POSSIBILITY OF USING THE PROCESS $\nu + e \to \nu + e + \gamma$ TO REGISTER NEUTRINOS OF ENERGY $\sim$ 1 MeV

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We consider the possibility of using the elastic scattering of a neutrino by an electron, with emission of a photon ($\nu + e \to \nu + e + \gamma$) to register neutrinos of energy $\sim$ 1 MeV. Some qualitative characteristics of the process are presented. The total cross sections of the processes $\nu + e \to \nu + e + \gamma$ and $\nu + e \to \nu + e$ are compared.

In a number of problems, for example in neutrino astrophysics, it is absolutely necessary to determine the direction to the neutrino source in order to prove a causal connection between the registered neutrino flux and its supposed source. This can be done in principle by using electronic methods of neutrino detection and by determining the direction of the predominant emission of electrons in the inverse beta decay or in ν-e scattering. The general requirements that electronic neutrino detectors must satisfy are spelled out in the papers of Zatsepin and Pontecorvo [1, 2]. At the present time it seems promising to develop electronic neutrino detectors on the basis of liquified noble gases and registration of the electrons from ν-e scattering (see, e.g., [2, 3]).

However, measurement of the electron emission angles in the scattering of neutrinos of kinetic energy close to 1 MeV in a condensed medium entails the following fundamental difficulties: the electron mean free paths are small ($\sim$ 1 mm), and the probability of their scattering is large. In liquid argon, an electron of 1 MeV energy travels not more than 3 mm and is deflected from its initial direction already in the first 5% of its path (owing to multiple scattering) by an average of 10°. In detectors that weigh many tons, it is difficult to expect a spatial resolution better than 1 mm, so that the possibility of determining the electron emission angle is doubtful, and the same holds for fluxes of neutrinos of $\sim$ 1 MeV energy. It is therefore expedient to consider the possibility of using inelastic neutrino-electron scattering with emission of a gremsstrahlung photon:

$$\nu + e \to \nu + e + \gamma. \tag{1}$$

In principle, a bremsstrahlung photon always accompanies the scattering process

$$\nu + e \to \nu + e \tag{2}$$

Practical interest, however, attaches only to cases of scattering with production of photons of sufficient energy to be readily recorded. A filmless electron detector based on liquid argon makes it possible to register ionization in which about 30 keV is released [3], and the need for observing a photon with this energy greatly decreases the efficiency of registration of the process (1).

Figure 1a shows the kinematic scheme of process (1), while Figs. 1b and 1c show the Feynman diagrams of this process. On the basis of these diagrams, we calculated the distributions of the secondary electrons and photons with respect to the energies and the emission angles. Since the expressions are quite cumbersome, we present only the qualitative characteristics of the process (1): 1) the differential probability of photon production is inversely proportional to its energy, 2) the differential probability of photon production increases with increasing neutrino energy, 3) the differential probability of photon emission is particularly large if the electron produced in the neutrino scattering has high energy, 4) the photons are emitted mainly in the direction of the neutrino flux.

Figure 2 shows some quantitative results of the calculation of the differential cross section for the production of photons emitted into different angle intervals following scattering of a 1-MeV neutrino.

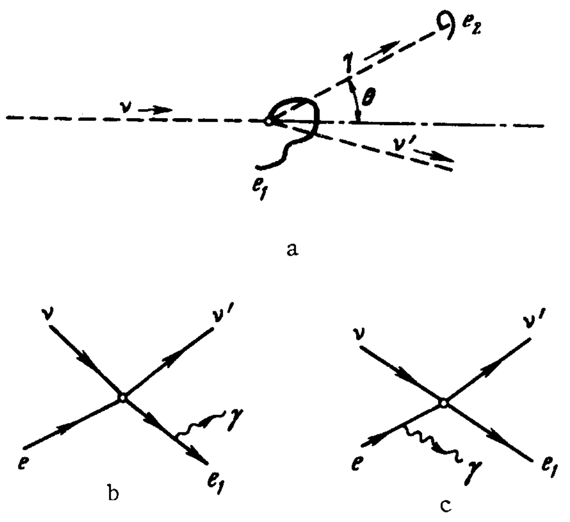

Fig. 1

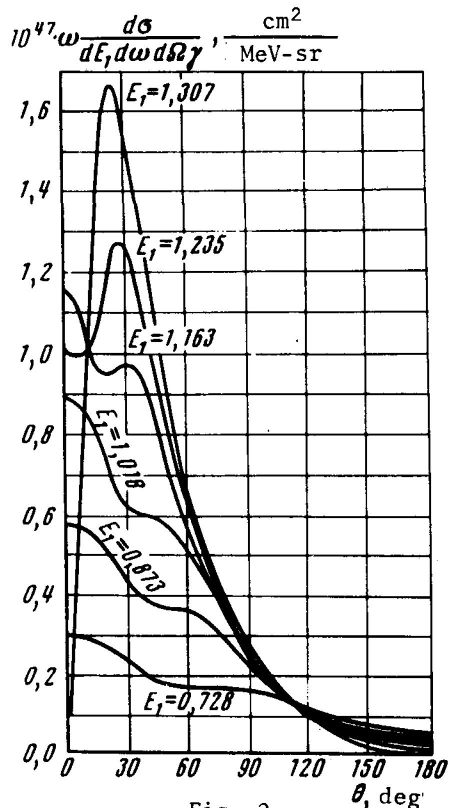

Fig. 2

Fig. 1. Typical case of reaction $\nu + e \rightarrow \nu + e + \gamma$ in a condensed medium: ν and ν' — neutrino before and after scattering, e_1 — scattering electron, e_2 — photoelectron, θ — angle between the momentum of the primary neutrino and the photon momentum; b) Feynman diagrams of the reaction $\nu + e \rightarrow \nu + e + \gamma$.

Fig. 2. Dependence of the differential cross section $d\sigma/dE_1/d\Omega_\gamma$ for neutrino scattering by an electron with formation of a photon on the photon-emission angle θ in a solid angle $d\Omega_\gamma$ at different total energies E_1 of the scattered electron. The neutrino energy is 1 MeV (the maximum total energy of the electron is 1.307 MeV, the photon energy is much less than the electron mass).

Although the process (1) is less probable under the considered condition than ν-e scattering, the registration of the inelastic process (1) is facilitated by the lower probability of imitation of this more complicated process by background phenomena. The possibility of separating the process (1) is facilitated also by the presence of correlations between the kinematic characteristics of the secondary electrons and photons (energies and emission angles) and the proposed energy and momentum direction of the primary neutrino. In liquid argon, the free path of a photon of 30 keV energy is on the average several millimeters, after which the photon is absorbed as a result of the photoeffect (see Fig. 1). From the two "points" (the point of electron production by neutrino scattering and the point of photoelectron production) we can determine the photone emission direction, even if the spatial resolution of the detector is somewhat worse than 1 mm. The preferred emission of photons in the direction of the indicent neutrinos enables us to find the direction to the neutrino source.

By way of example we consider the use of the process (1) to register solar neutrinos. We know that 99.99% of the neutrinos from the sun have an apparent energy lower than 2 MeV [4]. The total cross section of the process (1), when the photon energy ω lies in the interval from ω_1 to ω_2 ($\omega_1 < \omega_2 \ll m$, where m is the electron mass) is given by

$$\sigma = [4a\sigma_0 E/\pi m(m+2E)][(E+m)\ln(1+2E/m) - 2E]\ln(\omega_2/\omega_1) \quad (3)$$

where $\underline{a}$ = 1/137 is the fine structure constant, $\sigma_0 = 8.3\times10^{-45}$ cm^2, and E is the neutrino energy. The cross section for the production of a photon of energy higher than 30 keV can be easily estimated, namely, at a neutrino energy E = 1 MeV, ω_1 = 30 keV, and ω_2 = 0.1 MeV we obtain $\sigma \approx 3\times10^{-47}$ cm^2 (such photons can be registered in 0.3% of all ν-e scattering cases). It follows from (3) that the relative contribution of the process (1) increases with increasing interval of the energies of the registered photons and with increasing energy of the primary neutrino.

Owing to the high intensity of the neutrino flux in the energy region $\sim$ 1 MeV, in an electronic detector containing $\sim$ 300 m^3 of liquid argon, one can expect about a hundred inelastic events per year from only one monochromatic line of the solar spectrum — a neutrino of energy 0.86 MeV (assumed flux $\sim 10^9$ cm^{-2}sec^{-1}).

Thus, the magnitude of the effect of process (1) is comparable with the expected effect from the "boron" neutrinos in the known instrument of Davis [5]. At the same time, we can obtain more direct information on the processes occurring on the sun, since neutrinos of energy $\sim$ 1 MeV are produced during earlier stages of thermonuclear fusion than "boron" neutrinos. The accuracy with which the direction of the neutrino flux is registered is $\sim 10°$. Consequently, the solar origin of the registered neutrinos can be uniquely verified, in principle, whereas the "blind methods," including the radiochemical method used in the Davis instrument, leave open the question of the origin of the neutrino.

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STRUCTURE OF POMERANCHUK POLE AND INCLUSIVE SPECTRA

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We consider the connection between the approach to scaling in the inclusive reactions and the clustering of the produced particles. The analysis is carried from the point of view of the multiperipheral model. It is shown that the behavior of the inclusive spectra depends on the ratio of the densities with respect to the rapidity of the detected particles in fragmentation clusters (resonances) and in central ones.

The question of the dynamics of multiple particle production is at present of particular interest, since the new experimental data announced daily, obtained from high-energy accelerators (Serpukhov, Batavia, ISR-CERN) make it possible to verify the validity of various theoretical models, and also take into account in them many important factors.

Of particular interest from among the latest sutdies are the approach to scaling in the central region of inclusive spectra, and the appreciable correlations observed experimentally in two-particle inclusive reactions, and point to clustering of the produced particles [1].