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Photo-coulomb neutrino process

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Abstract

The photo-coulomb neutrino process ($Z + \gamma \rightarrow Z + \nu + \overline{\nu}$) has been considered in the electro-weak theory and the influence of this process to the evolution of stars has been outlined. The scattering cross-section of this process is calculated in both low and high energy limit. The neutrino mass has been taken into account in this calculation. In the low-energy limit the neutrino luminosity is computed in the temperature range 10^8–10^9 K and is also compared to the previous result obtained according to the current-current coupling theory. The process may be significant for the evolution of stars in the later phases.

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1. Introduction

The neutrino emission processes play an important role towards the understanding of the evolution of stars, particularly in the later phases. The emission of neutrinos during certain stages of stellar evolutions has some contribution due to the extremely large mean free path of a neutrino in matter. Though the probability of creation of this particle is very little, but once created, it is almost certain to escape directly from stars, carrying off whatever energy was used in its creation. Under some circumstances late in the life of a star neutrino radiation can be principal means of energy-loss. Gamow and Schoenberg [1] theoretically predicted this type of energy loss via β-decay. The development of V–A theory [2] of weak interaction helped the physicists to study different neutrino emission processes which are important in the stellar evolutions. Chiu et al. [3] and others [4,5] considered the energy-loss by neutrino pair in the collisions between electrons and nuclei. Their results showed the importance of detailed study of all neutrino emissions processes in stars. The major of those processes occurring in stars are as follows:

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(i) $e^+ + e^- \rightarrow \nu + \bar{\nu}$ (pair annihilation) [6]
(ii) $\gamma + e^- \rightarrow e^- + \nu + \bar{\nu}$ (photo production) [6]
(iii) $\gamma + \gamma \rightarrow \nu + \bar{\nu}$ (photon–photon scattering) [6–9]
(iv) $\gamma + \gamma \rightarrow \gamma + \nu + \bar{\nu}$ [10,11]
(v) $e^- + Z \rightarrow e^- + Z + \nu + \bar{\nu}$
(vi) $e^- + e^- \rightarrow e^- + e^- + \nu + \bar{\nu}$ (electron–neutrino bremsstrahlung) [12]
(vii) $e^- + e^+ \rightarrow e^- + e^+ + \nu + \bar{\nu}$
(viii) $\Gamma \rightarrow \nu + \bar{\nu}$ (plasma neutrino process) [6]
(ix) $\gamma + \nu \rightarrow \gamma + \nu$ [13,14], etc.

Most of the processes were considered in the current-current coupling theory. Gell–Mann [15] showed that the process (iii) is forbidden in the current–current coupling theory and this can occur according to the vector boson theory of the weak interaction. Later some of those processes were studied in the electro-weak theory to see their effect on the astrophysical phenomena such as the evolutions of stars.

In this paper we consider the photo-coulomb neutrino process given by

$$Z + \gamma \rightarrow Z + \nu + \bar{\nu}$$

This was considered previously by Matinyan et al. [16] and their analysis indicated that at high densities and temperatures the energy loss by neutrinos play an important role in the evolution of stars. Rosenberg [17] calculated the scattering cross-section and energy-loss rate for this above photo-coulomb neutrino process and pointed out that the previous calculation of the scattering amplitude [16] became incorrect due to the non-gauge invariant nature. He also suggested that since the amplitude is given by a divergent expression gauge invariance must be explicitly imposed to obtain a unique finite result. In both of the above-mentioned papers related to photo-coulomb neutrino process the calculations were carried out in the current–current coupling theory. Raychaudhuri [18] studied this process in the photo-neutrino coupling theory to compute the neutrino luminosities in the temperature range 10^8–10^9 K. According to the Standard Model any kind of neutrino emission process is based on electro-weak theory. To obtain the correct result the energy-loss by the photo-coulomb neutrino process should be calculated according to the Standard Model. It is known to us that the electro-weak theory corresponds to the almost same result compared to that obtained in the current–current coupling theory in the low energy, but in the very high energy ($\gg$100 GeV) second one fails as it is non-renormalizable.

We study the general structure of the interaction of the photo-coulomb neutrino process to calculate the scattering cross-section and the amount of energy loss by neutrino emission in the later stages of stellar evolution. Within the framework of Standard Model our calculations are motivated by some recent developments in particle physics. Unlike the previous calculations we consider all three type of neutrinos. Previously in all kind of physical processes the neutrino was used to treat as a mass-less fermionic particle, but the phenomena like *solar neutrino problem* and *atmospheric neutrino anomaly* [19] indicate that the possibility of existence of small neutrino mass. The solution of the *solar neutrino problem* suggests that

$$\Delta m_\nu^2 = 7 \times 10^{-5}\,\mathrm{eV}^2 \quad \sin^2 2\theta \cong 1$$

whereas the *atmospheric neutrino anomaly* indicates that

$$\Delta m_\nu^2 \cong 3 \times 10^{-3}\,\mathrm{eV}^2 \quad \sin^2 2\theta = 1$$

In some papers [13,14] related to the photon–neutrino interaction the neutrino-mass has been taken into account. Dicus et al. [13] not only considered the neutrino mass in their photon–neutrino interaction process but they also calculated the scattering cross-section in the electro-weak theory. It indicates that there will be no loss of generality of the Standard Model if the neutrino mass is introduced. We consider the neutrino as a massive particle in the calculations and it may have some effect in the low energy. In our paper we calculate the neutrino luminosity in the low energy region at the temperature range 10^8–10^9 K. The significance of the obtained result has been discussed briefly and compared with the earlier work [17].

2. Calculations of scattering cross-section

In the photo-coulomb neutrino process two photons are involved. One is real and another