Inadequecy of Classical Physics

- By end of 19th century, Classical physics had formulated theories for various physical phenomena.
- **Classical Mechanics** for describing dynamics of materials.
- **Electromagnetic theory** xplaining optical observations like Interference, Diffraction using wave nature of light.
- **Thermodynamics** for interaction between matter and energy.

- By 20th Century, Classical physics was challenged mostly in two fronts.

- In early 20th century, Eienstein's Relativity theory exposed the limitations of Newtonian mechanics at high speeds.

- At microscopic level, newly develop atomic and subatomic structures exposed Classical physics' inadequacy.

- Certain Electromagnetic phenomena like Black body radiation, Photo electric effect, etc could not be explained by Classical Physics

Some phenomena that couldn't be explained by classical mechanics

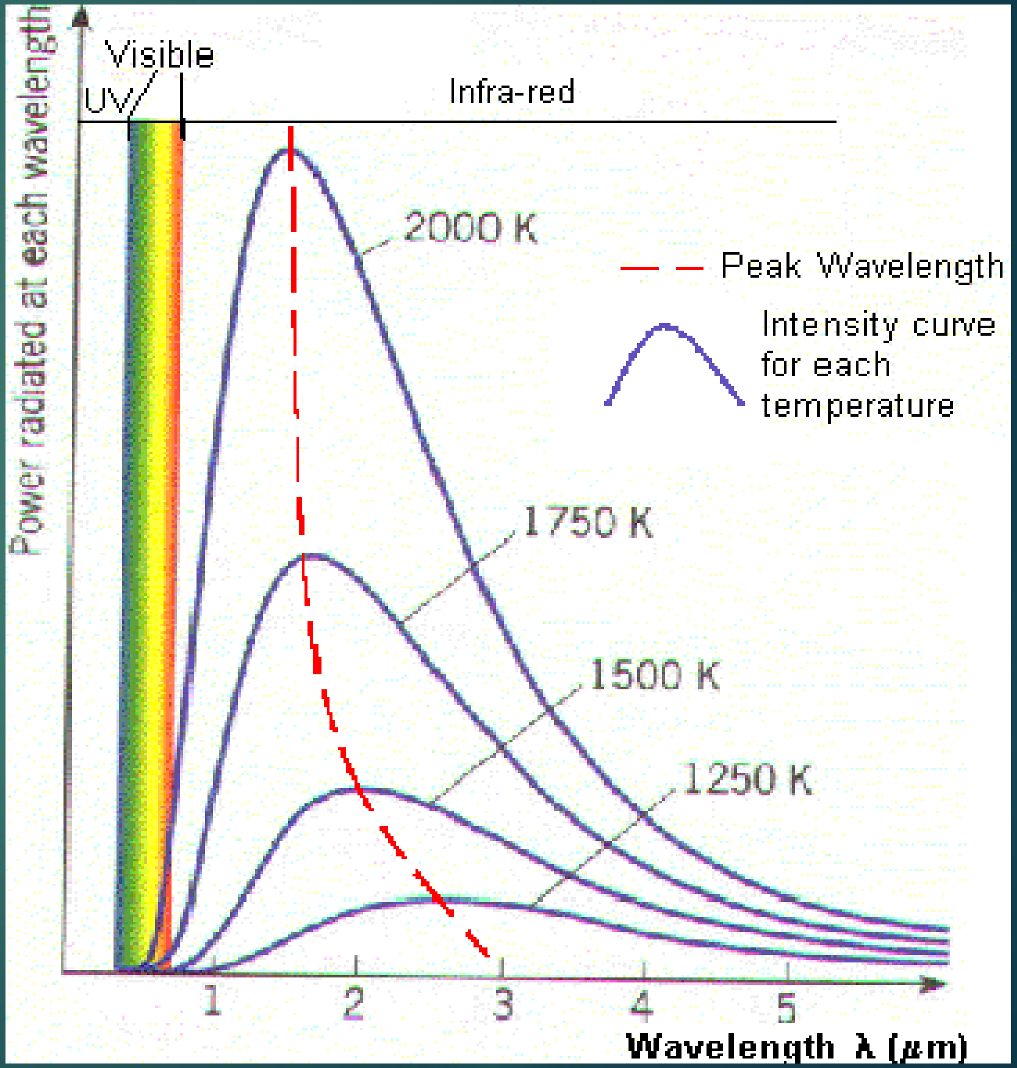
- Blackbody radiation
- Photoelectric effect
- Atomic structure

Black Body Radiation

- A black body is a theoretical object that absorbs 100% of the radiation that hits it. Therefore it reflects no radiation and appears perfectly black.
- At a particular temperature the black body would emit the maximum amount of energy possible for that temperature.
- Blackbody radiation does not depend on the type of object emitting it. Entire spectrum of blackbody radiation depends on only one parameter, the temperature, T.

Black Body Radiation

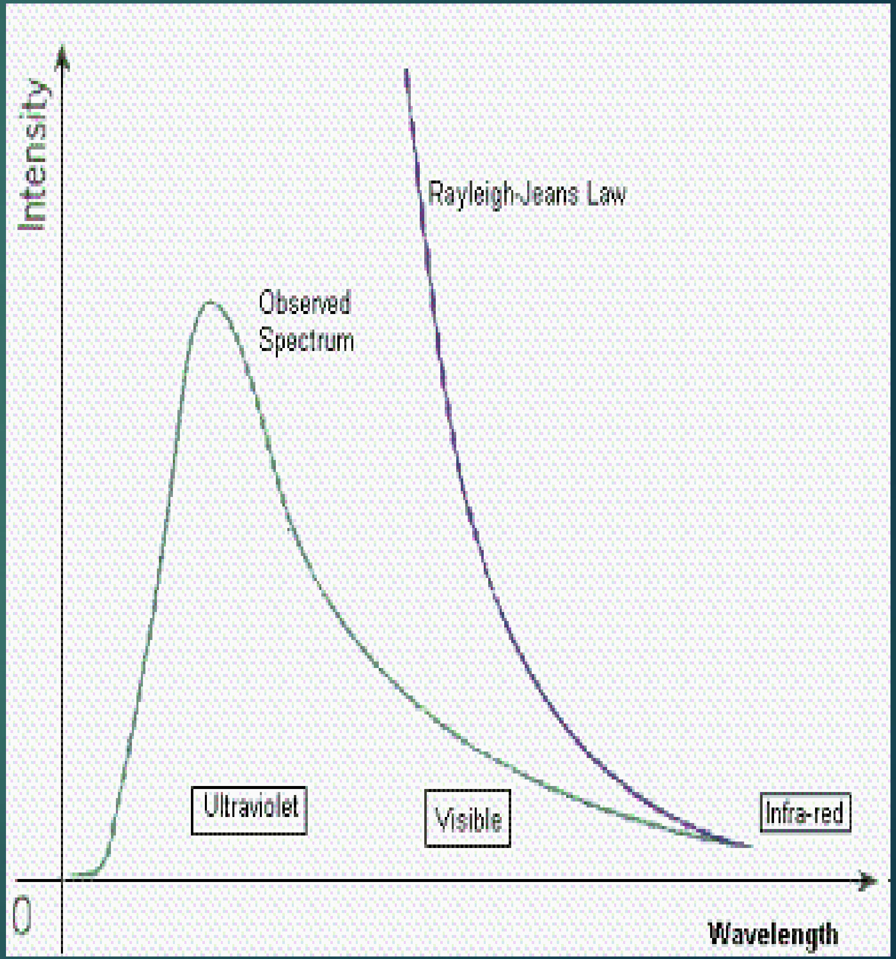
- As the temperature increases, the peak wavelength emitted by the black body decreases.
- As temperature increases, the total energy emitted increases, because the total area under the curve increases.
- The curve gets infinitely close to the x-axis but never touches it.



Black Body Radiation

- The classical physics law explaining Blackbody radiation is Rayleigh Jeans law.
- It agrees with experimental measurements for long wavelengths.
- It predicts an energy output that diverges towards infinity as wavelengths grow smaller.
- The failure has become known as the ultraviolet catastrophe thus exposing the inadequequcy of classical physics in explaining this phenomenon.

$$I(\lambda, T) = \frac{2\pi ckT}{\lambda^4}$$



Black Body Radiation

- Planck derived a formula for the observed spectrum by assuming that a hypothetical electrically charged oscillator in a cavity that contained black-body radiation could only change its energy in a minimal increment, *E*, that was proportional to the frequency of its associated electromagnetic wave.
- Thus he introduced the concept of quanta of energy which was different from classical physics approach.
- It is this new approach that successfully explained Black body radiation.

Photo-electric Effect

- The photoelectric effect is the emission of electrons from a material caused by electromagnetic radiation such as ultraviolet light.

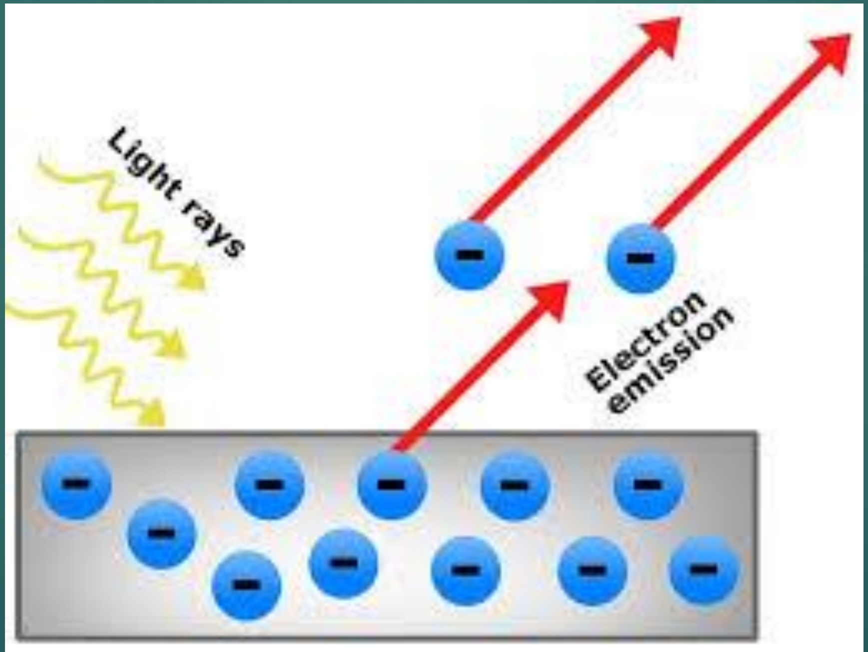


Photo-electric Effect

- The experimental results disagree with classical electromagnetism, which predicts that continuous light waves transfer energy to electrons, which would then be emitted when they accumulate enough energy.

- An alteration in the intensity of light would theoretically change the kinetic energy of the emitted electrons, with sufficiently dim light resulting in a delayed emission.

- The experimental results instead show that electrons are dislodged only when the light exceeds a certain frequency—regardless of the light's intensity or duration of exposure.

Photo-electric Effect

- Albert Einstein proposed that a beam of light is not a wave propagating through space, but a swarm of discrete energy packets, known as photons and was successful in explaining the photoelectric effect.

- Thus electromagnetic radiation could now be seen as a particle, opposite to the wave nature predicted by Classical physics.

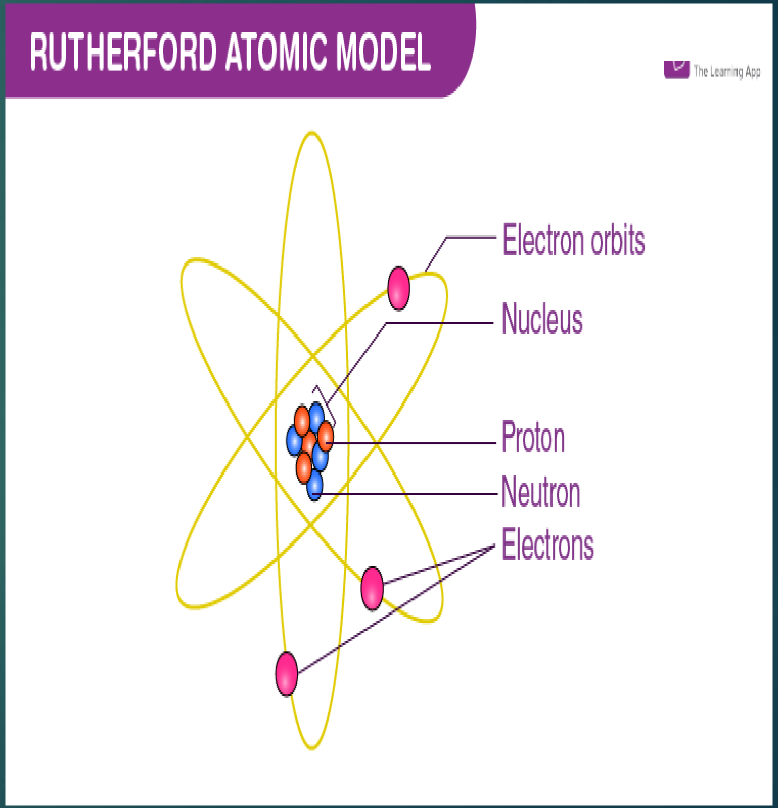
- In fact light is said to have a dual nature, both as a particle and wave, something unthinkable in classical physics, thus exposing the inadequacy of classical physics.

Atomic Structure

- Based on the scattering experiments, Rutherford proposed a model for atomic structure.

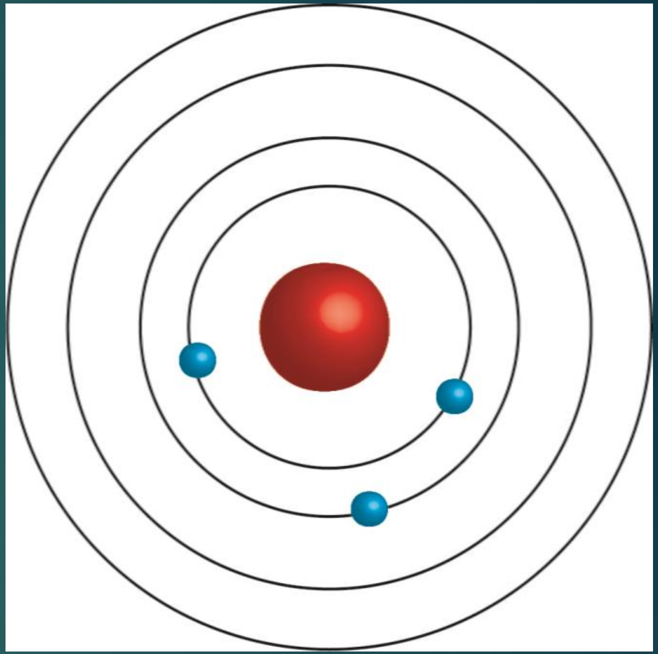
- Rutherford concluded that there must be a small, highly dense core of matter in an atom off which the alpha particles were bouncing. He theorized that this atomic nucleus was positively charged and surmised that the electrons orbited around it. Many physicists doubted the Rutherford atomic model because it was difficult to reconcile with the chemical behavior of atoms.

- According to Maxwell, accelerated charged particles emit electromagnetic radiations and hence an electron revolving around the nucleus should emit electromagnetic radiation. This radiation would carry energy from the motion of the electron which would come at the cost of shrinking of orbits. Ultimately the electrons would collapse in the nucleus which is not observed.



Atomic Structure and Line Spectra

- Danish physicist Niels Bohr, a student of Rutherford's, proposed his quantized shell model of the atom (see Bohr model) to explain how electrons can have stable orbits around the nucleus.
- To remedy the stability problem, Bohr modified the Rutherford model by requiring that the electrons move in orbits of fixed size and energy, again requiring quantization of energy.
- Bohr's starting point was the realization that classical mechanics by itself could never explain the atom's stability. Further advancements to Bohr's theory could explain the line spectrum of atoms (why upon heating, atoms emit only specific frequency of radiation?).
- Quantization of energy is the base for all such theories, which was absent in classical physics.



Bohr's model

Wave-Particle Duality

- We have now seen the dual nature of Radiation. For example, Light behaved as wave in diffraction experiment and as a particle in photoelectric experiment.

- On the other hand, according to the de-Broglie in the year 1924, matter consists of a wave nature, by the wavelength represented by: $h = p\lambda$, where h is Planck's constant and p is momentum of matter particle.

- The above formula was afterward confirmed experimentally through electron diffraction experiment. Thus matter could now also be seen as waves. This wave-particle duality of matter and radiation could not be reconcile;ed with the ideas of Classical physics.

Heisenberg’s Uncertainty Principle

- Classical physics states to recognize the future state of any particle, given the position and the momentum are known at any point. But as quantum physics was developed, an important principle was developed that was again opposite to this idea of Classical physics.

- Heisenberg's uncertainty principle prohibits the possibility of concurrently measuring the position and the linear momentum of any object with infinite accuracy. Certainly, any attempt to measure one of the quantities by infinite accuracy leads to infinite uncertainty in the other. In fact, if the uncertainty in position Δx and that of the linear momentum of the particle is Δp, then,

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

Birth of Quantum Physics.

- Therefore, our whole world of classical physics appears to have melted away as we can measure position and momentum of a body definitively in Classical physics. Though, classical mechanics has been tested and trusted for so long.

- Now the question arises why does it now seem to fail? This is due to the reason that we have been dealing by the matter on the large scale. Quantum mechanics makes the difference if we have to deal with small objects, for example on the scale of atoms.

- However, quantum mechanics has to agree by classical physics in certain limits, in conformity by the correspondence principle. Hence Classical physics is not incorrect but just inadequate.