Unit-IV

~~Quantum Mechanics~~

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Introduction

- At the end of the nineteenth century, physics consisted essentially of classical mechanics(CM), the theory of electromagnetism(EM), and thermodynamics.

Classical mechanics tells us how everyday objects move. It is the theory of **motion**.

1. An object in motion tends to stay in motion.
2. Force equals mass times acceleration.
3. For every action there is an equal and opposite reaction.

Sir Isaac Newton
1687

Mechanic

Spacecraft

Doctor

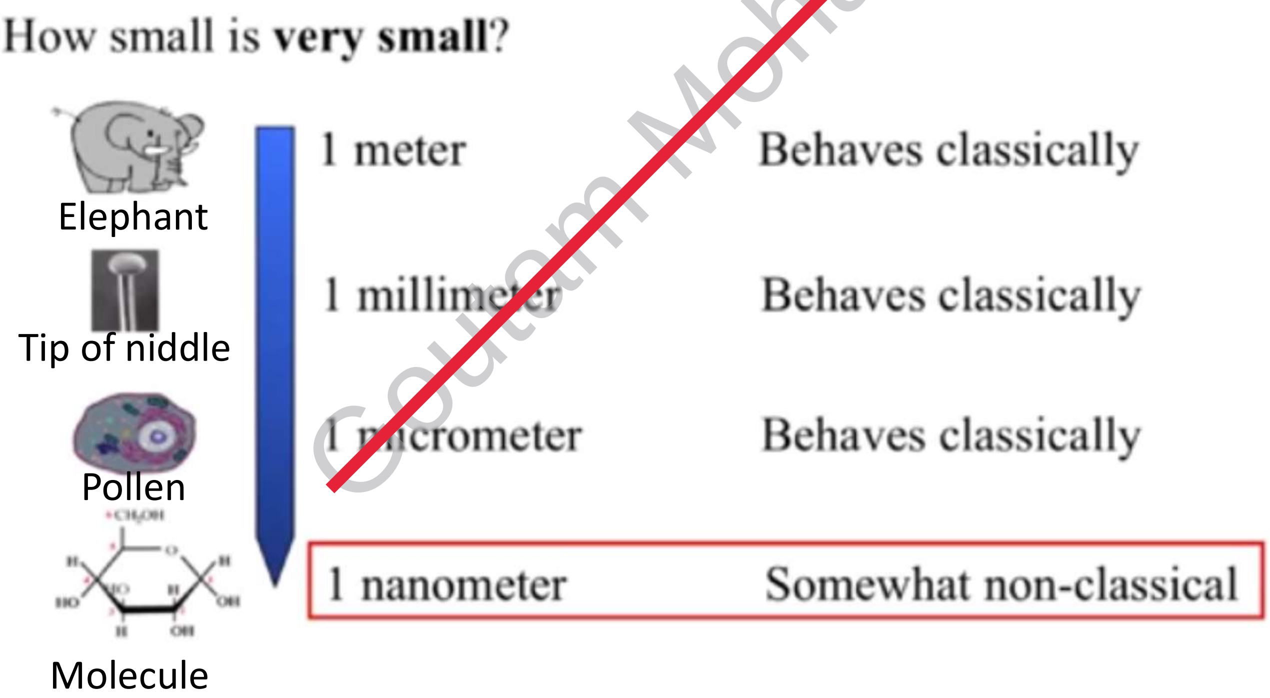
Electrician

- At the end of Nineteenth Century, Several people are reported to have said something like this:

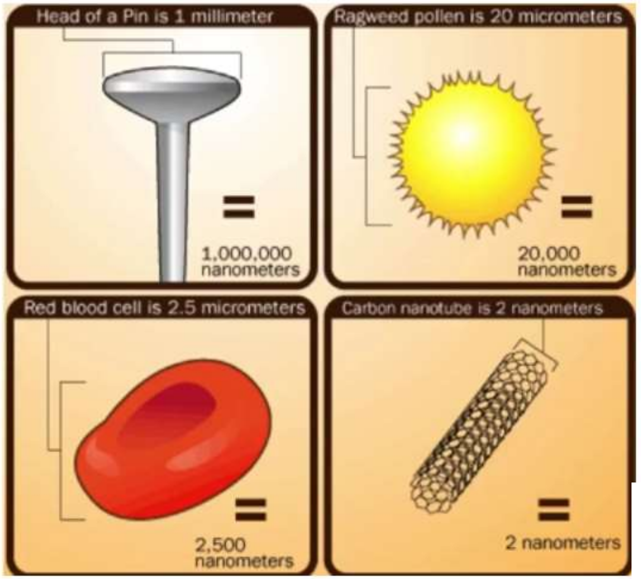
~~There is nothing new to be discovered in physics now. All that remains is more and more precise measurement !!~~

- At the turn of the twentieth century, however, classical physics, which had been quite unassailable, was seriously challenged on two major fronts: Relativistic Domain and Microscopic Domain.

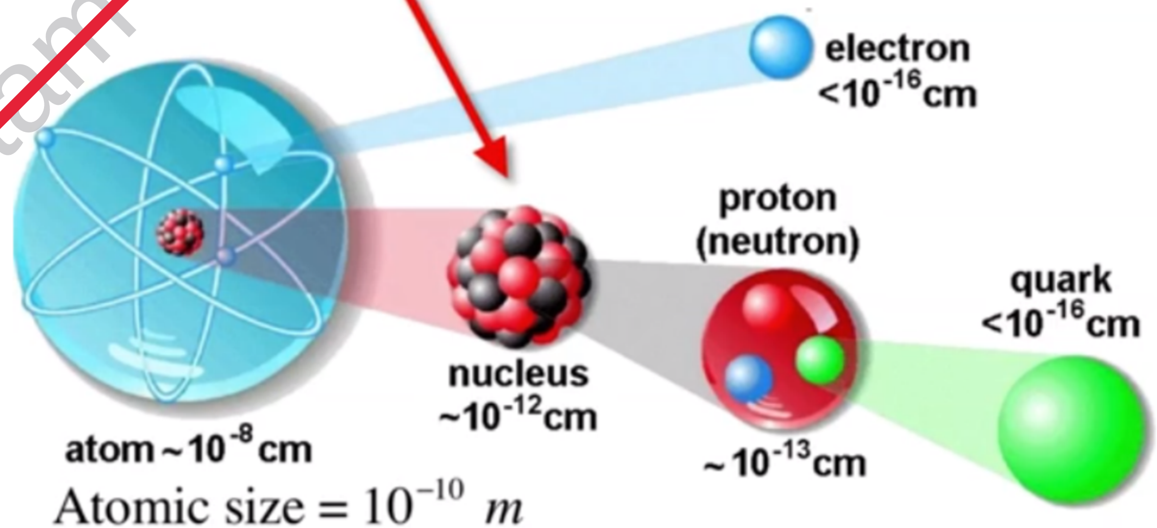
When dealing with very small things:



BIG and SMALL



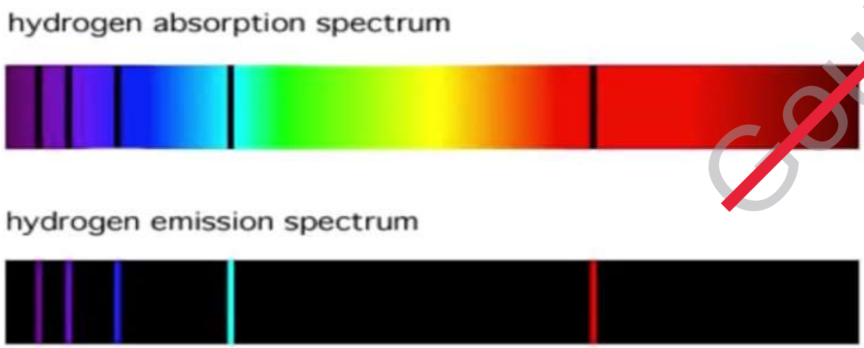
QM IS NEEDED FOR UNDERSTANDING OBJECTS THAT ARE STILL SMALLER



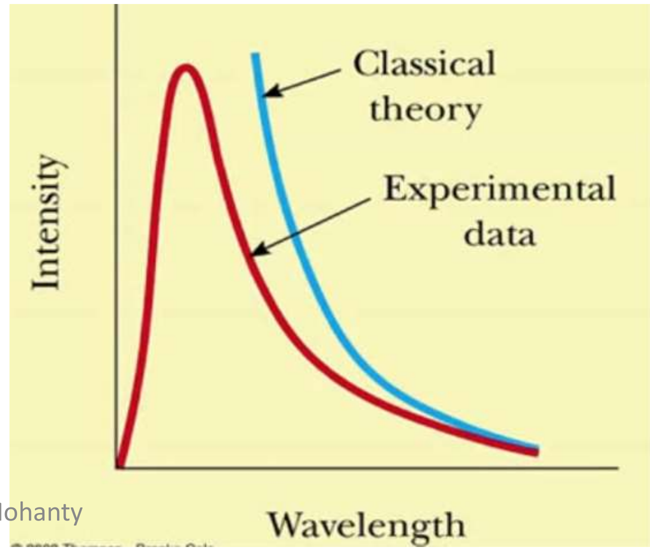
Atomic size $= 10^{-10}\ m$

Few puzzling questions

- Why do atoms absorb or emit light only at particular frequencies?
- Why do not electrons fall into the nucleus?
- Why do not atoms disintegrate on collisions?
- Where does the structure of periodic table come from?
- Why do atoms form chemical bonds?
- If you heat a body it will obviously emit radiate energy. Why is the amount of energy predicted by classical physics completely different from that which is experimentally observed?



This is a strong hint that atoms have quantized in nature.



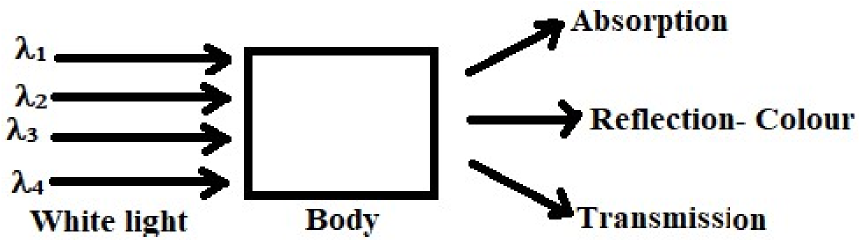
- Classical Mechanics couldn't explain the non relativistic motion of very small particles (i.e. electrons, protons etc.), stability of atoms, spectral distribution of blackbody radiation, photoelectric effect, Compton effect, Raman effect.

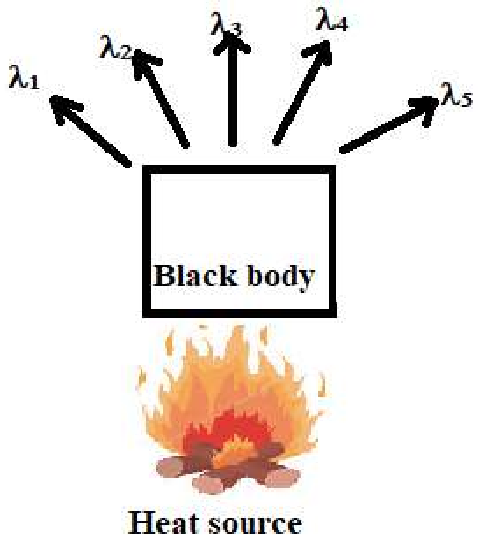
- Thus the failure of CM led to the birth of Quantum Mechanics (QM)

- In 1900, Max Planck introduced the concept of the quantum of energy. Energy exchange between an EM-wave of frequency (ν) and matter occurs only in integer multiples of hν, which he called the energy of a quantum, where h is a fundamental constant called Planck's constant and $h = 6.62 \times 10^{-34}$ J-s. ----→→explain the phenomenon of blackbody radiation.
- In 1905, Einstein explained light is made of discrete bits of energy (or tiny particles), called photons, each of energy hν, where ν is frequency of the light. The experimentally observed by Heinrich Rudolf Hertz.
- In 1913, Neils Bohr explained that that atoms can be found only in discrete states of energy and that the interaction of atoms with radiation, i.e., the emission or absorption of radiation by atoms, takes place only in discrete amounts of hν, because it results from transitions of the atom between its various discrete energy states.-→ Atomic stability and atomic spectroscopy.
- In 1923, Compton made an important discovery that gave the most conclusive confirmation for the corpuscular aspect of light.
- In 1923, De-Broglie introduced another powerful new concept --> Not only radiation does exhibit particle-like behaviour but, conversely, *material particles* themselves display *wave-like* behaviour. This concept was experimentally confirmed by Davisson and Germer (1927).

- Then after a new concept Quantum Mechanics was came in the TWO different forms: Matrix mechanics and wave mechanics
- In 1925, Heisenberg introduced matrix mechanics which describes atomic structure starting from the observed spectral lines. The only allowed values of energy exchange between microphysical systems. He describes the dynamics of microscopic systems using eigen value
- In 1926, Schrödinger described the dynamics of microscopic matter by means of a differential wave equation called the Schrödinger equation.
- In 1927 Max Born proposed his *probabilistic* interpretation of wave mechanics.
- In 1928, combining special relativity with quantum mechanics, Dirac derived an equation which describes the motion of electrons. This equation, known as Dirac's equation.
- In summary, quantum mechanics is the theory that describes the dynamics of matter at the microscopic scale.

Black Body Radiation:

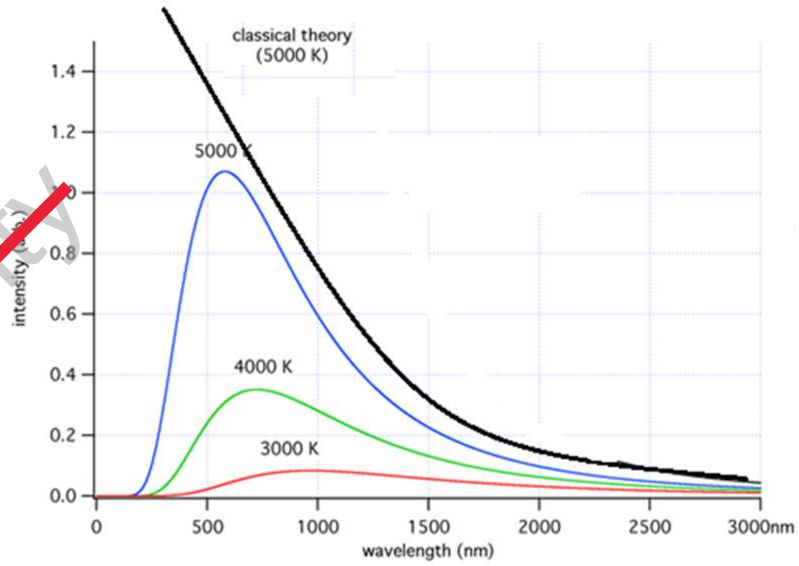




Black Body:

- A Blackbody is a body which absorbs all incident lights. But practically no perfect black body is existing.
- When black body heated it emits all radiations.
- At equilibrium, the emitted radiation has a well defined, continuous energy distribution: to each frequency there corresponds an energy density which depends neither on the chemical composition of the object nor on its shape, but only on the temperature of the cavity's walls.

- At a given temperature, the energy is not uniformly distributed in the radiation spectra blackbody.
- At a given temperature, the intensity of radiation increases with increase in wavelength and at a particular wavelength, its value is maximum. With further increase in wavelength, the intensity of radiation decreases.
- With the increase in temperature, λ_m decreases, where λ_m is the wavelength at which the maximum emission of energy takes place.
- There is increase in energy emission with the increase in temperature corresponding to all the wavelengths.
- The area under each curve gives the total energy emitted for the complete spectrum at a particular temperature. With the increase in temperature, this area increases. It is also observed that the area is directly proportional to the fourth power of the temperature of the blackbody.



$$\lambda_m T = constant$$

$$I_m/T = constant$$

$$I_{total} = \int_0^\infty I \, d\lambda = \sigma T^4$$

- Wien’s displacement law, $\boxed{\lambda_m T = b = constant}$, $b = 2.89 \times 10^{-3}\, mK$

- Wien’s spectral density, $\boxed{u(\lambda)d\lambda = \frac{A}{\lambda^5[e^{B/\lambda T} - 1]} d\lambda,}$

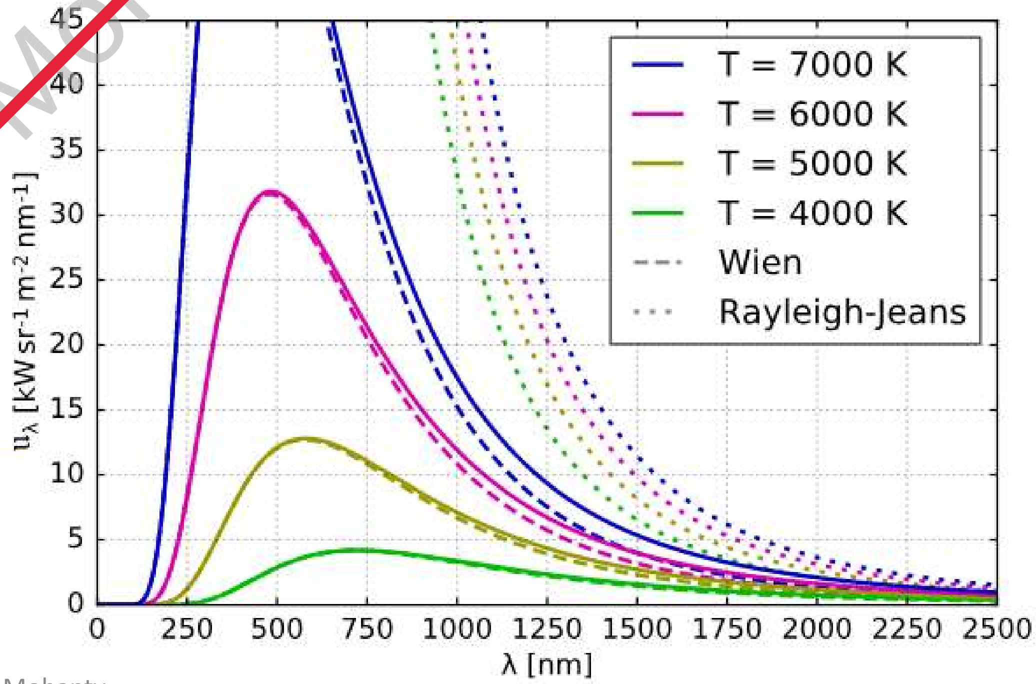
  where A and B are constant

- This Wien’s distribution law is valid for short wavelength only

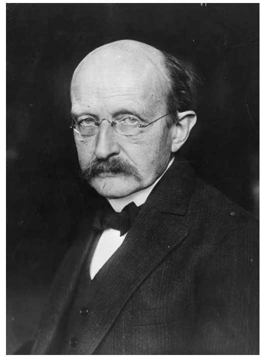
- From classical EM-theory, according to Rayleigh spectral energy density i.e. $\boxed{u(\lambda)d\lambda = \frac{8\pi kT}{\lambda^4} d\lambda}$. This is Rayleigh-Jeans Law

- This law is valid for long wavelength only.

$$\frac{I}{c} = u(\lambda) = spectral\ energy\ density$$



Planck's Hypothesis

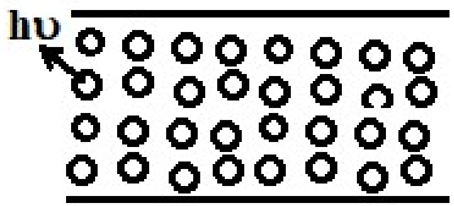


Max Planck

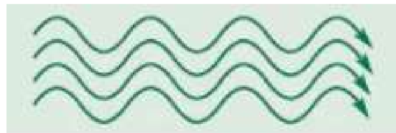
- In 1900, Planck argued that Light is made of packets of energy called quanta--> E = hν, where h= Planck's constant= 6.626x10^{-34} J-Sec
- Quantum theory began, E = hν =hc/λ
- E(eV) = 1242/λ(nm)= 1242/λ(Å)
- 1eV = 1.6 x 10^{-19} J
- From Quantum EM-theory, $u(\lambda)d\lambda = \frac{8\pi h}{\lambda^5[e^{hc/\lambda kT}-1]}d\lambda$

(or) $$\boxed{u(\nu)d\nu = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{e^{h\nu/kT}-1}d\nu,}$$

- This is called Planck's Radiation Law



Particle nature



Wave nature