THE UNIVERSAL FERMI INTERACTION AND ASTROPHYSICS

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THE hypothesis that there is a deep analogy between the various slow decay processes of elementary particles, both those involving leptons[1] and those not involving them,[2] has recently found a brilliant formulation in the theory of the universal (vector and axial-vector) interaction of Sudarshan and Marshak[3] and Feynman and Gell-Mann.[4] According to this theory the process of scattering of neutrinos by electrons is described by an interaction of the first order in the weak-interaction constant.[4,5] The experimental detection of such a process would be very desirable. But experimental work on the direct observation of the scattering of antineutrinos from a pile by electrons (that is, on the observation of ionization caused by the antineutrinos and not associated with inverse nuclear β processes) seems at present extremely difficult, though perhaps not altogether out of the question.

The purpose of the present note is to call attention to the fact that the existence of a first-order ν-e interaction would be capable of having macroscopic results. It follows from such an interaction that positron-electron annihilation can occur with the emission of neutrino-antineutrino pairs.* Therefore in electromagnetic processes it becomes possible for photon emission to be replaced by emission of a $\nu\tilde{\nu}$ pair (via a virtual e^+e^- pair). This general fundamental connection between electromagnetic phenomena and lepton processes follows directly from the universal Fermi interaction.

It is true that the emission of a $\nu\tilde{\nu}$ pair is extremely improbable relative to the emission of a photon, but the enormous penetrating power of neutrinos makes one think about the possibility of effects associated with the neutrino-electron interaction in large bodies at high temperature T. Let us examine the process of deceleration radiation of an electron with emission of a photon or a pair $\nu\tilde{\nu}$ in a collision of the electron with a nucleus A of charge Z:

$e + A \rightarrow e + A + \gamma$ (photon deceleration radiation)
$e + A \rightarrow e + A + \nu + \tilde{\nu}$ (lepton deceleration radiation)

Let us denote by α the ratio of the probabilities W_γ and $W_{\nu\tilde{\nu}}$ for the emission of a photon or a $\nu\tilde{\nu}$ pair when an electron of energy E is deflected by the nucleus. Dimensional considerations lead us to set

$$\alpha = \frac{W_\gamma}{W_{\nu\tilde{\nu}}} \approx \frac{(e^2Z/\hbar c)^2 e^2/\hbar c}{(e^2Z/\hbar c)^2 G^2 (E/mc^2)^4},$$

where $G = gm^2c/h^3$ is the dimensionless weak-interaction constant, $g = 1.4 \times 10^{-49}$ erg cm^3 is the Fermi constant, and m is the mass of the electron.

It is clear that α is an enormous quantity at any temperatures encountered in astrophysics. Because of the difference of the penetrating powers of photons and neutrinos, however, the emergence of a given energy (say $\sim$kT) from the stars into space in the form of photons will overall result from an enormous number of acts of photon deceleration radiation, incomparably larger than the number (~ 1) of acts of lepton deceleration radiation for the emergence of this same energy $\sim$kT into space in the form of neutrinos. Therefore at a certain stage of the evolution of stars it may be that the energies sent into space in the forms of neutrinos and photons are comparable, in spite of the smallness of the ratio $W_{\nu\tilde{\nu}}/W_\gamma$ for each elementary act. Our attention is attracted by the strong temperature dependence of the probability of the process of lepton deceleration radiation, which is due to the dimensions of the Fermi constant. Besides this, with increase of A there is a decrease of the mean free path of photons, which leads to an increase of the importance of the neutrino process for the energy balance.

All of this leads to the idea that the process can become important in a stage of stellar evolution at which the temperature and the average Z considerably exceed the corresponding values for the sun. It is not hard to see that the mechanism of lepton deceleration ratiation plays practically no part in the energy balance of the sun (kT $\sim$ 1 kev, Z $\sim$ 1).

The mechanism of neutrino emission by stars proposed here is due to the neutrino-electron interaction and is fundamentally different from the process proposed by Gamow and Schoenberg,[6] which is due to nuclear (direct and inverse) β processes. The lepton deceleration radiation of the electron is a thresholdless process, whereas the Gamow-Schoenberg process is an effect with a definite threshold.

Recently G. M. Gandel'man and V. S. Pinaev have made a quantitative study of the astrophysical effect produced by the mechanism of lepton deceleration radiation of the electron that has been described here. They have shown that in the temperature range $kT > 10$ kev and at densities $>10^5$ g/cm^3 the energy transferred from stars ($Z \approx 20$) is larger than the energy carried away by photons.

In conclusion I take great pleasure in thanking Ya. B. Zel'dovich, D. A. Frank-Kamenetskiĭ, and L. B. Okun' for critical comments and their interest in this work, and also G. M. Gandel'man and V. S. Pinaev, who have kindly informed me of the results of their work.

*In particular, the annihilation of orthopositronium with the emission of a $\nu\tilde{\nu}$ pair is less probable than three-photon annihilation by a factor of about 10^{15}. Because of the longitudinal character of the neutrino, parapositronium cannot undergo annihilation with the emission of a neutrino and antineutrino.

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