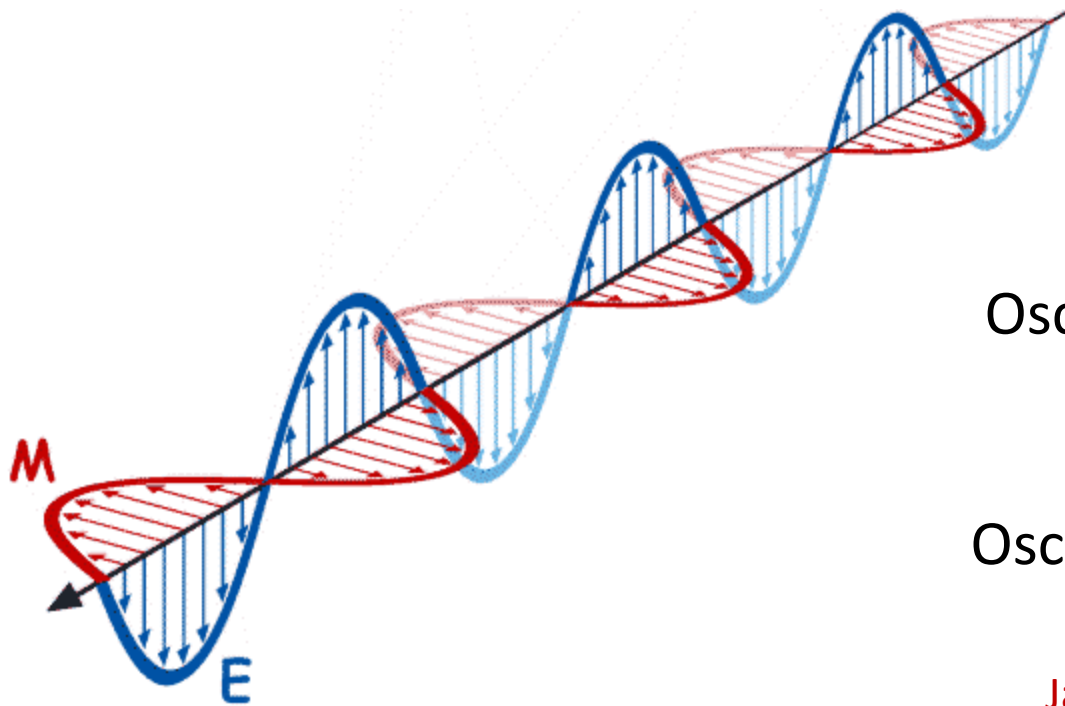


Failures of Classical Physics and the Birth of Quantum Mechanics

Mark Van Raamsdonk

The classical description of light

Light, X-rays, microwaves, radio waves, are all examples of *ELECTROMAGNETIC RADIATION*:



Oscillating electric field

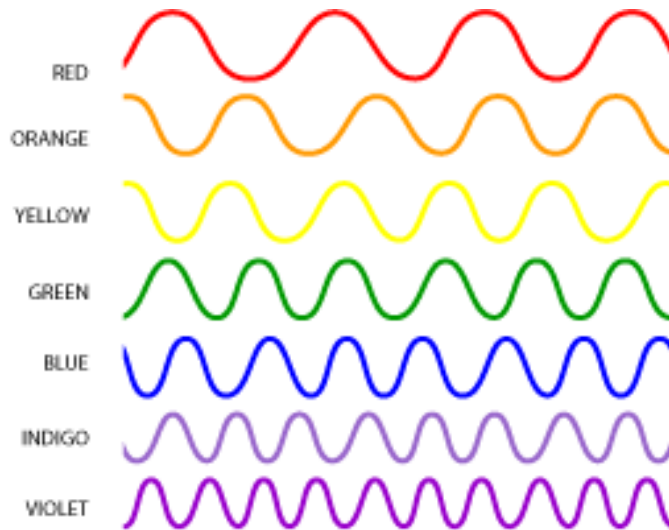


Oscillating magnetic field

James Clerk Maxwell 1864

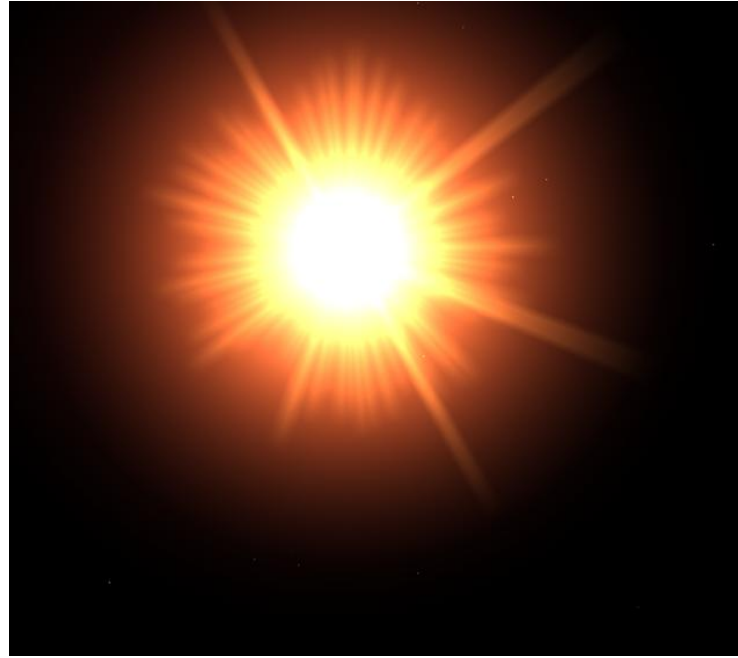
Properties of Light

Colour: determined by wavelength



Intensity: determined by amplitude

Light carries energy



Energy \longleftrightarrow Intensity \longleftrightarrow Amplitude Squared

Q: How can we make some
electromagnetic radiation?

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electromagnetic radiation?

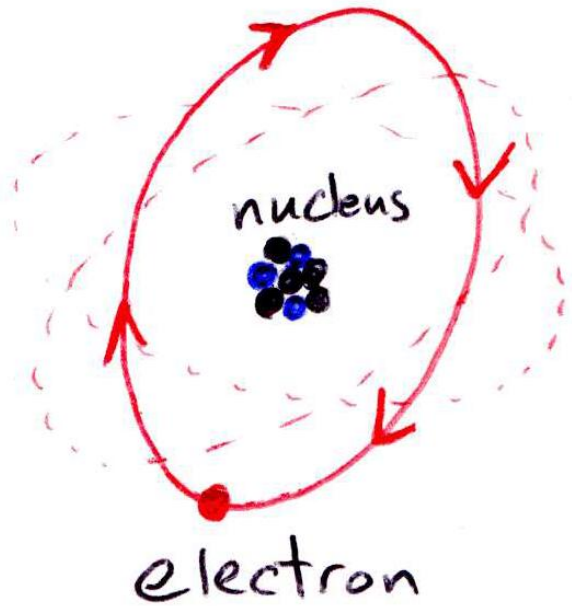
A: Shake some charges

Power radiated



acceleration squared

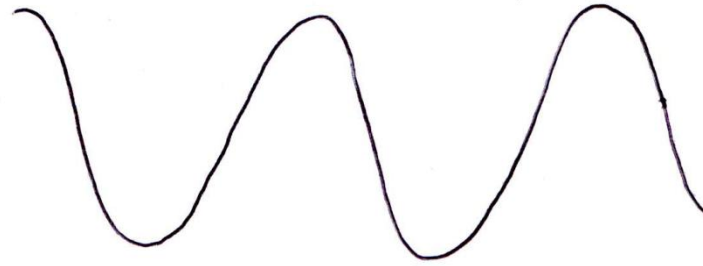
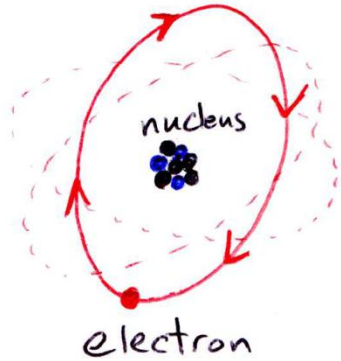
Failures of classical physics I



“Planetary” picture of atom:

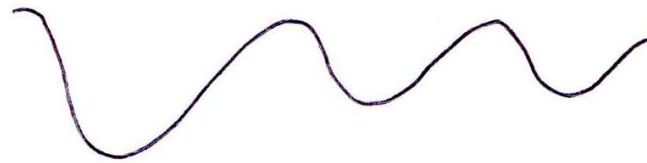
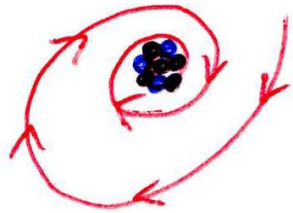
Electrons orbiting around nucleus

Sounds okay, but...



Orbiting charge would produce EM radiation

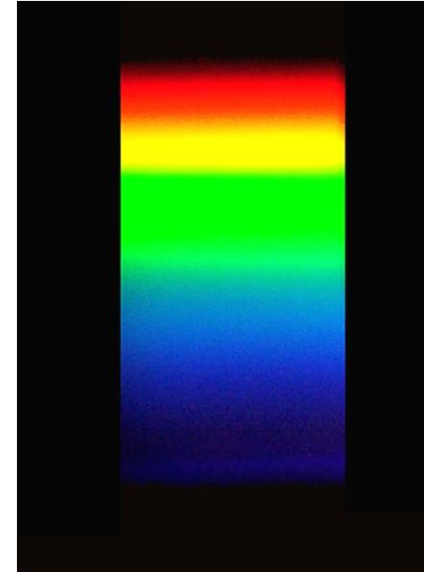
This carries away energy



Electron losing energy spirals into nucleus

All matter as we know it ceases to exist in 10^{-10} s.

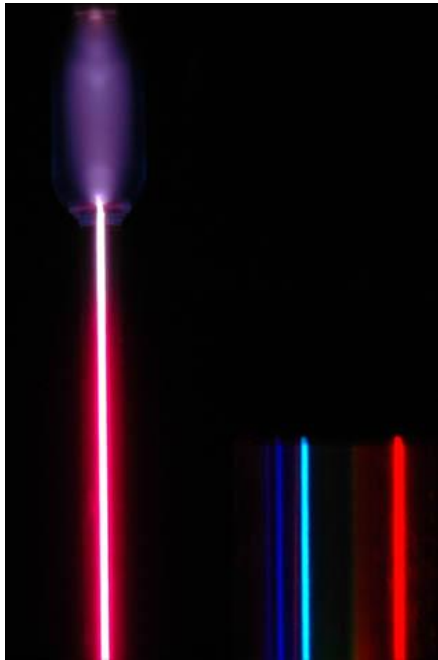
Failures of classical physics II



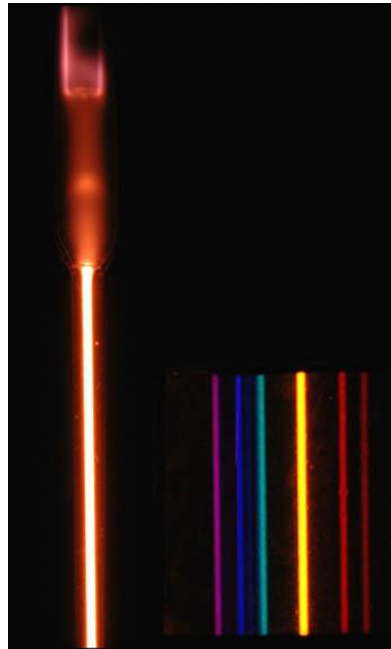
Light from any source is a combination of wavelengths and intensities.

19th century physicists completely failed to explain observed spectrum of light from hot objects

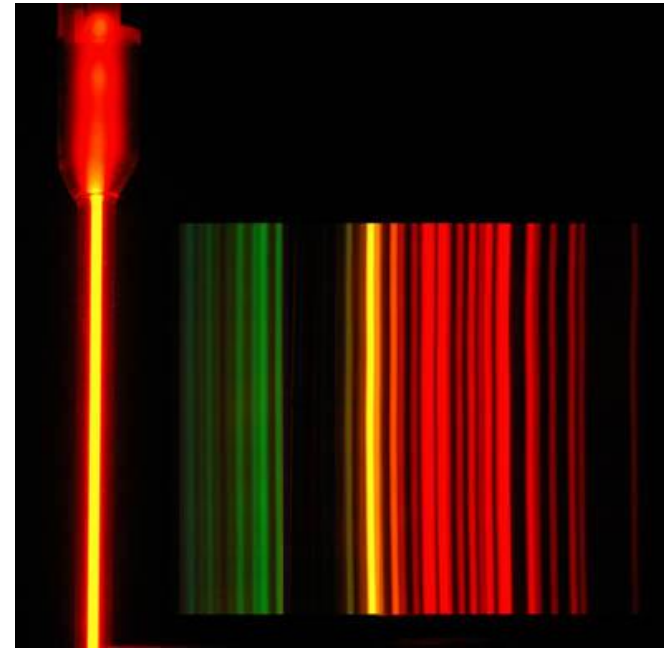
Even more mysterious: spectrum of light from gases of pure elements



Hydrogen

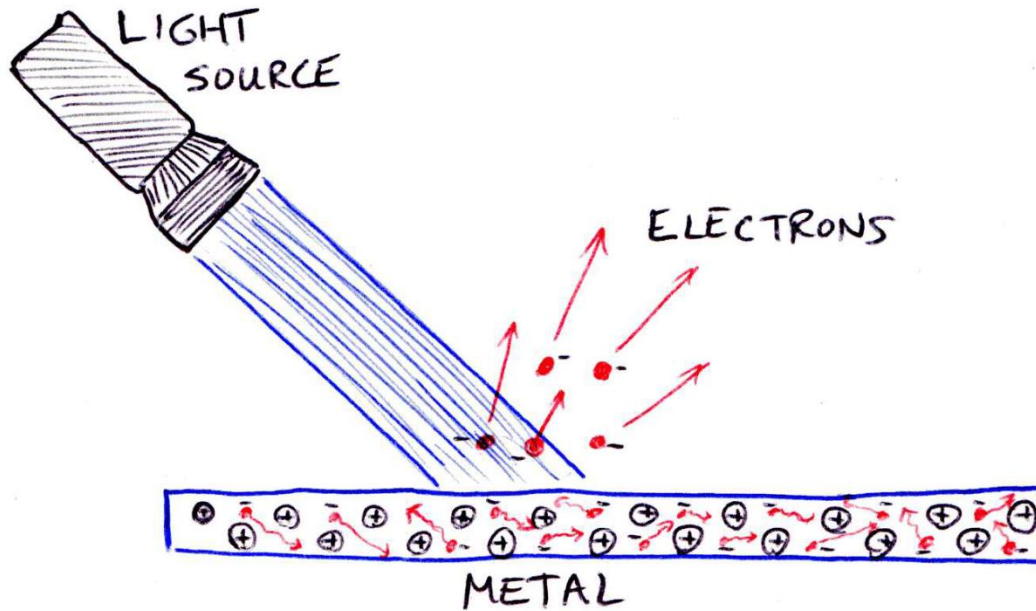


Helium



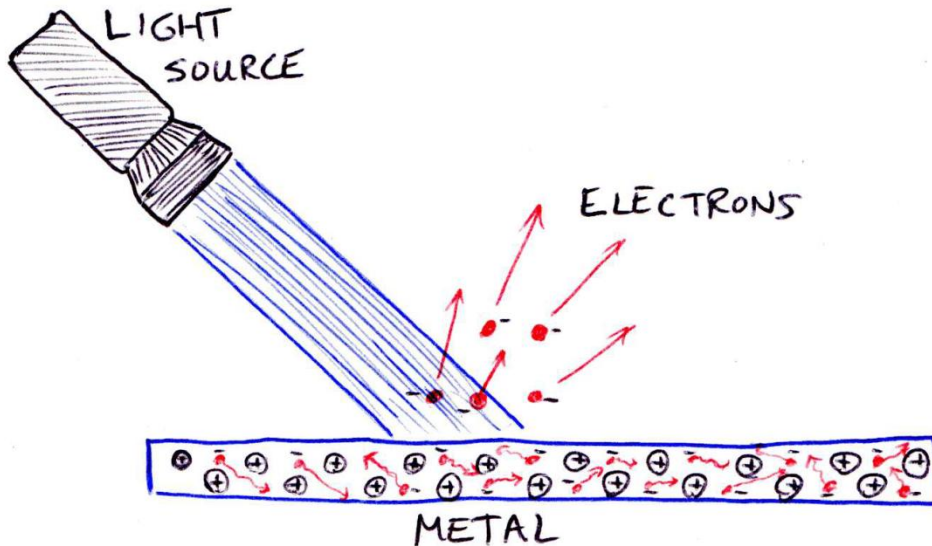
Neon

The photoelectric effect



Observation: electrons ejected from metal
when light is turned on

The photoelectric effect: explained

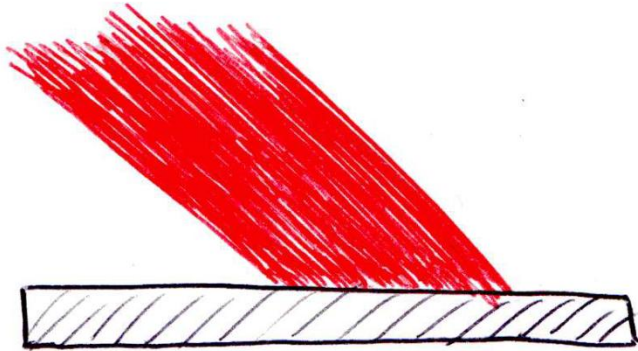


Electrons trapped in metal
(attracted to positive nuclei)

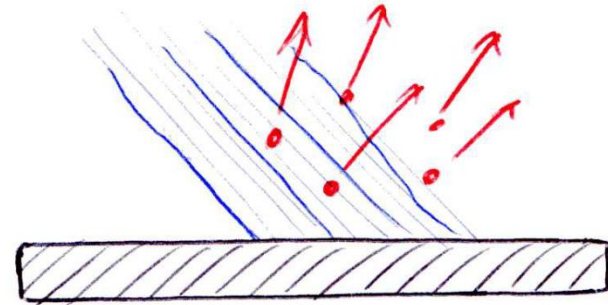
Can free them if we provide
enough energy

Energy carried by light can be
transferred to electrons

BUT: we only see the effect for certain colours!?



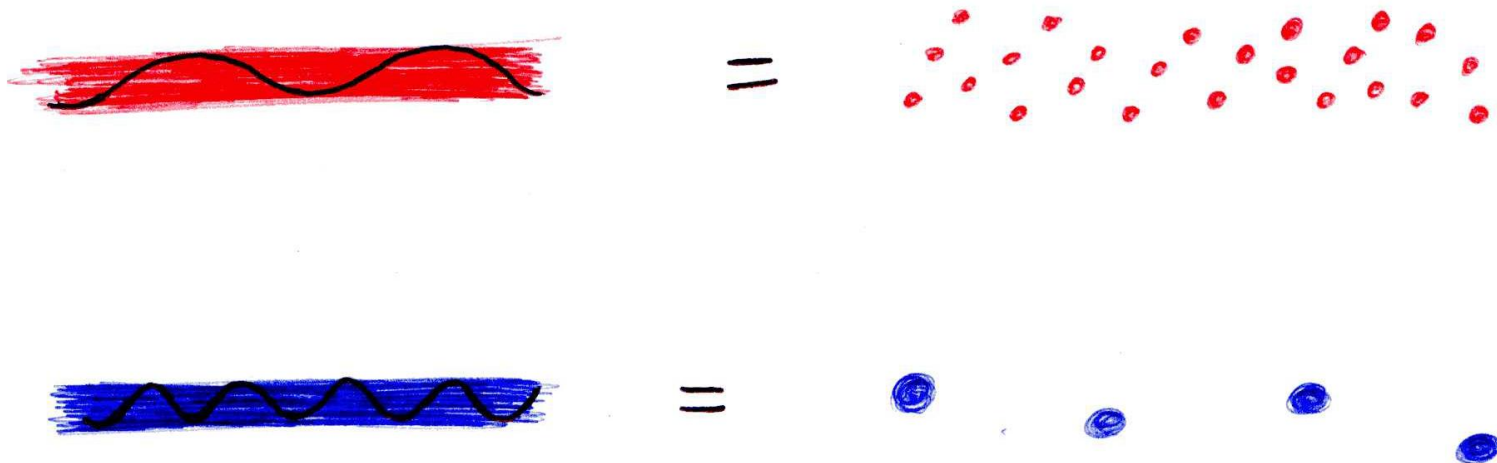
Very intense red light:
No electrons



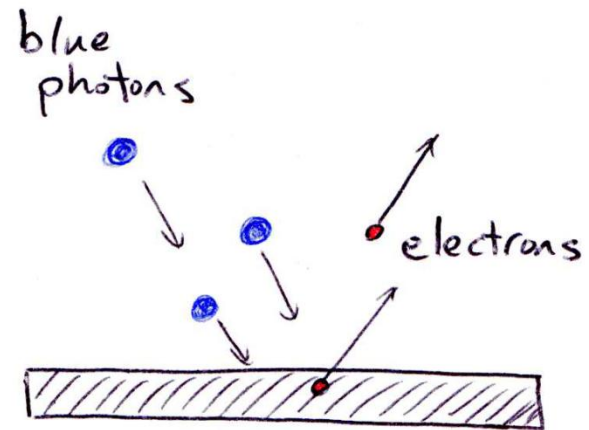
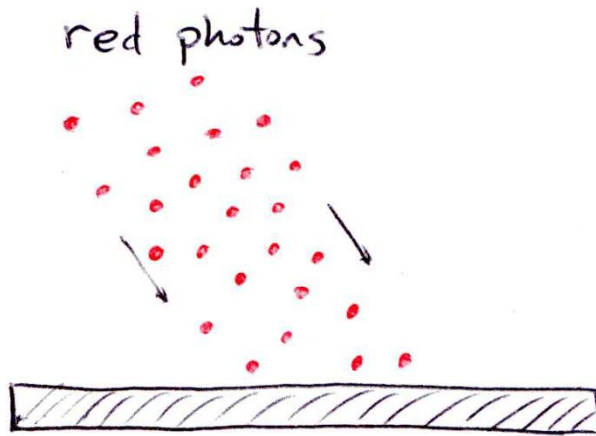
Feeble blue light:
Electrons emitted

Einstein to the Rescue

Einstein's idea: light made of "photons" = lumps with energy inversely proportional to wavelength



Einstein's explanation



Electrons can only absorb energy from individual photons

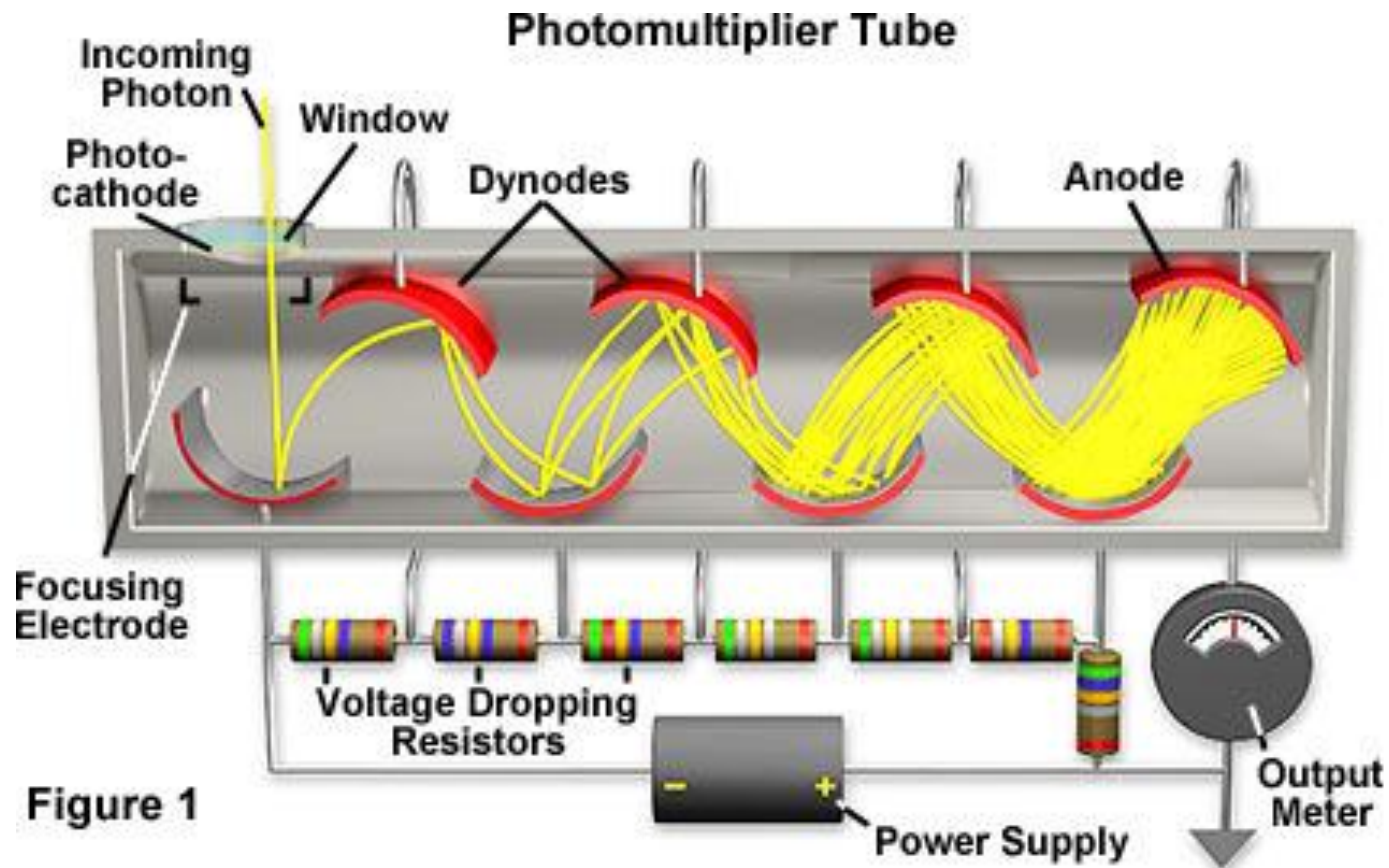
Only light with short enough wavelength has photons with enough energy to eject an electron

Einstein's Only Nobel Prize

Quantitative prediction (1905): maximum kinetic energy of ejected electrons increases linearly with inverse of wavelength (photon energy)

Experimental verification by Millikan in 1915

Nobel prize for Einstein in 1921



Today: can use photoelectric effect to “see” individual photons