Electromagnetic Radiation

Electromagnetic radiation as shown in figure 1.1 can be defined as the energy transmitted by the electromagnetic waves and contains two orthogonal compounds: electrical and magnetic waves. These two waves propagate at the speed of light, and generated by accelerating the electrical charge.

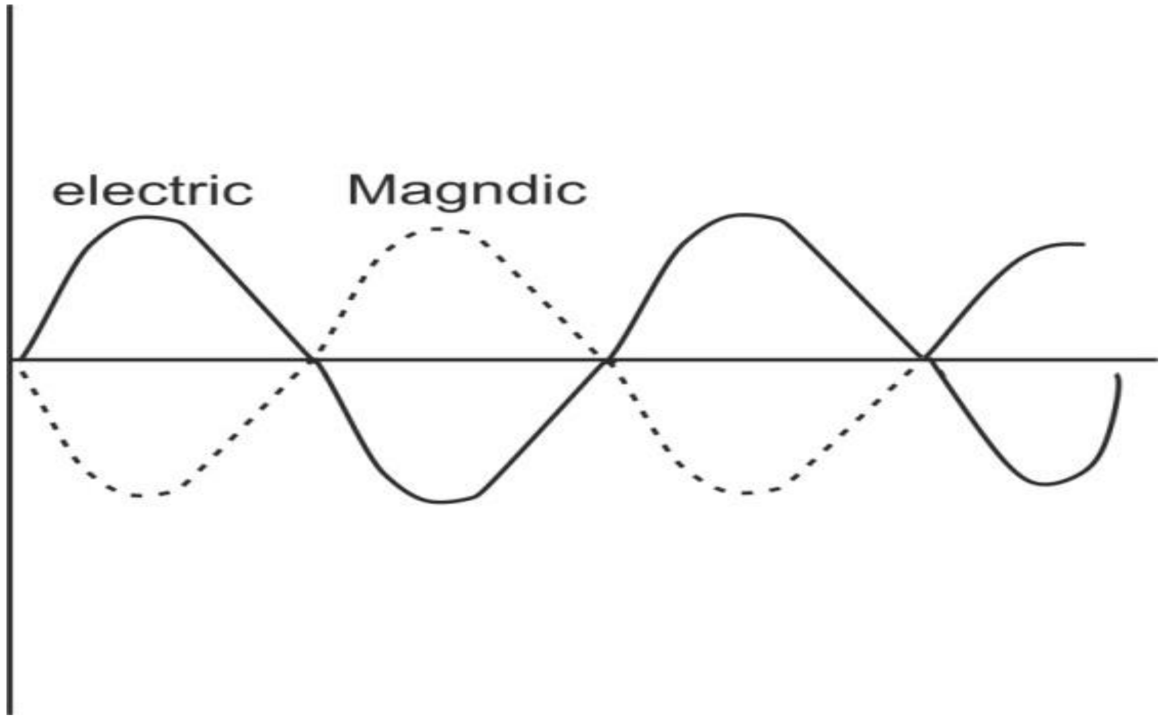


Figure 1.1 Electromagnetic radiation

- The electromagnetic spectra include radio and , TV waves, Microwaves, IR, visible, UV, γ-ray, X-ray and cosmic rays.
- The rate of the generated radiation energy (R) (Energy per second) can be calculated as follows:
- $R = \frac{2kq^2a^2}{3C^3}$.............(1.1)
- Where *k* is constant and equals $k = contant = 9 \times 10^9 \ \frac{N.m^2}{c^2}$ and *C* is the speed of light, which is
- C: $speed\ of\ light = 3 \times 10^8\ m\ /\ s$

***Example: A** particle charge is q, it oscillates on $the\ \acute{x}$:axis with angular velocity ω according to the equation $X = X_o$Cos ωt Derive the radiation energy formula, or the emission, energy per time. Where $X\ is\ the\ displacement\ , X_o\ is: the\ amplitude\ (constant)\ and\ t\ is$ $:\ time$

- **Solution:**
- $R = \frac{2kq^2a^2}{3C^3}$
- $X = X_o\ cos\omega t$
- $a = \frac{d^2x}{dt^2} = -x\omega^2$
- $a^2 = x^2\omega^4$
- $R = \frac{2kq^2(x_0{}^2cos^2\omega t)\omega^4}{3C^3} = \frac{2kq\ x^{2^2}\omega^4}{3C^3}$

- In the vacuum the electromagnetic radiation have a constant speed that equals to
- $C = 2.998 \times 10^{8}\ m / s$
- The photon energy (E) is:
- $E = n * h * \upsilon,$ ……….(1.2)
- Where
- $n = No. of\ quanta$
- $h = plank\ coustant = 6.6 \times 10^{-34}\ j.s$
- $\upsilon: the\ Frequeny = \frac{1}{t} = \frac{1}{s} = Hz$
- $E = h * \upsilon$
- $E\ is\ measured\ \ in\ ev\ or\ in\ Joul.$

- **1.2 Photoelectric Effect**
- In 1887 Heinrich Hertz discovered that when electromagnetic radiation falls on a clean metal surface the electrons are emitted from the surface. This phenomenon is called the photoelectric effect. Not surprisingly, the number of electrons emitted per unit time called the photocurrent (figure 1.2) depends on the intensity and frequency of the light that has incident on the metal surface.

- However, the details of the relationship were quite surprising to 19th century scientists, . The attempts to explain this effect by the classical electromagnetic was failed. In 1905 Einstein presented an explanation this phenomenon based on the quantum concept of Planck.

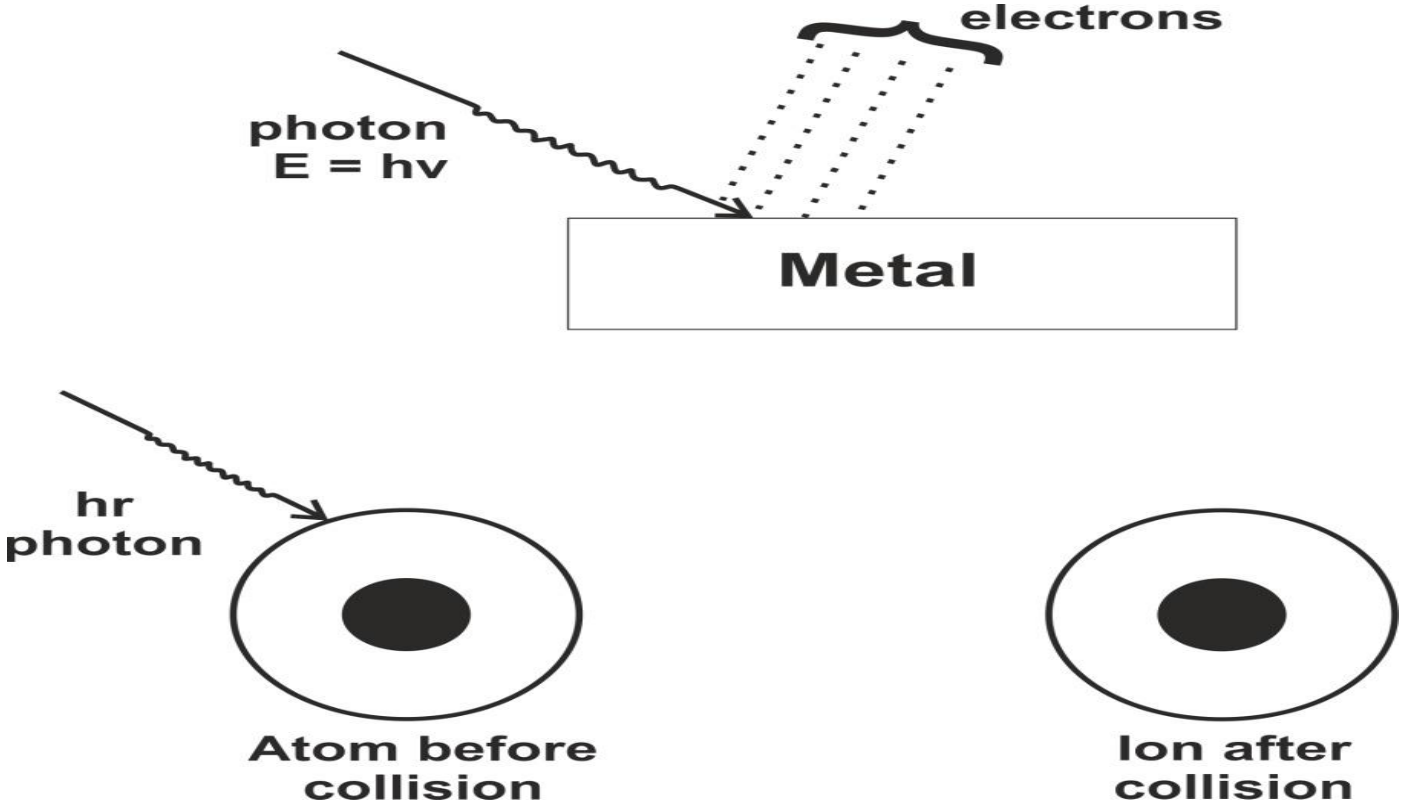


Figure 1.2 Photoelectric effect

- The photoelectric effect confirms several facts
- The photoelectric emission cannot occur unless the light frequency of incident gets greater than the critical frequency (threshold), where the
- 1. threshold frequency depends on the material type as shown in figure (1.3) .
- 2. The kinetic energy of the electronic emission (E_k) depends on the frequency and independent of light intensity $(E_k \propto \nu)$.
- 3. Increasing the incident light intensity leads to increase the emitted electrons only.
- 4. There is no time period between the incident light and the electrons emission.

- $hv = hv_o + E_k \dots\dots\dots\dots\dots\dots\dots (1.3)$
- **where**
- hv: Energy of incident light
- hv_o: Threshold energy
- E_k: Kinetic energy of eletrons emision .
- But $E_k = \frac{1}{2} m V_{max}^2 \dots\dots\dots\dots\dots\dots\dots\dots.. (1.4)$
- From equation 1 can be found that:
- $E_k = hv - hv_o \dots\dots\dots\dots\dots\dots\dots\dots. (1.5)$
- By substituting Equation 3 in Equation 2 will get:
- $\frac{1}{2} m V_{max}^2 = hv - hv_o$
- $E_k = h\nu - \omega$
- $\omega = hv_o = threshold\ energy$.

- The threshold energy (ω) is defined as the minimum energy or minimum work done that the electron needs to escape from metal and depends on the nature of metal. However, the absorption process of electron of radiation is achieved at once, so the electron does not need a period of time to escape from the metal surface.

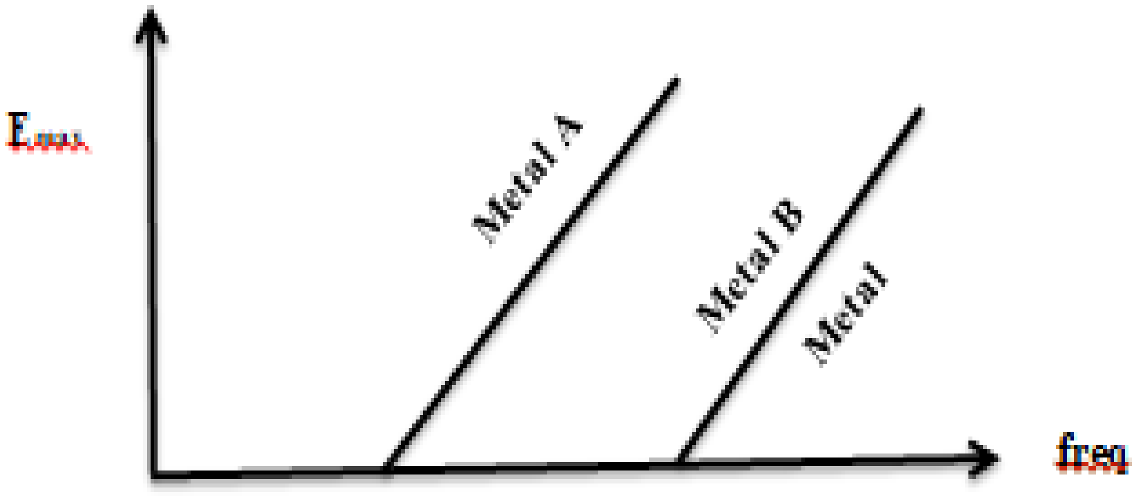


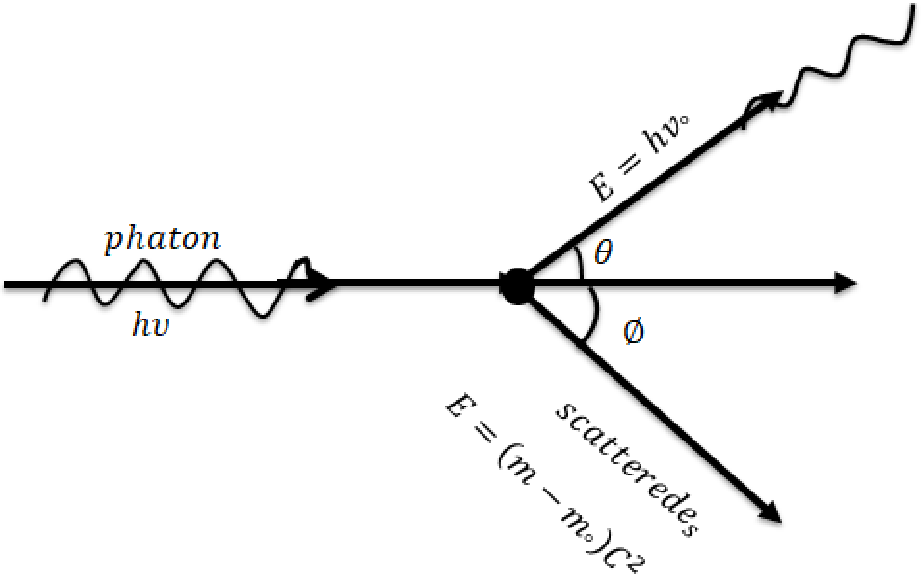
Figure 1.3Eaeh metal has its own critical frequency)

- **Example:** How much kinetic energy does an electron gain or loss when it is accelerated through a potential difference of 1 volt?
- **Solution:**
- $E_k = \acute{e}v = 1.610^{-19} \times 1 = 1.6 \times 10^{-19}\ ev$
- ***Example:** How much plank an $\acute{e}v$ unit contains .
- **Solution:**
- $h = \frac{6.6\times10^{-34}\ J.s}{1.6\times10^{-19}} = 4.136 \times 10^{-15}\ ev$

- **Test your understanding:** Ultraviolet radiation with wavelength of 240 *nm*
- shines on a metal plate and the voltage is 1.4 volt, answer the following:
- What is the energy of photons in the beam of light?
- What is the work function of the metal in eV?
- What is the longest wavelength that would cause the electrons to be emitted?

- **1.3 Compton effect:**
- **Notices about this effect:**
- This effect is related to the x-ray diffraction when it passes through metal foil and the collision between the x-ray and the electrons occurs as shown in figure (1.4)
- The incident x-ray photon collide with the rest of electrons, and the electrons and photons are scattered with Ø and θ angles, respectively.
- Thus, we can calculate the difference in photon frequency as a function of scattered angle as in the following.
- $let \quad \begin{matrix} \upsilon: freq\ of\ photon\ incident\ . \\ \upsilon_o: freq\ of\ scattered\ photon. \end{matrix}$
- In this case the difference in photon energy due to collision is
- $h\upsilon - h\upsilon_o = (m - m_o)\, C^2 = E_k$………(1.6)
- where m is the electron mass and m_o is the rest mass.
-
- The total energy of photon is
- $E = Pc \ldots\ldots\ldots..(1.7)$

- Test your understanding by proving that
- $E = Pc$
-



Figure(1.4) Compton Effect

- $hv - hv_o = (m - m_o)\ C^2$ ……..(1.8)
- Energy conservation Law
- The photon's momentum equals his energy divided by the light velocity (c)
- $\frac{E}{C}\, or\ \frac{h}{\lambda}$
- The photon vector quantity in $X\ Y$ plane are
- $\frac{h}{\lambda} = \frac{h}{\lambda_o}\ cos\theta + p\cos\emptyset$ in x – direction…1.9
- $o = \frac{h}{\lambda_o}\ sin\theta - p\sin\emptyset$ in y- direction…..1.10

- Where P is the momentum of scattered e_s; λ is the wavelength of incident photons; λ_o is the wavelength of the scattered photons.
- $P^2 = m^2v^2 = C^2\,(m^2 - {m_o}^2)$……1.11
- From Equations 1.9 and 1.10 will get
- $P cos\phi = \frac{h}{\lambda} = \frac{h}{\lambda_o}\, cos\theta$……..1.12
- $P sin\,\phi = \frac{h}{\lambda_o} sin\theta$ ……1.13

- $P^2 sin^2\phi = \frac{h^2}{\lambda^2} = \frac{2h^2}{\lambda\lambda_o} cos\theta + \frac{h^2}{\lambda_o{}^2} cos\theta^2$…1.14
- $P^2 cos^2\phi = \frac{h^2}{\lambda_o{}^2} = sin^2\theta$…..1.15
- by adding Equations 7 and 8 will get
- $P^2(\cos^2\phi + sin^2\phi)$
  $= h^2 \left(\frac{1}{\lambda^2} - \frac{1}{\lambda\lambda_o} cos\theta + \frac{\cos^2\theta}{\lambda_o{}^2} + \frac{1}{\lambda_o{}^2} sin^2\theta\right)$
- $P^2 = h^2 \left(\frac{1}{\lambda^2} - \frac{2\cos\theta}{\lambda\lambda_o} + \frac{1}{\lambda^2}\right)$…1.16

- $(m^2 - {m_o}^2)C^2 = h^2\left(\frac{1}{\lambda^2} - \frac{2\cos\theta}{\lambda\lambda_o} + \frac{1}{\lambda^2}\right)$.....1.17
- $m = m_o + \frac{h}{c}\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$
- $m^2 = {m_o}^2 + \frac{2\,m_o h}{C}\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right) + \frac{h^2}{c^2}\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)^2$ … …1.18
- Substituting m^2 from Equation(1.18) in Equation(1.17) the following equation is extracted

- $C^2\left[m_o^2 + \frac{2\,m_o h}{c}\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right) + \frac{h^2}{c^2}\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)^2 - m_o^2\right]$
- $= h^2\left(\frac{1}{\lambda^2} - \frac{2\cos\theta}{\lambda\lambda_o} + \frac{1}{{\lambda_o}^2}\right)$
- $2\,m_o hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right) + h^2\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)^2$
  $= h^2\left(\frac{1}{\lambda^2} - \frac{2\cos\phi}{\lambda\lambda_o} + \frac{1}{{\lambda_o}^2}\right)$
- Re-arrange the above equation
- $\frac{m_o c}{\lambda} - \frac{m_o c}{\lambda_o} - \frac{h}{\lambda\lambda_o} + \frac{2\cos\theta}{\lambda\lambda_o} = 0$

- $m_o c(\lambda_o - \lambda)h = -h\cos\theta$
- $m_o c\,\Delta\lambda = h - h\cos\theta$
- $\therefore \Delta\lambda = \frac{h}{m_o c}(1 - \cos\theta)$….1.19
- Where $\Delta\lambda$ is the difference in λ between the incident and scattered photons

• 1.4 Blackbody Radiation

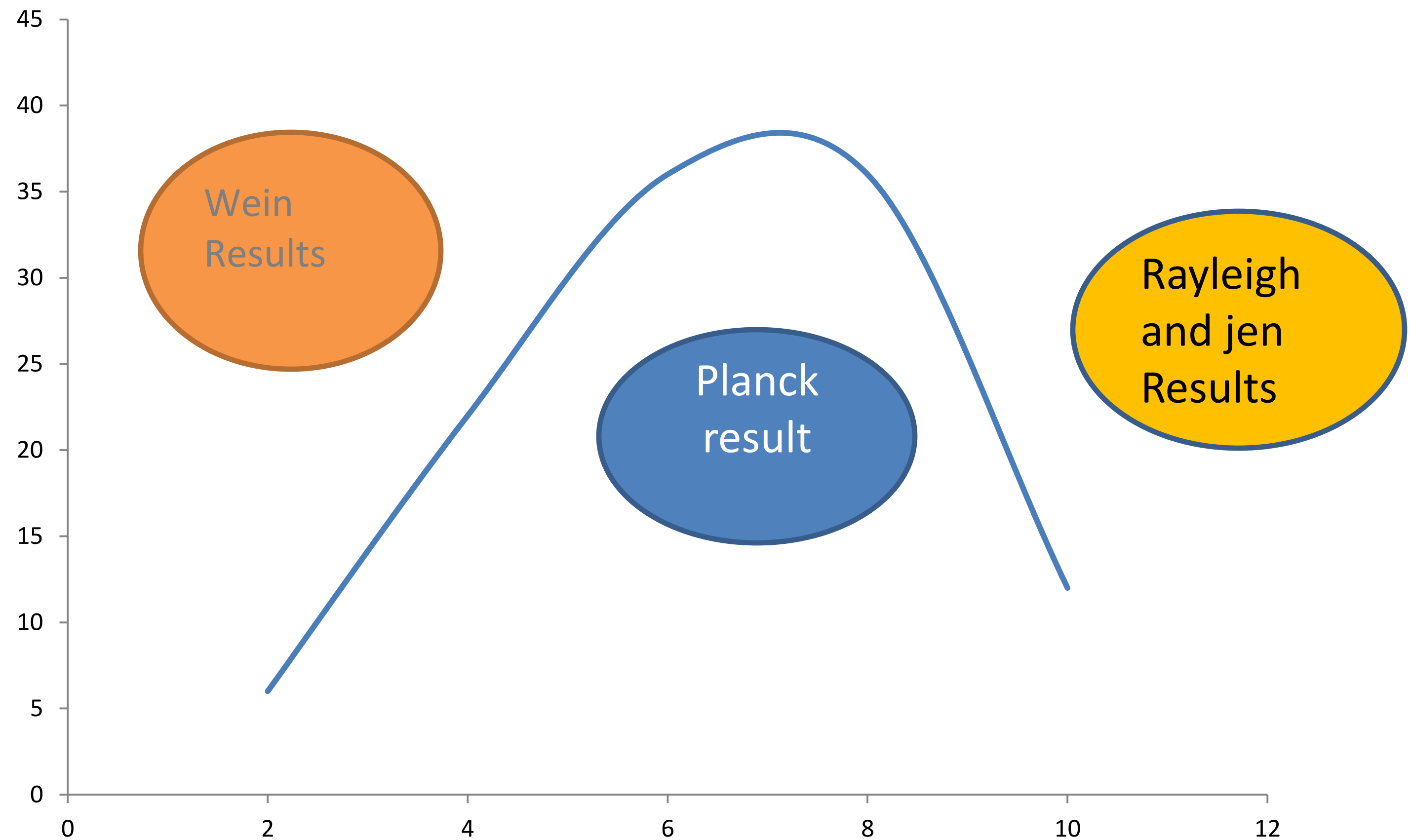
- Blackbody radiation or "cavity radiation" refers to an object or system that absorbs all radiation incidents upon it and re-radiates energy, this feature represents a characteristic of the radiating system only. The radiated energy can be considered as a standing wave or resonant modes of the radiating cavity. The spectrum of blackbody (figure1.5)is a continuous spectrum and does not contain any peak, node or sharp peak, as shown below.

- **Explanation of the continuous spectrum of the blackbody:-**
- The first attempt was by **Wein**, who has found the following experimental equation
- $\omega_\lambda = \frac{c_1}{\lambda^5 e^{c_2/\lambda T}}$
- Where C_1 and C_2 are constants, λ is the wavelength and *T* is the absolute temperature.

The results of Wein's equation agrees with the practical results for the short wavelength and differs from the practical results for long wavelength.

- The second attempt was by **Rayleigh** and **Jen.** It depends on the basic classical mechanics and assumes different vibration phase and energy rate for any vibration phase, which equals to KT (K is Boltzman's constant which equals1.38*10^{-16} erg/degree).
- $$\omega_\lambda = \frac{8\pi KT}{\lambda^4} \quad \text{......(1.20)}$$
- The results of **Reyleigh** and **Jen** equation is agree with the practical results for long wavelength and differs from the practical results for the short wavelength.

- The third one is **Planck attempt.** This is a successful attempt to explain the continuous spectrum of blackbody. It assumes the atom is a harmonic oscillator that emits and absorbs energy proportional with the frequency (υ)
-
- **E α υ**
- **E = hυ , h= 6.6*10^{-34} J.S**
- This means that the atoms emits and absorbs energy in quanta and the energy is called photon. The Planck attempt represent the basic of quantum mechanics.
- $\omega_\lambda = \frac{8\pi}{\lambda^5} \frac{hc}{e^{hc/kT} -1}$ …….(1.21)



The spectrum of black body radiation