QUANTUM NATURE OF LIGHT

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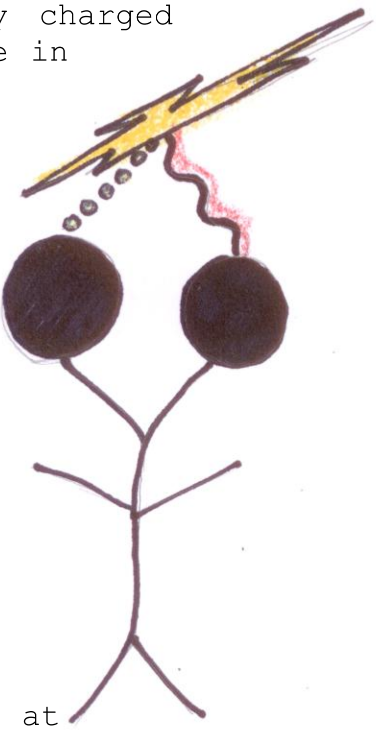
Introduction:

Light has a dual character i.e. particle and wave nature. It can possess both the characters. The classical theory of light (Maxwell's theory) supports the wave nature of light, which is not able to explain all the observable phenomena. To explain phenomena such as the photoelectric effect, black body radiation and the Compton effect we have to use the quantum (particle) nature of light. The Compton effect is easily observable and is the strongest evidence to show the particle nature of light. Results of the Compton effect are in agreement with the photoelectric effect and scattering of light by charged particles. Arthur Compton received the Nobel Prize in 1927 for his observations.



Principle:

The Compton effect is explained using the principle of momentum conservation, which states that in a collision, the sum of momentum before collision is equal to the sum of momentum after collision. This is applied along with energy conservation.

Compton Effect:

To study the Compton effect, high energy X-rays of known frequency are fired onto a graphite sheet (as valence electrons are loosely bound to their atoms in graphite). Considering the interaction of an electron with an X-ray, we look at the wavelengths of the reflected beam and the recoiling electrons. It is observed that the reflected X- ray has more wavelength than the incident beam.

On collision with an electron, the X-ray photon gives a part of its energy and momentum to the electron. Since the energy of an X-ray photon is directly proportional to its frequency (i.e. inversely proportional to the wavelength for a constant velocity), the observed wave should have longer wavelength than that of the fired X-ray. It is found true in the experiment. Here, collision of an electron and a photon is important as it shows observable particulate effects.

To observe the Compton effect, the photon must have a minimum amount of energy. A photon having less energy than required i.e. around a few eV can knock out electrons and show photoelectric effect or cause ionisation, but wavelength shift will not be observed; while a very high energy wave such as a cosmic or gamma ray (energy of about MeV) can lead to pair production i.e. production of an electron and positron.

The Compton shift of wavelength is given by the following formula :

$$\bar{\lambda} - \lambda = h(1 - \cos\theta)/ m_e c$$

Where
λ = is the wavelength of the photon **before** scattering,
$\bar{\lambda}$ = is the wavelength of the photon **after** scattering,
m_e = is the mass of the electron,
h = Planck’s constant,
c = speed of light in vacuum,
θ = angle through which the trajectory of the photon changes after the interaction.

From the above formula it is evident that the shift of wavelength is independent of the source of light energy and also independent of the substance we are using for wavelength shift as all electrons participating in the Compton effect are identical. It depends on the angle of incidence alone.

Applications:

Compton scattering is important in biological studies related to radiology as it helps to study the interactions of high energy X-rays with atomic nuclei in living organisms. It is also used in the study of electrons in matter and in the production of variable energy gamma ray beams.

Uses of Compton scattering experiments:

1) Compton scattering is shown by nuclei with low atomic masses. An elastic scattering of photon with low atomic mass nucleus helps us to know about exact mass of the nucleus, its structure and density. Nuclear Compton scattering below meson production

i.e. scattering by γ-ray photons provide a fundamental tool in the analysis of exchange effects in nuclei.

2) Head on collision of photon and electron within an angle of one radian produces inverse Compton effect. Inverse Compton scattering has importance in the production of high brightness (energy) X-ray beam. It helps us to know about crystal structures. For some small molecules, X rays generated by this (inverse Compton scattering) have high coherence length and time.

3) γ-Compton scattering has been used for making advanced telescopes with high resolution power. It uses a wide range of γ rays from 100keV to 10Mev. This is the region in which most of the galaxies, solar flares and super novae emit their radiation. The aperture of telescope used here can be very small as only a few γ rays which collide with electrons are sufficient to analyze trajectories of incoming γ rays and thus locate the source. It is very easy to calculate energy of a γ ray in a single collision though it may collide more than once. Small apertures remove the possibility of diffraction, also, a high resolution can be achieved. Thus, a Compton telescope is the ideal instrument to survey a wide area or a large target where the sources of radiation are distributed or unknown.

4) The degrees of freedom and electromagnetic polarizability of nucleus can also be understood by analyzing the emitted radiation from the nucleus. These rays collide again with other electrons, and hence we can know the energy of emission.

References:

http://venables.asu.edu/quant/proj/compton.html
Concepts of Modern Physics - Arthur Beiser
http://en.wikipedia.org/wiki/Compton_scattering