Observation of a weak charged current in the interaction of reactor antineutrinos with a deuteron

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The first results on the interaction of reactor antineutrinos with a deuteron by the mechanism of a weak charged current are reported: $\sigma_{\text{exptl}} = (1.1 \pm 0.3) \times 10^{-44}$ cm^2/fission.

In this letter we are reporting the first results of measurements of the cross section for the interaction of reactor antineutrinos with a deuteron. This process can go by two mechanisms:

$$\bar{\nu}_e + d \to n + p + \bar{\nu}'_e E_{\text{thr}} = 2.225 \text{ MeV (weak neutral current)},$$

$$\bar{\nu}_e + d \to n + n + e^+ E_{\text{thr}} = 4.02 \text{ MeV (weak charged current)},$$

where E_{thr} is the physical threshold for the reaction.

Our purpose was to experimentally determine the cross sections for both mechanisms and to search for neutrino oscillations. The first calculations for a charged current were carried out in Refs. 1 and 2, and those for a neutral current in Ref. 3. Subsequent calculations have incorporated an exchange-current effect,[4] the effect of the interaction in the final state of the two-nucleon system,[5,6] and also a recoil effect.[7] The large errors in the cross sections predicted by the theory create uncertainties regarding the spectra of antineutrinos from reactors. The primary difficulty is that we do not know the decay schemes for many of the β-active fragments, especially in the region $E_{\bar{\nu}_e} > 4$ MeV. As a rough guideline we can use the cross sections from Ref. 5:

$$\sigma_{\text{ns}} = 3.1 \times 10^{-44} \text{ cm}^2/\text{fission} \quad \sigma_{\text{cc}} = 1.13 \times 10^{-44} \text{ cm}^2/\text{fission},$$

which correspond to

$$\sigma_{\text{ns}} = 5.0 \times 10^{-45} \text{ cm}^2/\bar{\nu}_e \quad \sigma_{\text{cc}} = 1.8 \times 10^{-45} \text{ cm}^2/\bar{\nu}_e.$$

So far, only the Reines group has carried out experiments on the interaction of reactor antineutrinos with a deuteron.[8,9] The following results were reported in Ref. 9:

$$\sigma_{\text{ns}} = (3.8 \pm 0.9)\ 10^{-45} \text{ cm}^2/\bar{\nu}_e \quad \sigma_{\text{cc}} = (1.5 \pm 0.4) \times 10^{-45} \text{ cm}^2/\bar{\nu}_e.$$

These results are not very accurate, and in view of the uncertainty in the theoretical predictions, it is extremely worthwhile to pursue the experimental study of this process.

This process is interesting from the standpoint of seeking oscillations, since the parameters of the oscillations can be estimated from the ratio of the cross sections for

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the two mechanisms. This method substantially reduces the uncertainties stemming from our inexact knowledge of the spectrum of reactor antineutrinos, and it does not depend on the absolute flux of antineutrinos. By using this method in measurements at a single distance from the reactor, we can observe oscillations of the type $\bar{\nu}_e \leftrightarrow \bar{\nu}_{\mu,\tau}$ (the neutral mechanism is insensitive to oscillations of this type). If measurements are taken at some other distance, the combined results would make it possible to detect oscillations of the type $\bar{\nu}_e \leftrightarrow (\nu_e)^R$.

Our detector was positioned between two reactors, at distances of 34.0 m and 87.7 m. In an experiment of this nature one can, upon the observation of oscillations, determine not only their parameters but also their type.

The Deĭton detector; description of the experiment. The Deĭton detector consists of an array of graphite blocks (a neutron moderator and reflector) with outside dimensions of 1.8 × 1.8 × 1.5 m. At the center of this detector there is a tank filled with heavy water (a neutron target and moderator). The target volume is 406 liters, and the

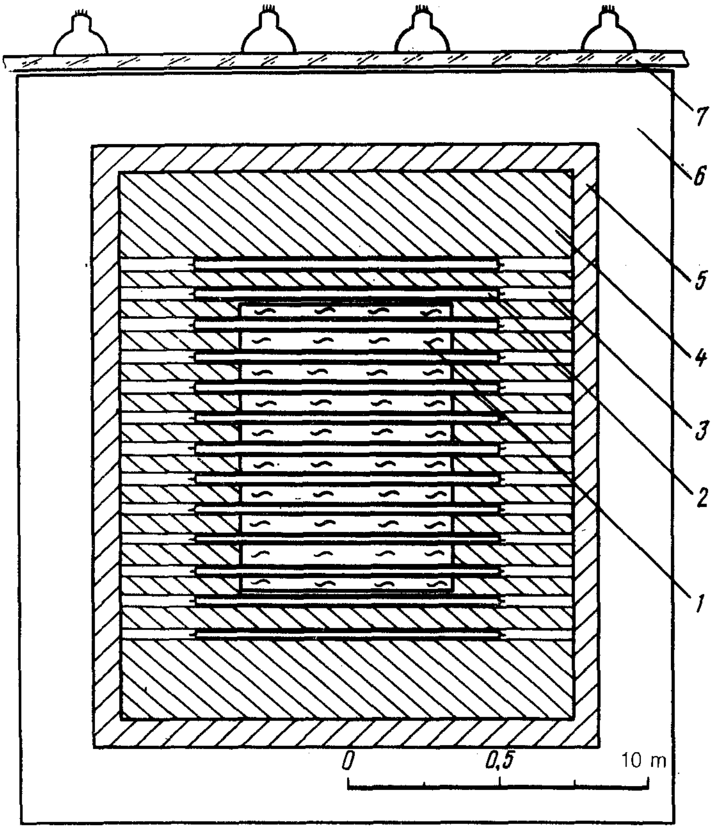

FIG. 1. The Deĭton detector. 1—Tank filled with heavy water; 2—neutron counter; 3—channels for the counters; 4—graphite array; 5—external neutron shielding (B_4C); 6—external neutron shielding (boron-loaded polyethylene); 7—active shielding against cosmic rays.

number of deuterium nuclei is $(2.7 \pm 0.01) \times 10^{28}$. The water is 99.83% pure. Running through the entire apparatus are 151 apertures (91 through the tank, and the rest through the graphite; Fig. 1) which hold 150 neutron proportional counters with a low intrinsic background level.[10] The central aperture is used for calibrations and also for studying the γ-ray background inside the detector. The measured neutron lifetime in the detector is $\tau = 190 \pm 2\ \mu\text{s}$.

The apparatus detects only neutrons (this is an integral detector). One neutron is detected in the case of the neutral-current mechanism, while two are detected in the case of the charged-current mechanism, in a time window of 4τ. The efficiency of the detection of one neutron is $(75.8 \pm 2.3)\%$, while the efficiency of the detection of two neutrons in the 4τ window is $(59.6 \pm 1.6)\%$. An important characteristic of the detector is its luminosity, by which we mean the product of the number of target nuclei and the efficiency. The luminosity of the Deĭton detector is $(20.5 \pm 0.6) \times 10^{27}$ in the detection of a single neutron and $(16.1 \pm 0.4) \times 10^{27}$ in the detection of two neutrons in the 4τ time window. The corresponding characteristics of the detector of the Reines group[8] are 5.2×10^{27} and 1.6×10^{27}.

The detector is surrounded on all sides by composite passive shielding, with a thickness of 52 cm on the side, to shield out the external radiation. The shielding layer (8 cm thick) nearest the detector is made of boron carbide (B_4C) and contains no hydrogen; the effect is to essentially eliminate the background correlated with the reactor (the reaction $\bar{\nu}_e + p \rightarrow n + e^+$). Next comes a 24-cm-thick layer of boron-loaded polyethylene ($CH_2 + 3\%\ B$). The rest of the shielding is a 20-cm-thick layer of steel shot (except on top). This shielding reduces the flux from external neutrons by a factor of more than 50. Above the detector, after the 32-cm-thick layer of shielding, are the plates of an active shielding against cosmic rays, with a total area of 6 cm^2. This apparatus is installed at a depth of several tens of meters water equivalent.

Experimental results. The detector was exposed for 47 days. For the neutral reaction mechanism we found the following results: a background of 1400 ± 19 events over the series, in comparison with an expected value of 29 events/series. The effect-to-background ratio was thus $\sim 1/48$, so it was not possible to measure the cross section for the neutral mechanism for the reaction. We are accordingly reporting the

TABLE I.

Reactor regime		Number of 2-neutron events over the series	Number of 3-neutron events over the series	Number of 4-neutron events over the series
Near	Far			
+	+	60.3 ± 1.4	14.1 ± 0.6	5.8 ± 0.4
−	+	52.2 ± 2.0	14.8 ± 0.9	6.2 ± 0.6
(+ +) −	(− +)	8.1 ± 2.4	− 0.7 ± 1.1	− 0.4 ± 0.7

(The + means that the reactor was operating, and the − means that it was shut down.)

results of only the measurements for the charged-current mechanism (two neutrons are measured in coincidence in an 800-μs time window). These results are shown in Table I, along with measurements of the number of triple events (three neutrons in the 800-μs time window) and quadruple events (four or more neutrons in the same window).

We thus find the cross section for the charged-current mechanism to be

$$\sigma_{cc} = (1.1 \pm 0.3) \times 10^{-44} \text{cm}^2/\text{fission}.$$

The measurements are continuing; measures are being taken to lower the background in the apparatus.

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