Quantum Mechanics-Section7

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0.1 Pair production

Like photoelectric and Compton effect, there are other processes by which photon may loose its energy through interaction with matter *e.g.* the phenomena of pair production. When the incident photon energy is low (but higher than material work function), of the order of eV, its energy is absorbed by atoms and photoelectrons emit out. For the case of moderate photon energy, of the order of keV, the incident photon has enough momentum to knock out electron out of its atomic bonding *via* direct impact - this results into Compton effect. When the incident photon has high energy, of the order of MeV, its direct encounter with the atomic nucleus results into the lose of total photon energy $h\nu$ creating an electron and a positron (a pair) with their respective kinetic energies. A positron has properties identical with electron, except its charge (and its magnetic moment) is opposite that of an electron. Energy of the photon equals to the total relativistic energy of the product particles.

$$h\nu = E_{-} + E_{+} = m_0c^2 + K_{-} + m_0c^2 + K_{+} = 2m_0c^2 + K_{-} + K_{+}$$

In this equation, E_{-} and E_{+} are the total relativistic energies of electron and positron, respectively whereas K_{-} and K_{+} are their respective kinetic energies and m_0c^2 is the rest mass energy, same for both of the particles. The kinetic energy of the recoil nucleus is neglected in this calculation, assuming that the nucleus is too massive to move.

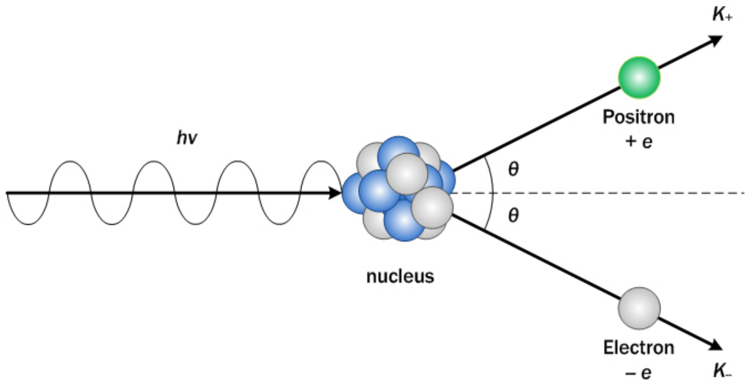

Figure 1: Pair production process

The kinetic energy of the positron is higher than the electron, $K_{+}>K_{-}$, since the Coulomb force by the nucleus is attractive for the case of electron and repulsive for positron.

Pair production is a high-energy phenomenon. To analyze this process we consider the before and after interaction situations, without going into the details of the interaction itself. The total relativistic energy, the linear momentum are conserved in the collision process. The incident photon is chargeless, the produced electron and positron has opposite charges which leads to charge conservation. We see that, the minimum energy of the incident photon must be $2m_0c^2$ or 1.02 MeV to create a pair. This amount of energy corresponds to an wavelength of 0.012 Å. If the incident light has lower wavelength than this value, which corresponds to higher energy, the photon endows kinetic energy to the electron and positron as well as rest mass energy.

Electron Positron pair is generated by cosmic rays in nature. In laboratory, bremsstrahlung photons obtained from particle accelerators has enough energy for pair production.

References

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[1] Figures are collected from online resources.