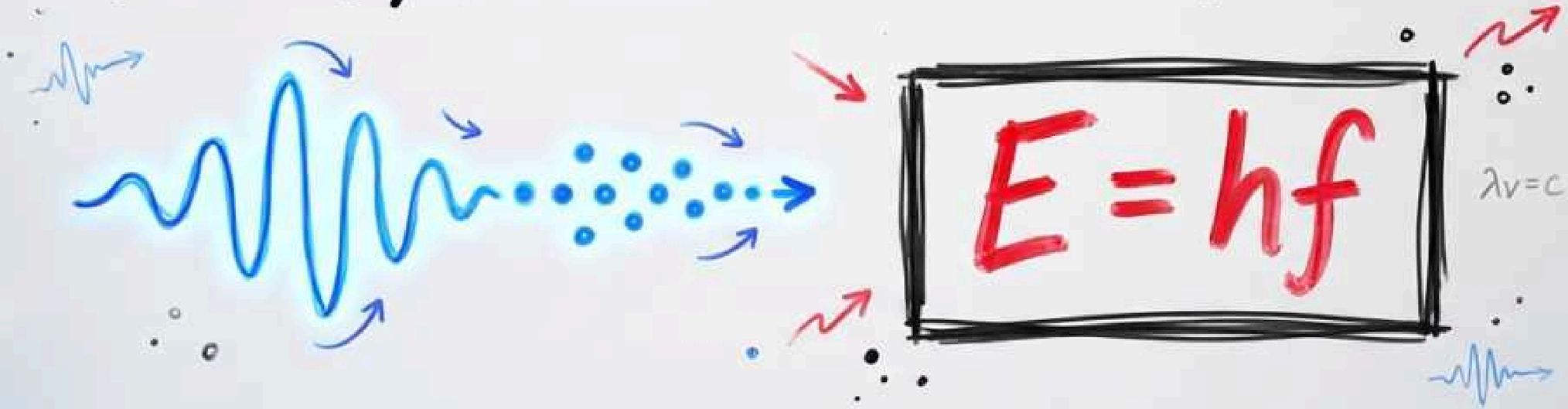
PHYS 220 B Lecture 1

Light Comes in Lumps: Planck, Einstein and the Photon

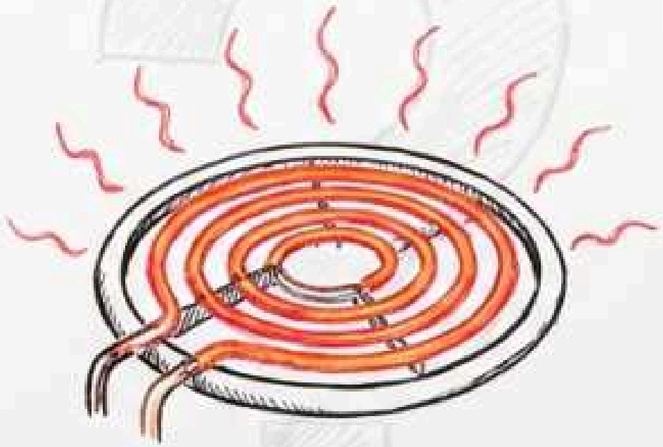


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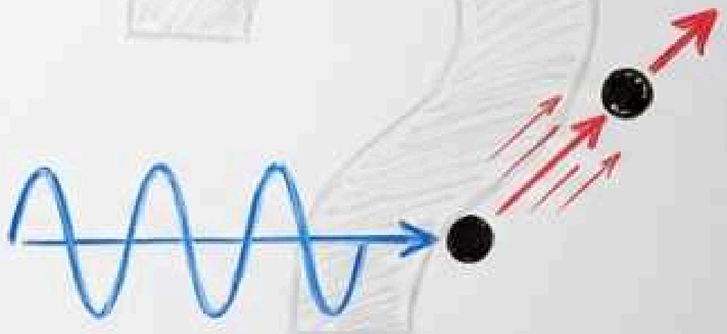
Paragraph 1.1 — The Three Questions



1. The Confidence of 1900.



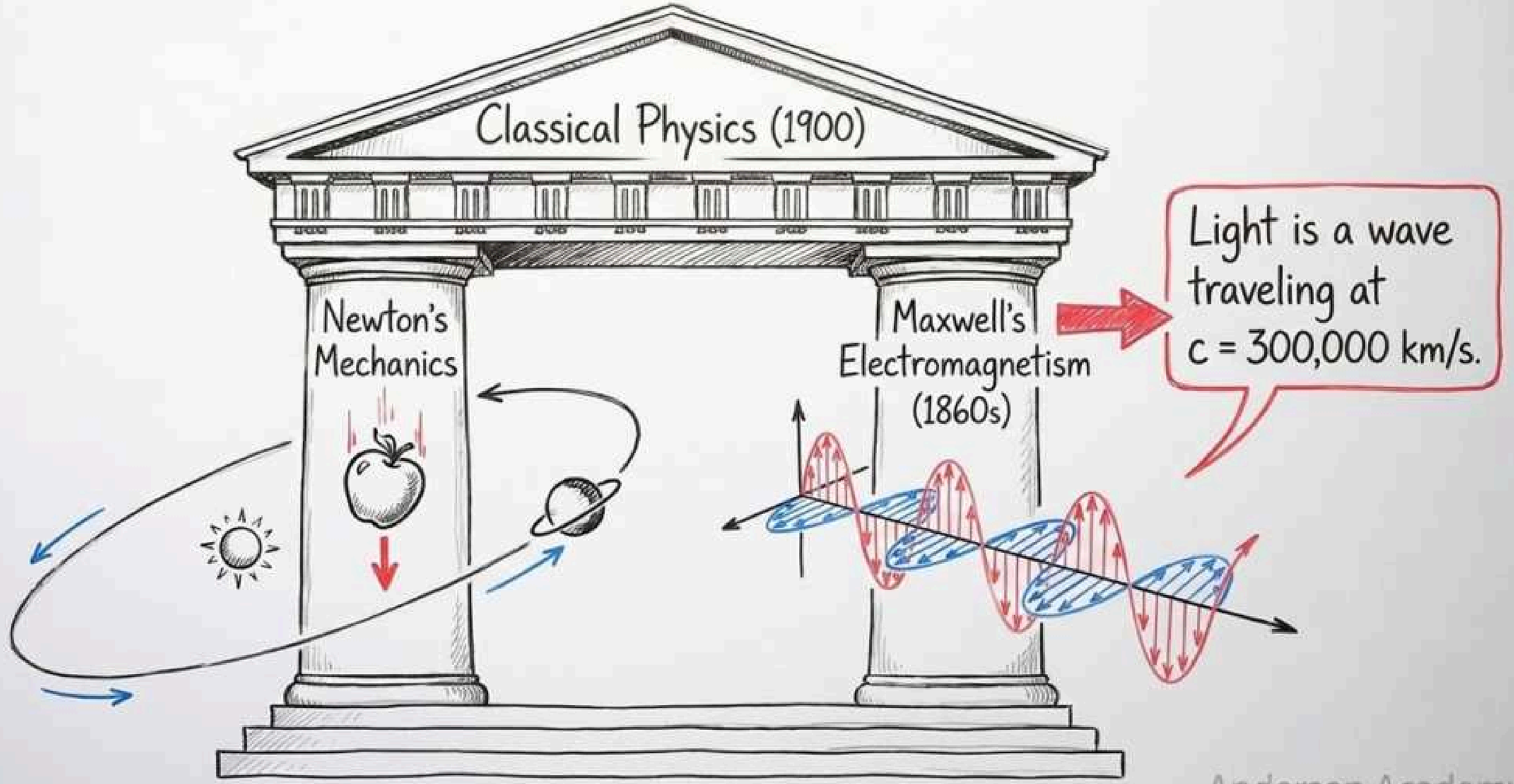
2. Planck's Puzzle.



3. Einstein's Photon.

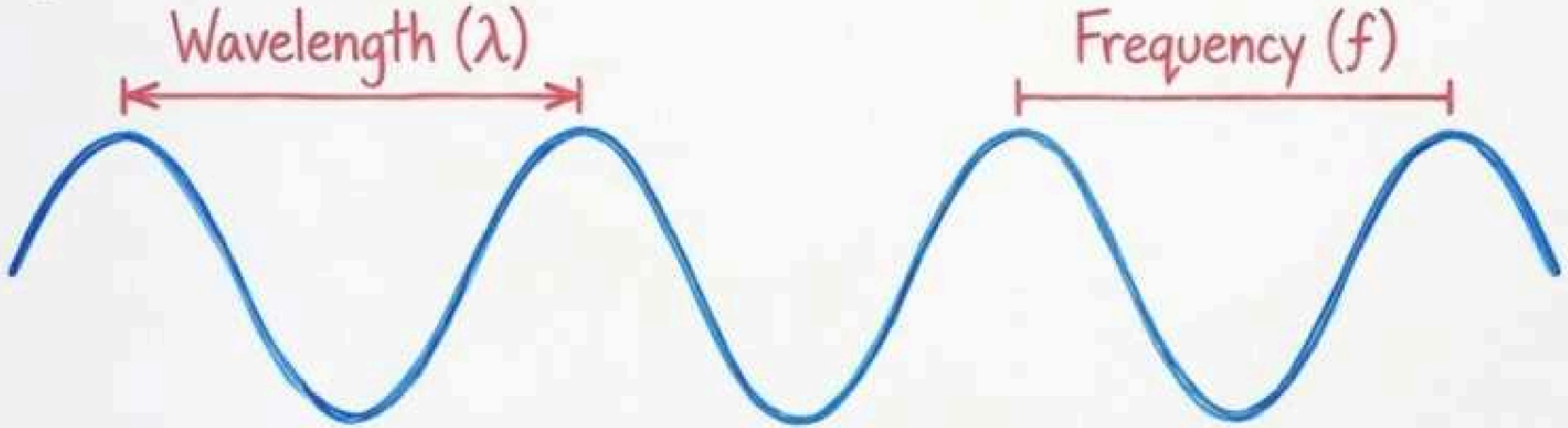
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Paragraph 1.2 — The Two Pillars

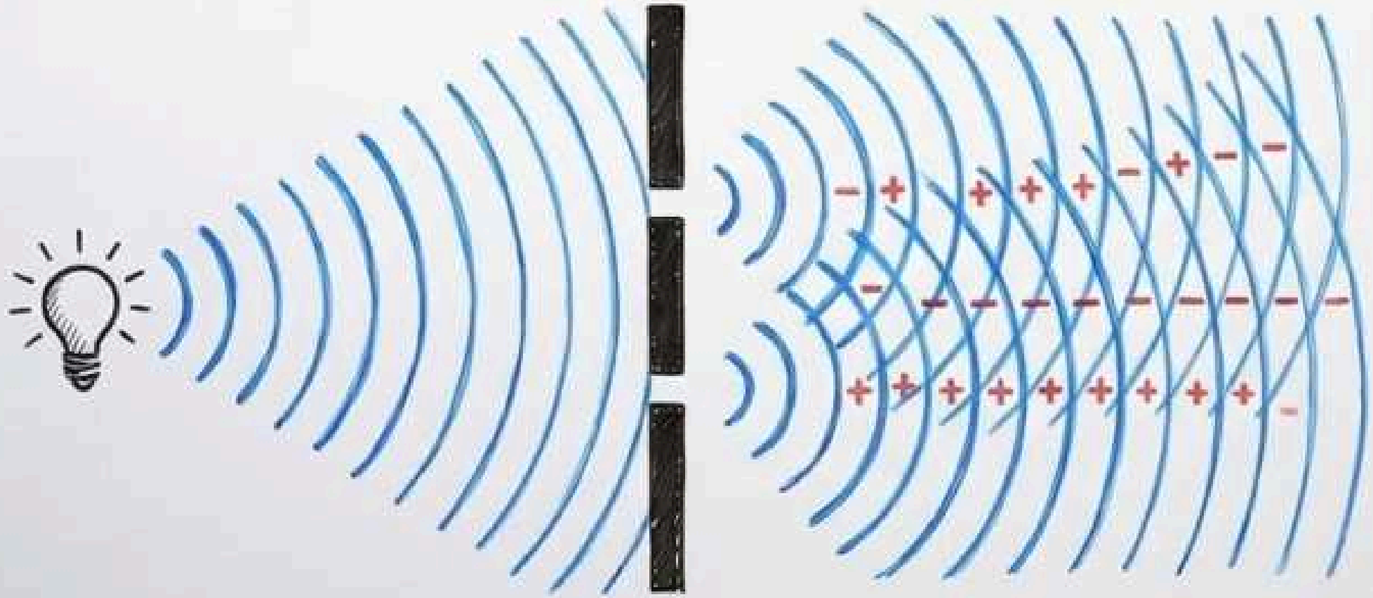


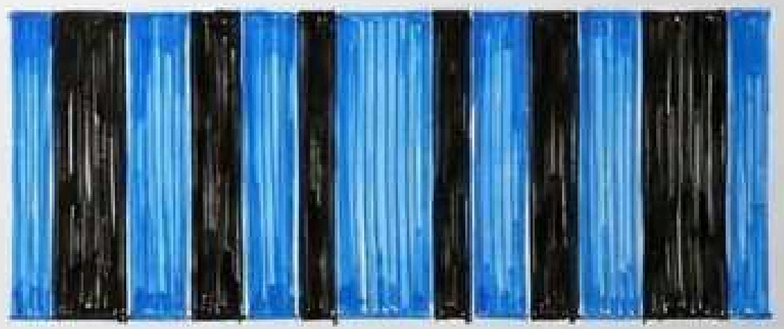
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Paragraph 1.3 — Waves and Interference



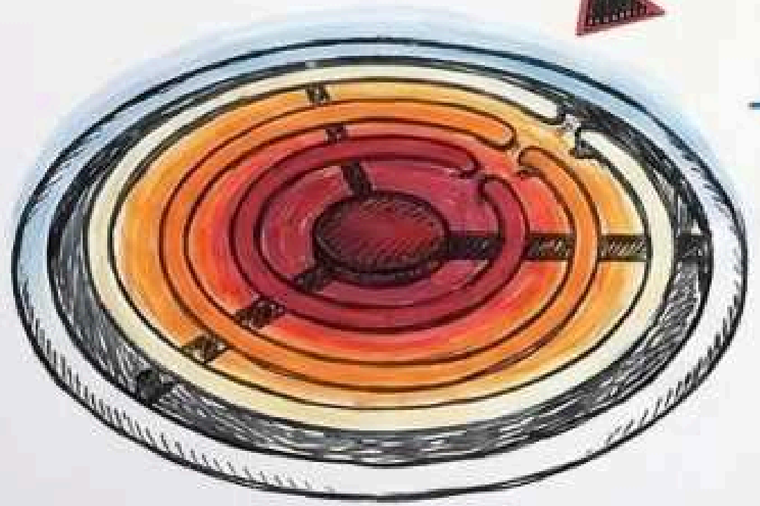
$$c = f\lambda$$





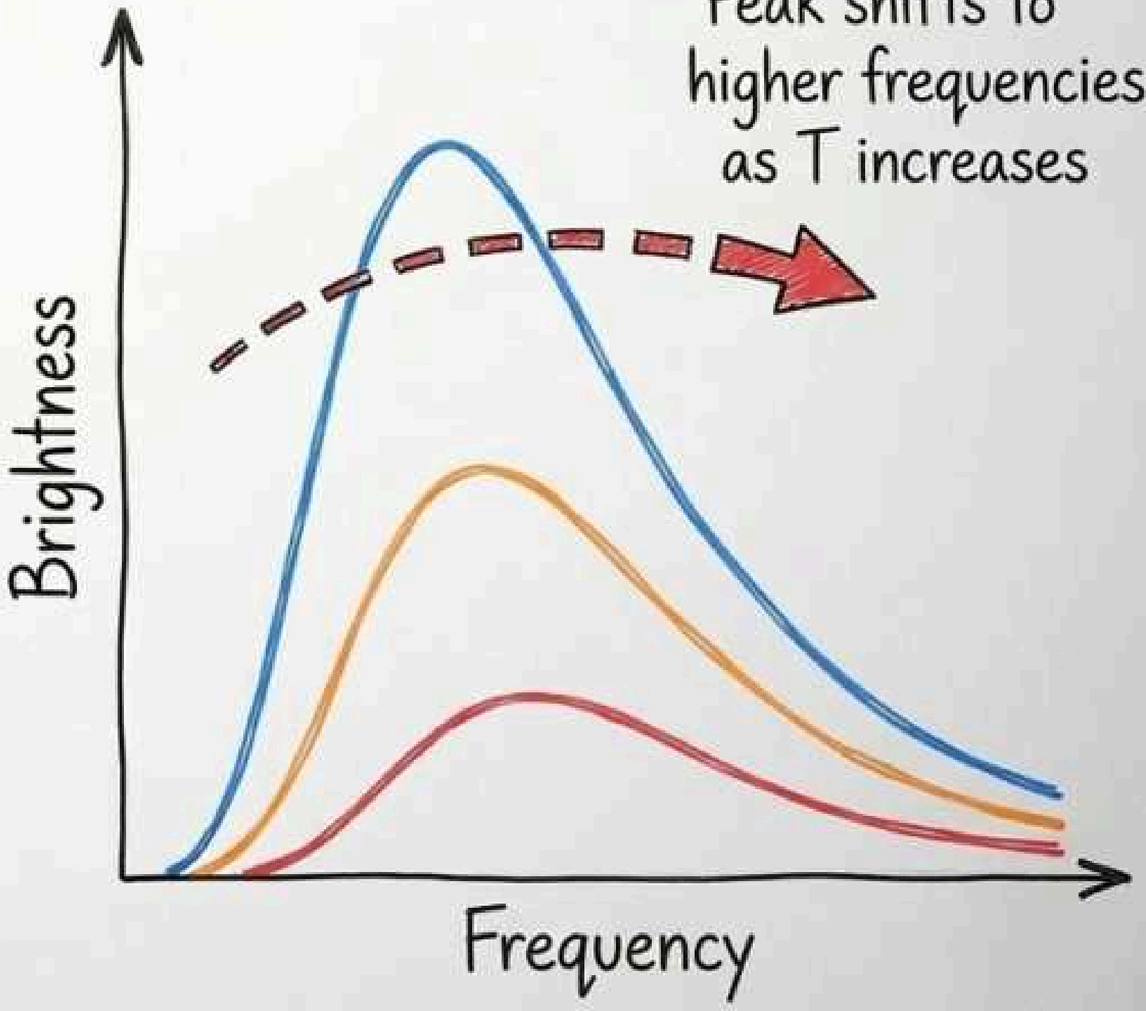
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Paragraph 1.4 — The Blackbody Puzzle



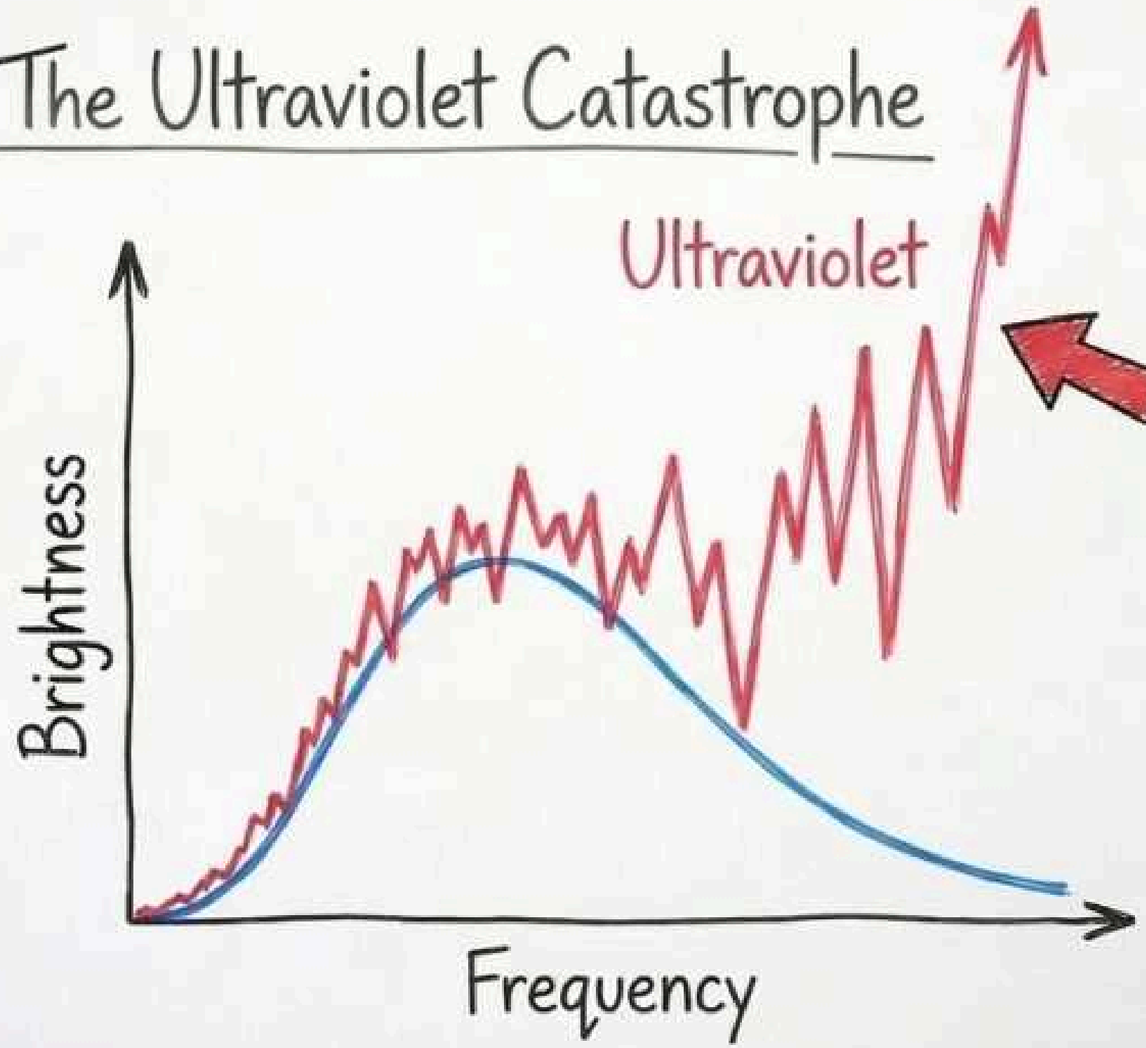
Dull red →
Orange →
Yellow-white
→ Bluish
(Stars)

The Blackbody: Absorbs all light, glow depends ONLY on temperature.



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Paragraph 1.5 — The Ultraviolet Catastrophe



Classical Prediction:
Every wave pattern gets an equal share of energy
= Infinite total.



If classical physics were true, warm tea would blaze with X-rays.
(Ehrenfest's "Ultraviolet Catastrophe").

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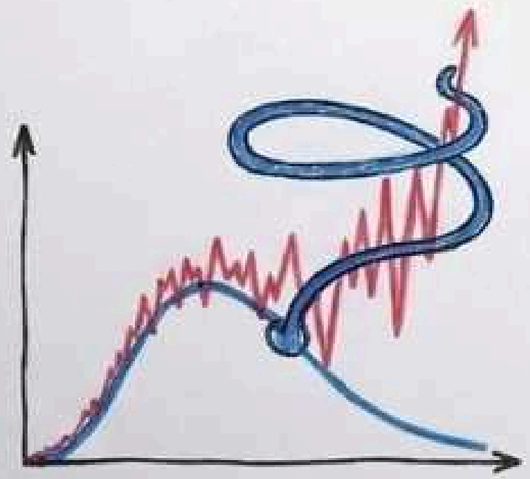
Paragraph 1.6 — Planck's Quantum

$$E = hf$$

E = Energy lump.

f = Frequency.

h = Planck's constant (6.63×10^{-34} J·s).

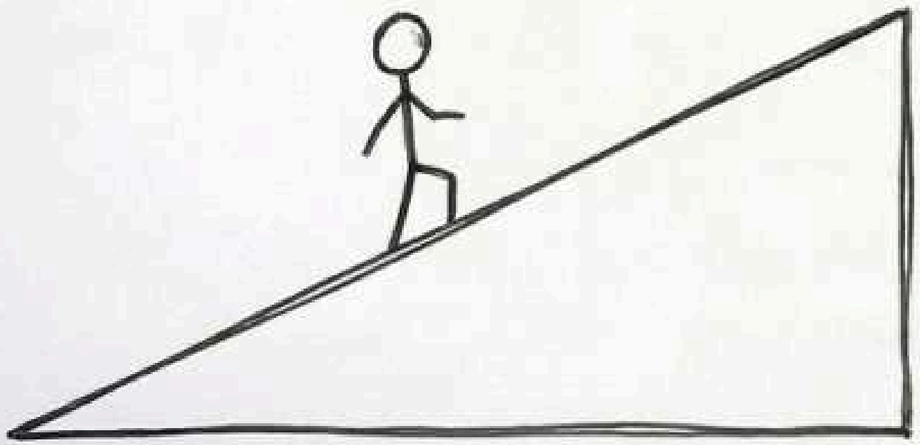


Late 1900: Max Planck's radical fix. High-frequency lumps are too "expensive" to be made by random thermal jostling. The catastrophe disappears.

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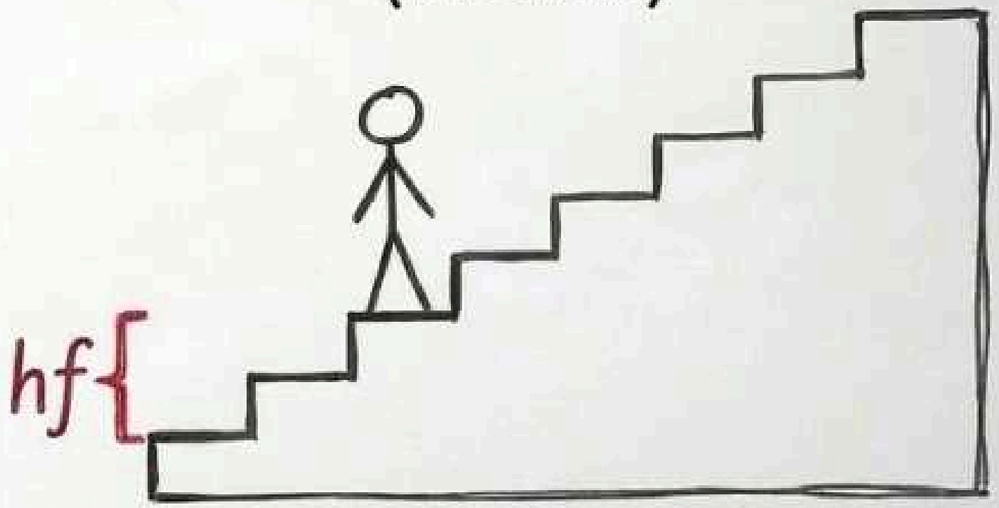
Paragraph 1.7 — What "Quantized" Means

Classical Physics
(Continuous)



You can stand at any height.

Quantized
(Discrete)

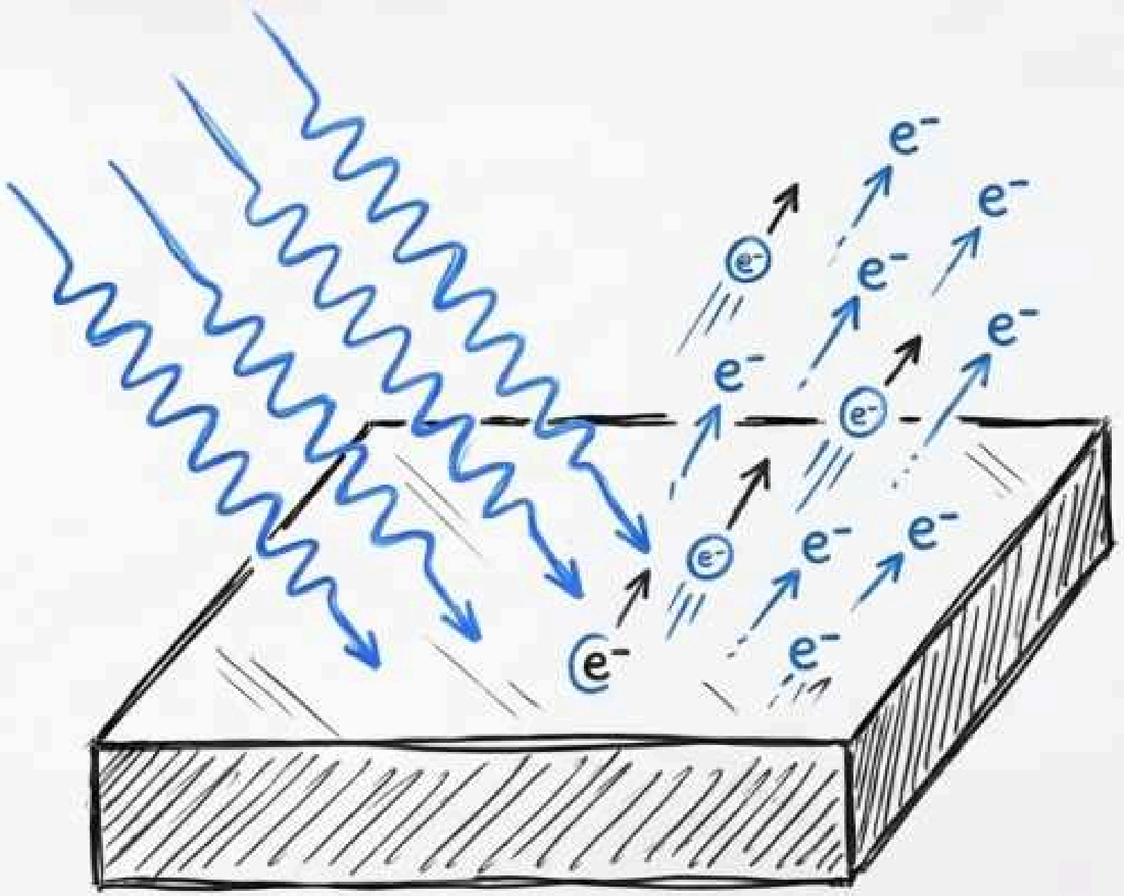


You can stand ONLY on the steps.

Planck saw these tiny steps as a mathematical trick.
Einstein took them seriously.

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Paragraph 1.8 — The Photoelectric Effect



Observations by Hertz (1887) and Lenard (1902)

- [x] Escaping energy depends on FREQUENCY, not brightness.
- [x] Below threshold frequency = ZERO electrons, no matter how bright.
- [x] Above threshold = INSTANT emission, even if dim.
- [x] Brighter light = MORE electrons, not faster ones.

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Paragraph 1.9 — The Wave Picture Fails

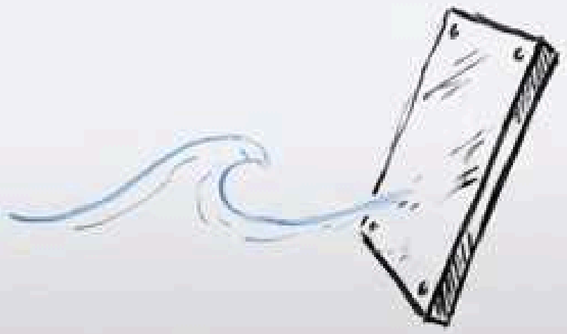
(Bright Light)



Expectation: Shakes electrons loose with huge energy.

Reality: Nothing happens if the frequency is too low.

(Dim Light)



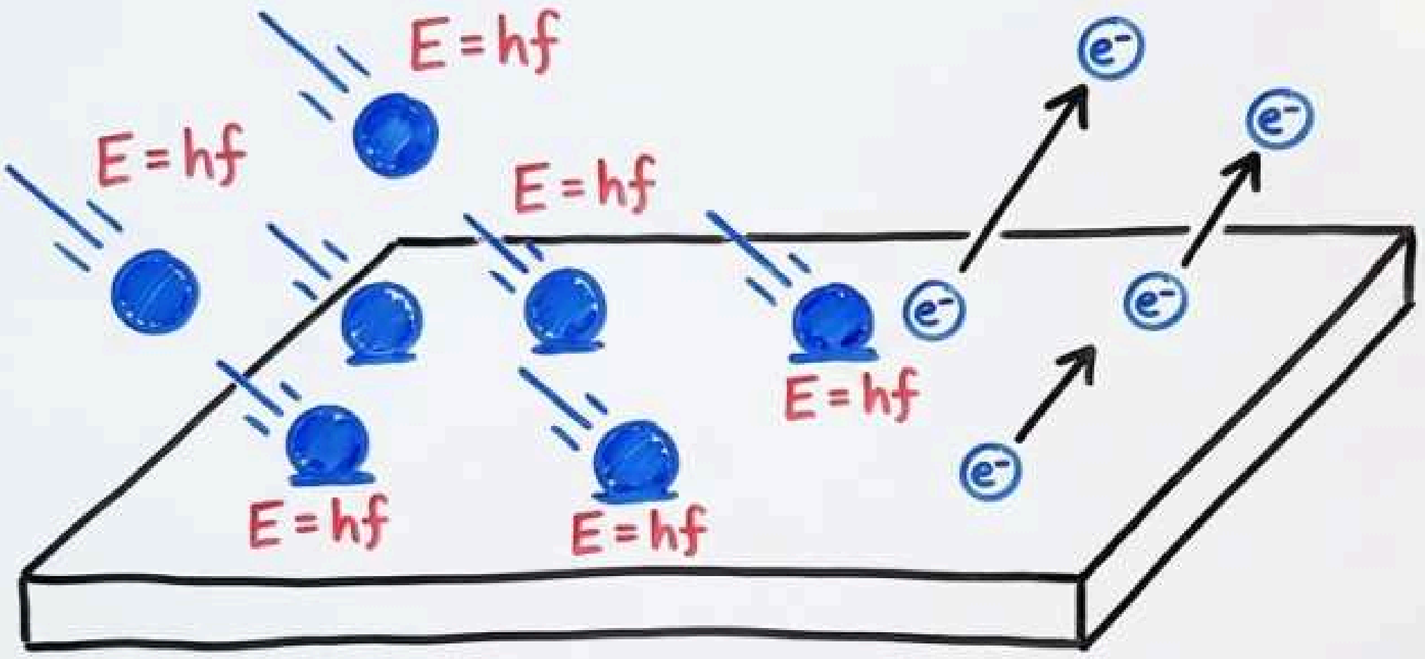
Expectation: Needs time to build up enough energy to free an electron.

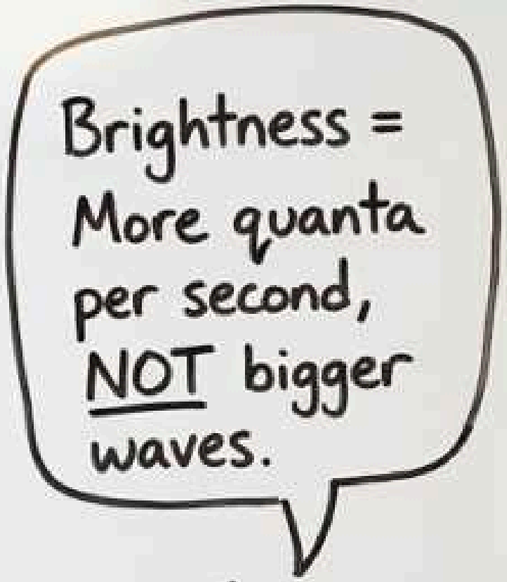
Reality: Instant emission.

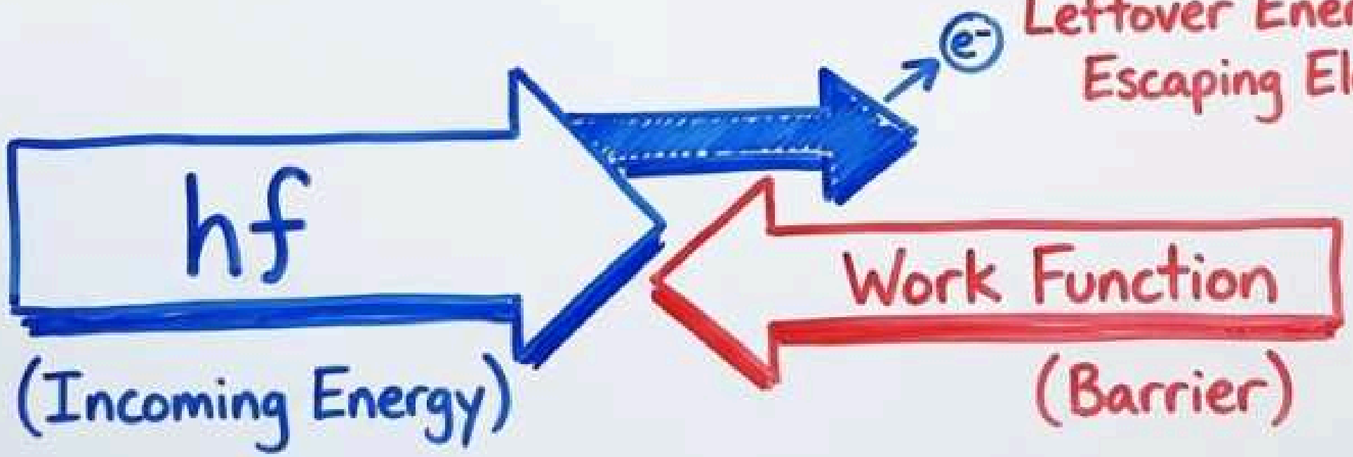
Something about the light itself depended on frequency in a way brightness couldn't fix.

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Paragraph 1.10 — Einstein's Photon



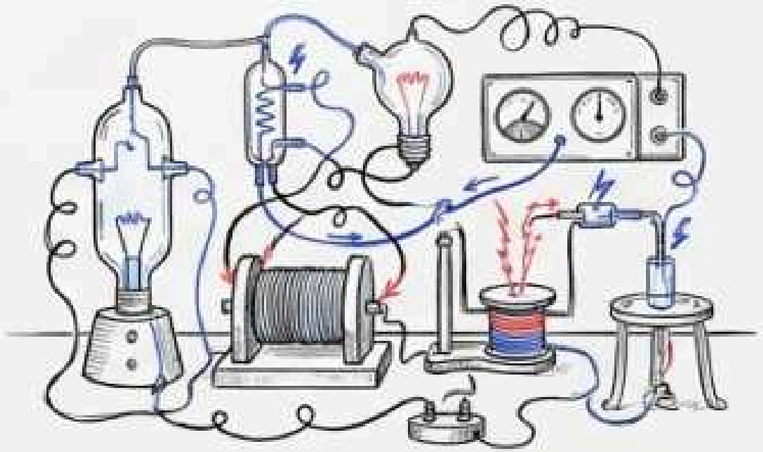






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Paragraph 1.11 — Confirmation





1905

Einstein proposes the Photon. Met with intense skepticism.

1916

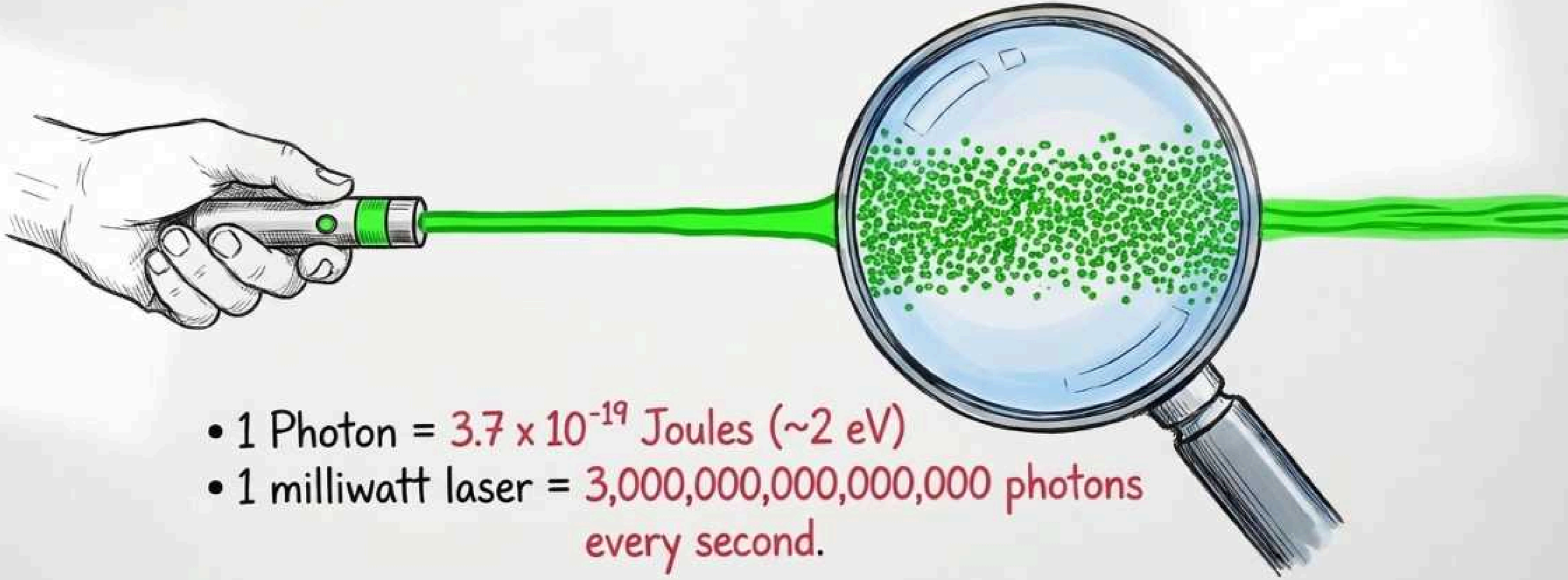
Robert Millikan spends years trying to disprove it, but accidentally confirms $E=hf$ perfectly.

1921

Einstein wins the 1921 Nobel Prize for his law of the photoelectric effect—NOT for relativity.

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Paragraph 1.12 — The Scale of the Quantum



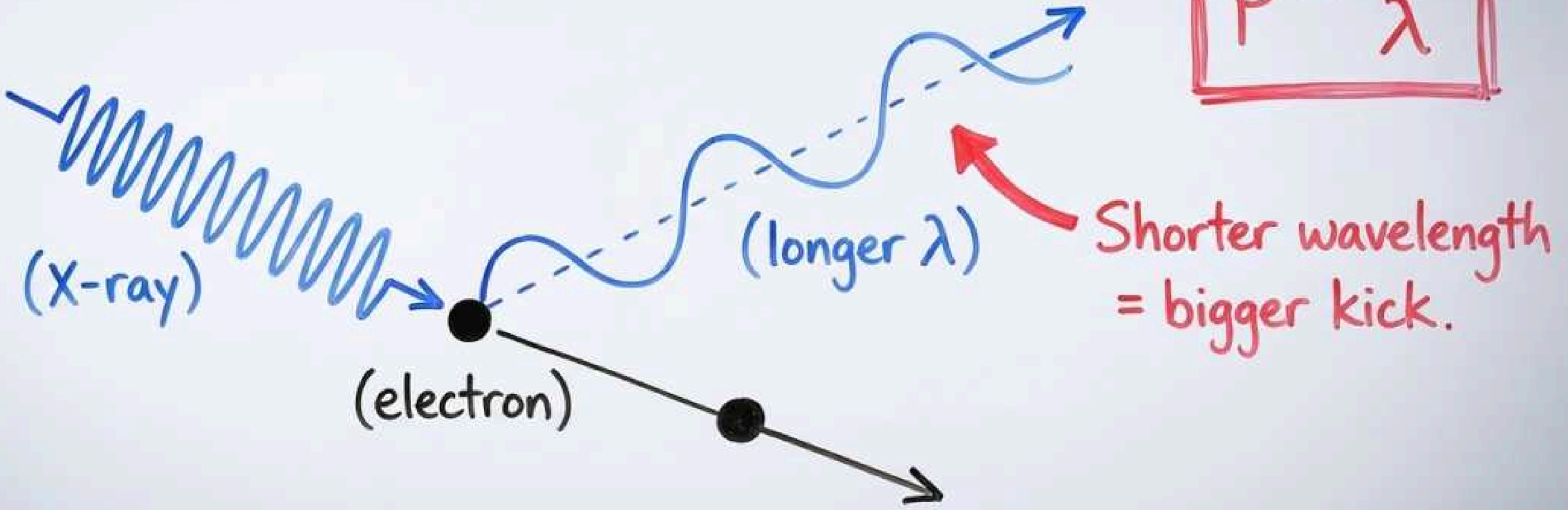
- 1 Photon = 3.7×10^{-19} Joules (~2 eV)
- 1 milliwatt laser = 3,000,000,000,000,000 photons every second.

Planck's constant (h) is the exchange rate. Because there are so many photons, the discrete lumps blur into a smooth stream.

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Paragraph 1.13 — Compton's Momentum

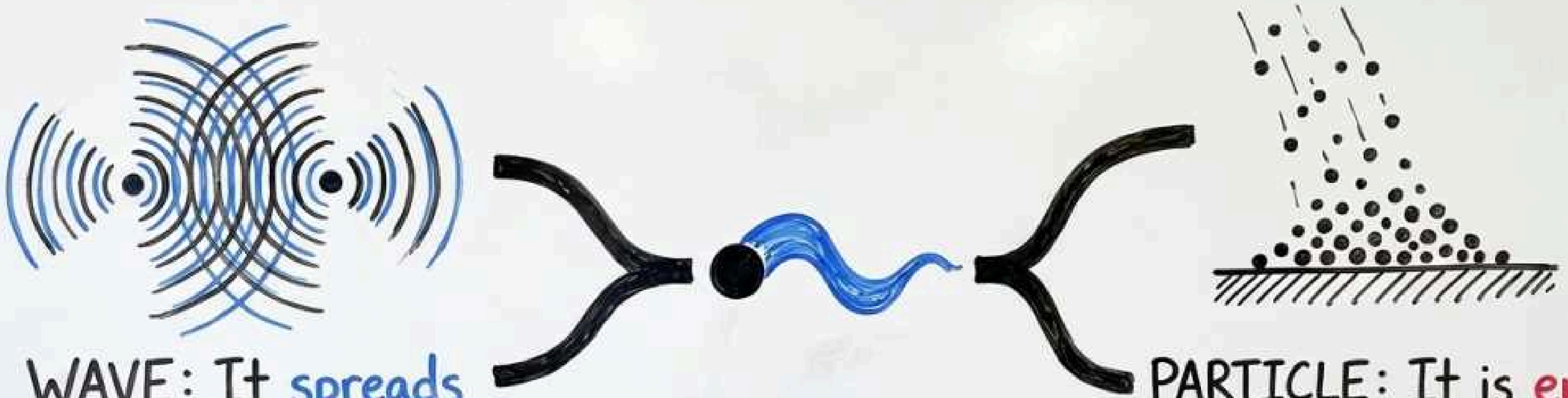
$$P = \frac{h}{\lambda}$$



Arthur Compton (1923) proves photons bounce like billiard balls, carrying momentum.

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Paragraph 1.14 — Wave-Particle Duality



WAVE: It spreads and interferes.

PARTICLE: It is emitted and absorbed in lumps.

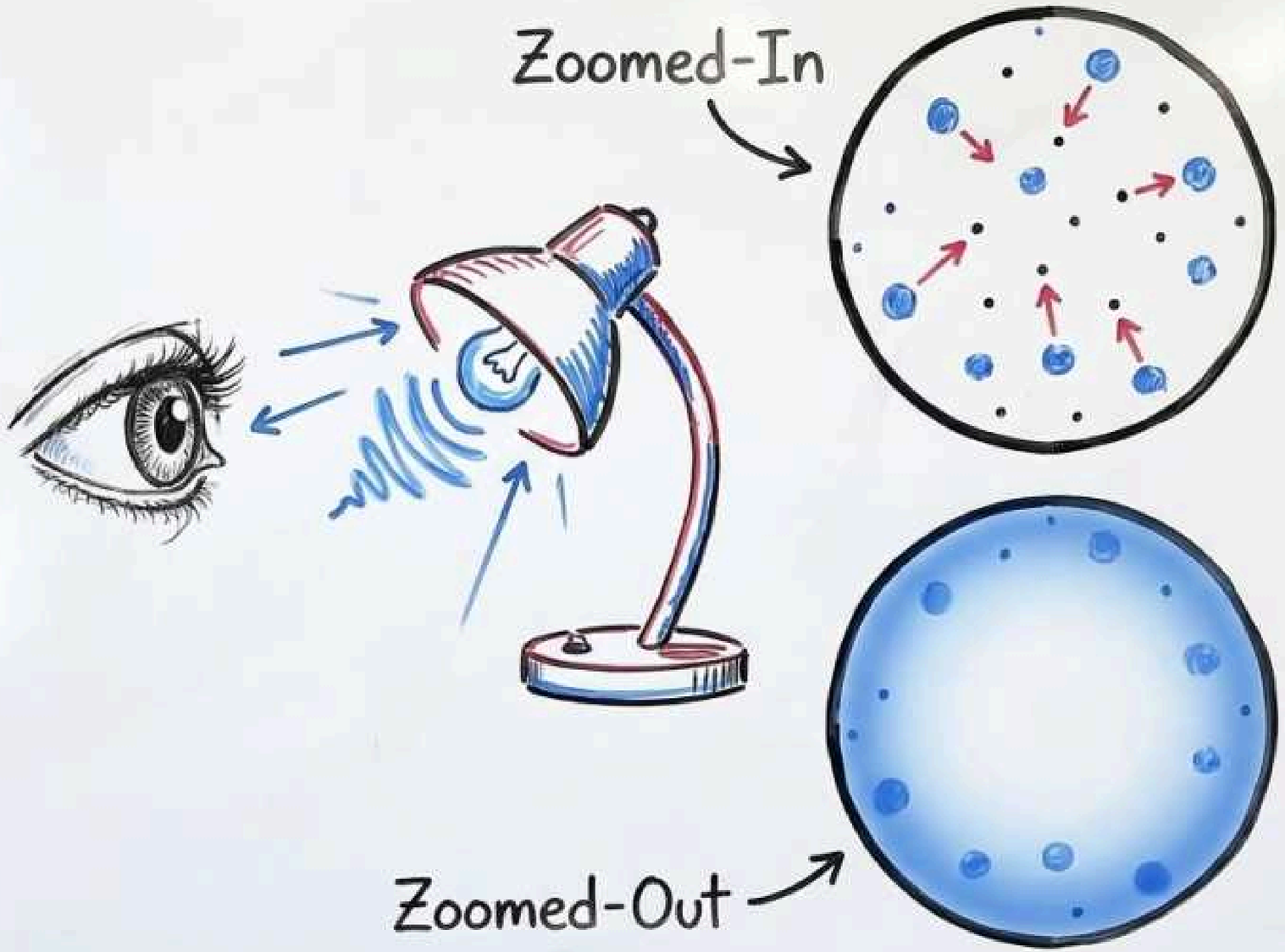
"It is like neither."

Everyday pictures are only partial guides to quantum objects.

— Richard Feynman

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Paragraph 1.15 — Why Light Looks Smooth



Why does everyday light look smooth?

Because h is unimaginably small (10^{-34}).

Our eyes and instruments respond to the average of an immense number of photons, hiding the granular reality.

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Paragraph 1.16 — Summary

The Puzzle	The Solver	The Math
Blackbody Radiation →	Max Planck (1900) →	$E = hf$ (Energy in lumps)
Photoelectric Effect →	Albert Einstein (1905) →	Photons carry hf
X-ray Scattering →	Arthur Compton (1923) →	$p = \frac{h}{\lambda}$ (Momentum)

Light behaves both as a wave and as a stream of particles.

Next: Do particles behave like waves?

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