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Implications of a nonzero neutrino mass for the process $\gamma\gamma \rightarrow \nu\bar{\nu}$*

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Recent considerations relating to neutrino oscillations and to the decay $\mu \rightarrow e\gamma$ suggest that neutrinos may acquire a small but nonzero mass. The process $\gamma\gamma \rightarrow \pi^0 \rightarrow \nu\bar{\nu}$ could then proceed via either an induced S,P coupling arising from a primitive V,A neutrino current or via a fundamental S,P neutrino coupling. Although the resulting $\gamma\gamma \rightarrow \pi^0 \rightarrow \nu\bar{\nu}$ cross section would, in the former case, be suppressed by a factor of order $(m_\nu/m_\pi)^2$, this process could, nonetheless, be of interest in astrophysical processes in a temperature region where the pion pole is significant.

The possibility that the process $\gamma\gamma \rightarrow \nu\bar{\nu}$ could proceed via an intermediate π^0 state has been raised recently by the present authors.[1] The mechanism $\gamma\gamma \rightarrow \pi^0 \rightarrow \nu\bar{\nu}$ could have potentially important astrophysical consequences since the presence of the pion pole leads to a resonant conversion of radiant energy into neutrinos at temperatures of order $10^{11}-10^{12}$ °K. Such a mechanism could thus be important in the early universe and in supernova formation.[1]

In order for the pion-pole mechanism (πPM) to contribute to the conversion of photons into <u>massless</u> neutrinos, it is necessary that the weak neutral current have a scalar (S) or pseudoscalar (P) component.[1] However, evidence from the processes $\nu p \rightarrow \nu p$,[2-4] $\nu p \rightarrow \nu X$,[5] and $\nu N \rightarrow \nu N \pi$ (Ref. 6) suggests that the neutral current is not predominantly S, P if indeed it contains these components at all. The purpose of this Comment is to point out that if neutrinos have a small but nonvanishing rest mass, then the πPM could proceed through an effective S, P coupling induced from a primitive V,A coupling. The possibility that neutrinos have a mass has been raised recently in connection with the phenomenon of neutrino oscillations[7] and also in light of the possible observation of the decay $\mu \rightarrow e\gamma$.[8] It is also possible that neutrinos associated with the leptons recently discovered[9] at SLAC may have a nonzero mass. Although the coupling so obtained would be suppressed by a factor of order $(m_\nu/m_\pi)^2$, where m_ν and m_π are the neutrino and pion masses, respectively, one finds that it could contribute significantly to the process $\gamma\gamma \rightarrow \nu\bar{\nu}$ in the temperature region where the πPM would be expected to dominate over other contributions because of the pion pole. The presence of this pole distinguishes the πPM from other mechanisms for $\gamma\gamma \rightarrow \nu\bar{\nu}$, including those[10] in which the $\gamma\gamma \rightarrow \nu\bar{\nu}$ cross section is also proportional to m_ν^2.

For present purposes we assume that a massive neutrino ν_1 exists, whose coupling to π^0 has the form

$$\mathcal{L} = \frac{G}{\sqrt{2}} r f_\pi \bar{\nu}_1 \gamma_\lambda (1+\gamma_5) \nu_1 \partial_\lambda \pi^0 . \tag{1}$$

Here G, the Fermi constant, and f_π, the charged pion decay constant, are known, and $|r|^2 \cong 0.2$ reflects the suppression of the neutral-current couplings relative to those for the charged current. Using the Dirac equation, the $V-A$ coupling in Eq. (1) can be transformed into the effective P coupling

$$\mathcal{L}' = 2 m_1 \frac{G}{\sqrt{2}} r f_\pi \bar{\nu}_1 i \gamma_5 \nu_1 \pi^0 , \tag{2}$$

where m_1 is the mass of ν_1. Equation (2) can be used to estimate $\Gamma(\pi^0 \rightarrow \nu_1\bar{\nu}_1)$, and in turn the cross section for $\gamma\gamma \rightarrow \nu_1\bar{\nu}_1$:

$$\Gamma(\pi^0 \rightarrow \nu_1\bar{\nu}_1) = \frac{|G r f_\pi|^2}{4\pi} m_1^2 (m_\pi^2 - 4 m_1^2)^{1/2} , \tag{3}$$

$$\sigma(s) = \frac{8\pi (s^2/m_\pi^4) \Gamma(\pi^0 \rightarrow \gamma\gamma) \Gamma(\pi^0 \rightarrow \nu_1\bar{\nu}_1) F(s)}{(s - m_\pi^2) + m_\pi^2 \Gamma_\pi^2} . \tag{4}$$

Here s is the square of total energy in the center-of-mass system, Γ_π is the pion width, and $F(s)$ is a form factor which we set equal to unity following Ref. 1. From (2) and (3) we find that

$$\Gamma(\pi^0\to\nu_1\bar{\nu}_1)/\Gamma(\pi^0\to\gamma\gamma)\cong 7\times10^{-13}, \qquad (5)$$

which compares to the value[11] 10^{-8} used in Ref. 1. In obtaining (5) we have assumed for illustrative purposes that $m_1\cong1$ MeV, which is the present limit on the mass of ν_μ. The energy-loss rate Q for $T\gtrsim10^{11}$ °K can then be obtained by simply rescaling the results of Ref. 1 by a factor of 7×10^{-5}. Thus, for example, at a temperature of $m_\pi/3$ we find

$$Q(k_BT=m_\pi/3)\cong1\times10^{36}\ \mathrm{erg\,cm^{-3}\,sec^{-1}}\ . \qquad (6)$$

This is comparable to the loss rate from the mechanism $(\gamma\gamma\to e^+e^-\nu\bar{\nu})$ suggested by Soni and Vermaseren.[12] Thus the πPM with massive neutrinos could be a potentially significant process for conversion of radiant energy into neutrinos, provided that some neutrinos are found in the 1-MeV mass range.[13] However, as noted by Soni and Vermaseren,[12] there are other mechanisms in the literature whose estimated loss rates are higher.

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