

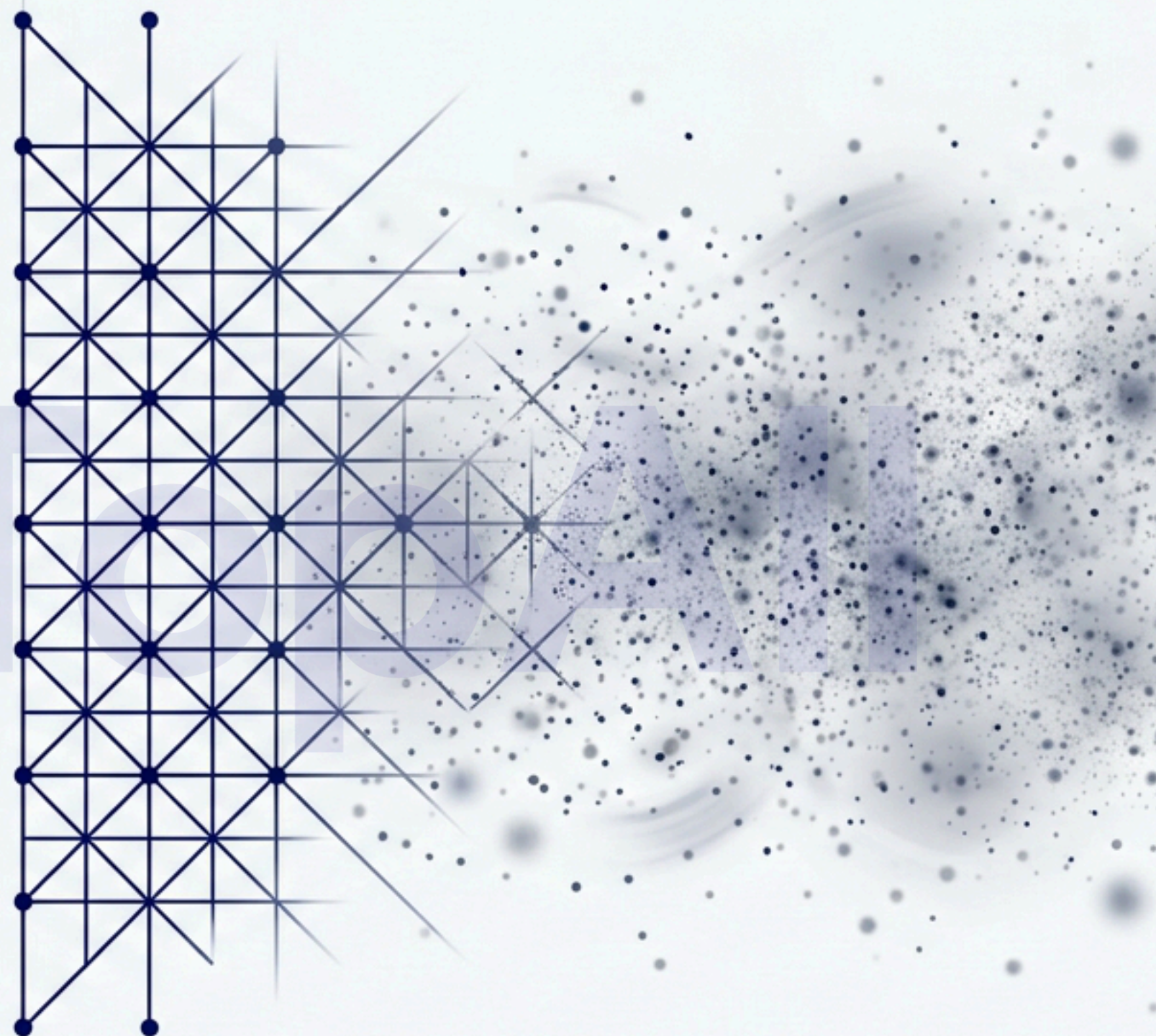
CLASS 11 CHEMISTRY • UNIT 2: STRUCTURE OF ATOM

2.5.2 Heisenberg's Uncertainty Principle

The fundamental limit of precision in the quantum world.

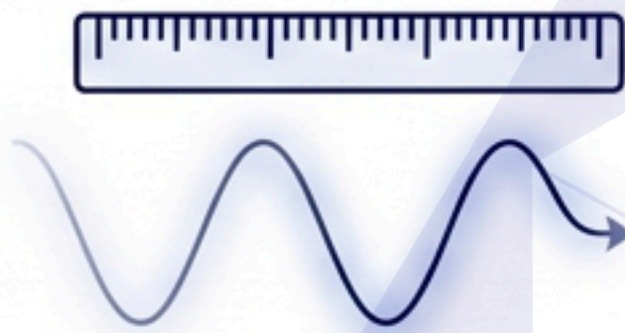


It is impossible to determine simultaneously, the exact position and exact momentum of an electron.



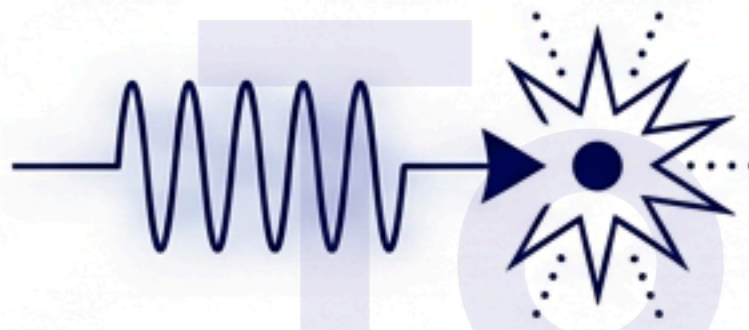
The Act of Observation Alters the Target

1. The Requirement



To "see" an electron, we must illuminate it with electromagnetic radiation. The photon's wavelength must be smaller than the electron.

2. The Collision



Short-wavelength light carries high energy and momentum. The photon collides with the electron to reveal its precise location.

3. The Uncertainty



The collision transfers momentum. By precisely finding the electron's position, we drastically and unpredictably alter its velocity.

The outcome of physical measurements on microscopic particles will always depict a fuzzy or blurred picture.

The Uncertainty Relation

Δx = Uncertainty in position

Δp = Uncertainty in momentum
(Δv = velocity)

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

m = Mass of the particle

$$\Delta x \cdot (m\Delta v) \geq \frac{h}{4\pi}$$

h = Planck's constant
(6.626×10^{-34} J s)

The Inverse Rule

If position is known with high accuracy (Δx is small), then velocity becomes highly uncertain (Δv is large). They cannot both be zero.



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$$E=mc^2$$



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Insignificant Impact on Everyday Objects

Macro



The 1-Milligram Object

Mass (m): 10^{-6} kg

Calculation: $\Delta v \cdot \Delta x = h / (4\pi m)$

Navy Badge $\Delta v \cdot \Delta x \approx 10^{-28} \text{ m}^2 \text{ s}^{-1}$

The Classical Conclusion

The value of $\Delta v \cdot \Delta x$ is extremely small. For heavier objects (milligrams, golf balls, planets), the uncertainty is virtually zero. Classical mechanics and Newtonian trajectories hold perfectly true.

Micro



The 1-Milligram Object

Mass (m): 10^{-6} kg

Calculation: $\Delta v \cdot \Delta x = h / (4\pi m)$

Navy Badge $\Delta v \cdot \Delta x \approx 10^{-28} \text{ m}^2 \text{ s}^{-1}$

The Classical Conclusion

The value of $\Delta v \cdot \Delta x$ is extremely small. For heavier objects (milligrams, golf balls, planets), the uncertainty is virtually zero. Classical mechanics and Newtonian trajectories hold perfectly true.

The Dominating Effect in the Sub-Atomic World

Macro

Micro

Rock Car Card

Mass (m): 9.1×10^{-16} kg
Calculation: $\Delta v \cdot \Delta x = h / (4\pi m)$
...the uncertainty in velocity Δv
skyrockets to $\sim 5.79 \times 10^6$ m/s!

The Electron

Mass (m): 9.11×10^{-31} kg
Calculation: $\Delta v \cdot \Delta x = h / (4\pi m)$

$$\Delta v \cdot \Delta x \approx 10^{-4} \text{ m}^2 \text{ s}^{-1}$$

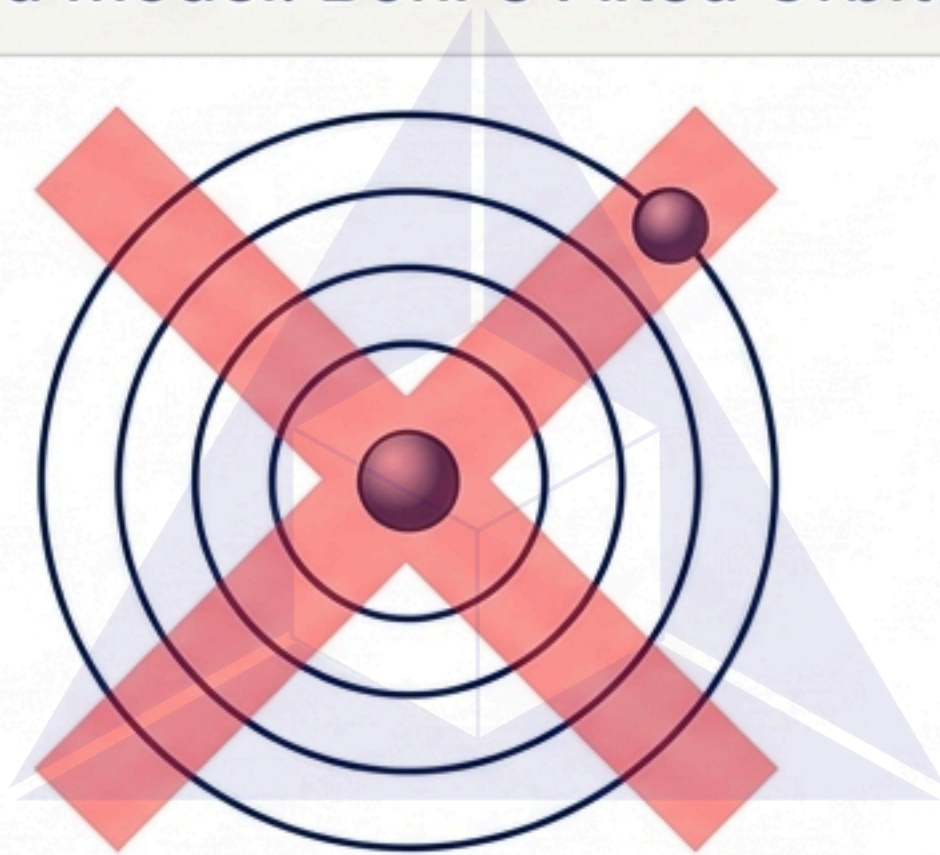
➔ If we locate an electron to an accuracy of $\Delta x = 10^{-8}$ m...
...the uncertainty in velocity Δv skyrockets to $\sim 5.79 \times 10^6$ m/s!

The Quantum Conclusion

Because the electron's mass is so tiny, the uncertainty product is mathematically massive. We cannot predict where the electron is going or how fast.

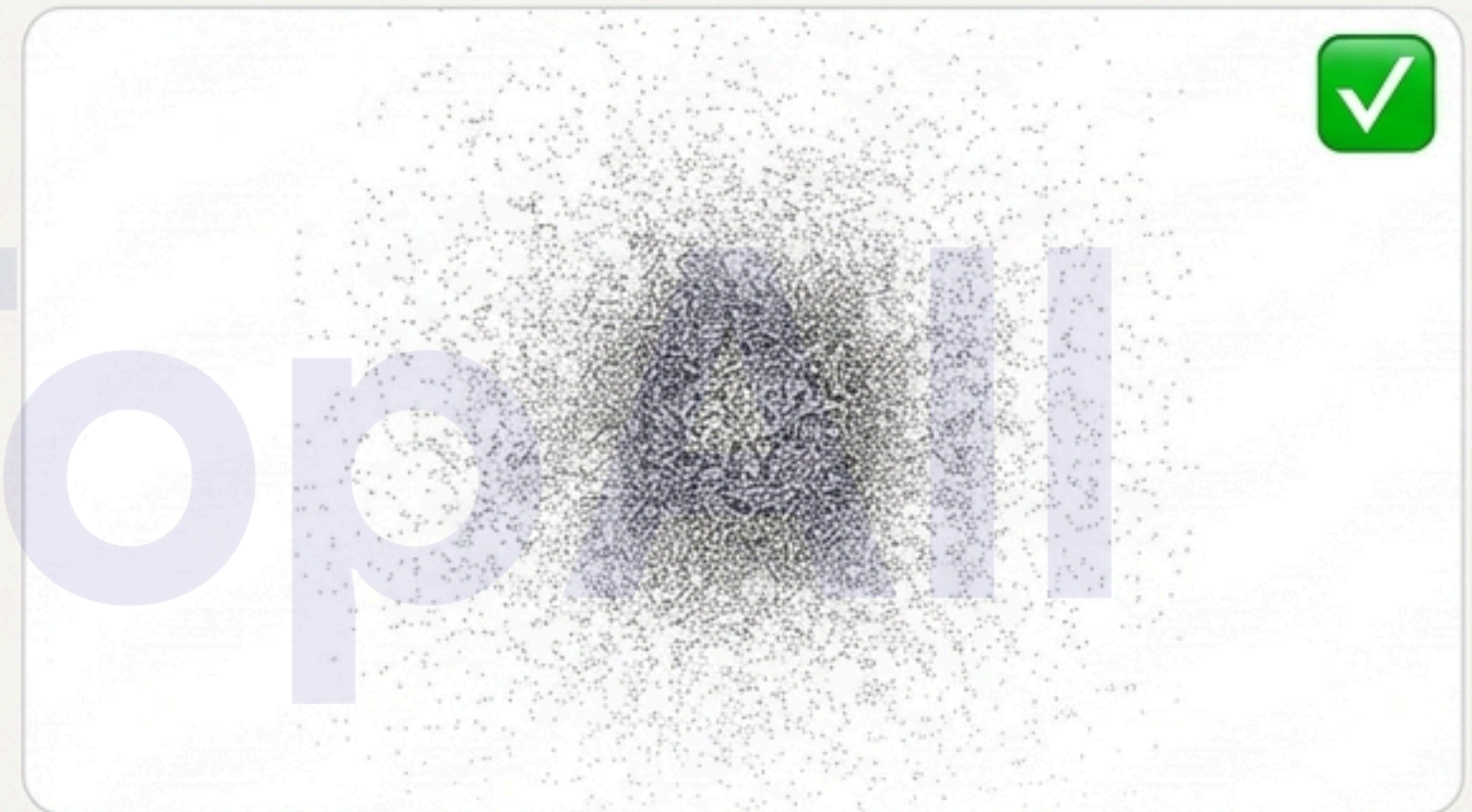
From Fixed Orbits to Probability Clouds

Failed Model: Bohr's Fixed Orbits



- Requires knowing exact position and velocity simultaneously.
- Directly contradicts Heisenberg's Uncertainty Principle.

New Reality: Quantum Mechanics



- Exact trajectories are mathematically impossible to define.
- Replaces exact paths with probability densities ($|\psi|^2$), defining regions where finding an electron is most likely.

Precise statements of position and momentum are replaced by statements of probability. This is the foundation of the Quantum Mechanical Model.



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