Quantum Mechanics-Section8

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1 Pair annihilation

Pair annihilation may be referred as the inverse process of pair production. Two oppositely charged particles, electron and positron, which are at rest and near each other annihilate. This results into vanishing of the total mass, which is replaced by radiant energy. The disappearance of the particles produces photons. The total charge of the annihilating particles is zero (the electron and the positron have negative and positive charges of same magnitude). Photons, on the other hand, are charge neutral. This conserves the total charge in pair annihilation process. The conservation of total energy predicts that, the produced photons shall have a total energy of $2m_0c^2$, where m_0 is the rest mass of the electron or positron (both have same rest mass).

There may be speculations, that the electron and positron annihilation process creates one photon of energy $2m_0c^2$. However, this not true. Before annihilation, the electron and the positron are at rest. Their total momentum is zero. On the other hand, a single photon can never have zero momentum. From the point of view of the conservation of momentum, it may therefore be concluded that the annihilation process will produce two photons of equal and opposite momentum. The creation of three photons is also possible but less probable.

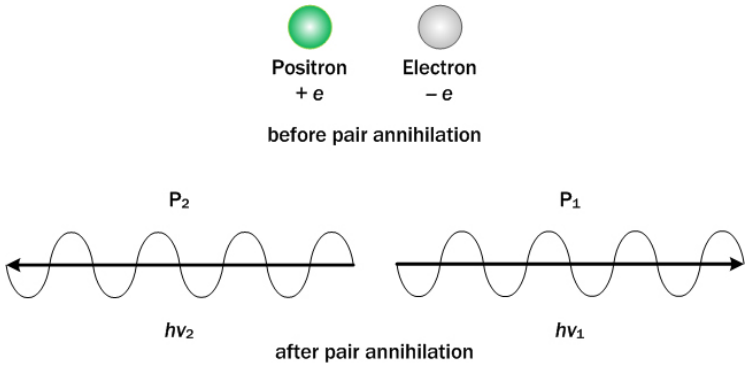

Figure 1: Pair annihilation process

If the photons have opposite and equal momenta $\mathbf{p}_1$ and -$\mathbf{p}_2$, then $\mathbf{p}_1$=-$\mathbf{p}_2$. Therefore their total momentum is $\mathbf{p}_1+\mathbf{p}_2=0$. Since photon has momentum $\frac{h\nu}{c}$, the momentum conservation equation may be expressed as: $\frac{h\nu_1}{c}+\frac{h\nu_2}{c}=0$, which concludes $\nu_1=\nu_2$. Therefore the resulting each photon will be of equal energy, which is m_0c^2 or $(9.1\times10^{-31})\times(3\times10^8)^2=0.51$ MeV. This corresponds to a photon wavelength 0.024Å. If the pair particles had some kinetic energy before annihilation process, then the resulting photons shall have wavelength less than 0.024Å.

Positrons are created in pair production process. They move inside matter and loses energy through multiple collisions until they combine with electrons. The bound state of a positron and an electron is called '*positronium*'. In a positronium atom the electron and the positron revolves around their centre of mass. This is a transient state with a life time of 10^{-10} sec. After this short duration mutual annihilation process destroys the positronium into photons.

References

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[1] Figures are collected from online resources.