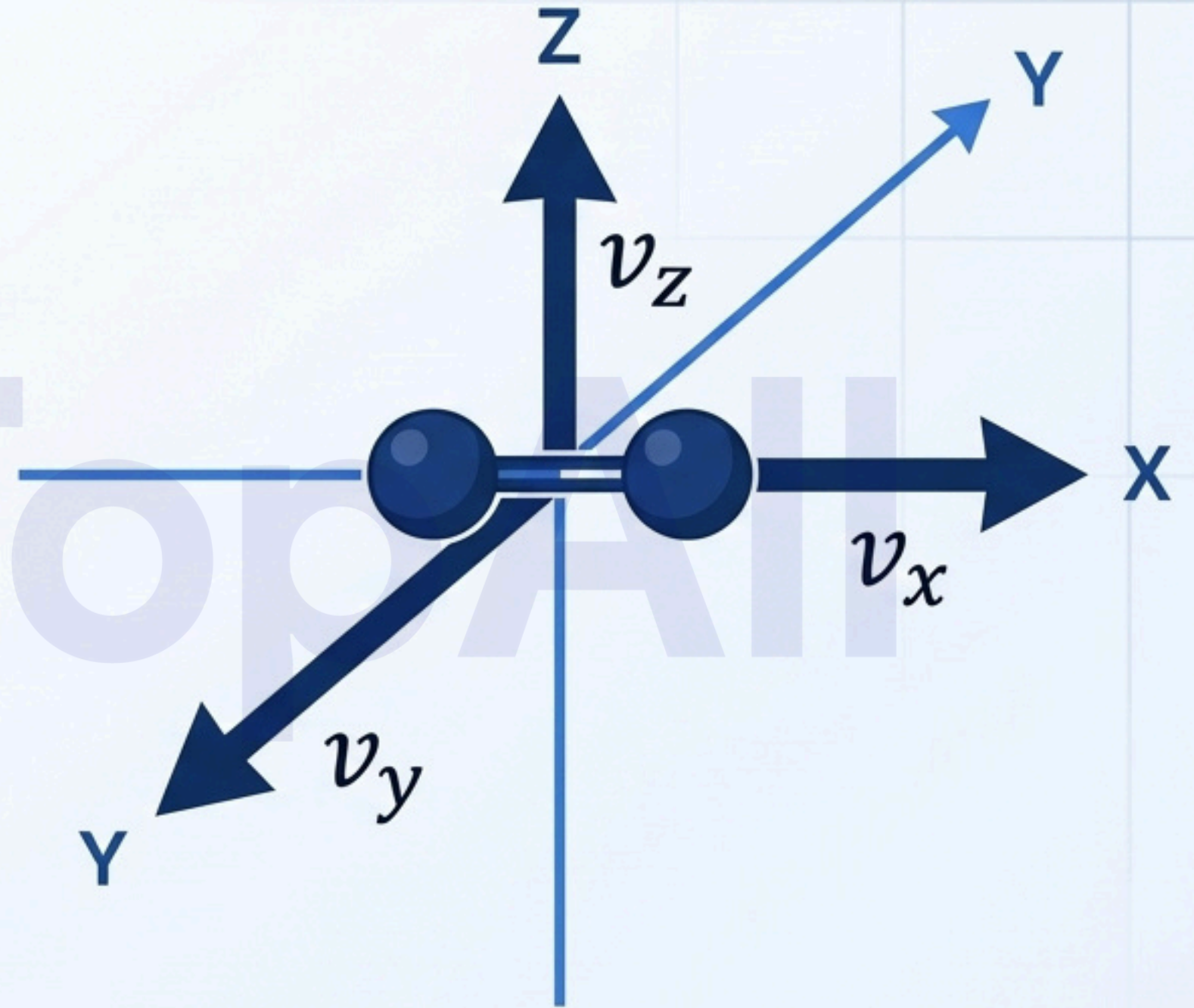
Moving Through Space in Plus Jakarta Sans

A diatomic molecule is free to move linearly in any direction in 3D space.

- Motion can be resolved into 3 independent axes: X, Y, and Z.
- This provides 3 Translational Degrees of Freedom.

$$E_{trans} = \frac{1}{2}mv_x^2 + \frac{1}{2}mv_y^2 + \frac{1}{2}mv_z^2$$

$$\text{Average Energy} = 3 \times \left(\frac{1}{2}k_B T\right) = \frac{3}{2}k_B T$$





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$$E=mc^2$$



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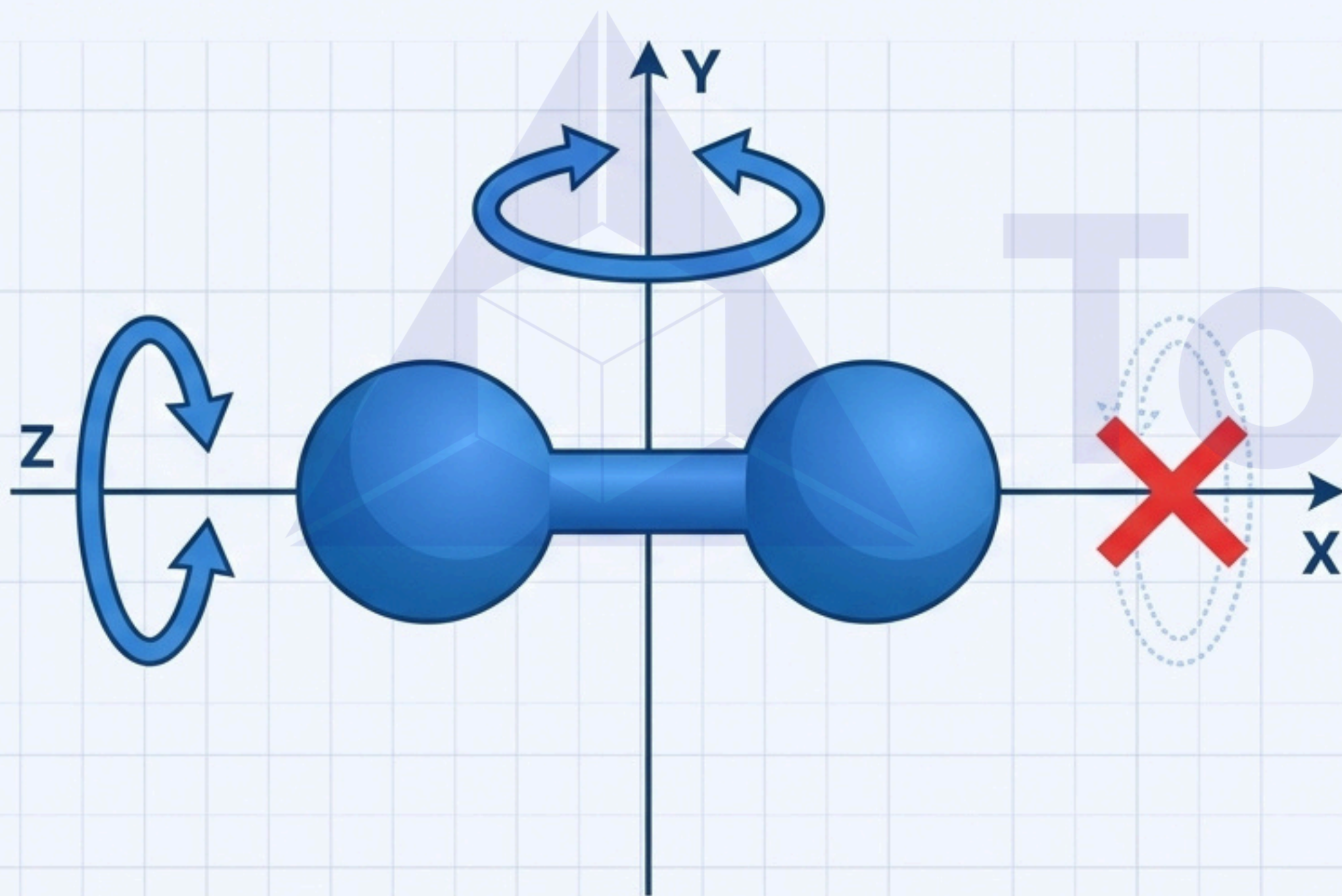
Key Highlights

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H1 Spinning on Two Axes

The molecule can rotate about axes mutually perpendicular to the line joining the atoms.



- Rotation about the Y and Z axes involves significant moment of inertia (I_1, I_2).
- Rotation along the interatomic axis (X-axis) has negligible moment of inertia and doesn't contribute.
- This provides exactly 2 Rotational Degrees of Freedom.

$$E_{rot} = \frac{1}{2} I_1 \omega_1^2 + \frac{1}{2} I_2 \omega_2^2$$

The Magic Number: 5

By the Law of Equipartition of Energy, each degree of freedom contributes $\frac{1}{2} k_B T$ per molecule.

Rigid Diatomic Molecule



+



=

**5 Active Degrees
of Freedom ($f = 5$)**

Total Internal Energy per mole (U) = $\frac{5}{2} R T$

⚠ EXAM TIP: Non-rigid molecules at high temps add vibrational modes ($f=7$), but assume rigid ($f=5$) unless stated otherwise!

Why Diatomic Gases Hold More Heat

Because diatomic molecules can store energy in rotation, it takes more heat to raise their temperature compared to monatomic gases.

Parameter	Monatomic (f=3)	Diatomic (f=5)
C_v (Constant Vol)	$\frac{3}{2} R$ (12.5 J/mol·K)	$\frac{5}{2} R$ (20.8 J/mol·K)
C_p ($C_v + R$)	$\frac{5}{2} R$ (20.8 J/mol·K)	$\frac{7}{2} R$ (29.1 J/mol·K)
Ratio γ (C_p / C_v)	$\frac{5}{3}$ (≈ 1.67)	$\frac{7}{5}$ (1.40)

Section Summary



Key Takeaways

- **The Model:** Diatomic gases are treated as rigid rotators (dumbbells).
- **The Breakdown:** They possess 5 degrees of freedom (3 translational, 2 rotational).
- **The Energy:** Total internal energy per mole is $U = 5/2 RT$.
- **The Heat Capacity:** They have higher specific heats than monatomic gases: $C_v = 5/2 R$, $C_p = 7/2 R$, $\gamma = 7/5$.

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