Neutrino Velocity

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1 Problem

Estimate the velocity of a neutrino of rest energy $E_0 = m_0c^2 = 0.1$ eV, where c is the speed of light, when produced with energy $E \approx 1$ MeV in a nuclear decay or reaction. Compare this with the velocity of cosmic-microwave-background neutrinos, whose average temperature is 2 K.

2 Solution

A neutrino with energy $E = 1$ MeV has

$$\gamma = \frac{E}{E_0} = 10^4 = \frac{1}{\sqrt{1 - v^2/c^2}}\,, \qquad \frac{v}{c} \approx 1 - \frac{1}{2\gamma^2} \approx 1 - 5 \times 10^{-9}. \tag{1}$$

That is, such neutrinos have velocity $v = c$ "for all practical purposes".

Neutrinos in the cosmic microwave background have typical temperature $T = 2\text{ K} = \frac{2}{3}\,3$ K, with corresponding kinetic energy

$$\text{KE} = \frac{m_0v^2}{2} = \frac{m_0c^2}{2}\frac{v^2}{c^2} = \frac{E_0}{2}\frac{v^2}{c^2} = 0.05\text{ eV}\frac{v^2}{c^2} = \frac{3}{2}kT = \frac{3}{2}\frac{2}{3}\frac{1}{4000}\text{ eV}, \tag{2}$$

recalling that $kT \approx 1/40$ eV for $T = 300$ K and $k =$ Boltzmann's constant. Hence, for cosmic-microwave-background neutrinos with $m_0 = 0.1$ eV,

$$\frac{v^2}{c^2} \approx \frac{1}{200}\,, \qquad \frac{v}{c} \approx \frac{1}{14}\,, \qquad v \approx 2 \times 10^7\text{ m/s}. \tag{3}$$

This problem was suggested by Anwar Shiekh.