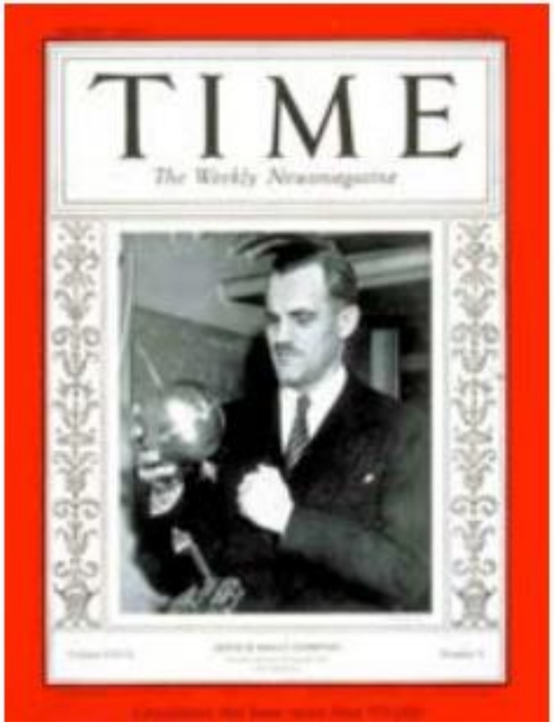
From last time

- Photons can transfer energy to beam of electrons.
- Determined by conservation of momentum, energy.
- Compton awarded 1927 Nobel prize for showing that this occurs just as two balls colliding.

$$\boxed{\lambda_2 - \lambda_1 = \frac{h}{m_0 c}(1 - \cos\theta)}$$

Compton shift

Compton wavelength
0.0243 angstrom



Arthur Compton
Jan 13, 1936

Quantum Mechanics: Compton Scattering

mom. cons. $\vec{p_1} = \vec{p_2} + \vec{p_e}$

$\vec{p_e} = \vec{p_1} - \vec{p_2}$, $p_e^2 = p_1^2 + p_2^2 - 2p_1p_2\cos\theta$ — (1)

energy cons. $p_1c + E_0 = p_2c + (E_0^2 + p_e^2c^2)^{1/2}$ — (2)

$$E_0 + c(p_1 - p_2) = (E_0^2 + p_e^2c^2)^{1/2}$$

$$\cancel{E_0^2} + c^2(p_1 - p_2)^2 + 2E_0c(p_1 - p_2) = \cancel{E_0^2} + p_e^2c^2$$

$$p_e^2 = p_1^2 + p_2^2 - 2p_1p_2 + \frac{2E_0}{c}(p_1 - p_2) \quad \text{— (3)}$$

(1) and (3) $\cancel{p_1^2} + \cancel{p_2^2} - 2p_1p_2\cos\theta = \cancel{p_1^2} + \cancel{p_2^2} - 2p_1p_2 + \frac{2E_0}{c}(p_1 - p_2)$

$$\frac{E_0}{c}(p_1 - p_2) = p_1p_2(1 - \cos\theta)$$

multiply by $\frac{hc}{p_1p_2E_0}$

$$\frac{h}{p_1p_2}(p_1 - p_2) = \frac{hc}{E_0}(1 - \cos\theta)$$

$p_1 = \frac{h}{\lambda_1}$ $\quad p_2 = \frac{h}{\lambda_2}$

$E_0 = m_0c^2$

$$\boxed{\lambda_2 - \lambda_1 = \frac{h}{m_0c}(1 - \cos\theta)}$$

compton wavelength

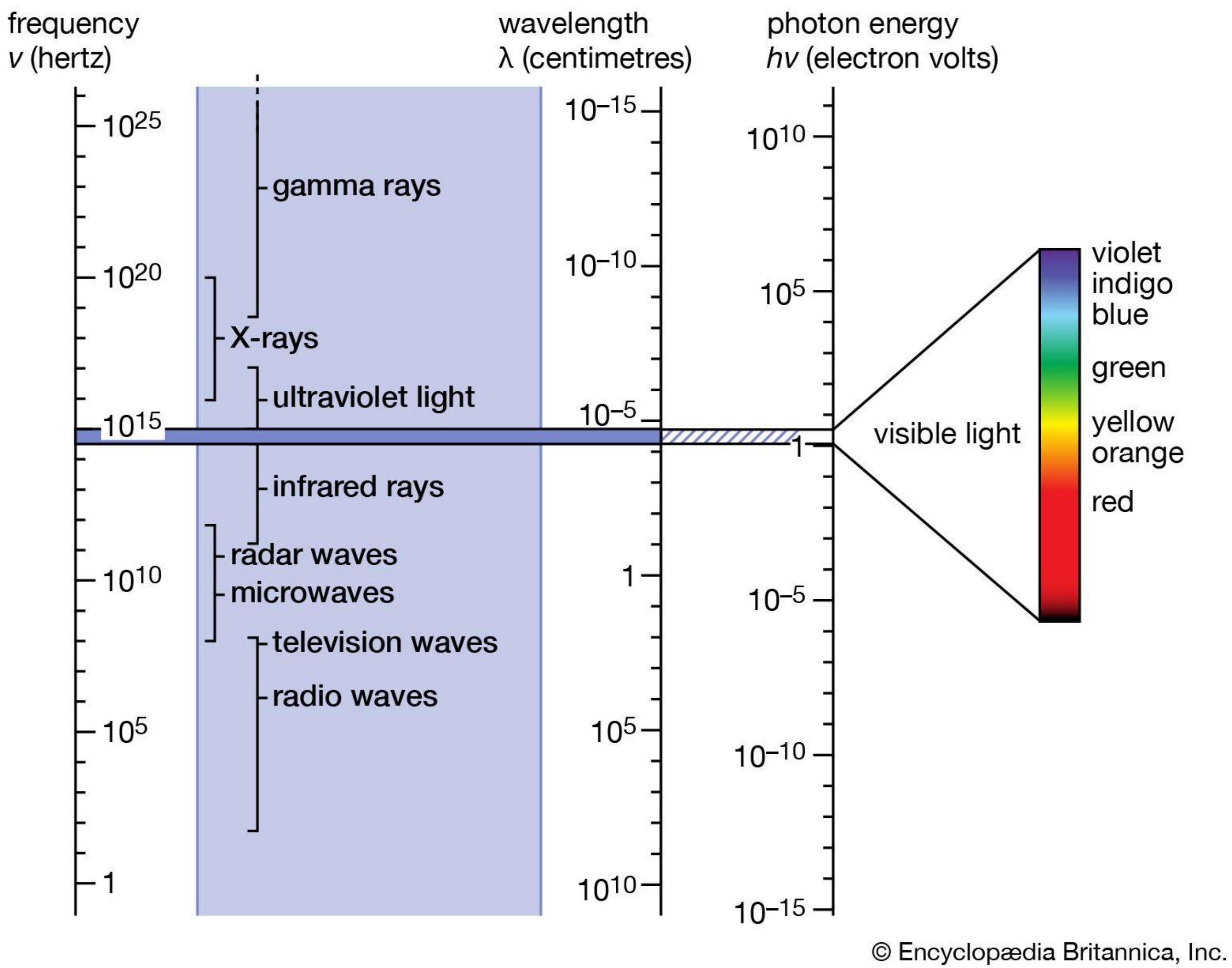
Quantum Mechanics: Photoelectric effect

1. Photoelectric effect: Hertz in 1887 noticed that sparks occurred more readily in the air gap of his transmitter when ultraviolet light was directed at one of the metal balls.
2. He did not follow up his observation, but others did.
3. They discovered that cause of electron emission is sufficiently **high frequency wave**, later this phenomena is termed as PHOTOELECTRIC EFFECT

Ref. Concepts of Modern Physics by Arthur Beiser

Quantum Mechanics: Photoelectric Effect

Electromagnetic Spectrum



Quantum Mechanics: Photoelectric Effect

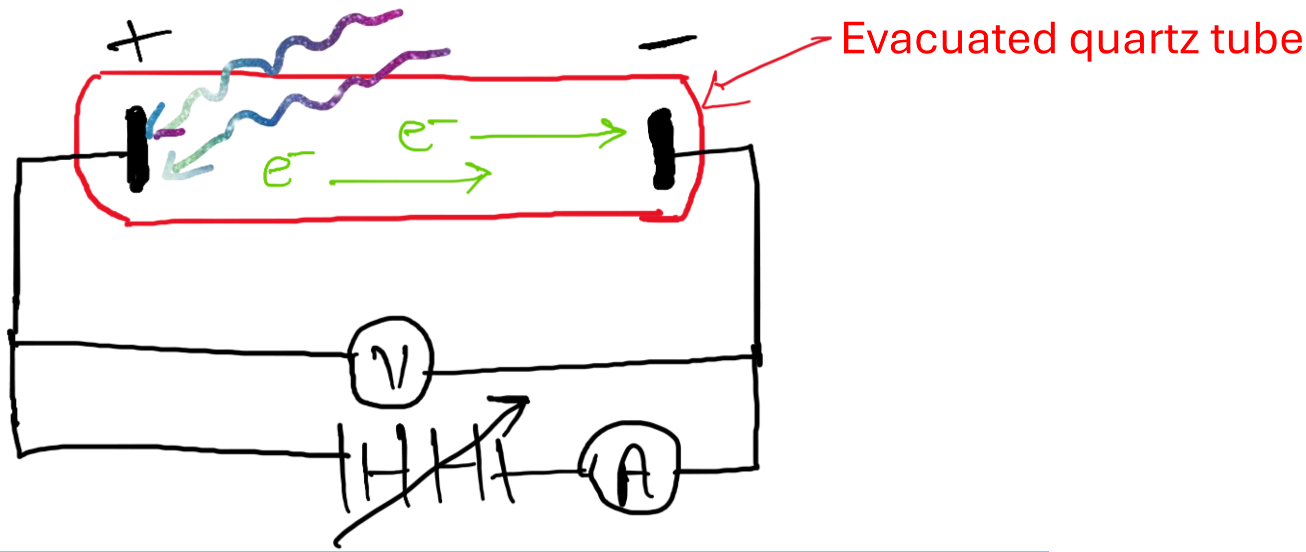
FEW WORDS

1. Threshold frequency(ν_o): Minimum energy required to eject electron (**INCIDENT LIGHT property**)
2. Work function (ϕ): Minimum energy to eject electron from metal (**METAL property**)
   1. Sodium: 2.3eV
   2. Cobalt: 5eV
3. Photoelectron: Electron emitted after absorbing PHOTONS
4. Stopping potential: Minimum potential required to stop electrons from moving between plates.
5. Intensity= no. of photons/second

Beiser

Quantum Mechanics: Photoelectric effect

Phenomena of emission of electrons on shinning light on metallic surface is known as *photoelectric effect*.
Electrons emitted in the process are called photoelectrons.



Existence of photoelectric effect is not surprising, but observations are

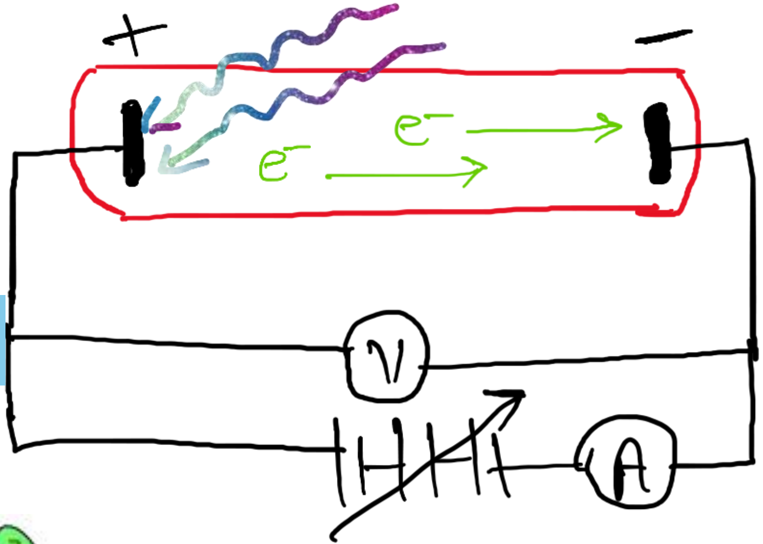
Observations from experiment

1. Electrons ejected from the metal instantaneously.
2. There is a cut-off wavelength λ_o such that beam of light (radiation) of wavelength larger than λ_o does not cause electrons to be ejected from the metal, however strong be the source.
3. The maximum kinetic energy of the photoelectrons from a metal depends only on the wavelength of light and not on intensity.

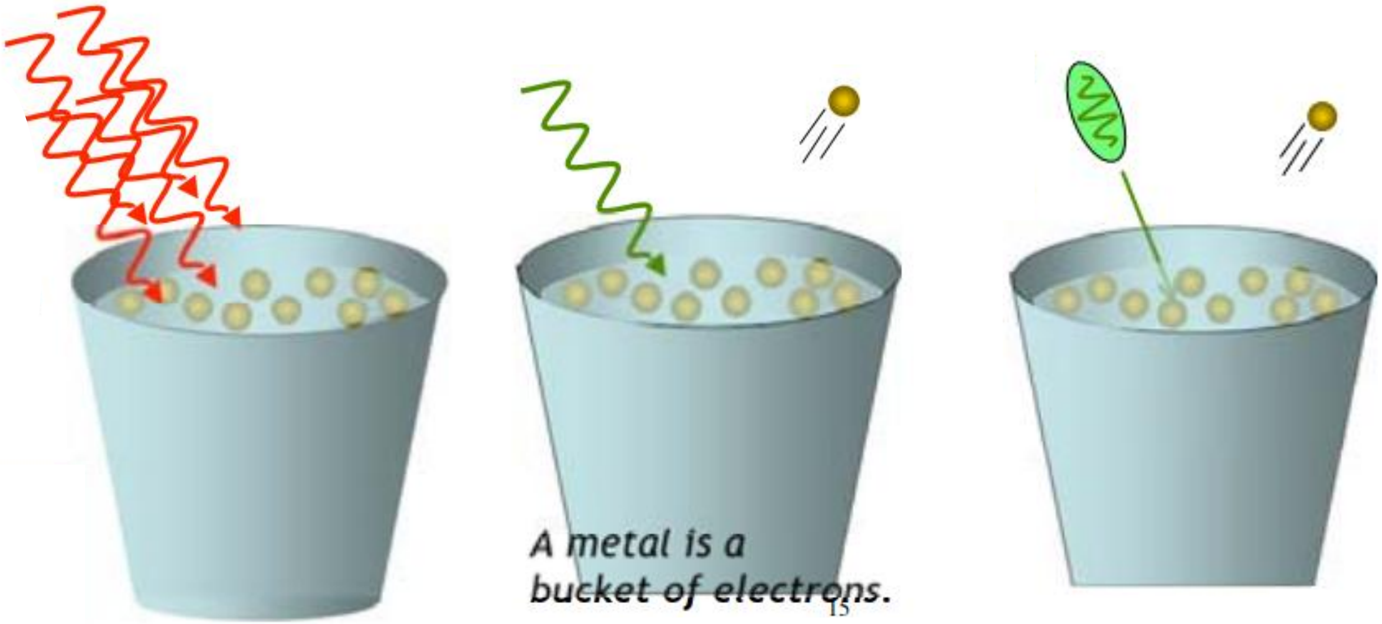
Quantum Mechanics: Photoelectric effect

Let me put this in following way

Metal-> bucket filled with electrons
In order to jump out from bucket, electron need some energy
Incident light supply this energy



EVIDENCE OF PARTICLE NATURE OF LIGHT



Quantum Mechanics: Photoelectric effect

Can wave theory of light explains this??

1. Electrons ejected from the metal instantaneously.

Energy of em waves supposed to spread across wavefront , a period of time should elapse before an individual electron accumulates enough energy to leave the metal. E.g. A detectable photoelectron current results when 10^{-6} W/m^2 of em energy is absorbed by a sodium surface. A layer of sodium 1 atom thick and 1m^2 in area contains 10^{19} atoms. Each atom receives energy at an average rate of 10^{-25} W. At this rate over a month would be needed for an atom to accumulate energy of the magnitude that photoelectrons from sodium surface are observed to have.

2. There is a cut-off wavelength λ_o such that beam of light (radiation) of wavelength larger than λ_o does not cause electrons to be ejected from the metal, however strong be the source.
3. The maximum kinetic energy of the photoelectrons from a metal depends only on the wavelength of light and not on intensity.

EM theory of light predicts more intense the light, greater is the energy of electrons.

Quantum Mechanics: Photoelectric effect

Einstein's explanation in 1905 ; GOT NOBEL PRIZE FOR HIS WORK

- Light consist of particles, individual ***particles known as photon***, each with energy hν (where ν is frequency).
- PHOTON term was coined by the chemist Gilbert Lewis in 1926.

- Photon must have minimum energy (with frequency ν_o) to knock electron out of the metal.

- If photon doesn't have enough energy, cannot knock electron out.

- *More intensity of incident radiation will increase the* ***number of photoelectron*** *and not their kinetic energy.*

$$\phi = h\nu_o$$

$$h\nu = \phi + KE_{max}$$

$$h\nu = h\nu_o + KE_{max}$$

$$KE_{max} = h(\nu - \nu_o)$$

- *With fixed ν_o,* ***kinetic energy of emitted photoelectrons*** *is dependent only on frequency of incident EM radiation (ν).*

Quantum Mechanics: Photoelectric effect

Einstein's explanation in 1905 ; GOT NOBEL PRIZE FOR HIS WORK

- Summarizing the photoelectrons properties

Photoelectron

photocurrent

Depends on no. of photoelectrons generated

Intensity of incident light

kinetic energy

Depends on incident energy of em radiation

Frequency of incident light

$$\phi = h\nu_o$$

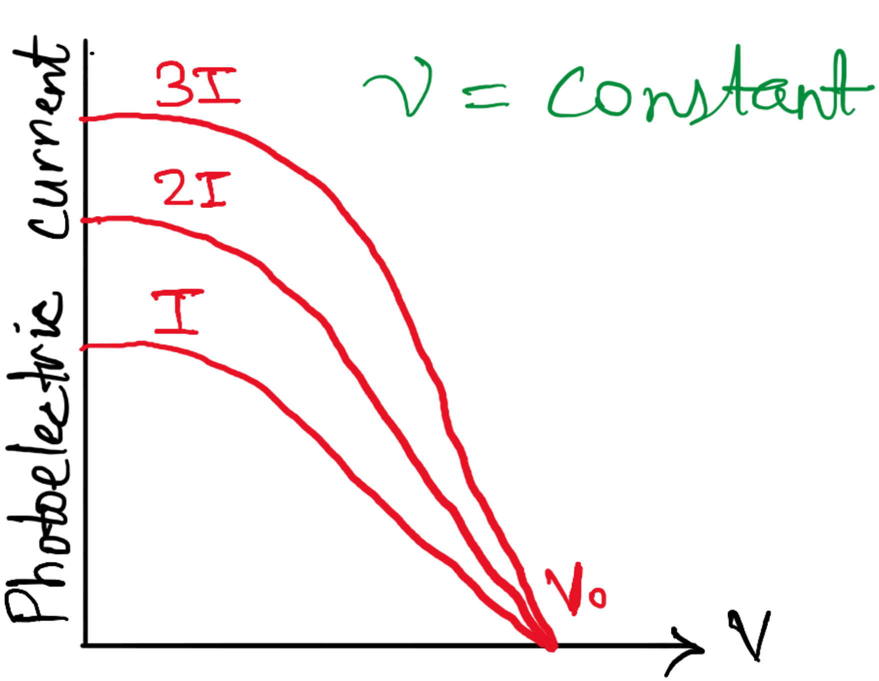
$$h\nu = \phi + KE_{max}$$

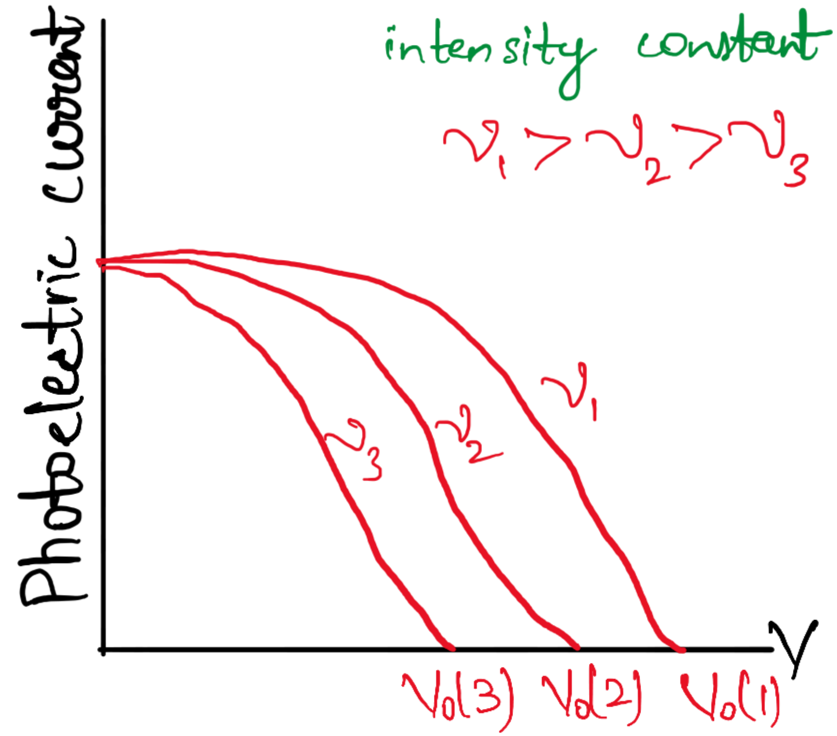
$$h\nu = h\nu_o + KE_{max}$$

$$KE_{max} = h(\nu - \nu_o)$$

- *With fixed ν_o, Kinetic energy of emitted photoelectrons is dependent only on frequency of incident em radiation (ν).*

Quantum Mechanics: Photoelectric effect





Since ν is constant, so as V_o
But the number of photoelectrons -> photocurrent
Photocurrent-> dependent on intensity
Greater the intensity, greater is amount of photocurrent

Since $Intensity$ is constant, so as photocurrent
KE of photoelectrons -> incident ν
Higher ν -> higher KE
Greater the KE, greater is stopping potential