Pair Production and Annihilation

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mass of electron $= 9.1 \times 10^{-31}$ kg, mass of proton $= 1.67 \times 10^{-27}$ kg, $h = 6.64 \times 10^{-34}$ J s.

1. An electron and positron annihilate producing two gamma ray photons. Calculate the frequency of the photons if

   (a) the electron/positron pair are stationary,

   (b) the electron/positron pair are each travelling at $0.1c$,

   (c) the electron/positron pair are each travelling at $0.5c$,

   where c = speed of light $= 3 \times 10^8\,\mathrm{m\,s^{-1}}$.

   [Ignore any effects due to relativity.]

2. A proton and antiproton, each travelling at a negligible speed, collide and annihilate according to the following reaction: $\mathrm{p\overline{p}} \rightarrow \mathrm{K^0\overline{K}^0}$. Assuming that the kaons move off at the same speed,

   (a) by conservation of energy show that the speed of the kaons can be found by

   $$v = \left(\frac{2c^2}{m_{\mathrm{K^0}}}(m_{\mathrm{p}} - m_{\mathrm{K^0}})\right)^{\frac{1}{2}},$$

   where $m_{\mathrm{K^0}}$ is the mass of the kaon, m_{p} is the mass of the proton, and c is the speed of light.

   (b) given the $\mathrm{K^0}$ has a mass of 8.9×10^{-28} kg, calculate the speed of the kaons.

3. Gamma ray photons can cause pair production, such as the production of an electron–positron pair, according to $\gamma \rightarrow \mathrm{e^-e^+}$.

   (a) What is the minimum energy of a gamma ray photon needed to produce this reaction?

   (b) What is the frequency of this photon?

   (c) The gamma ray has to interact with another object, such as a nucleus. Why is this so?

4. A proton–antiproton pair may interact according to $\mathrm{p\overline{p}} \rightarrow \Sigma^+\overline{\Sigma}^+$ if the protons are given enough energy.
   Calculate the minimum velocity of the protons for this reaction to occur.

   [mass of $\Sigma^+ = 1.99 \times 10^{-27}$ kg.]