Engineering Physics (2025)
Course code 25PY101
Unit 2: Quantum mechanics

Course Instructor:
Dr. Sreekar Guddeti
Assistant Professor in Physics
Department of Science and Humanities
Vignan's Foundation for Science, Technology and Research

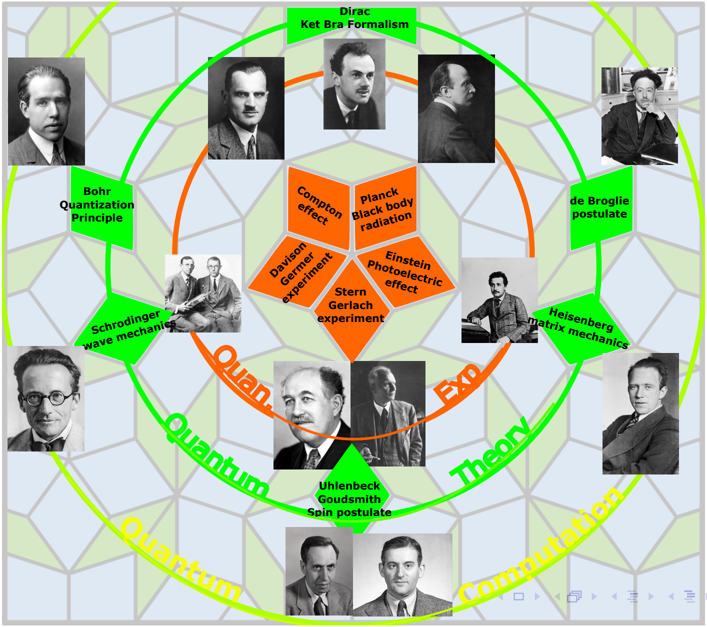
October 23, 2025

Unit 2 Plan

1. Introduction to QM
2. Dual nature of radiation
3. de Broglie's concept of matter waves
4. Heisenberg's uncertainty principle
5. Schrödinger's time dependent wave equation
6. Particle in a 1D box
7. Quantum dots
8. Finite Potential well – Quantum tunnelling

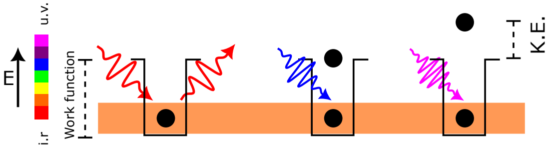
Unit 2 Plan

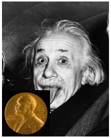
Quantum mechanics jigsaw puzzle



Definition

Light of **suitable** frequency leads to **instantaneous** emission of electron from a metal surface.



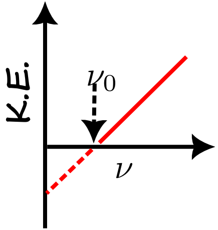


A. Einstein

- Discovered by Albert Einstein in 1905.
- The emitted electron is called the **photo-electron**.
- The minimum energy required to emit an electron is a material property and is called the **work function** of the metal.

Classical explanation of photo-electric effect

- Light is a wave with energy given by its intensity.
- Therefore, even low-frequency light (if sufficiently intense) should eventually provide enough energy to eject electrons — though perhaps after some time delay.
- But it is observed that
  - Emission of electrons is instantaneous – even for low intensity light as long as frequency of light is above a certain threshold ν_0.
  - No electrons are emitted if the frequency is below the threshold, no matter how intense the light is.
  - The kinetic energy of emitted electrons depends on the frequency of light, not its intensity.



Key Insight

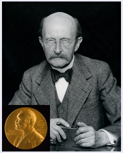
Classical electromagnetic theory cannot explain photoelectric effect!

Quantum mechanical explanation of Photoelectric effect

- Albert Einstein borrowed the idea of **quantum**[1] from Max Planck's theory of blackbody radiation and applied to photoelectric effect.

Planck's law

- Max Planck postulated that the light energy is absorbed or emitted by matter in is a packet of energy. The quantum of energy is related to the frequency ν by $E = h\nu$ where h is the **Planck's constant** given by 6.625×10^{-34} J s.
- The quantum of light energy is called **photon**.



Max Planck

Estimate: Energy of infra-red photon

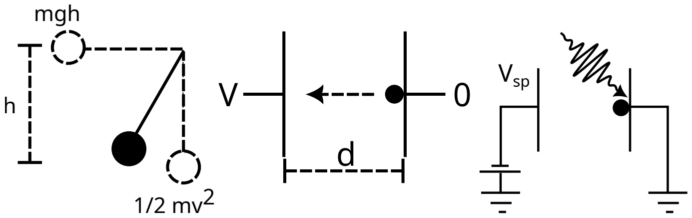
Wavelength of infra-red photon is 1 µm. [Hint: $c = \nu\lambda$]

[1] "Quantum" is Latin for "a certain amount". In the context of physics, the word quantum refers to a **packet**.

Photoelectric effect: experiment

Theorem

An electron under potential difference of V gains kinetic energy of eV.



Proof.

- Electric field is $E = \frac{V}{d}$.
- Acceleration is $|a| = \frac{eE}{m}$.
- Initial velocity $u = 0$. Final velocity is $v^2 = 2ad$.
- Kinetic energy K.E. $= \frac{1}{2}mv^2 = eV$.

□

Photoelectric effect: energy equation

- Photon with energy $E = h\nu$ transfers energy to the electron, to overcome the work function Φ. The rest of the energy is photoelectron's kinetic energy.

$$\text{K.E.} = h\nu - \Phi$$

- The photoelectrons generate photocurrent.
- In the experiment, the photo electron emitted is decelerated by applying a **stopping potential** V_{sp} till the photocurrent is zero. Thus,

$$\text{K.E.} = eV_{sp}$$

- Therefore, frequency is related to stopping potential as

$$eV_{sp} = h\nu - \Phi$$

- The plot of $\nu(\rightarrow x)$ vs $V_{sp}(\rightarrow y)$ is a straight line $y = mx + c$ with slope $m = h/e$ and y-intercept $c = -\Phi$.
- The x-intercept is the minimum frequency of photon to generate photo-current and is called the **threshold frequency** $\nu_0 = \frac{\Phi}{h}$.

Photoelectric effect: momentum equation

- From Einstein's special theory of relativity, the momentum of a particle of mass m is related to its total energy E by

$$E^2 = p^2c^2 + m^2c^4$$

  where c is the velocity of light.

- If the light is considered as a massless particle i.e. $m_{\text{photon}} = 0$, then

$$E = p_{\text{photon}}c \Rightarrow p_{\text{photon}} = \frac{E}{c}$$

- However, the velocity of light is related to its wavelength and frequency by

$$c = \nu\lambda$$

- Using the Planck's law for the energy of photon, the momentum is given by

$$p_{\text{photon}} = \frac{h}{\lambda}$$

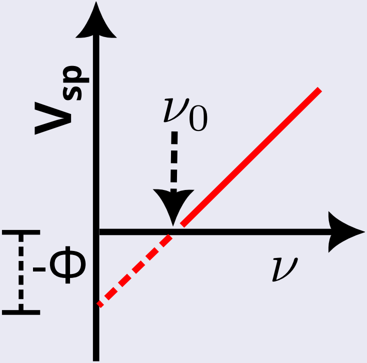
Photoelectric effect: problems

Estimate: Energy of X-ray photon

Wavelength of X-ray photon is 0.708 Å.

[Hint: (a). $E \propto 1/\lambda$. (b). $E_{\lambda=1\,\mu\mathrm{m}} = 1.24\,\mathrm{eV}$]

Problem



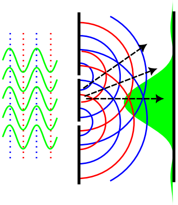
The work function Φ of Au is 4.90 eV.

1. *A blue photon is incident on Au. Does it emit photo-electron? If yes, what is the stopping potential required to have zero photocurrent.* [$\lambda_{\mathrm{blue}} = 460\,\mathrm{nm}$]
2. *Determine the threshold frequency* ν_0 *for photon emission of electrons for Au.*

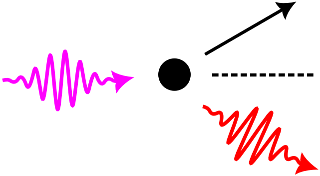
Repeat the above steps for Cs with work function 1.90 eV.

Unit 2 Plan

Radiation: Wave vs Particle

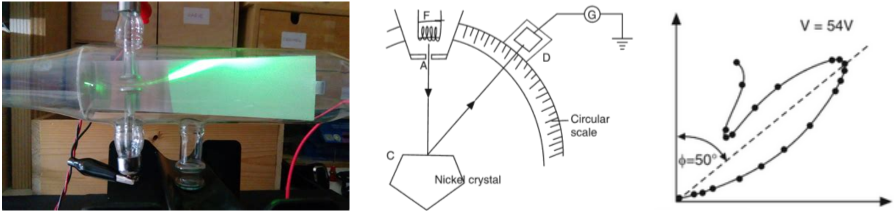


- Young's double slit experiment
- Discovered in 1801
- Light is a wave with amplitude, frequency and wavelength
- **Principle of superposition**: Waves superpose leading to constructive and destructive fringes.
- Animation for double slit experiment [Click]



- Compton effect
- Discovered in 1923.
- Light is a particle with momentum!
- **Conservation of momentum**: Light redshifts (wavelength increases) upon scattering off an electron.

Matter: Particle vs Wave



(a)cathode ray tube, Davison-Germer experiment (b) and data (c).

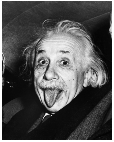
- Thomson's cathode ray tube experiment
- Discovered in 1897
- Electron is a particle

- Davisson and Germer experiment
- Discovered in 1927.
- Electron is a wave!

Key Insight

The name of the game is light-matter interaction. And nature plays the game in a **symmetric** fashion!

Summary of nature of light-matter interaction

	Wave	Particle
Light	 Young's double slit[2]	    Einstein's photo-electric effect Compton's scattering effect
Electron	   Davison's and Germer's diffraction experiment	  Thomson's cathode ray tube experiment

[2]British polymath who has been described as "The Last Man Who Knew Everything" and disproved Newton's corpuscular theory of light.