Solutions to Problems in Goldstein, Classical Mechanics, Second Edition

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Chapter 1

Problem 1.1

A nucleus, originally at rest, decays radioactively by emitting an electron of momentum 1.73 MeV/c, and at right angles to the direction of the electron a neutrino with momentum 1.00 MeV/c. (The MeV (million electron volt) is a unit of energy, used in modern physics, equal to 1.60×10^{-16} erg. Correspondingly, MeV/c is a unit of linear momentum equal to 5.34×10^{-17} gm-cm/sec.) In what direction does the nucleus recoil? What is its momentum in MeV/c? If the mass of the residual nucleus is 3.90×10^{-29} gm, what is its kinetic energy, in electron volts?

Place the nucleus at the origin, and suppose the electron is emitted in the positive y direction, and the neutrino in the positive x direction. Then the resultant of the electron and neutrino momenta has magnitude

$$|\mathbf{p}_{\mathbf{e}+\nu}| = \sqrt{(1.73)^3 + 1^2} = 2 \text{ MeV/c},$$

and its direction makes an angle

$$\theta = \tan^{-1} \frac{1.73}{1} = 60^{\circ}$$

with the x axis. The nucleus must acquire a momentum of equal magnitude and directed in the opposite direction. The kinetic energy of the nucleus is

$$T = \frac{p^2}{2m} = \frac{4 \text{ MeV}^2 \text{ c}^{-2}}{2 \cdot 3.9 \cdot 10^{-22} \text{ gm}} \cdot \frac{1.78 \cdot 10^{-27} \text{ gm}}{1 \text{ MeV c}^{-2}} = 9.1 \text{ ev}$$

This is much smaller than the nucleus rest energy of several hundred GeV, so the non-relativistic approximation is justified.

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