Possibility of developing an intense neutrino source

N. G. Basov and V. B. Rozanov
P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow

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The possibility of converting the neutrons produced in a pulsed fusion reaction into neutrinos and antineutrinos by means of various nuclear reactions is examined.

Various experiments pertinent to a possible nonconservation of electron and muon lepton numbers and the existence of neutrino oscillations in a vacuum have been under discussion for a long time now.[1–3] Nuclear reactors, accelerators, the sun, and cosmic-ray neutrinos have all been discussed as sources for such experiments. The use of cosmic-ray neutrinos and solar neutrinos in various experiments with deep underground or underwater detectors has been discussed.[3–5] The characteristics of these sources are estimated in Table I.

In the present letter we wish to call attention to the possibility of developing an exceptionally bright (for laboratory conditions on the earth) pulsed source of electron neutrinos or antineutrinos, by converting the neutrons produced in a pulsed fusion reaction induced by a laser beam (or a particle beam) into neutrinos or antineutrinos through various nuclear reactions. The possibility of an inductive acceleration of particles in a microscopic explosion and the production of meson neutrinos was discussed in Ref. 6.

The use of such a source, with a pulse length between a fraction of a second and several minutes, would provide the further opportunity of making use of a temporal selection of events during detection; temporal selection could improve the resolution and accuracy of an experiment.

Numerical calculations which have been carried out for laser fusion targets by means of programs which have been tested in a variety of experiments have shown that at a laser radiation energy of several megajoules a fusion energy of 10^3–10^4 MJ could be released.[7,8] This energy release corresponds to the emission of 3.5×10^{20} to 3.5×10^{21} DT neutrons in a pulse of length 3×10^{-11} s.

We know of several nuclear reactions in which electron neutrinos or antineutrinos are produced in the β decay of a nucleus which is produced in the reaction: $Be^9 n\alpha He^6$,

TABLE I.

Source	Particle	Energy range (MeV)	Intensity (s^{-1})	Flux-density range ($cm^{-2}\cdot s^{-1}$)
Reactor	$\bar{\nu}_e$	$1\div2$	10^{19}	$10^{12}-10^{13}$
Accelerators	ν_μ, $\bar{\nu}_\mu$	$(1\div200)\cdot10^3$	10^8-10^{10}	–
The sun	ν_e	$0\div1{,}44$	–	7×10^{10} [3]
	ν_e	14,1	–	5×10^6
Cosmic rays	$\nu_e+\bar{\nu}_e$, $\nu_\mu+\bar{\nu}_\mu$	10^3	–	1 [5]

$Li^6 np He^6$, $C^{12} np B^{12}$, $B^{11} n\gamma B^{12}$, $B^{11} n\alpha Li^8$, $Li^7 n\gamma Li^8$, $C^{12} pn N^{12}$, $Al^{27} n2n Al^{26}$, $Si^{28} n2n Si^{27}$, and $S^{32} n2n S^{31}$.

Furthermore, the fission reactions of U, Th, and Pu give rise to neutron-excess nuclei, which produce antineutrinos in their β decay; some of the decays (of isotopes of I, Xe,and Rb, for example) have short half-lives. The most interesting of these reactions are those that lead to decays of B^{12} (decay half-life $T_{1/2} = 0.027$ s) and N^{12} ($T_{1/2} = 0.0125$ s), which give rise to particles with a maximum energy ($E_{\max} = 13.43$ and 16.6 MeV), and the reaction $Al^{27} n2n Al^{26}$ ($T_{1/2} = 6.3$ s, $E_{\max} = 3$ MeV), which produces neutrinos. The cross sections for the neutron reactions are given in Ref. 9. It would be extremely desirable to refine the behavior of the cross sections in connection with the problem under consideration here, since the data available are incomplete and not always consistent (the data on $B^{11} n\gamma$, for example).

The thresholds for the np, $n\alpha$,and $n2n$ reactions are close to 14 MeV; the threshold for the $C^{12} pn$ reaction is 20 MeV; and the cross sections for neutron reactions for 14-MeV neutrons are on the order of 10^{-3}–10^{-2} b. It can be seen from the magnitudes of the cross sections that the conversion of neutrons into ν and $\bar{\nu}$ is not a simple task, and special "neutrino" targets would have to be developed in order to produce these particles in a laser fusion reactor. Such targets could be fabricated as spherical shells, at whose center a microscopic explosion occurs. The inside radius of the shell would be determined by the conditions required to avoid destruction of the target (e.g., heating might be allowed only up to the melting point), while the thickness of the shell would be determined by the reaction cross sections. For the np, $n\alpha$, and $n2n$ reactions, this thickness would be determined by the transport range of 14-MeV neutrons. In the case of the $n\gamma$ reaction, the loss of neutrons due to escape from the target and absorption by impurities would have to be small in comparison with the useful process. For example, if a B^{11} target ($\sigma_{n\gamma} \simeq 0.01$ b) contains a B^{10} impurity ($\sigma_{n\gamma} \simeq 10^3$ b), the concentration of this impurity could not exceed 10^{-5}. Estimating the neutron yield in the diffusion approximation, we find that the shell thickness would have to satisfy $\Delta \gtrsim \sqrt{(\pi^2/12) L_t L_{n\gamma}}$, where L_t is the total range of the neutrons, and $L_{n\gamma}$ is the range for the $n\gamma$ reaction. Estimates show that for $E_{\text{fus}} = 10^4$ MJ the inside radius of the neutrino target should be chosen to be 1–1.5 m (depending on the particular material), and the thickness of the shell would have to be 10–15 cm for the np, $n\alpha$, and $n2n$ reactions or about 1–1.5 m for the $n\gamma$ reaction.

In our examples, the ν yield in the $Al^{27} n2n$ reaction and the $\bar{\nu}$ yield in the np and $n\alpha$ reactions, divided by the total number of neutrons, are equal to the ratio of the reaction cross section to the transport cross section (1/65 for Al^{27} or 5×10^{19} neutrinos). In the case of the $n\gamma$ reaction, the number of antineutrinos may be equal to the number of neutrons that are moderated and captured, i.e., 3.5×10^{21}. Since the scale time for the moderation and capture of a neutron is about 10^{-3} s, the source intensity is determined by the decay half-life of the product nucleus.

Antineutrinos might be produced in a fission reaction in a laser hybrid reactor.[10] It is believed possible to achieve from one to several fissions per 14-MeV neutron; it would then be possible to produce $\simeq 10^{23}$ antineutrinos at $E_{\text{fus}} = 10^4$ MJ.

It would be possible in principle to use the reaction $C^{12} pn N^{12}$, since several processes leading to the production of protons with energies above 20 MeV would occur

TABLE II.

Reaction	ν or $\bar{\nu}$	Scale time (s)	Max. energy (MeV)	Number	Flux density ($cm^{-2} \cdot s^{-1}$)
$B^{11}n\gamma B^{12}$	$\bar{\nu}$	0,027	13,43	$3,5\times 10^{21}$	10^{16}
$Al^{27}n2nAl^{26}$	ν	6,3	2 – 3	5×10^{19}	10^{12}
Unf	$\bar{\nu}$	1 – 100	1 – 2	10^{23}	10^{16}

during the burning of the target, but quantitative estimates are unreliable here, and we will not go into them.

The overall layout of a neutrino apparatus, a "laser neutrino factory," might be imagined as follows: A neutrino target is assembled from hemispheres (or sectors of spheres) inside an explosion chamber by means of apertures in the wall of the chamber. The chamber would have a radius of 5–7 m, with the appropriate shielding, the system for injecting the laser radiation, the laser fusion targets, etc. The total neutron flux could be collected from each microscopic explosion or from a series of successive explosions. With cooling, a neutrino target could be reused repeatedly.

Table II shows some possible parameter values of neutrino sources (for $E_{\text{fus}} = 10^4$ MJ; the flux densities are given at a distance $R = 10$ m from the reactor).

Sources of neutrinos and antineutrinos with these parameters might also prove useful for solving the problem of neutrino oscillations (for determining the mixing angle and length).

We note in conclusion that the NOVA laser,[11] recently brought into operation, could be expected to produce 3×10^{16} neutrons. If the reaction $B^{11}n\gamma B^{12}$—the most economical reaction—is used, the flux density of antineutrinos at a distance of 10 m from the explosion chamber could be predicted to be 10^{11} $cm^{-2} \cdot s^{-1}$.

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