

JEE Class 11 Chemistry • Quantum Mechanics

The Heisenberg Uncertainty Principle

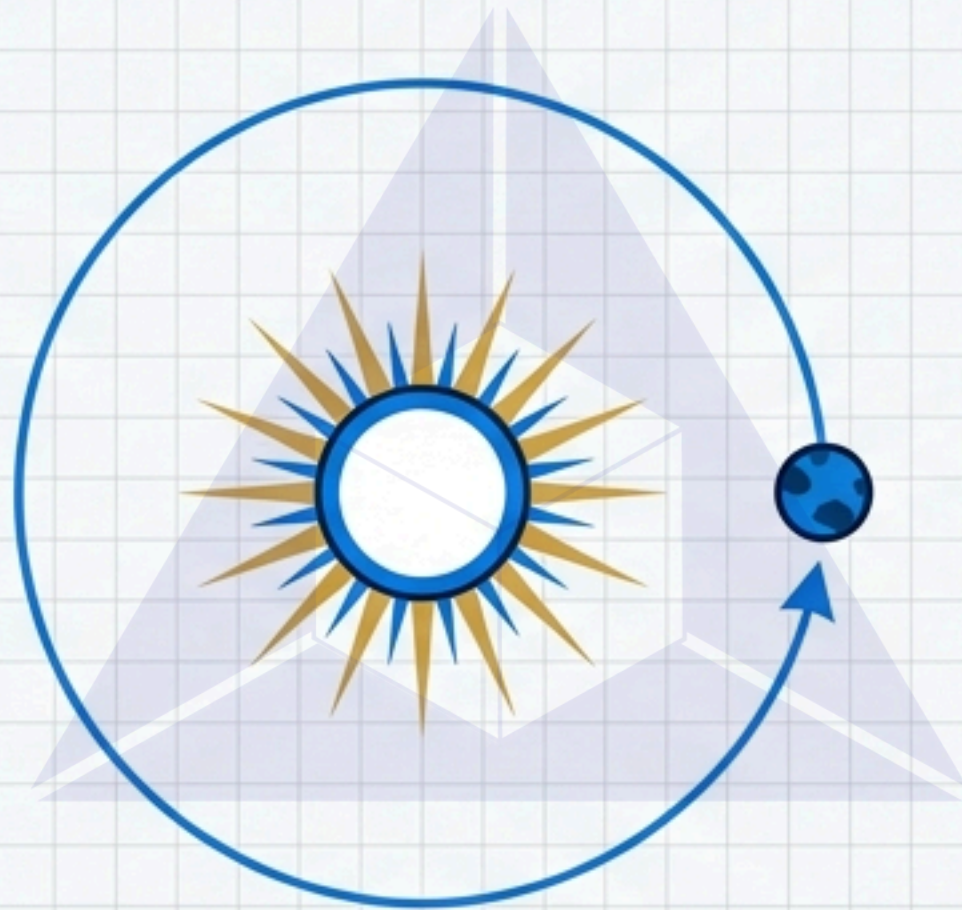
The Death of the Classical Orbit and the Limits of
Microscopic Measurement.

$$\Delta x \cdot \Delta p \geq h/4\pi$$

The Core Idea: Mutually Exclusive Precision

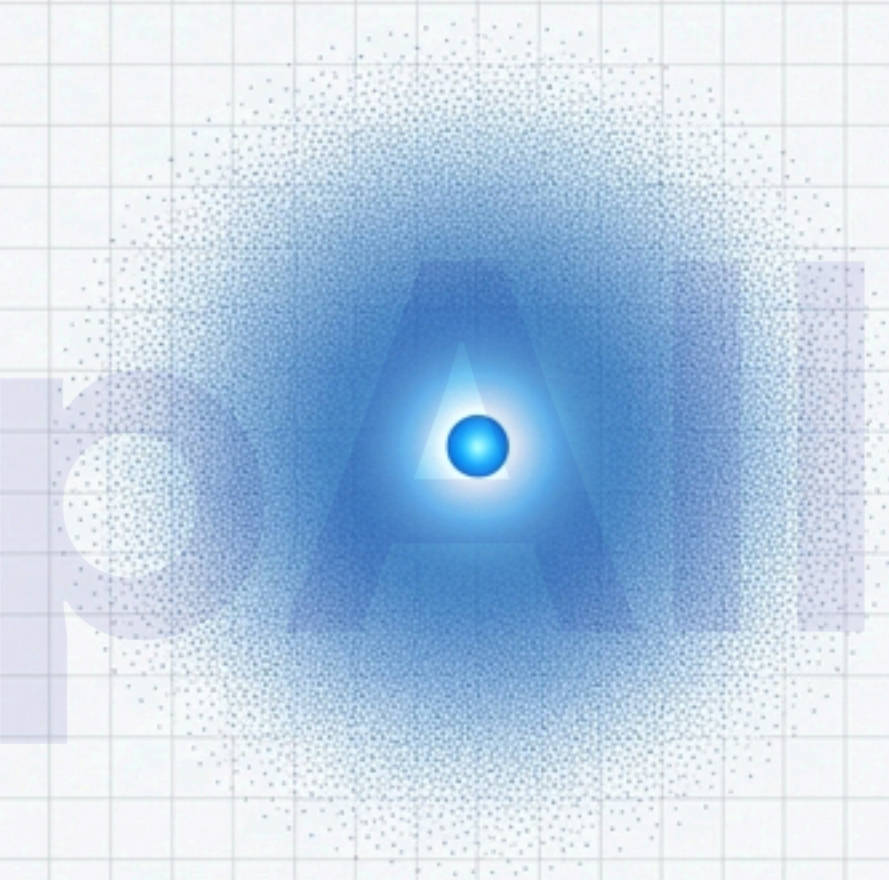


Classical Mechanics



Macroscopic World: We can precisely know a moving object's exact location and its exact momentum simultaneously.

Quantum Mechanics



Microscopic World: It is impossible to determine simultaneously, the exact position and exact momentum (or velocity) of an electron.

The Mathematical Formulation

Uncertainty in position (m)

Uncertainty in momentum (kg·m/s)

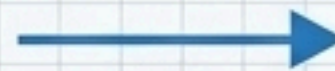
$$\Delta x \cdot \Delta p_x \geq \frac{h}{4\pi}$$

Planck's constant ($6.626 \times 10^{-34} \text{ J}\cdot\text{s}$)

Velocity Form Derivation

Step 1: Since $\mathbf{p} = \mathbf{m} \cdot \mathbf{v}$, substitute to get

$$\Delta x \cdot \Delta(mv_x) \geq h/4\pi$$



Step 2 (Final Velocity Form):

$$\Delta x \cdot \Delta v_x \geq \frac{h}{4\pi m}$$

Mass in the denominator foreshadows why scale matters.



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Let's Test Them Now.**

$$E=mc^2$$



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Key Highlights

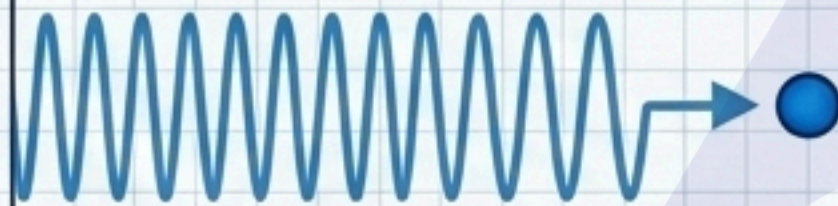
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The Physicality of Measurement

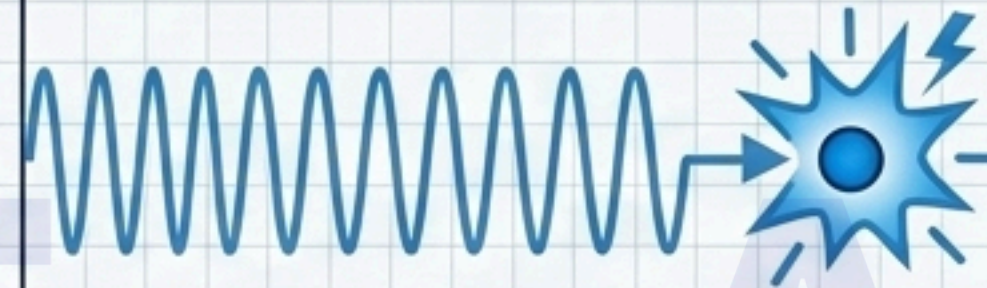
To determine the position of an electron, we must illuminate it with light of a wavelength smaller than the electron.

1. Illumination



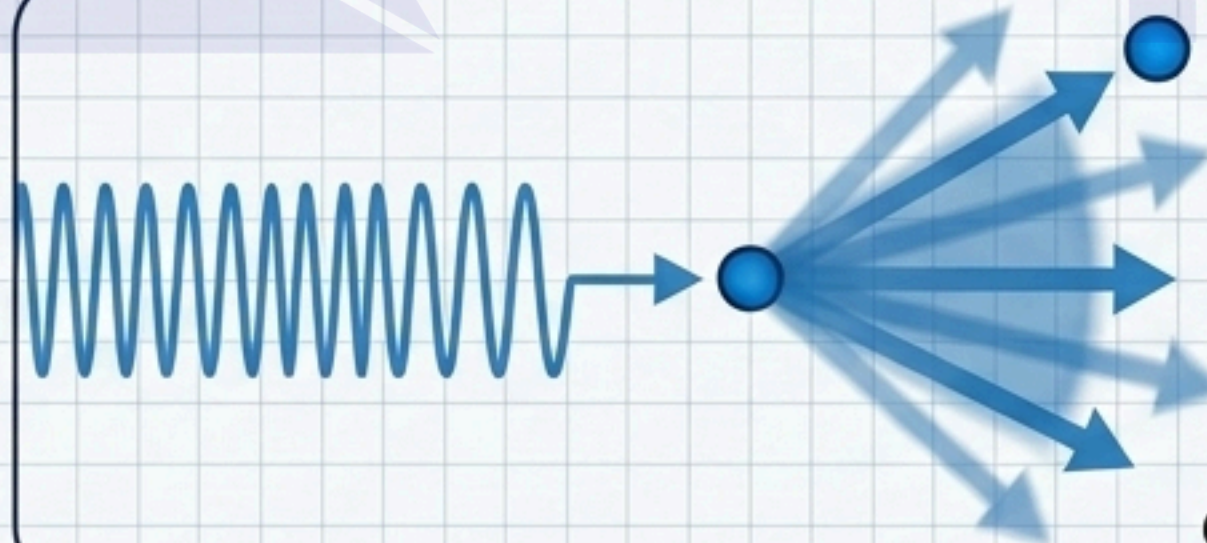
Short wavelength (λ) = High momentum ($p = h/\lambda$).

2. Collision



Photon transfers significant energy to the electron during collision.

3. Uncertainty



Position is found, but velocity is drastically and unpredictably changed.

The Misconception Trap



Uncertainty exists because our microscopes aren't powerful enough. Better technology will eventually allow us to measure both.

The Truth

It is a fundamental property of nature. The uncertainty is intrinsic to the wave-particle duality of matter. Even with a hypothetically perfect instrument, the act of measurement itself fundamentally alters the system serving a quantum system without participating in it.

Scale Dependency: Why we don't see it daily

The product of uncertainties ($\Delta x \cdot \Delta v$) is inversely proportional to mass

Macroscopic: 40g Golf Ball

Speed: 45 m/s (measured to 2% accuracy).

$$\Delta x = \frac{h}{4\pi \cdot m \cdot \Delta v} \rightarrow \Delta x \approx 1.46 \times 10^{-33} \text{ m}$$

Uncertainty is $\sim 10^{18}$ times smaller
than an atomic nucleus.
Completely insignificant.

Microscopic: $9.11 \times 10^{-31} \text{ kg}$ Electron

Constraint: Position known to 10^{-8} m

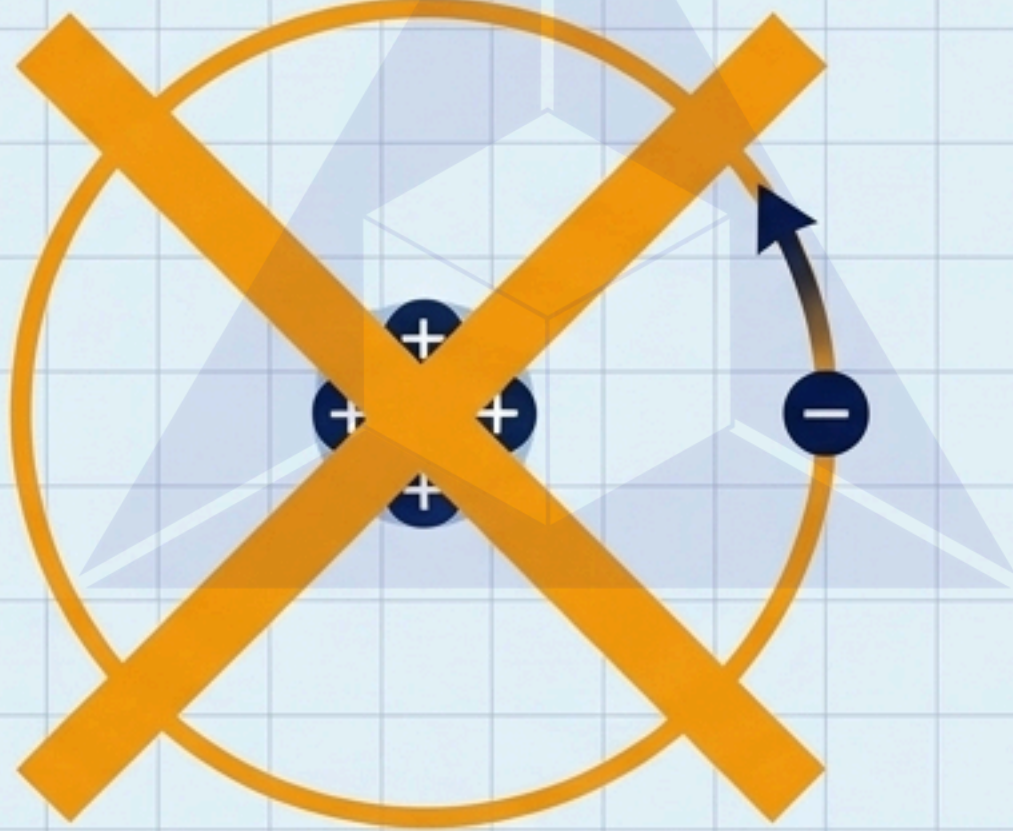
$$\Delta v = \frac{h}{4\pi \cdot m \cdot \Delta x} \rightarrow \Delta v \approx 5.79 \times 10^6 \text{ m/s}$$

The velocity is entirely uncertain.
Highly significant.

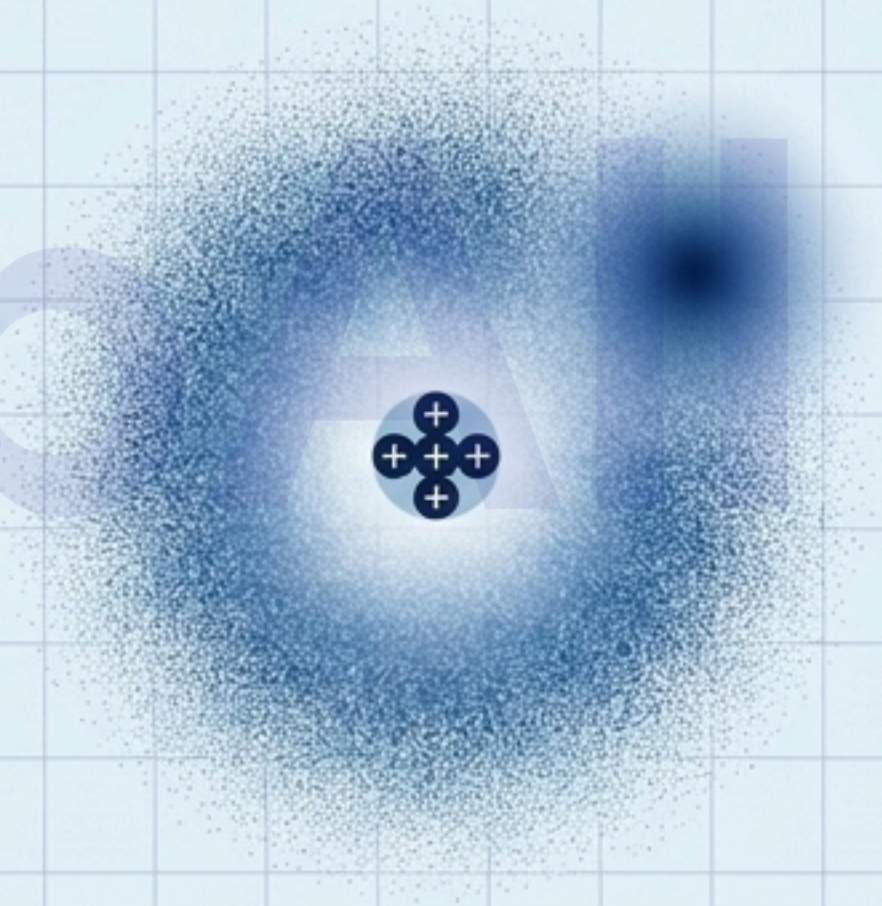
Significance: The Fall of the Bohr Model



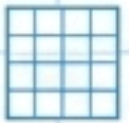
Logical Premise: A “trajectory” requires knowing the exact position AND exact velocity at any given instant.



Ruled Out: Fixed circular paths contradict Heisenberg's Principle.



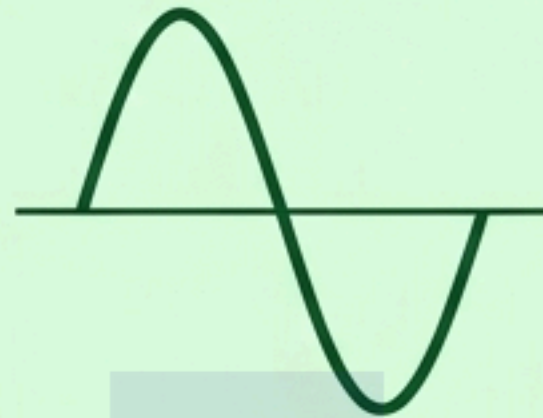
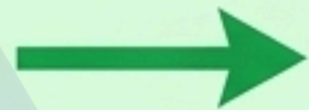
Reality: The precise position and momentum cannot be stated simultaneously. Definite paths do not exist.



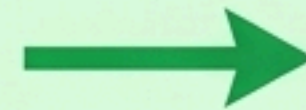
Key Takeaways: The Birth of Probability



Particle



Duality



Probability Density

- ✓ Precise statements of position and momentum must be replaced by statements of probability.
- ✓ We can only predict the likelihood of finding an electron in a specific region of space around the nucleus.

Heisenberg's Principle mathematically necessitates the transition from classical orbits to quantum orbitals.



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