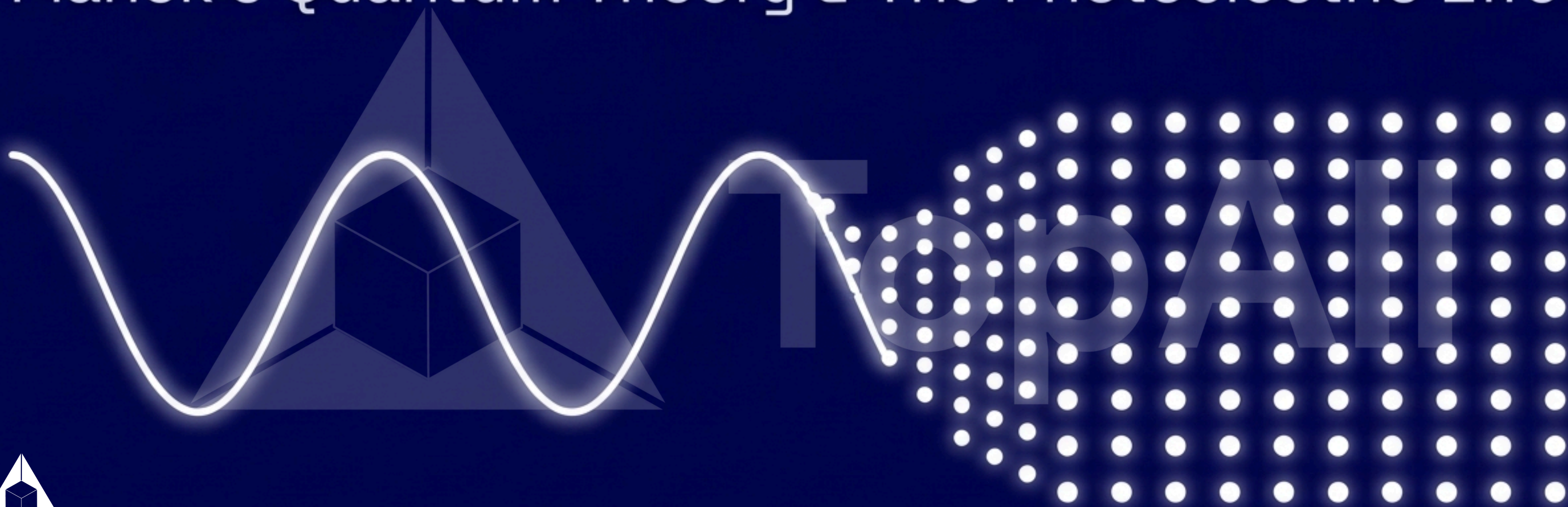


# Particle Nature of Radiation

Planck's Quantum Theory & The Photoelectric Effect

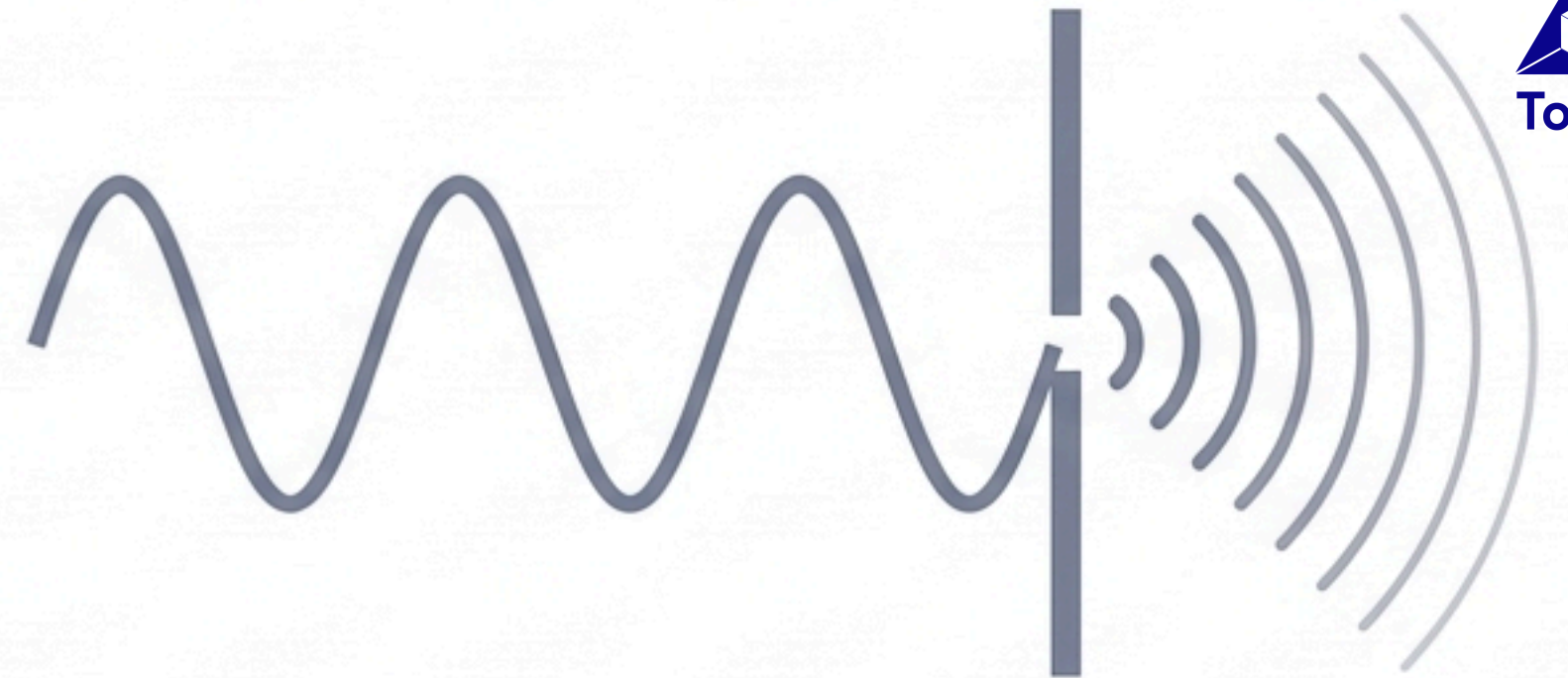


# The Limits of Wave Theory

By the late 19<sup>th</sup> century, classical physics perfectly explained wave phenomena like diffraction and interference.



However, it catastrophically failed to explain three major observations:



Card 1

## **Black-Body Radiation**

The specific emission of radiation from hot bodies.

Card 2

## **Photoelectric Effect**

The ejection of electrons when light strikes certain metals.

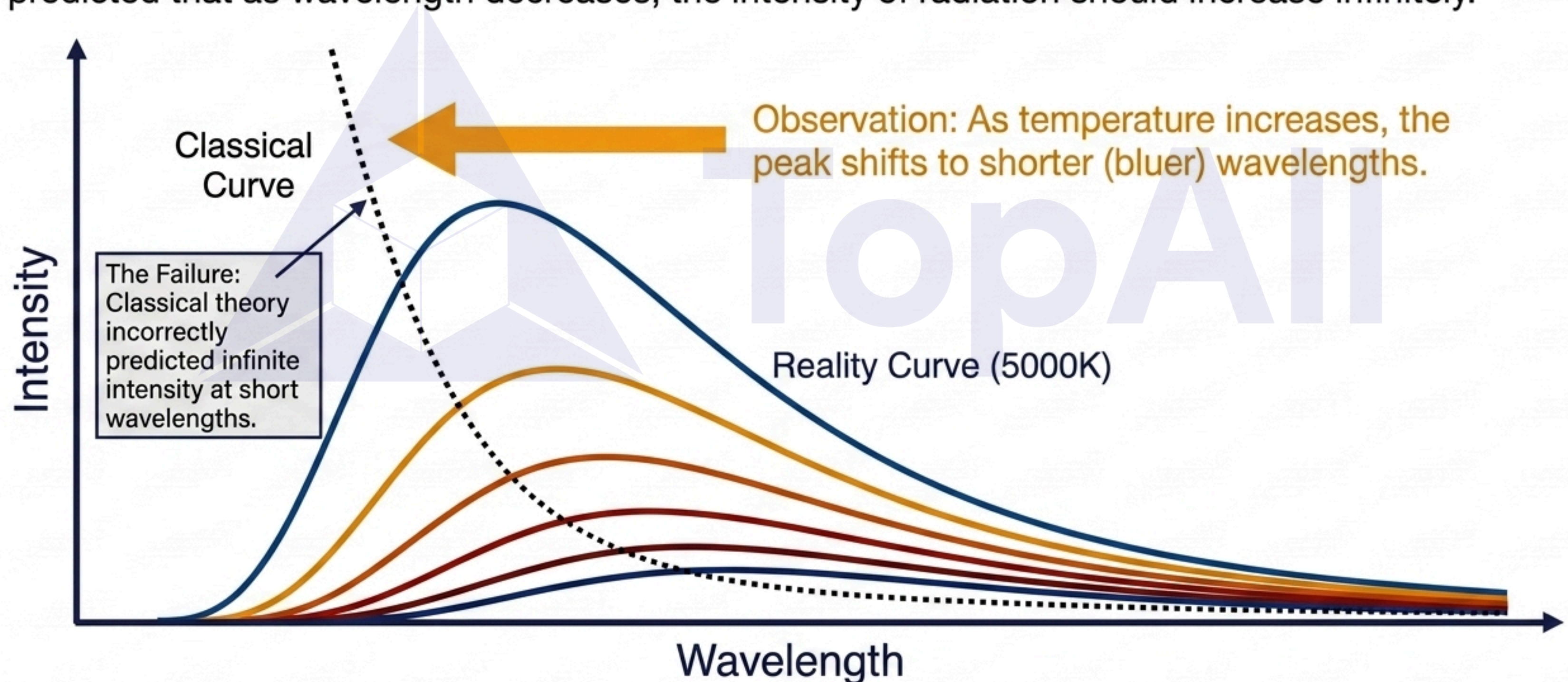
Card 3

## **Atomic Spectra**

The distinct line spectra emitted by atoms like Hydrogen.

# The Black Body Anomaly

An ideal black body absorbs and emits all frequencies perfectly. Classical wave theory predicted that as wavelength decreases, the intensity of radiation should increase infinitely.





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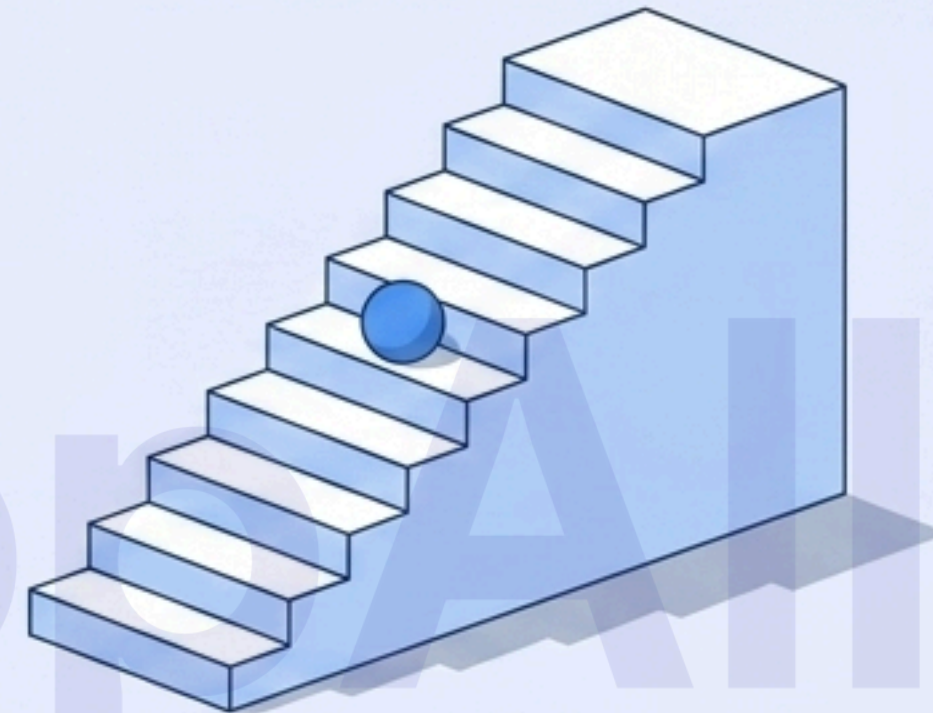


# Planck's Quantum Hypothesis (1900)

Max Planck proposed a radical idea to fix the anomaly: atoms and molecules emit or absorb energy in discrete chunks, not in a continuous stream.



**The Ramp (Classical):**  
You can stand at any exact height.



**The Staircase (Quantum):**  
You can only stand on specific steps.  
Nothing exists between them.

## The Quantum

The absolute smallest, discrete quantity of energy that can be emitted or absorbed as electromagnetic radiation.

$$E = h\nu$$

$E$  = Energy of a single quantum ( $6.626 \times 10^{-34}$  J s)

$h$  = Planck's constant

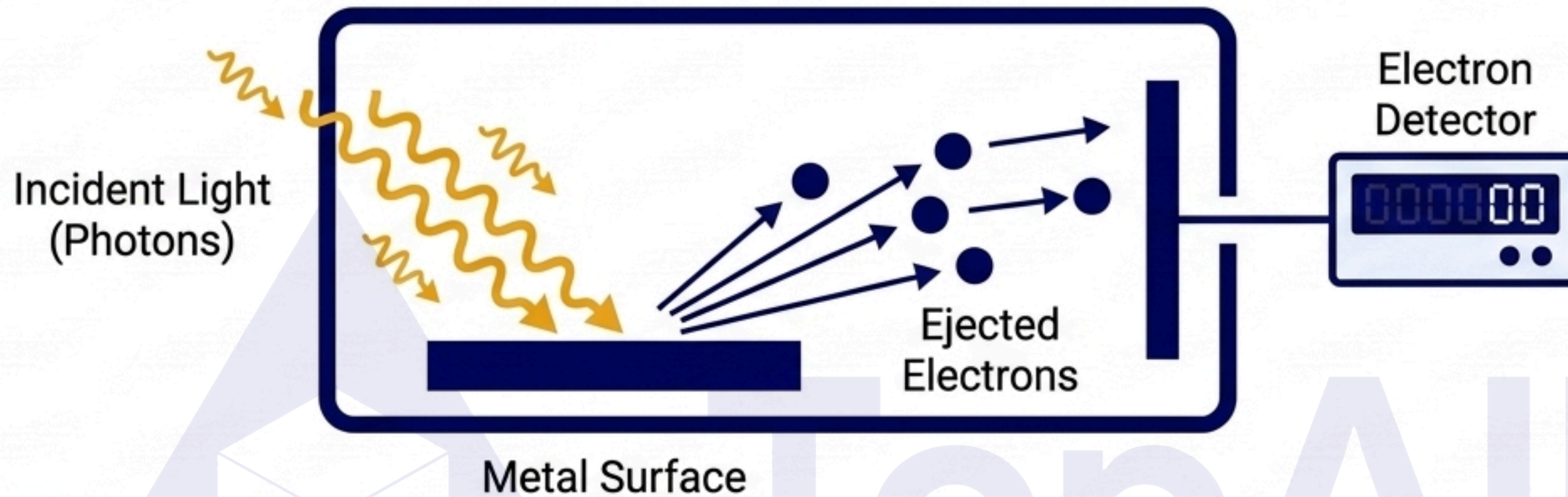
$\nu$  = Frequency of radiation

Energy is only exchanged in integral multiples of  $h\nu$ .

✓ Allowed:  $0, h\nu, 2h\nu, 3h\nu \dots nh\nu$

✗ Forbidden:  $1.5h\nu, 2.7h\nu$

# The Photoelectric Effect (Hertz, 1887)



## 1. Instantaneous

Zero time lag between the light striking the metal and the electron ejecting.

## 2. Threshold Frequency ( $\nu_0$ )

The absolute minimum frequency required. Below this, zero electrons are ejected, no matter how bright the light.

## 3. Proportional Kinetic Energy

If  $\nu > \nu_0$ , the kinetic energy of the ejected electron increases proportionally with the light's frequency.

# Einstein's Photoelectric Equation (1905)

Einstein applied Planck's theory, proving light acts as a stream of particles called photons.

$$\text{K.E.} = h(\nu - \nu_0)$$

**Input**

$$h\nu$$

(Total energy of the incoming striking photon)

**Toll**

$$h\nu_0 \text{ or } W_0$$

(Work Function: The minimum energy consumed just to free the electron from the metal)

**Output**

$$\text{K.E. or } \frac{1}{2}m_e v^2$$

(The leftover remainder energy transferred into the electron's velocity)

# The Ultimate JEE Trap: Intensity vs. Frequency

Classical physics assumes brighter light = more energy = faster electrons. This is completely false in the quantum world.

## The Trap Card



Assuming that increasing the intensity (brightness) of light increases the Kinetic Energy of the ejected electrons.

## The Reality Card



- ✓ **Intensity** controls the **NUMBER** of electrons ejected (brighter light = more photons = more collisions).
- ✓ **Frequency** controls the **KINETIC ENERGY** of the electrons (higher frequency = more energy per photon = faster electrons).

# Summary: The Dual Nature of Radiation



The classical crisis is resolved: light exhibits dual behavior depending on how it interacts with matter.

## Wave Nature (Continuous)

Explains how light propagates through space (Interference and Diffraction).

## Particle Nature (Discrete)

Explains how light interacts with matter (Black Body Radiation and Photoelectric Effect via Photons).

## The Bridge

The equation  $E = h\nu$  mathematically connects a purely particle property (Energy,  $E$ ) with a purely wave property (Frequency,  $\nu$ ).



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