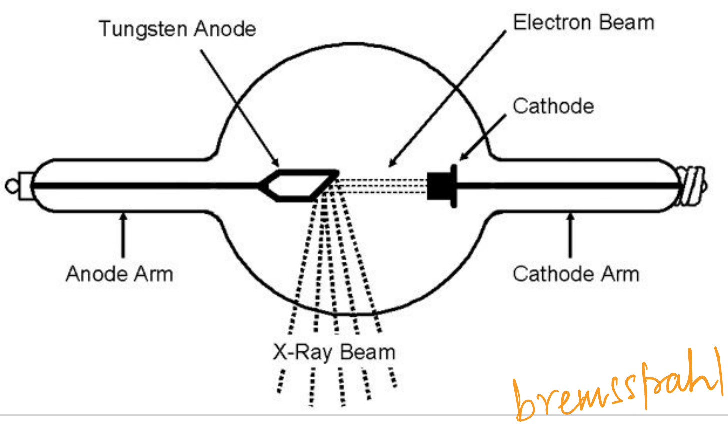
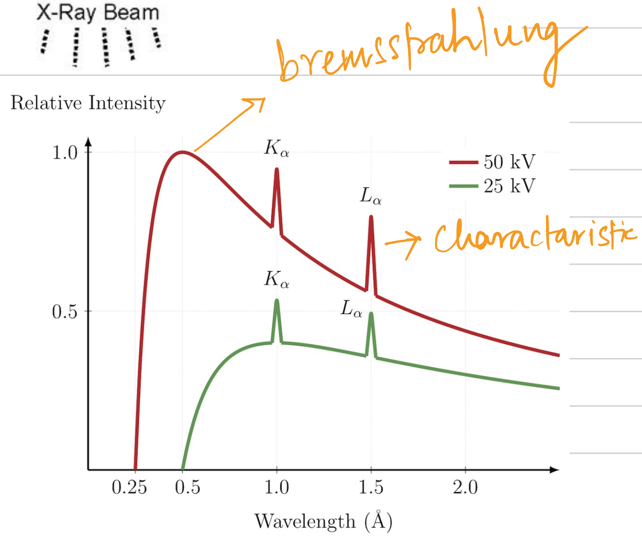
* Photoelectric Effect shows that the photons of a light ray can transfer energy to electrons. The inverse of this process also happens - ie, kinetic energy of electrons can be converted to photons. Reverse photo electric effect takes place in X-Ray production. X-Rays are very high frequency EM waves that travel in straight lines, pass through opaque materials and make phosphorscent substances glow.



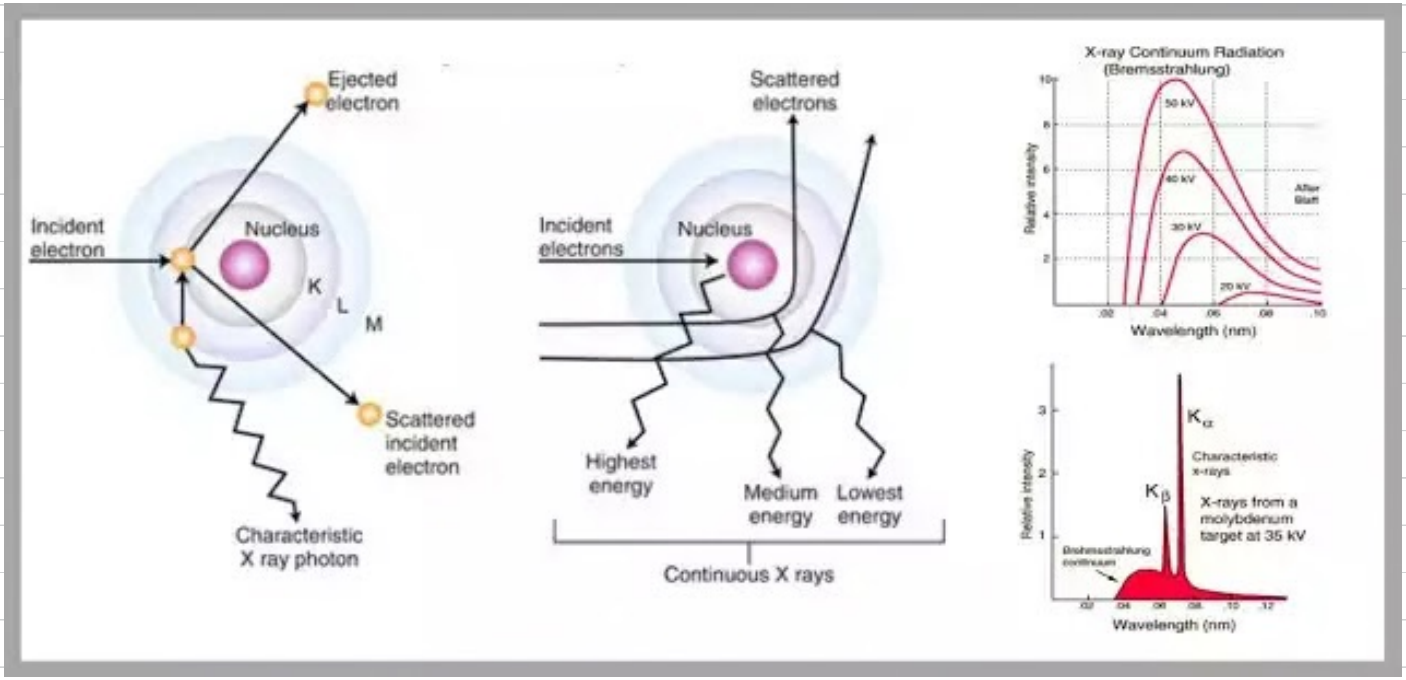
* Electrons from cathode ray is produced by thermionic emission - emission of electrons by heat. It works through photo electric effect.



* X-Ray Spectrum: X-Ray Spectrum has two distinct characteristics:

a) Bremsstrahlung: According classical electromagnetic theory accelerated particles emitt radiation

b) Characteristic spectra: Incoming electrons knock off an electron from the lower orbit of the target metal. An electron from high orbit jumps to fill the gap and thereby releases energy in terms of photons.



*Compton Effect ⇒ Compton effect shows that photons do behave like particles when they collide with particles, like electrons. Consider a photon at rest being hit by a photon of frequency ν. The electron is deflected at angle θ and the photon at an angle ϕ.

Frequency of intial photon : ν (spelled as "nu", it is a Greek letter)

" " final photon : ν'

Loss in energy of photon = gain in the KE of electron

$$h\nu - h\nu' = KE$$

For a photon $E = pc = h\nu$ & $E' = p'c = h\nu'$

Hence $p = h\nu/c$ & $p' = h\nu'/c$ { p & p' are initial & final photon momentum

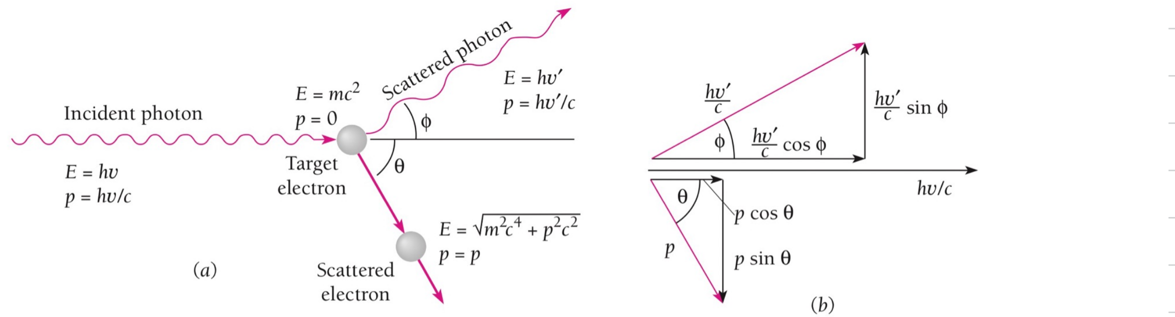


Figure 2.22 (*a*) The scattering of a photon by an electron is called the Compton effect. Energy and momentum are conserved in such an event, and as a result the scattered photon has less energy (longer wavelength) than the incident photon. (*b*) Vector diagram of the momenta and their components of the incident and scattered photons and the scattered electron.

* Conservation of momentum in the initial photon direction

$$\frac{h\nu}{c} + 0 = \frac{h\nu'}{c}\cos\phi + p\cos\theta \Rightarrow pc\cos\theta = h\nu - h\nu'\cos\phi$$

* for the perpendicular direction

$$0 = \frac{h\nu'}{c}\sin\phi - p\sin\theta \Rightarrow pc\sin\theta = h\nu'\sin\phi$$

* Squaring and adding the equations we get

$$p^2c^2 = (h\nu)^2 - 2(h\nu)(h\nu')\cos\phi + (h\nu')^2$$

* Energy conservation:

Initial total energy: photon energy + electron rest mass energy

$$h\nu + mc^2$$

Final total energy: photon energy + electron rest mass energy

$$h\nu' + \sqrt{(p^2c^2) + (mc^2)^2}$$

$$\Rightarrow h\nu + mc^2 = h\nu' + \sqrt{p^2c^2 + m^2c^4}$$

Squaring $p^2c^2 = (h\nu)^2 - 2(h\nu)(h\nu') + (h\nu')^2 + 2mc^2(h\nu - h\nu')$

We also had in the previous page $p^2c^2 = (h\nu)^2 - 2(h\nu)(h\nu')\cos\phi + (h\nu')^2$

Equating these two equations we get

$$2mc^2(h\nu - h\nu') = 2(h\nu)(h\nu')(1-\cos\phi)$$

Substituting $\frac{\nu}{c} = \lambda$ & $\frac{\nu'}{c} = \lambda'$ we get

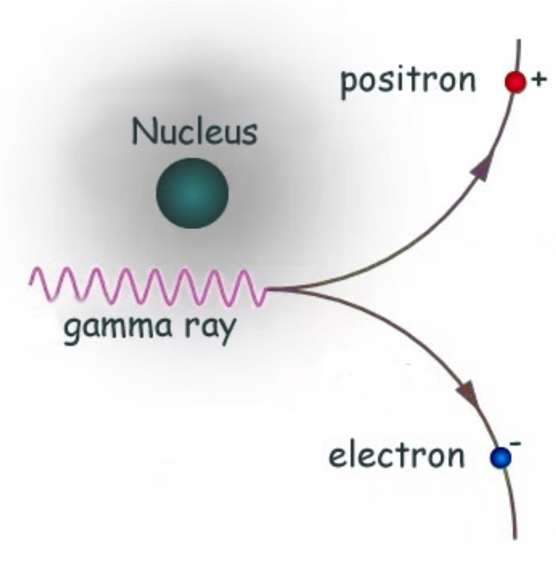
$$\frac{mc}{h}\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) = \frac{1-\cos\phi}{\lambda\lambda'}$$

$$\Rightarrow \boxed{\lambda' - \lambda = \frac{h}{mc}(1-\cos\phi)}$$

This equation gives the change in frequency of a photon when it collides with an electron at rest.

$\lambda_c = h/mc$ is called the Compton Wavelength.

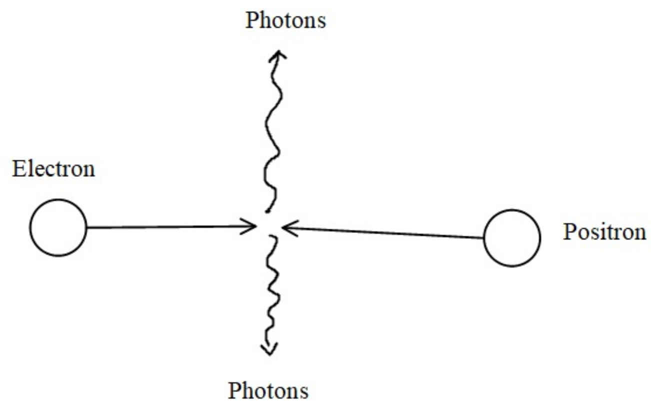
Pair Production: The electromagnetic energy of photons can be converted into a pair of electron & positron and vice versa.



A photon converts to e^+e^- pair in the presence of a nucleus. {Q: why is the nucleus needed for pair production?

Inverse of this process, also called pair annihilation also happens when a e^+e^- pair converts to two photons

$$e^+e^- \to \gamma\gamma$$



* Wave Nature of Particles: The PE effect, Compton effect, & the pair production show that light has dual nature - it can behave both like wave & particle.

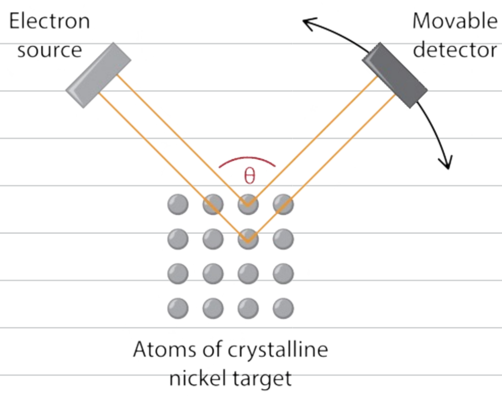
In 1924 Louis de Broglie proposed that wave-particle duality is universal - in other words, according de Broglie particle must also exhibit wave nature.

A photon has momentum $p = \frac{h\nu}{c} = \frac{h}{\lambda} \Rightarrow \lambda = \frac{h}{p}$

de Broglie proposed that this formula must be general - a material particle with momentum p will have an wavelength

$$\boxed{\lambda = \frac{h}{p} = \frac{h}{\gamma m v}} \qquad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

This is called de Broglie wavelength.



* de Broglie's hypothesis was experimentally proven in the Davison-Germer experiment where it was found that electrons also show diffraction like X-Ray

Waves of What? Born Interpretation:

Water wave: what changes periodically is the height of the wave

Sound Wave : pressure changes in periodic manner

Light Wave: the electric & the magnetic field vary

What about de Broglie wave?

Max Born interpreted that the quantity whose variation makes up the particle wave is the wave function Ψ. The value of the wave function at any point x, y, z & at time t is the likelyhood of finding the particle at that location and at that time.

Wave function of particle wave Ψ can be positive, negative, or even be a complex number. Therefore Ψ has no physical significance - it can not be measured in experiment.

What is of physical significance is $|\Psi|^2$ - it is called the probability density of finding a particle of wave function Ψ at a small region around

x, y, z and t. Large $|\psi|^2$ mean higher possibility of the particle's presence.

* Note that even when ψ describes a particle in terms of wave that is spread out, the particle in itself is not spread out - when experiment is performed to detect a particle it is always found at a given location at some time t.