

1: Suppose a particle of mass M decays into two other particles (labeled 1 and 2) with masses m_1 and m_2 . In the rest frame of the original particle, the energies of the two daughter particles are E_1 and E_2 , and their momentum vectors are \vec{p}_1 and \vec{p}_2 .

(a) By writing down the equations for energy and momentum conservation, show that in the rest frame of the original particle, the energy of particle 1 is given by

$$E_1 = \frac{M^2 - m_2^2 + m_1^2}{2M}.$$

(b) Apply the result from (a) to predict the energy of an electron in the beta decay of a neutron if one were not to assume the existence of the neutrino, i.e., find the electron energy in the decay $n \rightarrow p e^-$. (Use $m_n = 939.566$ MeV, $m_p = 938.272$ MeV, and $m_e = 0.511$ MeV.) How does this compare to the difference between the neutron and proton masses? (From your answer you should be able to conclude that the electron gets almost all of the available kinetic energy in the decay and the proton almost none.)

2: For the following reactions, sketch all of the possible lowest order Feynman diagrams and also at least one higher order correction. Where possible, state how the amplitudes corresponding to each of the diagrams depends on the coupling constants involved.

(a) $e^+e^- \rightarrow e^+e^-$ (four lowest order diagrams)

(b) $e^+e^- \rightarrow \nu_e \bar{\nu}_e$ (two lowest order diagrams)

(c) $qg \rightarrow qg$ (two lowest order diagrams)

(d) $e^+e^- \rightarrow ZZ$ (one lowest order diagram)