# Chapter One: The Origen of Quantum theory

## Introduction

### The Physical Foundations of Quantum Mechanics

**Classical mechanics:** can explain MACROSCOPIC phenomena such as motion of billiard balls or rockets.

**Newton's mechanics** (particle is particle)

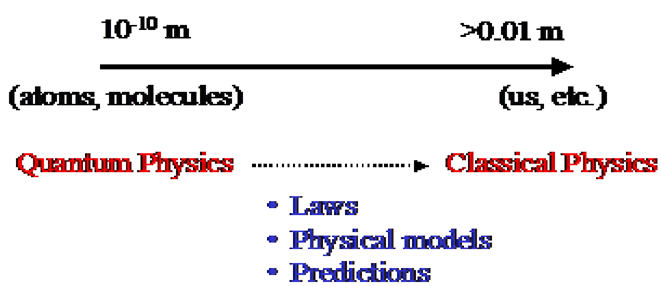
Properties (mass *m*, position **r**, velocity ***v***) ⇒ Behaviour (collisions, momentum)

**Maxwell's equations** (electromagnetics theory) (wave is wave)

Properties (wavelength, frequency) ⇒ Behaviour (diffraction, interference)

***Classical mechanics fail when we go to the atomic regime then we need to consider Quantum Mechanics.***

Quantum mechanics is used to explain microscopic phenomena such as photon-atom scattering and flow of the electrons in a semiconductor.




### Experimental Evidence for the Breakdown of Classical Mechanics

By the 20th Century, there were number of experimental results and phenomena that could not be explained by classical mechanics.

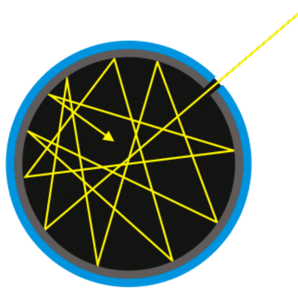
- **Black-body radiation (**1860-**1901)**
- **Atomic Spectroscopy (**1888-**)**
- **Photoelectric Effect (**1887-**1905)**
- **Compton Effect (1923).**
- **Electron Diffraction Davisson and Germer (1925).**

## 1.1 Black Body Radiation

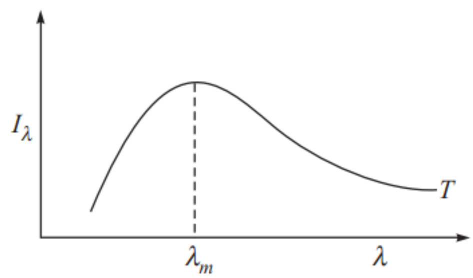
The quantum theory had its origin in the search for an explanation of the spectral distribution of radiant energy emitted by a blackbody.

An ideal blackbody is defined as one that absorbs all electromagnetic radiation incident upon it. that such a body is also a better radiator of energy, of all frequencies, than any other body at the same temperature. *An ideal blackbody does not exist.*

The nearest approximation is a hollow enclosure having blackened inner walls and a small hole. Any radiation entering the enclosure through the hole will suffer reflections repeatedly and get absorbed inside. There is very little chance of its coming out. If the enclosure is heated to a certain temperature *T*, it emits radiation. A very small fraction of the radiation will pass out through the hole. Since the hole acts as a blackbody, this radiation is called the *blackbody radiation* at temperature *T*.



Conceptual Black Body




**Wien's law**: Wien obtained the following semiempirical formula to explain the shape of blackbody radiation curve, known as **Wien's law**:

$$I(\lambda, T) = \frac{ae^{-b/\lambda T}}{\lambda^5} \quad \ldots(1.1)$$

where a and b are adjustable parameters. This law fitted the experimental curve fairly well except at long wavelengths.

**The Rayleigh-Jeans Law** was derived by applying the principles of classical physics based on the classical electrodynamics and thermodynamics.

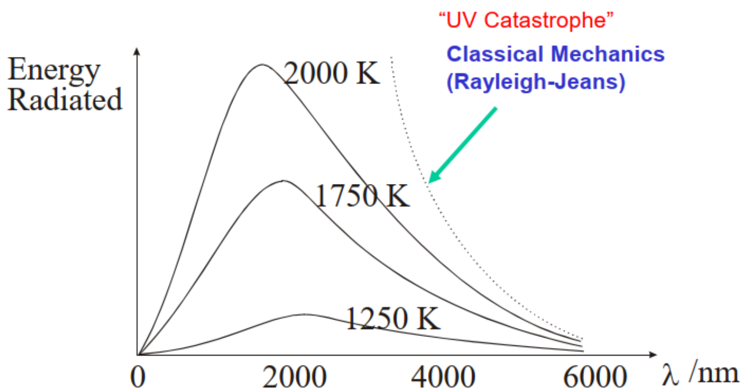
The energy density $U(\lambda, T)$ of the radiation of wave length $\lambda$ in the cavity, at temperature T,

$$U(\lambda, T) = \frac{8\pi}{4\lambda^4} kT$$

The intensity $I(\lambda, T)$ of the radiation emitted by the cavity hole is;

$$\boxed{I(\lambda, T) = \frac{8\pi c}{4\lambda^4} kT} \quad \ldots(1.2)$$

The law was derived by applying the principles of classical physics based on the classical electrodynamics and thermodynamics.




It is found that the Rayleigh-Jeans law agrees with the experimental results in the long wavelength region. However, it diverges as the wavelength tends to zero.

## Planck's Quantum Theory

**Planck (1900)** proposed that the light energy emitted by the black body is quantized in units of $h\nu$ ($\nu$ = frequency of light)

**Planck's quantum hypothesis:** *(The material oscillators (in the walls of the cavity) can have only discrete energy levels rather than a continuous range of energies as assumed in classical physics. If a particle is oscillating with frequency $\nu$, its energy can take only the values:*

$$\Delta E = nh\nu \quad (n = 1, 2, 3, \ldots) \quad \ldots(1.3)$$

- High frequency light only emitted if thermal energy $KT \geq h\nu$.
- $h\nu$ a quantum of energy.
- Planck's constant $h = 6.626 \times 10^{-34}$Js
- If $h \to 0$ we regain classical mechanics.

**The Planck's radiation law**. In terms of the wavelength $\lambda$ of the radiation,

$$\boxed{U(\lambda, T) = \frac{8\pi hc}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}} \qquad \ldots(1.4)$$

Planck's law agrees very closely with the observed spectral distribution curves for all values of $\lambda$ and T.

**PROBLEM:** Show that Planck's law reduces to Wien's law in the short wavelength limit and Rayleigh-Jeans' law in the long wavelength limit.

***Solution:*** When $\lambda$ is small, $e^{hc/\lambda kT} >> 1$. Therefore,

$$U(\lambda,\ T) \sim \frac{8\pi hc}{\lambda^5} e^{-hc/\lambda kT}$$

which is *Wien's law* (see Equation 2.1).

When $\lambda$ is large,

$$e^{hc/\lambda kT} \sim 1 + \frac{hc}{\lambda kT}$$

Therefore,

$$U(\lambda,\ T) \sim \frac{8\pi hc}{\lambda^5} \frac{\lambda kT}{hc}$$

$$= \frac{8\pi kT}{\lambda^4}$$

which is Rayleigh-Jeans' law

**Conclusions:**

Energy is quantized (not continuous).

Energy can only change by well-defined amounts.