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# Possibility of studying the difference between $\tilde{\nu}_e$ and $\nu_e$ in gallium through the use of an artificial source of $\tilde{\nu}_e$

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The possibility of improving the existing limitation on the difference between $\tilde{\nu}_e$ and $\nu_e$ through the use of an artificial source of $\tilde{\nu}_e$ in a gallium-germanium neutrino telescope is analyzed.

The question of calibrating a gallium-germanium neutrino telescope with the help of an artificial neutrino source of ultrahigh activity ($\sim 1$ MCi) has recently been discussed widely.[1,2] In this connection it is interesting to analyze the possibility of setting up an experiment to determine the difference between $\tilde{\nu}_e$ and $\nu_e$ through the use of an artificial source of antineutrinos. Experiments of this sort have been carried out at a nuclear reactor[3] and at an accelerator.[4] Barabanov *et al.*[5] have suggested using a gallium target in the flux of antinuetrinos from a reactor for this purpose.

The $\tilde{\nu}_e$ source might be a $\beta^-$-active isotope whose decay half-life is on the order of several tens of days, whose energy release is as large as possible, and whose decay is not accompanied by the emission of hard $\gamma$ rays. The most suitable sources are $^{32}$P($Q_B = 1.710$ MeV, $t_{1/2} = 14.28$ days), $^{89}$Sr ($Q_B = 1.492$ MeV, $t_{1/2} = 50.5$ days), $^{143}$Pr ($Q_B = 0.935$ MeV, $t_{1/2} = 13.58$ days), and $^{170}$Tm ($Q_B = 0.968$ MeV, $t_{1/2} = 128.6$ days). It would not seem possible to collect enough $^{89}$Sr or $^{143}$Pr ($\sim 3.5$ g and $\sim 15$ g, respectively), so we will not discuss them further.

The cross section for the reaction $^{71}\text{Ga}(\nu_e, e^-)^{71}\text{Ge}$, averaged over the $\tilde{\nu}_e$ spectrum from $^{32}$P, is $1.18 \times 10^{-44}$ cm$^2$, while that averaged over the $\tilde{\nu}_e$ spectrum from $^{170}$Tm is $0.50 \times 10^{-44}$ cm$^2$. The number of $^{71}$Ge atoms which we would expect under the assumption $\tilde{\nu}_e \equiv \nu_e$ reaches a maximum after an 18-day exposure in the case of $^{32}$P and after a 43-day exposure in the case of $^{170}$Tm. Using 10 metric tons of metallic gallium, allowing for the actual geometry of a gallium-germanium experiment,[1] assuming that the flux of neutrinos from the sun—the primary source of background—corresponds to the standard solar model[6] (the effect at the $^{71}$Ga would be $\sim 10^2$ solar neutrino units), and assuming that the initial activity of the source is $\sim 1$ MCi, we can place the following limitation on the value of $\alpha^2 = \sigma_{\text{expt}}/\sigma_{\text{theo}}\,(\tilde{\nu}_e \equiv \nu_e)$:

$$\alpha^2 \lesssim 0.006 \tag{1}$$

in the case of $^{32}$P. This figure is an order of magnitude lower than what is currently the best limitation, which was found from Ref. 4. For the case of $^{170}$Tm we find

$$\alpha^2 \lesssim 0.01. \tag{2}$$

In 0.144% of the cases, the $^{170}$Tm will decay through electron capture ($Q_e = 0.314$ MeV), but this reaction will not result in the formation of a significant amount of $^{71}$Ge ($\sim 0.1$ at over 43 days).

The most natural way to obtain the necessary isotopes appears to be the $(n,\gamma)$ reaction involving thermal neutrons, since the natural abundance of both $^{31}$P and $^{169}$Tm is 100%, and the cross sections for the radiative capture of neutrons are fairly large (averaged over the spectrum of reactor neutrons, they are 0.18 b and 106 b, respectively[7]). For a neutron flux density of $3 \times 10^{15}$ cm$^{-2}\cdot$s$^{-1}$, the amount of natural phosphorus which we would have to irradiate in order to produce a source of the required activity would be 5–5.5 kg, while in the case of thulium we would need 0.5 kg for a bombardment time of 40 days. The cross section for neutron activation of $^{170}$Tm has been assumed to be[7] 92 b, and the interval of values given here for phosphorus corresponds to a variation of the neutron activation cross section for $^{32}$P from 0 to 20 b.

Another method for producing $^{32}$P which might turn out to be practical would be to make use of the reaction $^{32}S(n,p)^{32}$P in the flux of a fast-neutron reactor (the natural abundance of $^{32}S$ is 95.02%).

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