8.5: Photon Used to Create Mass

Photon hits Electron to create an Electron-Positron Pair

It should not be surprising that a photon can deliver energy without having any mass of its own. After all, an electron does have mass of its own; yet an electron traveling sufficiently close to light speed can impart to its target an amount of energy ten, a hundred, or a thousand times as great as its own mass. Not mass but momentum governs the size of punch that either photon or electron can deliver.

Matter is born

Incredibly, however, a photon in the presence of an electron can create matter out of empty space. To bring about this process, double the energy of the quantum of radiant energy shown in Figure 8.4.2. When a photon with energy equal to four electron masses hits an electron at rest, the photon most often recoils; in other words, it suffers backward scattering, an instance of the Compton process. Occasionally, however, the impacting photon produces out of empty space, near the struck electron, a new pair of electrons, one with a negative electric charge like all everyday electrons, the other with an identical amount of positive charge. The electron with positive charge has the name positron (Box 8-1).

This process goes on all the time high in Earth's atmosphere, where cosmic rays pour in from outer space. There, however, energies of cosmic-ray photons often far exceed four electron masses. In consequence, the struck electron and the two newly created electrons go off in slightly different directions and at different speeds. However, when the energy of the incoming photon is sufficiently finely tuned, in the immediate vicinity of an energy of four electron masses, the three particles can stick together as a super-light molecule, a polyelectron, a system analogous to what chemists call the hydrogen molecule ion (Figure 8.5.1).

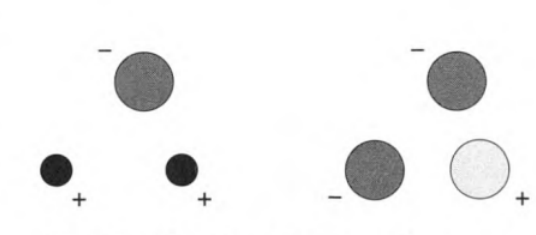

Figure 8.5.1: Comparison an contrast: Left: Two protons and an electron forming the Left: Two protons and an electron forming the hydrogen molecule ion of chemistry, (A proton is hydrogen molecule ion of chemistry. (A proton is much more massive than an electron but can be envisioned as occupying less volume.) Right: electron created by impact of a properly tuned electron created by impact of a properly tuned photon rest. System momentum means all system energy available to create particles other particles

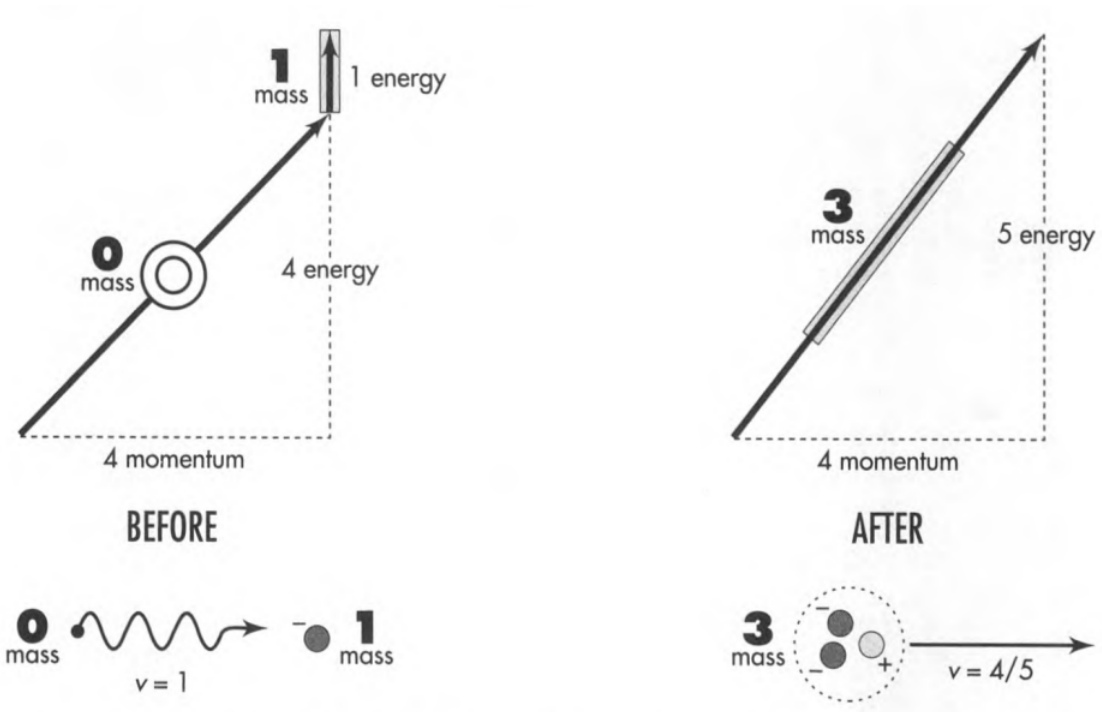

Figure 8.5.2: Conservation of energy a n d momentum in the process o f creating a p a ir {a positive a n d a negative electron) in the field of an electron. Before: A photon that has energy {and momentum) equal to four electron masses (sloping arrow) strikes an electron essentially at rest (vertical arrow). After: The photon has ceased to exist, and the two newly created particles have gone off in company with the original electron at 8 0 percent of light speed— a combined "particle" of three electron masses

Why does it take a light quantum with an energy of four electron masses to create (Figure 8.5.2) a polyelectron, a super-light hydrogen molecule ion, an object with a mass of three electron masses (in truth, a tiny bit less than three electron masses because of the negative binding energy among the three particles)? The question becomes all the more insistent when we recall that the electron that got hit already brought to the consummation of the deal a rest energy equal to one electron mass.

System momentum means not all system energy available to create particles

In brief, why do we have to put in five electron masses of energy to get out a three-electron-mass product? Simply asking this question points out where the explanation lies. The incident photon brings in a great momentum, and the electron with which it reacts has no momentum. So all that momentum has to go into the output product, the polyelectron. Since the polyelectron must have momentum, it must also have kinetic energy - energy not available for creating additional mass. In consequence, that object has so much energy of motion that only a much diminished part of the energy of the incident photon is available for the creation process itself.
