ELECTRON-POSITRON COLLISION MUST PRODUCE AT LEAST 2 PHOTONS

Link to: physicspages home page.

To leave a comment or report an error, please use the auxiliary blog and include the title or URL of this post in your comment.

Post date: 22 June 2021.

When an electron and positron collide, they can decay into a pair of photons as we've seen. However, 2 photons is the minimum number of photons that can be produced. To see why a single photon is not possible, re-examine the solution we had earlier. In that post, we started with the electron and positron moving towards each other, one with velocity v and the other with velocity $-v$. We then transformed to the frame in which the electron is at rest. We can just as easily reverse the process, and start with the electron's frame. Let's say that in the electron's frame, the positron is moving with speed $-v'$ towards it. Then the total momentum before the collision is

$$\mathbf{p}' = [m, 0] + \gamma' [m, -v'] \tag{1}$$

where $\gamma' = 1/\sqrt{1-(v')^2}$.

We can now transform to a frame in which the two particles are moving towards each other with the same speed v. That is, we want the four-velocities to be

$$\mathbf{u}_e = [\gamma m, v] \tag{2}$$

$$\mathbf{u}_p = [\gamma m, -v] \tag{3}$$

From our earlier analysis, we see that this works if

$$v' = \frac{2v}{1+v^2} \tag{4}$$

$$v = \frac{1-\sqrt{1-(v')^2}}{v'} \tag{5}$$

Thus it's always possible to find v such that the particles are moving towards each other with the same speed, and in that frame, the total momentum is

$$\mathbf{p} = [2\gamma m, 0] \tag{6}$$

Since the x component of a photon's momentum is always ±1, there is no way this momentum can be conserved after the collision if only a single photon is emitted. However, it's always possible to produce 2 photons moving in opposite directions, since then the x component of momentum can add up to zero, as required.

If we analyze the problem in the rest frame of the electron, then since the positron is moving towards the electron it might seem that we could conserve 3-momentum after the collision by producing a single photon with the same 3-momentum as the positron.

The key point is that if we analyze the problem in the centre of mass frame where the total 3-momentum is zero before the collision, then the total 3-momentum must also be zero after the collision. If the collision produced only a single particle, that particle would need to be at rest and, since a photon is never at rest, the single particle cannot be a photon. We need at least two photons of equal energy moving in opposite directions in order for the 3-momenta to cancel out.