Observation of weak neutral current in interaction of fission antineutrinos with deuterons

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The first results have been obtained in an effort to measure the cross section for the interaction of fission antineutrinos with deuterium nuclei in the channel of the weak neutral current: $\sigma_{nc} = (3.0 \pm 1.0) \times 10^{-44}$ cm^2/fission. The statistical accuracy has been improved for the cross section for the channel of a weak charged current: $\sigma_{cc} = (1.1 \pm 0.2) \times 10^{-44}$ cm^2 fission. The ratio of the cross sections for the two channels has been determined: $\Gamma_{expt} = \sigma_{cc}/\sigma_{nc} = 0.37 \pm 0.14$.

The Deĭton detector, designed for studying the interaction of fission antineutrinos with deuterium nuclei, was described in Ref. 1. In that paper we reported results for only the charged channel of the reaction under study. Further experiments have been carried out to determine the nature of the background of this apparatus. A layer of boron carbide was removed from the passive shielding of the detector, with the result that the background was reduced by 15%. Some special experiments were carried out to measure the background of the aluminum, of which the detector tank and the tubes running through the graphite assembly were made (there is a total of ~130 kg of aluminum in the detector). It was found that the additional 27 kg of aluminum in the central part of the detector increased the background by 250 events over the series, primarily because of the reaction

$$\gamma + d \Rightarrow p + n .$$

The source of the γ rays in aluminum is the natural impurity of the isotope Th-232 ($E_\gamma = 2.61$ MeV). On this basis we estimated the background from the 130 kg of aluminum in the detector to be 750–800 events over the series. In replacing the aluminum with stainless steel, we hoped to reduce the detector background to a level of ~400 events over the series or, in other words, to change the effect-to-background ratio to 1:20. The background could apparently be reduced further by replacing the graphite by a material (e.g., a fluoroplastic) which is cleaner in the radiation sense.

Experimental results. Measurements were carried out in the neutral channel for three different background environments (which we will designate as A, B, and C). The background environment changed as a result of the sequential modernization of the passive shielding of the detector.

A: The boron carbide was removed from the ends of the detector shielding.
B: The boron carbide was removed from the top shielding of the detector.
C: The boron carbide was completely removed from the detector shielding.

For each of these regimes we measured the count rate of individual neutrons (the effect) which was correlated with the operation of the reactor (the difference between the count rates with the nearby reactor operating and shut down). We obtained the following results:

A: effect $= 35.1 \pm 11.4$ events over the series;
B: effect $= 23.0 \pm 22.1$ events over the series;
C: effect $= 31.0 \pm 13.1$ events over the series.

In order to correct all these regimes to the same conditions, we need to make corrections in each case for the events involving the production of neutrons in the hydrogenous shielding of the detector through the reaction

$$\tilde{\nu}_e + p \Rightarrow n + e^+$$

Boron carbide completely suppresses this component of the background correlated with the operation of the reactor. In removing the carbide from the shielding, we significantly reduced the overall background, while generating a small correlated background. This correlated background amounted to 2.6 ± 0.3 events over the series, 3.3 ± 0.3 events over the series, and 5.8 ± 0.5 events over the series in regimes A, B, and C, respectively.

Subtracting these corrections, and adding the weighted results for all three regimes, we find

effect $= 28.1 \pm 7.9$ events over the series.

To determine the effect associated exclusively with $\tilde{\nu}d$ interactions, we need to correct this quantity for (1) the impurity of ordinary water in the heavy water (0.17%), (2) the impurity of ordinary water in the graphite (0.1%), and (3) the transfer of events from the charged channel to the neutral channel due to the finite efficiency of the neutron detection. The corresponding corrections are (1) 0.9 ± 0.1 events over the series, (2) 1.2 ± 0.1 events over the series, and (3) 3.3 ± 0.7 events over the series. The overall correction is thus 5.4 ± 0.8 events over the series. Finally, the observable effect in the channel of the weak neutral current is

$N_{\rm nc} = 22.7 \pm 8.0$ events over the series,

and the cross section is

$$\sigma_{\rm nc} = (3.0 \pm 1.0) \times 10^{-44}\ {\rm cm^2/fission}.$$

The background associated with the charged reaction channel (two neutrons are detected in coincidence in a time window of 800 μs) is the same in regimes A, B, and C, within the statistical error. By analogy with Ref. 1, we are thus reporting only the final table (Table I), which reflects the increased statistical accuracy of the measurements.

We then find the cross section for the charged channel to be

$$\sigma_{\rm cc} = (1.1 \pm 0.2) \cdot 10^{-44}\ {\rm cm^2/fission}.$$

TABLE I.

Status of reactors		Number of two-neutron events over the series	Number of three-neutron events over the series	Number of four-neutron events over the series
Near	Far			
+	+	59.5 ± 0.9	13.8 ± 0.4	5.3 ± 0.2
−	+	51.4 ± 1.2	13.9 ± 0.6	5.6 ± 0.4
[+ +] − [− +]		8.1 ± 1.5	− 0.1 ± 0.7	− 0.3 ± 0.5

The ratio of measured cross sections is

$$\Gamma_{\mathrm{expt}} = \frac{\sigma_{\mathrm{cc}}}{\sigma_{\mathrm{nc}}} = 0.37 \pm 0.14 \,.$$

These measurements are continuing. We hope to replace the basic structural materials of the detector in the near future and thereby improve the effect-to-background ratio significantly.

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[1]G. S. Vidyakin *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **49**, 130 (1989) [JETP Lett. **49**, 151 (1989)].

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