BEFORE MTE

UNIT 1 Electromagnetic Theory

UNIT 2 Laser and Application

UNIT 3 Fiber Optics

Quick QUIZ

Quick Quiz Response on the 9/14/2018 Lecture

No	Question	Attempts	Right	Wrong
1	The loss in signal power as light travels down a fiber is called	43	31	12
2	A dielectric waveguide for the propagation of electromagnetic energy at light frequencies is know as	43	31	12
3	Which of the following is used as an optical transmitter on the Fiber Optical Communications?	43	11	32
4	Which of the following is used as an optical receiver in fiber optics communications?	43	14	29

The loss in signal power as light travels down a fiber is called

a. Dispersion

b. Scattering

c. Absorption

d. Attenuation

Ans: D

A dielectric waveguide for the propagation of electromagnetic energy at light frequencies is know as

a. Stripline
b. Microstrip
c. Laser beam
d. Optical Fiber

Ans: D

Which of the following is used as an optical transmitter on the Fiber Optical Communications?

a. Avalanche Photo Diode APD

b. Tunnel diode

c. PIN diode

d. Light Emitting Diode

Ans: D

Which of the following is used as an optical receiver in fiber optics communications?

a. Avalanche Photo Diode (APD)

b. Tunnel diode

c. Laser diode

d. Light Emitting Diode (LED)

Ans: A

UNIT 4 Quantum Mechanics

LECTURE 1

UNIT 4: Quantum Mechanics

Syllabus

Need of quantum mechanics, photoelectric effect, concept of de Broglie matter waves, wavelength of matter waves in different forms, Heisenberg uncertainty principle, concept of phase velocity and group velocity (qualitative), wave function and its significance, Schrodinger time dependent and independent equation, particle in a box

Lecture Schedule

Lecture 1 Sept 26: Need of quantum mechanics, photoelectric effect,

Importance of quantum mechanics and quantum nature of light

Lecture 2 Sept 27 : Concept of de Broglie matter waves, wavelength of matter waves in different forms,

Wave/Dual nature of matter and relation between wavelength and momentum/energy

Lecture 3 Sept 28: concept of phase velocity and group velocity (qualitative), Heisenberg uncertainty principle,

Uncertainty principle to calculate uncertainty in the measurements of physical quantities

Lecture 4 Oct. 3*:* Wave function and its significance,

Introduction to wave functions and concept of probability, basic principle in quantum physics

Lecture 5 Oct. 4 *:* Schrodinger time dependent and independent equations

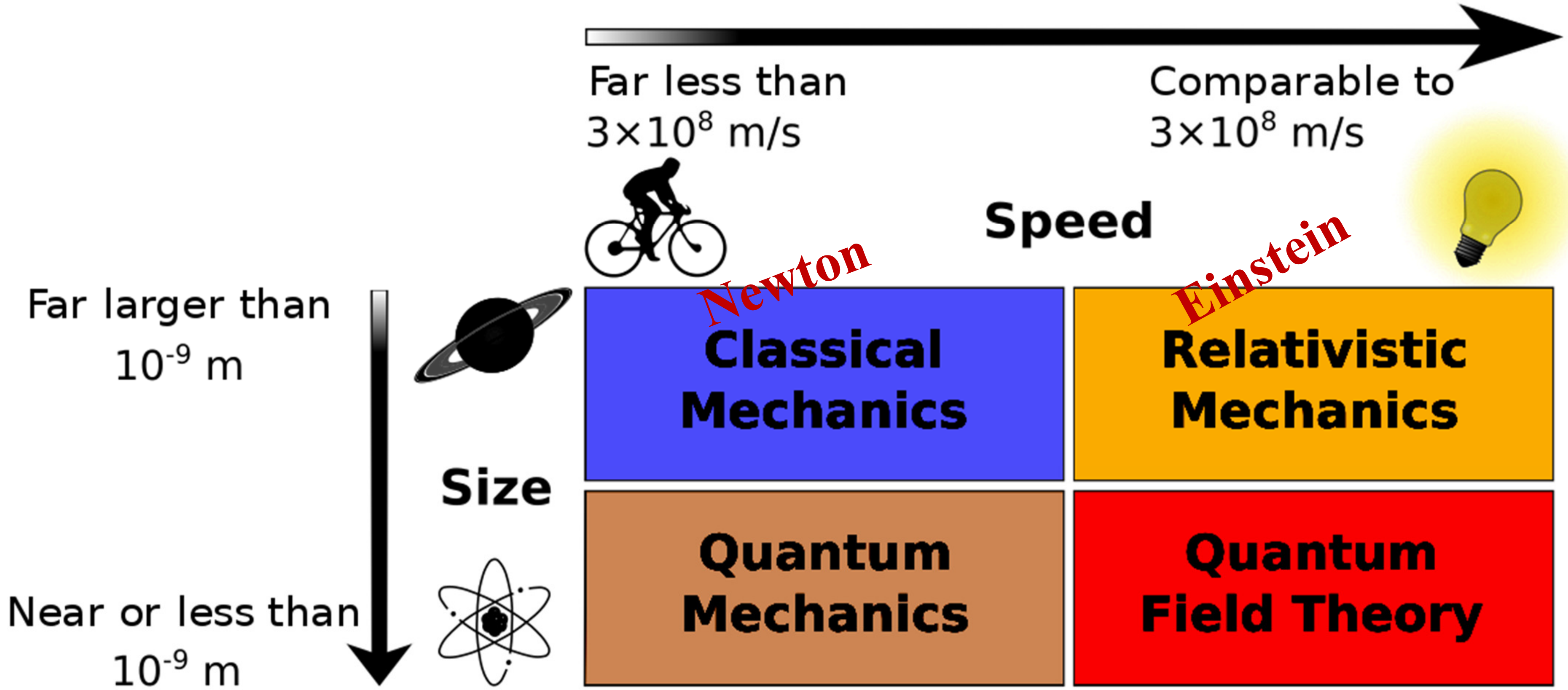
Probabilistic behavior of quantum physics

Lecture 6 Oct. 5 *:* Particle in a box (e.g., electron confined in a potential)

Energy of the particles/electrons is discrete and is quantized.

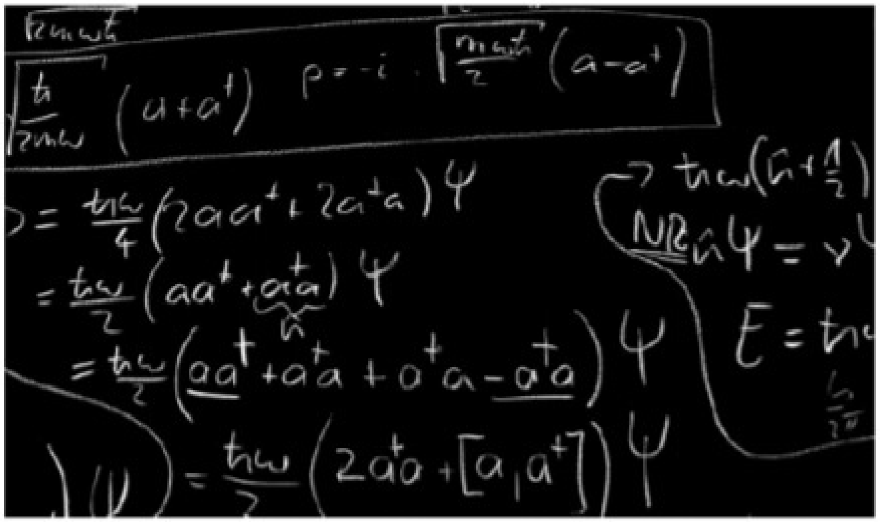
Introduction

Mechanics is one of the branches of physical sciences dealing with the behaviour of particle and wave



Introduction

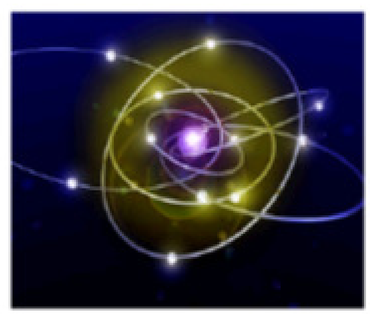
- Classical mechanics explains the very large



WHY DO WE NEED

QUANTUM MECHANICS?

Classical mechanics is the study of the motion of everyday objects in accordance with the general principles first developed by Newton with later modifications by Einstein.

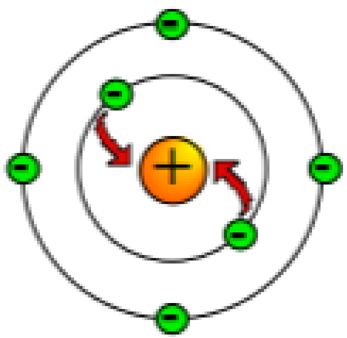


Quantum mechanics is a set of mathematical principles that attempts to explain the behavior of atoms and sub-atomic particles.

Quantum mechanics explains the very small

Classical mechanics failed to explain….

In the early 20th century experiments produced results that could not be explained by classical physics. For example, the solar system picture of an atom, first introduced by Ernest Rutherford in 1911 and modified by Neils Bohr in 1913



1. **Stability of atom** could not be explained by classical mechanics.. Because Motion of electron, protons etc could not be explained by Newton's law

Physics was in Danger! And Quantum Mechanics saved it☺

Classical mechanics also failed to explain….

2) Spectral distribution of black body radiation

Planck's quantum hypothesis

3) Origin of discrete spectra of atoms

4) Photoelectric effect

particle nature of light by Einstein

5) Crompton effect

6) Raman effect

Wherever classical mechanics fails Quantum mechanics rises!!

Unexplained Phenomena

- Two unexplained events in the study of optics led to the creation of quantum theory.
- Why does molten metal emit light? (hotbody or blackbody radiation)
- Why does UV light discharge electrically charged metal plates? (photoelectric effect)

We will learn these two events today!

Down the memory lane

Quantum mechanics is one of the branches of physical sciences dealing with the behaviour of particle and wave on the scale of atoms or subatomic level.

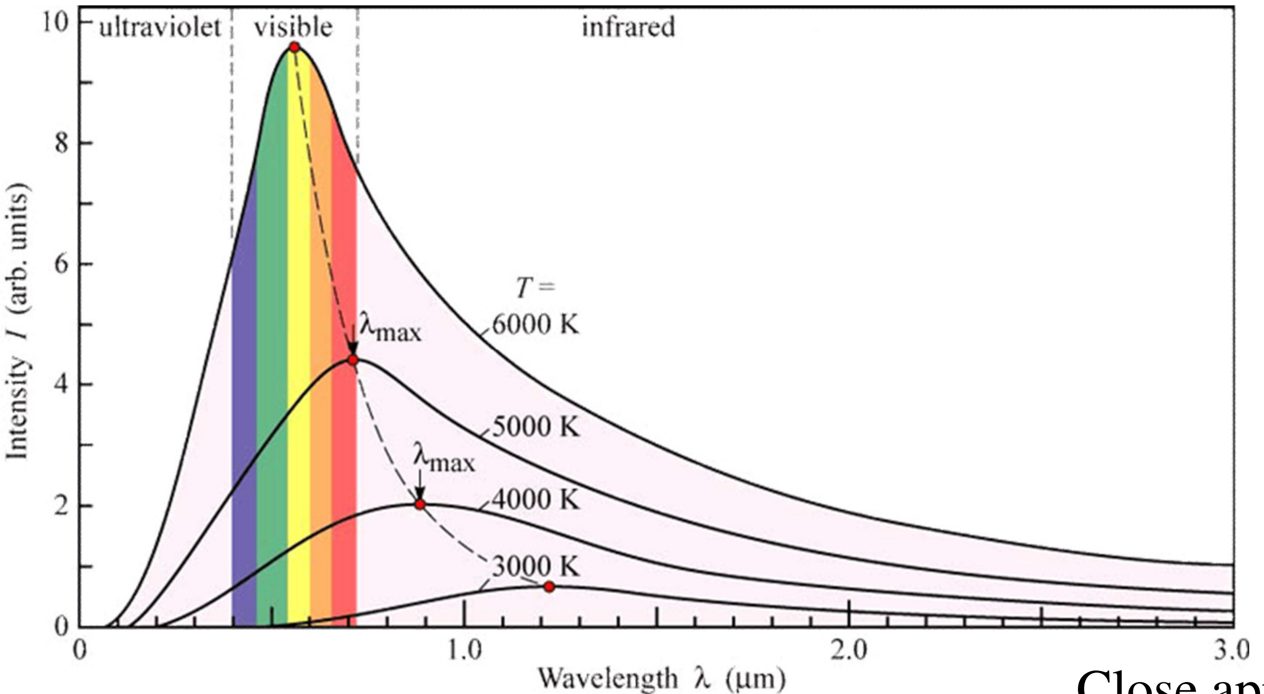
- 1900 It all started with Max Planck with the black-body problem
- 1905 Proof of the quantization of light by Einstein: Explained photo electric effect
- 1923 Louis de Broglie extends wave–particle duality to particles

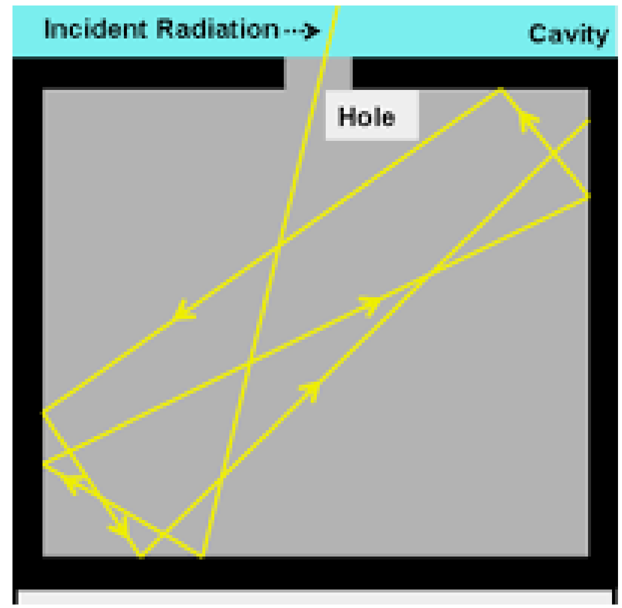
The **Planck, Einstein** and **de Broglie** relations illuminate the deep connections between energy with time, and space with momentum, and express wave–particle duality

- 1924 Quantum mechanics, first coined by Max Born
- 1926 Erwin Schrödinger developed wave equation
- 1927 Werner Heisenberg formulates the quantum uncertainty principle

Intense research between 1900 - 1928 led to the developments of quantum mechanics and we are going to study that in UNIT 4☺

BLACK BODY RADIATION





Close approximation of a black body

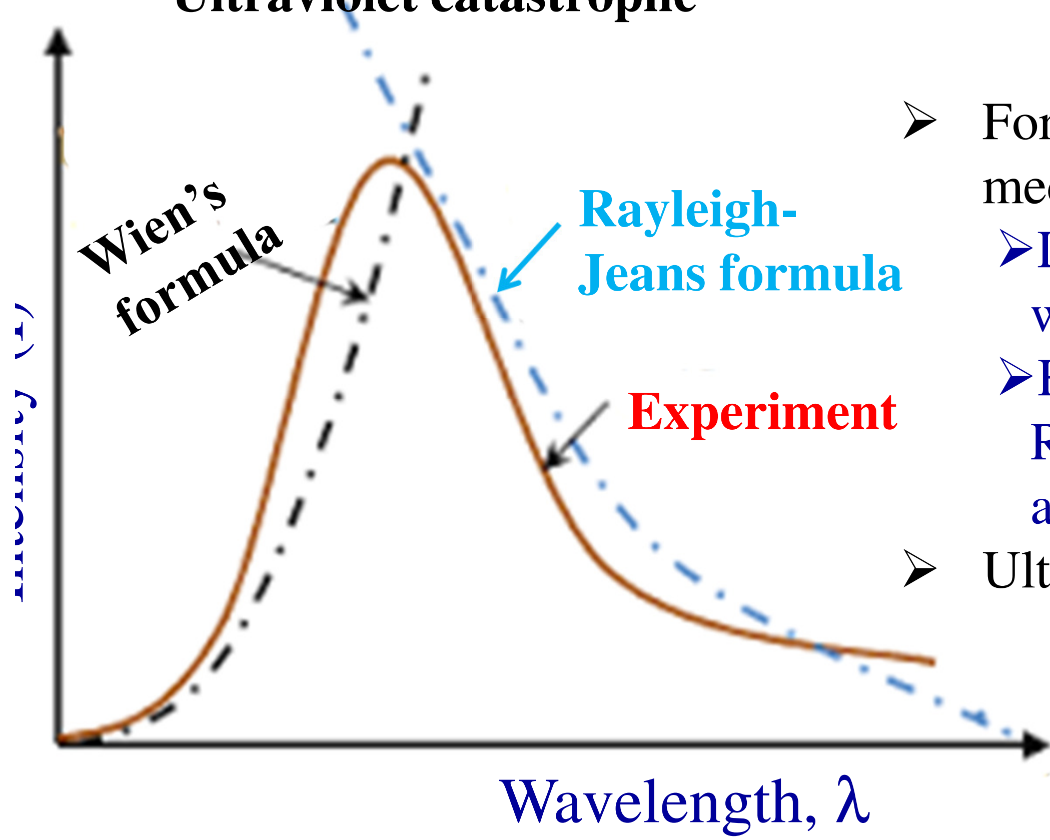
How do we see color?

What about the perception of color 'black' ??

When we heat this black body it radiate EM radiation of all frequencies as depicted in the graph of Intensity vs. wavelength

BLACK BODY RADIATION and Max Planck solution

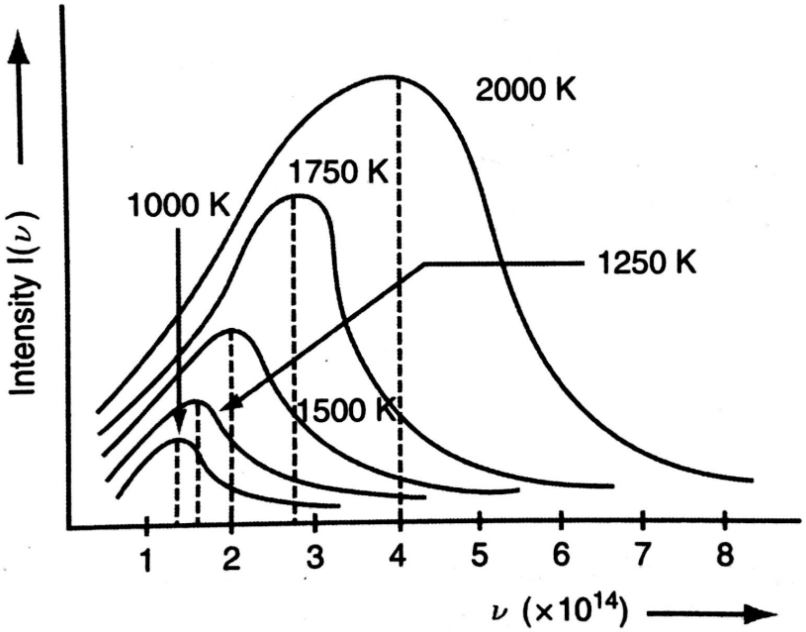
Ultraviolet catastrophe



- Formula derived using the classical mechanics partially explained
  - Low wavelength or higher frequencies wein's formula applied but valid at low T
  - Higher wavelength or lower frequencies Rayleigh-Jeans formula applied but valid at high T
- Ultraviolet catastrophe observed..

At this stage Max Planck stepped in and solved the problem
But how?... That paved the way for quantum mechanics!

BLACK BODY RADIATION and Max Planck solution



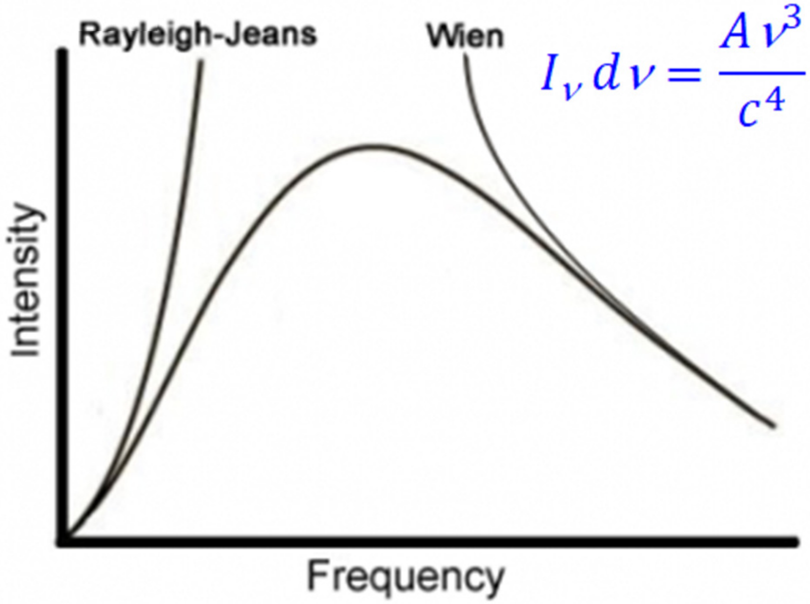
Intensity vs. Frequency

1) Distribution of frequencies depends on the Temperature of the black body
2) Intensity of radiation also depends on the temperature
3) All curve a goes through a peak, and peak position shift towards higher frequencies as the temperature increases.

BLACK BODY RADIATION and Max Planck solution

$$I_\nu d\nu = \frac{8\pi \nu^2}{c^3} kT\, d\nu$$

$$I_\nu d\nu = \frac{A \nu^3}{c^4} e^{-B\nu/T}\, d\nu$$



Explanations based on classical physics

- ➢ Standing waves and modes→ Rayleigh –Jean law
- ➢ Intensity of radiation reached a maximum at particular frequency or wavelength →Wien law

BLACK BODY RADIATION and Max Planck solution

Max Planck in 1900 assumed atomic oscillator responsible for EM radiation from black body.. But he again imposed few restrictions on it as follows, collectively known as Planck's hypothesis for black body radiation..

1. An oscillator can not have any arbitrary value of energy but can have only discrete energies as per the following relation

$E = nh\nu$ Where n =0,1,2,3…. ν and h are the frequency of oscillation and Planck's constant.

2. This oscillator can emit or absorb energy only in the form of packets of energy (hν) but no continuously.

$$\Delta E = \Delta n\, h\nu ; where\ \Delta E = E_2 - E_1\ and\ \Delta n = n_2 - n_1$$

BLACK BODY RADIATION and Max Planck solution

Planck's radiation formula

The energy density of radiation I_ν in the frequency range ν and ν+dν is given by

$$I_\nu d\nu = \frac{8\pi \nu^2}{c^3} d\nu (\bar{E})$$

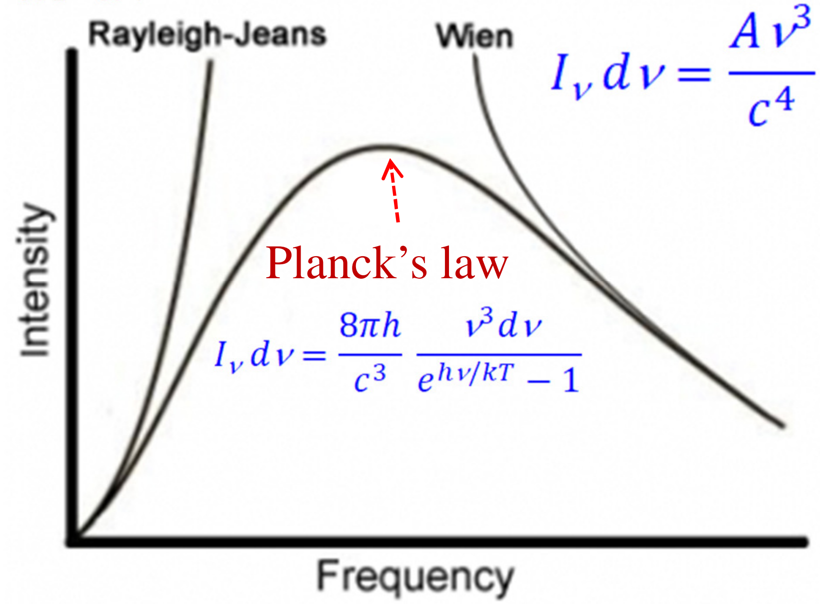
But average energy of a Planck's oscillator is given by $\bar{E} = \dfrac{h\nu}{e^{h\nu/kT} - 1}$ and the above equation changes to

$$I_\nu d\nu = \frac{8\pi h}{c^3} \frac{\nu^3 d\nu}{e^{h\nu/kT} - 1}$$

This equation is known as Planck's radiation formula. Found some where a few weeks back.. Can you remember??

$$I_\nu \, d\nu = \frac{8\pi \nu^2}{c^3} kT \, d\nu$$

$$I_\nu \, d\nu = \frac{A \nu^3}{c^4} e^{-B\nu/T} \, d\nu$$



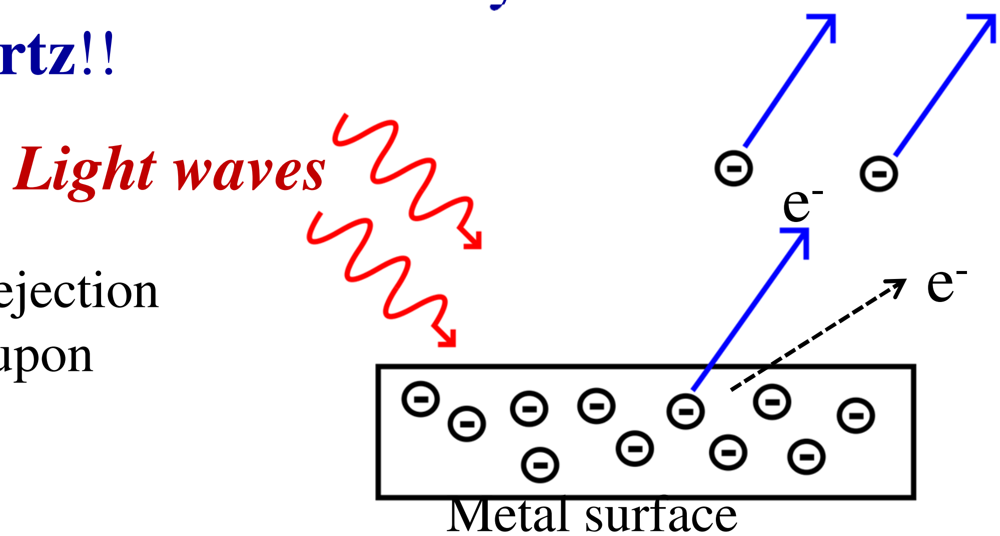
$$I_\nu \, d\nu = \frac{8\pi h}{c^3} \frac{\nu^3 \, d\nu}{e^{h\nu/kT} - 1}$$

Planck's law successfully explained black body radiation. Further, from this law Wien law and Rayleigh –Jeans law can be derived as special cases.

What does that mean?

Photoelectric effect

The photoelectric effect was discovered in 1887 by the German physicist **Heinrich Rudolf Hertz**!!

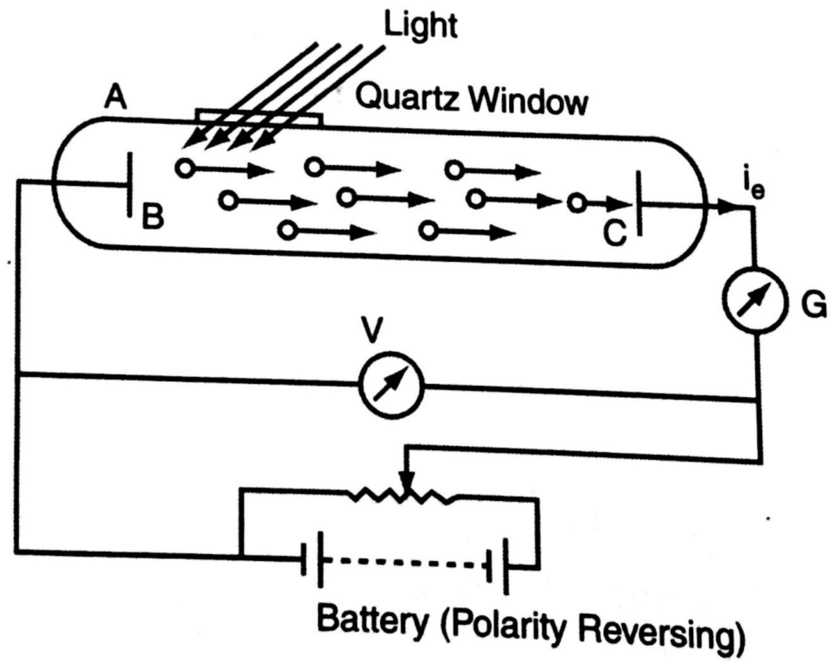


This effect says about the emission/ejection of electrons from the metal surface upon irradiation with light waves

Now we will see how this experiment is done and how to explain the result with classical mechanics

Photoelectric effect- Experiment

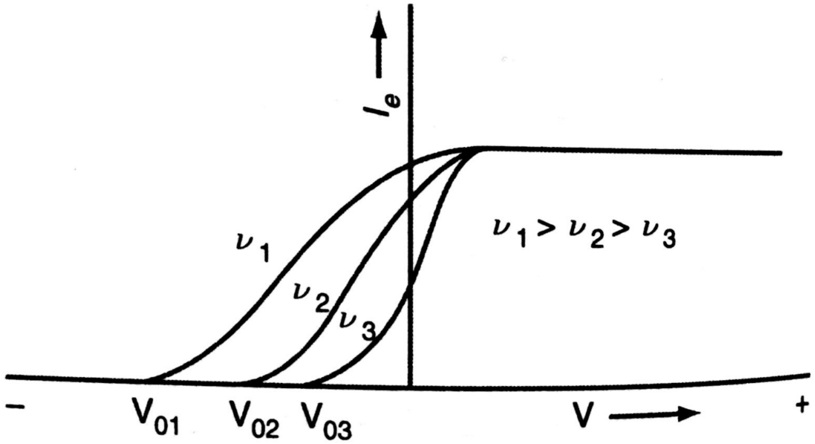
1) Vacuum tube with a quartz window
2) Two metallic plates A and B
3) Voltage source
4) An ammeter
5) Voltmeter
6) Light



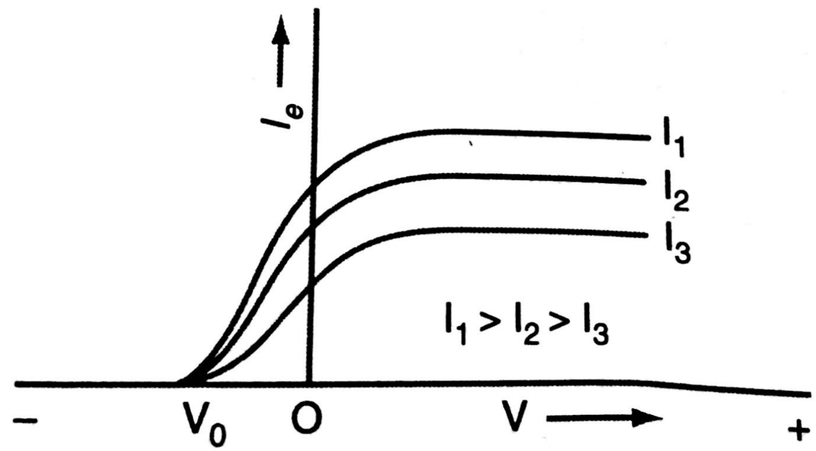
- ➢Voltage is applied to plate B while plate A is grounded
- ➢Light is allowed to fall on plate A
- ➢Photo electrons produced at plate A move towards plate B where it get collected and current Ic flow through the circuit

PE effect- I-V characteristics

At various energies of light



At various intensities of light



What classical electro dynamics (Maxwell's EM theory) say about it…

- Electron with more energy will be ejected if irradiated with highly intense light (eg. LASER)
  - But more electrons with same energy came out (same V_o)
  - Energy increased only when the frequency of light increased (V_o changes)

Leonard found the intensity does not have any influence on the energy of the ejected photoelectron, rather than it depended only on the frequency.

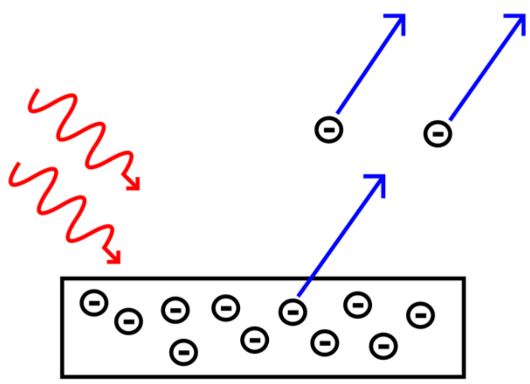
Photoelectric effect- Einstein's model

Another paradox unresolved until Einstein touched it in 1905!! But for that he used Max Planck's hypothesis used for solving black body radiation

Einstein proposed

- ✓ Incident light is like individual particles, quanta
- ✓ He coined the name **PHOTON** for quanta
- ✓ For a given frequency (ν), each photon carries the energy $E=h\nu$

a) For photoemission , one quantum is absorbed by one atom
b) Inside the metal electrons loose more energy for traveling to the surface
c) Surface electron come out with maximum energy



Photoelectric effect- Einstein's model

So electrons leave the surface with some kinetic energy, (E_k) if the photon energy is sufficiently high to knock out electron from the surface

$$E_k = h\nu - \phi_0$$

where, ϕ_0 is work function of the metal; energy required to remove electron from the surface to vacuum level

$$E_k = h\nu - h\nu_0$$

where

$$h\nu_0 = \phi_0$$

So there is minimum light frequency called *threshold frequency* (ν_0) for given metal at which quantum of energy is equal to the work function

Light having energy below this will not cause photoemission

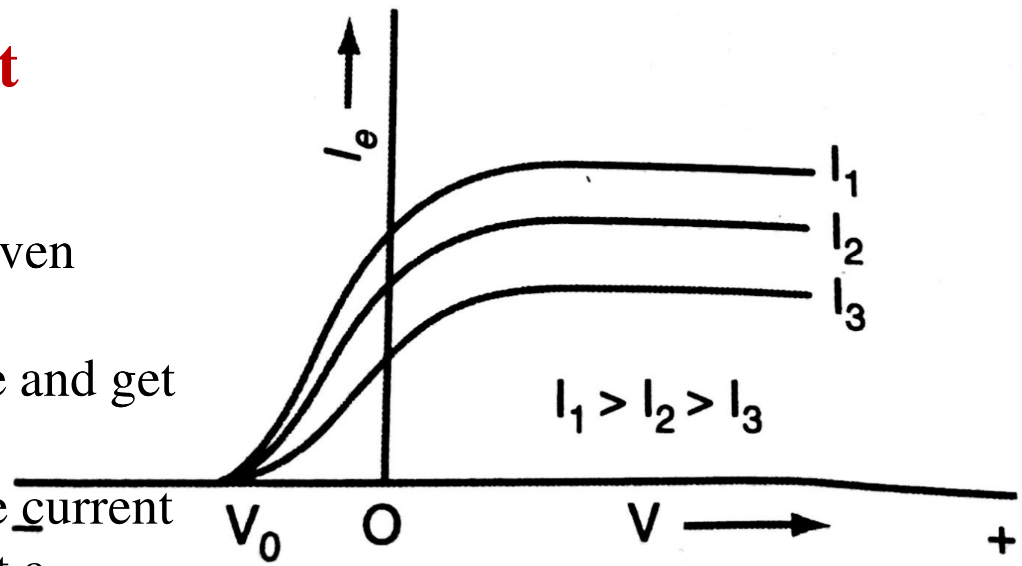
High intensity (number of photons/unit time) cause ejection of more electrons with the same kinetic energy

Excess energy is the kinetic energy of the photoelectron

PE effect- I-V characteristics

At various intensities of light
(frequency constant)

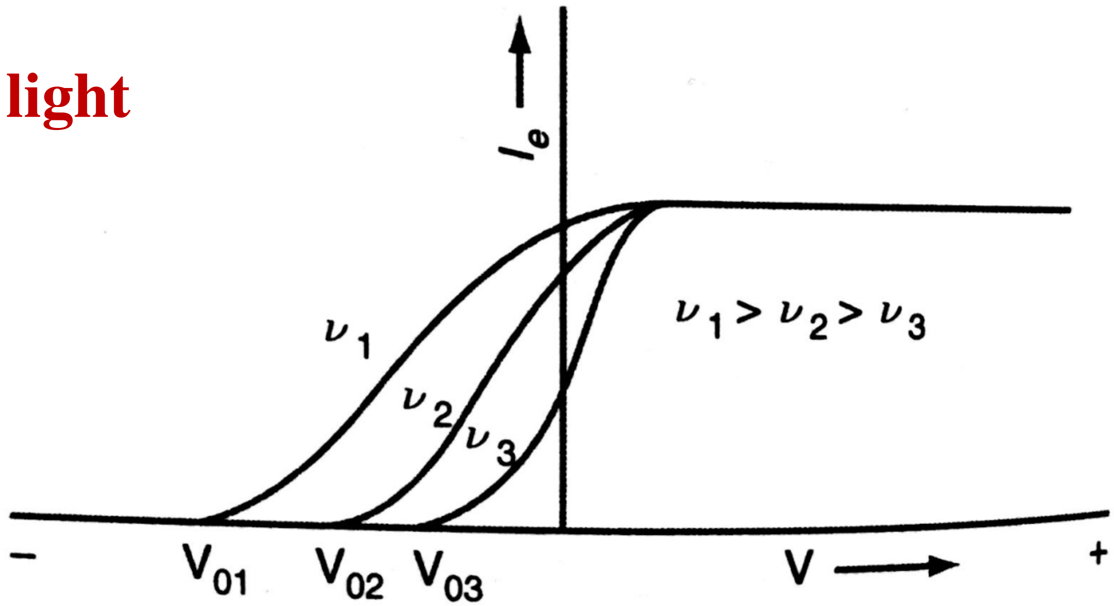
a) Current flow through the circuit even when there is voltage
b) As the voltage increase it increase and get saturated
c) Reversing the polarity reduces the current and finally current become zero at a particular voltage $\mathbf{V_0}$ called the stopping potential



- Photoelectric current I_c increases with increasing intensity
- Current flows as soon as the plate is illuminated
- The maximum kinetic energy is independent of the intensity of radiation (same V_0 for different intensity)

Photoelectric effect- Einstein's model

At various energies of light
(Constant intensity)



✓Maximum kinetic energy of the ejected electron depends on the energy of the incident radiation..

- ✓ Saturation current independent of the energy of incident radiation
- ✓ Higher energy higher is the stopping potential V_0

Photoelectric effect- Einstein's model

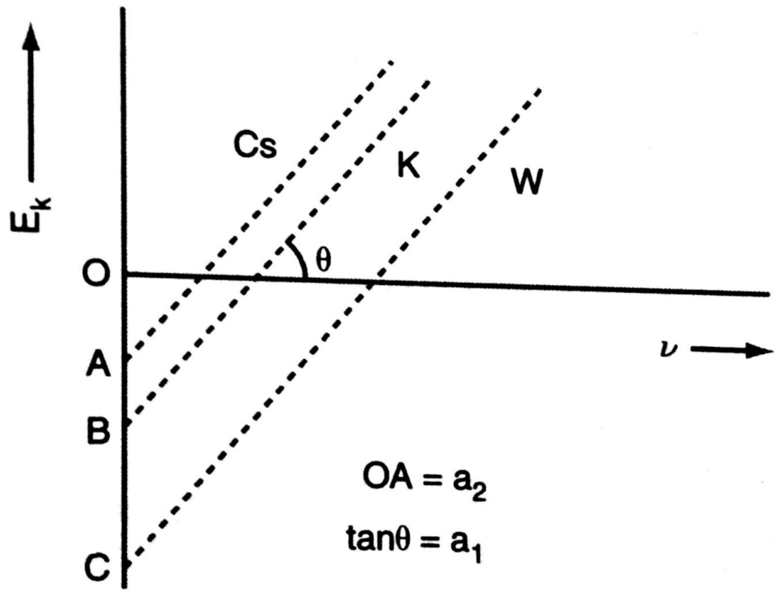
Have a look at PE equation of Einstein

$$E_k = h\nu - h\nu_0$$

And compare with the linear equation

$$y = mx + c$$

That means kinetic energy $\mathbf{E_k}$ linearly depended on the frequency $\boldsymbol{\nu}$



$$E_k = a_1\nu + a_2$$

$\mathbf{a_1}$ is the slope and $\mathbf{a_2}$ is the Y-intercept.

a_2 different for different metals

a_1 remain same for all metal and is a constant

Seed for the development of QM

An outstanding achievement.. Constant is nothing but the Planck's constant..

Particle nature of light is thus undeniable and more over supported Max Planck's hypothesis.. And quantum mechanics started to evolve from these break through ideas.

So, to answer the original question,

Why do we need quantum mechanics?

I offer the following answers.

Newton's equations and Einstein's relativity explain the properties of macroscopic objects. But quantum mechanics is essential for understanding and quantifying ...

- the growth and properties of the universe after the Big Bang,
- the structure and properties of atoms,
- the microscopic and macroscopic properties of solids such as metals and semiconductors,
- the arrangement and properties of atoms at surfaces,
- the structure and stability of molecules,

Quick QUIZ

A black body appears black because it

a) Does not reflect light

b) Does not transmit light

c) Does absorb light

d) All of the above

If we heat a black body, it does

a) radiate electromagnetic radiation in the visible region only
b) radiate electromagnetic radiation in the infrared region only
c) radiate electromagnetic radiation in the ultra violet region only
d) radiate electromagnetic radiation in the entire EM spectrum

According to Planck's hypothesis, the frequency of radiation from a black body is not continuous, but only in the multiples of a small unit called

a) Phonon
b) Proton
c) Photon
d) Polaron

Quantum Mechanics

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