DETECTION OF SOLAR NEUTRINOS BY MEANS OF THE $Ga^{71}(\nu,e^-)Ge^{71}$ REACTION

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The possibilities are examined of detecting solar neutrinos by means of the low threshold reaction $Ga^{71}(\nu,e^-)Ge^{71}$, which can be efficiently employed for recording neutrinos from the $H^1(p,e^+\nu)H^2$ and $Be^7(e^-,\nu)Li^7$ reactions. The merits of the radiochemical method based on this reaction are compared with those of other reactions. The cross section for absorption of solar neutrinos by the Ga^{71} nucleus and the magnitude of the effects on the earth due to neutrinos from various reactions occurring in the interior of the sun are presented. It is pointed out that transitions to the excited states of the Ge^{71} nucleus may be important for neutrino absorption.

1. In connection with the extensively discussed problems of detection of solar neutrinos and studies of the internal structure of the sun[1-10], we wish to call attention in this communication to unique possibilities connected with the development of a radiochemical method based on the reaction $Ga^{71}(\nu, e^-)Ge^{71}$. This reaction was pointed out in [1, 5, 9] as being the most convenient for the detection of solar neutrinos from the reactions $H^1(p, e^+, \nu)H^2$ and $Be^7(e^-, \nu)Li^7$ (and Li^{7*}).

2. We wish to point out here the advantages of the method, based on the reaction $Ga^{71}(\nu, e^-)Ge^{71}$, which make it especially attractive compared with other possible realizations on the idea of the radiochemical method proposed by Pontecorvo.[11]

1) The rather low energy threshold for neutrino absorption, $E_\nu^{thr} = 0.237$ MeV, makes it possible to register neutrinos from practically all reactions in the interior of the sun and, most importantly, the neutrinos with the greatest flux density,[6] from the reactions $H^1(p, e^+ \nu)H^2$ and $Be^7(e^-, \nu)Li^7$ (Li^{7*}). The only neutrinos that cannot be registered are those from $He^3(e^-, \nu)H^3$, with energy ~ 18 keV. We note that in accordance with the Pontecorvo-Davis method,[11, 4] which is based on the reaction $Cl^{37}(\nu, e^-)Ar^{37}$, the threshold amounts to $E_\nu^{thr} = 0.816$ MeV.

2) The cross section for the absorption of a neutrino by the Ga^{71} nucleus is relatively large even for the transition to the ground state of Ge^{71}, log ft ≈ 4.3. This ensures, by the same token, a very high sensitivity of such a detector to low-energy neutrinos (we note by way of comparison, for example, that Mn^{55}, with a low threshold $E_\nu^{thr} = 0.0220$ MeV, has log ft = 6.0, while Cl^{37} has log ft = 5.0).

3) The Ge^{71} half-life, $t_{1/2} = 11.4$ days,[12] which is very convenient for purposes of chemical extraction of Ge^{71} atoms from a large quantity of Ga (or its compounds), makes it possible to assume that the efficiency of the method can be made sufficiently high if the extraction procedure lasts about five days. The method of [10], connected with the use of $Rb^{87}(\nu, e^-)Sr^{87m}$, has from this point of view the shortcoming that the half-life of Sr^{87m} is small, ~ 2.9 hours, and the extraction procedure can hardly be carried out with sufficient speed. In the case of Fe^{55}, the half-life, to the contrary, is too long, $t_{1/2} = 2.6$ years.

4) The energy released by K-capture in Ge^{71}, ~ 12 keV, is noticeably larger than for K-capture in Ar^{37} (~ 2.8 keV), giving grounds for hoping to be able to discriminate more readily the false background in the counter.

5) The considerable abundance of the Ge^{71} isotope, ~ 40%, makes it possible to obtain a noticeable effect per unit mass of the natural isotope mixture.

3. Finally, we wish to call attention to the transitions that are possible under the influence of neutrinos and excited states of Ge^{71}, and can greatly increase the total cross section for the absorption of solar neutrinos. The scheme and identification[12] of the Ge^{71} levels allows us to think that the transitions to the level E = 1.75 MeV ($5/2^-$) will play a noticeable role in neutrino absorption. The role of other states is not clear. In estimating the influence of this transition on the total cross section and the change in the selective sensitivity of the detector, we have assumed that the matrix element of the transition to the 0.175 MeV level in one spin state is equal to the corresponding matrix

Table. Cross sections for the absorption of solar neutrinos in the reaction $Ga^{71}(\nu, e^-)Ge^{71}$.

Reaction	Neutrino flux from the sun Φ, $cm^{-2}sec^{-1}$	$\bar{\sigma}_{gr.\ state}$, $10^{-45}\ cm^2$	$\bar{\sigma}_{exc.\ state}$, $10^{-45}\ cm^2$	$\Phi\bar{\sigma}_{gr.\ state}$, $10^{-35}\ sec^{-1}$	$\Phi\bar{\sigma}_{total}$, $10^{-35}\ sec^{-1}$
$H^1(p, e^+\nu)H^2$	$5.8\cdot10^{10}$	1.3	0	7.5	7.5
$H^1(pe^-, \nu)H^2$	$1\cdot10^8$	15.6	41	0.16	0.6
$N^{13}(e^+\nu)C^{13}$	$0.48\cdot10^9$	5.3	11	0.7	2.2
$O^{15}(e^+\nu)N^{15}$	$0.48\cdot10^9$	9.2	21		
$Be^7(e^-, \nu)Li^7$	$0.74\cdot10^{10}$	7.2	15	5.5	16.7
$Be^7(e^-, \nu)Li^{7*}$	$0.08\cdot10^{10}$	2.2	0		
$B^8(e^+\nu)Be^{8*}$	$1.9\cdot10^7$	320	920	0.6	2.5
$He^3(p, e^+\nu)He^4$	$1.3\cdot10^6$	550	1600	0.07	0.3

element of the transition to the ground state of Ge^{71}. The table lists the intensities of the neutrino fluxes from the sun[3,6,8] and the cross section for the absorption of these neutrinos by the Ga^{71} nucleus.

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[1] G. T. Zatsepin, Proc. Int. Conf. Cosmic Rays, **6**, Jaipur, India, (1964), p. 6 (See also loc. cit. H.-Y. Chiu, p. 131). M. A. Markov, Neĭtrino (Neutrinos), Nauka, 1964, p. 130.

[2] J. N. Bahcall, W. A. Fowler, I. Iben, Jr., and R. L. Sears, Astrophys. J. **137**, 344 (1963).

[3] J. N. Bahcall, Phys. Rev. **135**, B137 (1964).

[4] R. Davis, Phys. Rev. Lett. **12**, 302 (1964).

[5] V. A. Kuz'min, Preprint A-62, Phys. Inst. Acad. Sci. 1962; Izv. AN SSSR ser. fiz. **29**, 1743 (1965), transl. in press.

[6] R. L. Sears, Astrophys. J. **140**, 477 (1964).

[7] F. Reines and W. R. Kropp, Phys. Rev. Lett. **12**, 457 (1964).

[8] V. A. Kuz'min, Preprint A-40, Phys. Inst. Acad. Sci. 1965; Phys. Lett. **17**, 27 (1965).

[9] V. A. Kuz'min, Preprint A-81, Phys. Inst. A Acad. Sci. 1965.

[10] M. Goldhaber and A. W. Sunyar, Phys. Rev. **120**, 871 (1960).

[11] B. Pontecorvo, Nat. Res. Council of Canada, Rep. No. 205 (1946).

[12] B. S. Dzhelepov and L. K. Peker, Skhemy raspada radioaktivnykh yader (Decay Schemes of Radioactive Nuclei), AN SSSR, 1958.

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196