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NEUTRINO AND THE MATTER DENSITY IN THE UNIVERSE

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Abstract*

The possibility is considered that the energy density of neutrinos and antineutrinos in the universe is comparable with the energy density associated with the mass of hydrogen. The assumption about a large energy density of neutrinos and antineutrinos does not contradict the experimental data available up to day.

Methods are discussed which might test such an assumption, which came about in considering the PC -asymmetry of the world together with the hypothesis of the existence of antiworlds. The great role of the Fermi $(e\nu)(e\nu)$ interaction in providing the transfer of the energy to the $\nu\bar{\nu}$ component is pointed out.

It is shown that the small value of the density of 'visible' kinetic energy (much smaller than the energy density connected with the rest mass of nucleons) does not contradict the 'fluctuation' hypothesis, i.e. the statement that the matter and antimatter were separated as a result of fluctuations in a charge symmetrical universe. The fluctuation hypothesis requires only that sometimes in the past there was an energy density of neutrino and antineutrino by many orders larger than the nucleon energy density.

Introduction

Up to the present time there are no well-founded evaluations of the neutrino and antineutrino density in the space. Since these particles practically are not absorbed even in dense materials and since the conditions of their creation in the past are unknown, their number might be very large. Though it is generally assumed that the matter in the universe is represented by the hydrogen, naturally there arises the question: might it be that the neutrino and antineutrino density of energy in the universe turns out to be comparable or even larger than the total hydrogen energy density?

Charge Asymmetry of the World and the Fluctuation Hypothesis

The assumption about a large number of ν and $\bar{\nu}$ in the universe arises, for example, when considering the charge (more exactly CP) asymmetry of the world. In numerous papers there was mentioned the possible existence of antiworlds which might have originated from fluctuations in a charge-symmetrical universe. Although at present there is no experimental evidence allowing to assume the existence of the antiworlds nevertheless it is interesting to note that the fluctuation hypothesis requires that either now or sometims in the past there should have been in the universe a large charge-symmetrical 'background'. Such 'background', in principle, should consist to a large extent of ν and $\bar{\nu}$ of equal density. The fluctuation hypothesis leads

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* This paper is a revised translation of the Russian preprint, published already under the same title.

therefore to consequences which can be tested. Note at once that if such a background existed then the measurement of the flux and of the energy of ν and $\bar{\nu}$ would yield the value of a very important parameter -- the mean energy density of the universe. At present the energy density in the universe is estimated by 'spreading' out the Galaxies. All the astronomical estimations give for the mean density of such 'spreaded' Galaxies a value not exceeding 10^{-29}g/ cm^3 ($\sim 10^{-2}$ MeV/cm^3) or less than 10^{-5} protons per cm^3 /1/*. According to the general theory of relativity it follows that the average energy of relativistic particles (neutrino in our case) falls proportionally to the space curvature a^{-1} (the energy density of these particles falls as a^{-4}). In other words in the past the average neutrino energy was larger than the present day energy by so much as much greater was the curvature.

Consequently in the past, when the matter density was colossal the neutrino energy density should have been by many order of magnitude greater than the nucleon energy density. These may well be the condition under which fluctuation s took place. The fluctuation mechanism is not discussed here, in particular the question as to whether the $\nu\bar{\nu}$ component should be considered as a primeval fluid remains open.

At least we are unable to say anything on this point. We might notice, however, that from our point of view the presence of antimatter in our galatic is not excluded a priori. It is clear that an estimate of the ν and $\bar{\nu}$ energy density in the universe strongly depends on the particular consmogonical model.

We should underline again, that the fluctuation hypothesis requires that in the universe there should have been present, sometimes in the past, a very large 'background' of $\nu\bar{\nu}$ pairs. If it should turn out, as it is likely, that the energy density of ν and $\bar{\nu}$ is much smaller than the nucleon energy density, this would not be an argyment against the fluctuation hypothesis. At the same time it would be said that the available data, which will be discussed below, do not exclude even extremely large energy densities of ν and $\bar{\nu}$ (comparable with nucleon densities) and very large energies ($\gtrsim$ 100 MeV) of these particles. Consequently it seems important to test whether the contribution of ν and $\bar{\nu}$ to the general energy density in the universe is essential even at the present time (from a different point of view the importance of measuring cosmic neutrino intensities had already emphasized in references 3 and 4).

Universal Weak Interaction and the Energy 'Pumping' in to $\nu\bar{\nu}$ -component

If we take seriously the possibility that at the present time, there is an energy density of ν and $\bar{\nu}$ of the order of 10^{-2} MeV/cm^3 in the universe, the question arises as to why there is not a flux of γ -rays of

* The problem of the matter density in the universe is of especial importance for the choice of the cosmogonical model of the universe. The magnitude of the mean density which corresponds to a flat universe (the transition from the close to the open model) is about 5.10^{-29}g/cm^3 /2/. Since recently the scale of cosmic distances has increased more than twice it is necessary to reduce this value to about 2.10^{-29}g/cm^3, which is close to the above estimate of the matter density. Therefore, the contribution of the neutrino component may turn out to be essential.

energies and intensities comparable with those of the assumed neutral lepton flux. It may be answered that (quite apart from the general relativity effects), the energy of the photons emited by 'annihilation of π^{0}' must degrade in dense matter because of the electromagnetic interactions. This fact would explain the absence of high-energy photon. However, this 'degraded' energy cannot vanish and at first glance it should appear in the universe in form of thermal energy, photon energy etc, its amount being not smaller than the energy related to the proton rest mass. However, as is well-known, the thermal and photon energy density in the universe, that is the density of "symmetrical" energy, is small in comparison with the energy density ('non-symmetrical') related to the rest mass of protons and it would seem difficult to reconcile this fact with an assumed energy density of ν and $\bar{\nu}$ comparable or even larger than that of nucleons. Such an objection can be overcome if there exists first order electron-neutrino scattering (as, for example, there should be according to the universal Fermi weak interaction theory). Then, instead of photon emission, in electromagnetic processes the emission of a $\nu\bar{\nu}$ pair becomes possible (through virtual or real $e^{+}e^{-}$ pairs[5]). At very high temperatures and densities (all the more, under the conditions we are interested in) the $\nu\bar{\nu}$ pair emission becomes the only effective machanism of energy radiation by the dense bodies[5,6,7,8]

Since ν and $\bar{\nu}$ are not in equilibrium with the matter (due to the weak interaction), a large fraction of the 'symmetrical' energy can be transferred into the neutrino component.

Existing Evidence on the ν and $\bar{\nu}$ Energy Density

We discuss now experimental data on the ν and $\bar{\nu}$ energy density in space. One can obtain direct evidence on the maximum densities of ν and $\bar{\nu}$ by assuming that in the experiments of Reines-Cowan[9] and Davis[10], carried out by means of reactors, the effect which was observed when the reactor was switched off, is due entirely to neutral leptons from the cosmic space. In the Reines-Cownn's experiment one could record antineutrinos with energies 3-10 MeV. From this experiment it follows that in the cosmic space the flux of antineutrinos with energies 3–10 MeV cannot considerably exceed 10^{13} cm $^{-2}$ sec^{-1}. This corresponds to a maximum energy density of antineutrinos with energies 3–10 MeV of the order of 10^{3}MeV/cm^{3}.

As to high-energy antineutrinos, the selection of events of the type $\tilde{\nu} + p \rightarrow n + e^{+}$ in the Reines-Cowan's experiment gave no possibility to record $\bar{\nu}$ with energies $>$ 10 MeV so that the experiment yields no evidence on high energy $\tilde{\nu}$.

From the experiments by Davis one can conclude that

$$\int_{0}^{\infty} c\rho(E)\,\sigma(E)\,dE \leq 10^{-33}\ \mathrm{sec}^{-1}$$

where $\rho(E)$ is the density of cosmic neutrinos with the energy E (including the neutrino from the

Sun) in MeV^{-1} cm^{-3} and $\sigma(E)$ in the cross section of the reaction $\nu + Cl^{37} \rightarrow Ar^{37} + e$. This cross section, roughly speaking, is proportional to the square of the neutrino energy in the region from several MeV to several tens of MeV. The analysis of the Davis' results shows that the energy density of cosmic space neutrino's with an energy of several MeV cannot exceed several tens of MeV/cm^3. On the other hand the Davis'experiment do not yield any evidence on the neutrinos with energies of the order of 1 BeV, because these will produce the disintegration of the argon. As to the neutrinos with energies up to 100 MeV, an evaluation of the energy density of these neutrinos is obtained by assuming that the Devis' detector was irradiated by mono-energetic neutrinos with an energy equal to the maximum one at which the nucleon recoil does not prevent the formation of **Ar**. In this extreme case too the maximum (i.e. allowed by experiment) energy density of neutrinos is of the order of several MeV/cm^3 and considerably exceeds W_H, the maximum value of the hydrogen energy density ($W_H \sim 10^{-2}$ MeV cm^{-3}) in the universe.

Now we consider what evidence can be obtained from experiments carried out under the earth. At large depths the cosmic neutrinos and antineutrinos will produce charged leptons which are distributed isotropically and with an intensity not depending upon the depth. If their energy exceeds considerably the muon rest energy then ν and $\bar{\nu}$ will produce effectively muons. The latter must slow down and stop: and under conditions of equilibrium, the number of muons produced is equal to the number of muons stopped. From the measurements /11/ at a depth of 6000 g/cm^2 it follows that the number of muons coming into an emulsion chamber from the lower semisphere and stopping in it equals $\sim 10^{-8} sec^{-1} cm^{-3}$. This number can be considered as the maximum possible number of muons produced by cosmic neutrinos (since most if not all of the slow muons coming into the emulsion from the lower hemisphere are due to the decay of pions emitted in stars which are formed by the penetrating component). From the foregoing it follows that

$$\int_0^{\infty} c\rho(E)\,\sigma(E)\,dE \leq 10^{-32}\ sec^{-1}$$

where $\sigma(E)$ is the neutrino-nucleon cross section. For the neutrinos and antineutrinos with energies of about 1 BeV $\sigma(E)$ lays /12/ between 10^{-38} and 10^{-39} cm^2. The underground measurements of the intensity of slow muons require therefore that the density energy of ν and $\bar{\nu}$ possessing an energy of about 1 BeV be $\lesssim 10^{-1}$ MeV/cm^3. This value is rather close to W_H. We would obtain even a smaller limit of the possible energy density of ν and $\bar{\nu}$ with energies about 1 BeV if we were taking into consideration the results of the experiments carried out in ref. /13/ by means of a counter telescope at a depth of about of $10^5 g/cm^{-2}$. However, it is difficult from our point of view to analyse these data and we can therefore only conclude that the maximum energy density of ν and $\bar{\nu}$ with energies higher or equal to 1 BeV cannot greatly exceed W_H and is very likely smaller than W_H. In any case, the present day status of experimental technique the problem of recording a flux of ~ 1 BeV-neutrinos and antineutrinos of the order of 10^5 cm^{-2}sec^{-1} is quite real. This task is far less difficult than the recently widely discussed problem of detecting neutrinos from accelerators[/14/]. In our case 10–100 isotopically distributed charged particles (electrons and muons) per day per ton of material will be produced inside the earth by such a flux of cosmic ν and $\bar{\nu}$.

It is necessary to stress that at energies of ν and $\bar{\nu}$ of the order or less than $m_{\mu}c^2$ the production of muons by neutrino is not possible; the underground measurements do not exclude at all the possibility that the energy density of ν and $\bar{\nu}$ is more than W_H.

Experiments on the detection of high energy cosmic neutrinos have been discussed earlier[/15,16/], it being assumed that these particles are produced in collisions of 'cosmic radiation protons' with the earth atmosphere or with the interstellar matter. It is clear that in this case the number of neutrinos is very small and this can be seen immediately by considering that high energy γ -rays from π^0 decay have a very small intensity.

Conclusion

From the foregoing it follows that a priori one can not exclude the possibility that in the universe the energy density of neutrinos and antineutrinos is comparable or greater than the mean energy density related to the rest mass of nucleons. This must be tested by the experiment.

We should notice that for very large densities and very high energies the predominance of the unobservable $\nu\bar{\nu}$ 'symmetrical' form of energy over other symmetrical forms of energy is a quite general property connected with the scattering of neutrinos by electrons and can be of interest irrespective of the fluctuation hypothesis. In general the mechanism of 'energy pumping' into the neutrino component might lead to a considerable density of ν and $\bar{\nu}$ in the universe. The existence of this mechanism casts doubt on the estimations of the matter density in the universe which have been done taking into account only 'visible' form of the matter.

It should be emphasized that the lower is the mean energy of neutrinos the more difficult becomes the experimental task of excluding the existence of a given energy density $\int \varrho(E) E\, dE$. Roughly speaking, the energy density of ν and $\bar{\nu}$ which can be discovered experimentally is inversely proportional to the square of the neutral lepton energy in the region of energies higher than several MeV. At lower energies the detection difficulties become tremendous. So, for example, the hypothesis on the existence of an energy density of ν and $\bar{\nu}$ equal to W_H or larger can be easily tested by experiment (perhaps it can be disproved already by the data available so far on underground muons), if the neutrino energy is greater than 1 BeV. If the neutral leptons possess energies of about 100 MeV the test of the hypothesis is a real proposition but it meets serious difficulties. At neutrino energies smaller than 1 MeV, it is difficult to disprove experimentally even the existence of energy densities of ν and $\bar{\nu}$ exceeding W_H by many order of magnitude*.

To measure neutral lepton fluxes with enegies ~1 BeV it is most convenient to detect secondary muons created by neutrinos/14,15/. In the energy region of ν and $\bar{\nu}$ from several MeV to several hundreds of MeV the Reines-Cowen and Devis' types of experiment are quite convenient. As to the detection of ν and $\bar{\nu}$ with energies $<$ 1 MeV, the only possibility in our opinion is the use of the neutrino-electron scattering. Unfortunately this is only a theoretical possibility.

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* However a density much large than W_H will contradict the cosmological data. (Zeldovich, private communication).

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