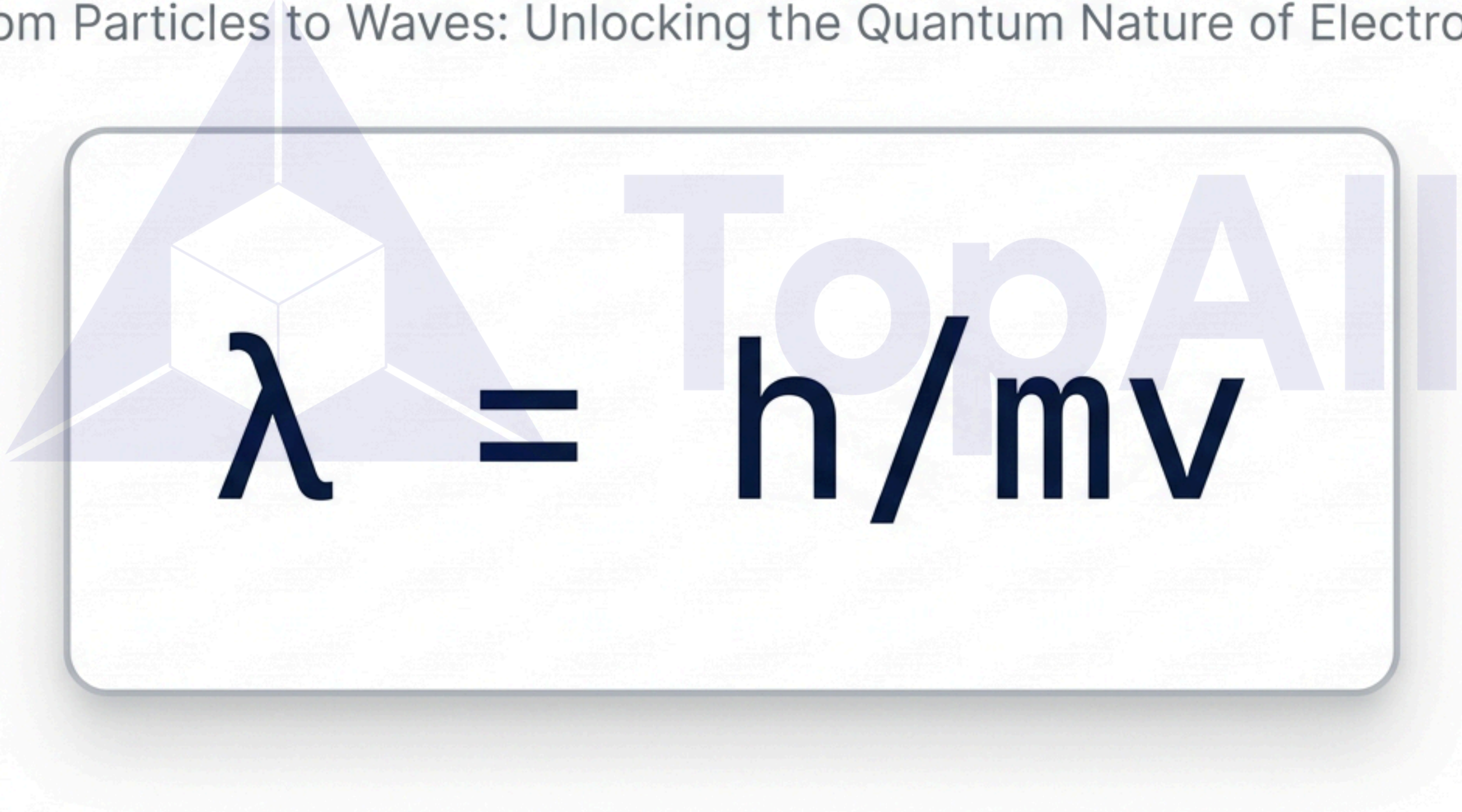


2.5.1 Dual Behaviour of Matter

From Particles to Waves: Unlocking the Quantum Nature of Electrons

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$$\lambda = h / mv$$

Why de Broglie Extended Duality to Matter

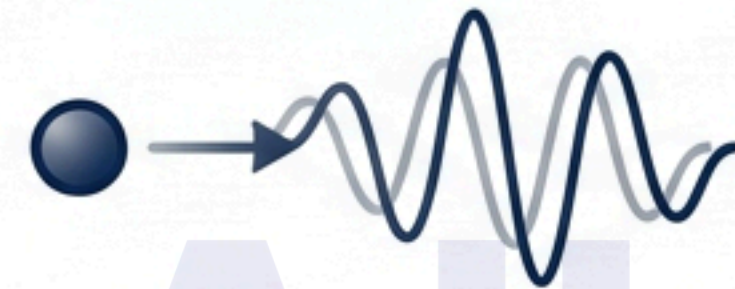


Electromagnetic Radiation

By 1905, Einstein and Planck proved that light (traditionally a wave) exhibits **particle-like properties** (photons) during phenomena like the photoelectric effect.

Dual Nature Accepted

de Broglie's Symmetry (1924)



Sub-atomic Particles

de Broglie proposed that matter (traditionally particles) must also exhibit **wave-like properties**. Just as a photon has momentum and wavelength, an electron must too.

Dual Nature Proposed

Core Concept: Electrons possess both mass-driven momentum and wave-driven frequency.

The Matter Wave Relation

$$\lambda = h / mv$$

λ (Lambda)

Wavelength of the matter wave.

m (meters)

h (Planck's Constant)

The fundamental quantum of action.

$6.626 \times 10^{-34} \text{ J s}$

mv (Mass $\times$ Velocity)

The momentum (p) of the particle.

kg m s⁻¹

Because mass times velocity equals momentum (p), the de Broglie relation is fundamentally written as: **$\lambda = h / p$**



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Why Macroscopic Objects Hide Their Waves

Wavelength is inversely proportional to mass. Heavy objects have wavelengths too small to detect.

Macroscopic Object (A Ball)

Mass is too large.



Mass (m): 0.1 kg
Velocity (v): 10 m/s
Wavelength (λ): $\sim 10^{-34}$ m

Result: Wavelength is unfathomably small. Wave properties are utterly impossible to detect.

Undetectable

Microscopic Object (An Electron)

Mass is infinitesimally small.



Mass (m): 9.1×10^{-31} kg
Velocity (v): 812 m/s
Wavelength (λ): 896.7 nm

Result: Wavelength is in the nanometer range. Wave properties are easily measured.

Detectable

Electron Diffraction as Confirmation

The Phenomenon of Diffraction

Diffraction is a characteristic property exclusive to waves—the bending and spreading of waves around obstacles.

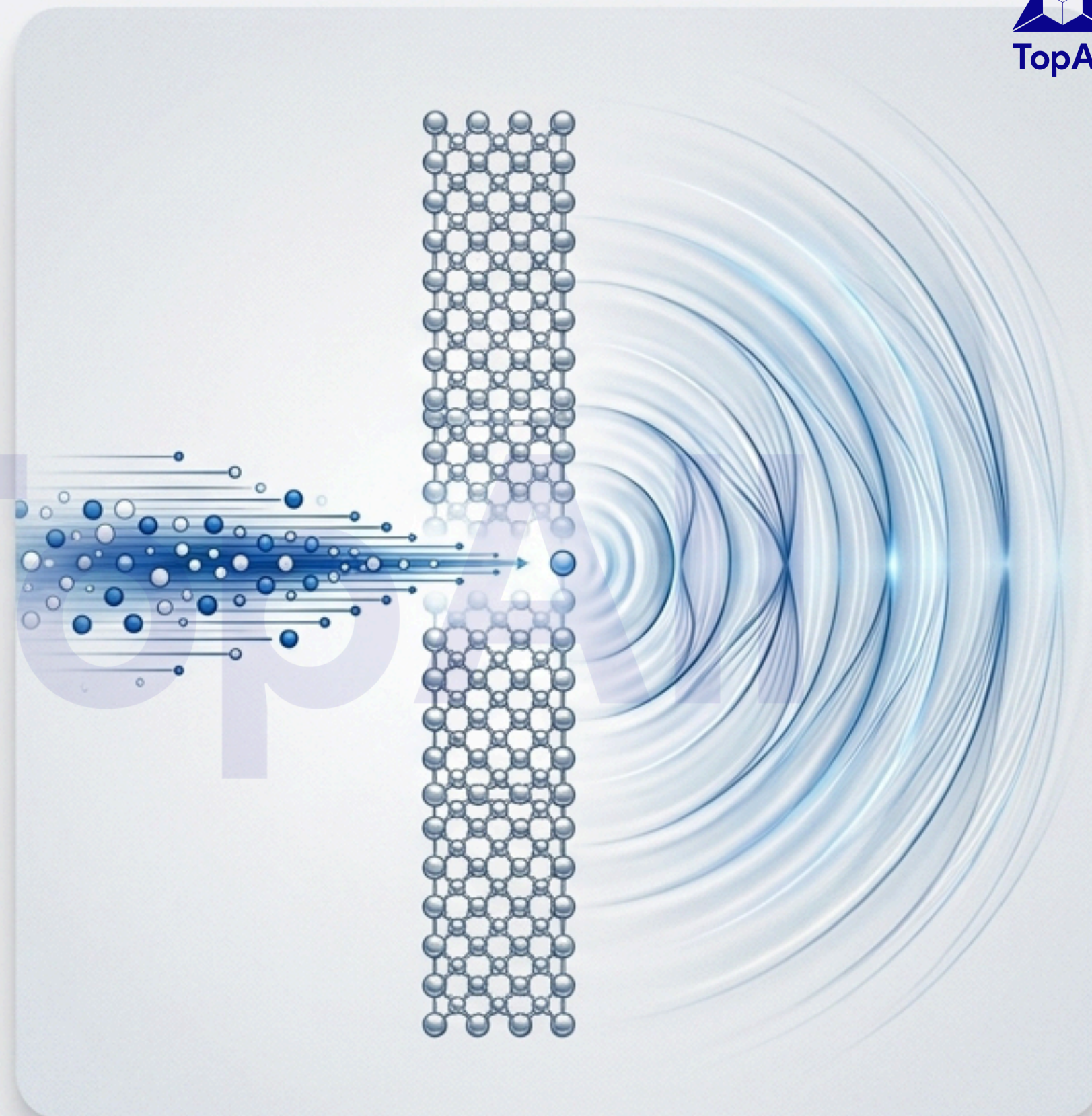
The Discovery

Shortly after de Broglie's prediction, experiments confirmed that an electron beam undergoes diffraction when passed through a crystal lattice—proving beyond doubt that electrons act as waves.

Real-World Application

The Electron Microscope

Harnessing this wave-like behaviour, electron microscopes use the extremely short wavelength of electrons to achieve magnification of up to 15 million times, far surpassing ordinary optical microscopes.



Final Recap: The Dual Nature of Matter



1. The Dual Nature is Universal

Every object in motion has a wave character. Moving particles do not just *have* wave properties; they *are* waves.



2. The Mathematical Bridge

The de Broglie relation $\lambda = h/mv$ mathematically links the wave property (wavelength) to the particle property (momentum).



3. The Boundary of Observation

Due to the inverse relationship with mass, wave behaviour is only observable in sub-atomic particles, laying the foundation for quantum mechanics.



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