Search for the axion in the IBR-2 pulsed reactor

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Plastic scintillation counters have been used in a search for the axion in the IBR-2 pulsed reactor. No gamma pairs were detected outside the reactor shielding, in contradiction of Faissner's data, which show the observation of an axion at a reactor in Jülich, but in support of the conclusion by Zehnder *et al.* that the "standard axion" does not occur in nature.

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We are reporting here the results of a search for the axion, a new particle introduced by Weinberg[1] and Wilczek[2] in an effort to resolve a contradiction associated with a breaking of *P* and *CP* parity in a unification of the theories of the electroweak and strong interactions.

Our search for the axion was carried out on the IBR-2 pulsed reactor, which has come on-line.[1)] The average reactor power was 1 MW; the pulse length (at half-maximum) was 230 μs; and the pulse repetition frequency was 25 Hz. The pulsed operation of the reactor makes it possible to substantially suppress the effects of the cosmic-ray background and the natural radioactivity, which constitute the primary source of noise in the search for the axion. We used a gating pulse 400 μs long (95% of the intensity of the reactor pulse); the duty factor of the apparatus was thus 1/100.

The apparatus consists of two polystyrene scintillation counters each $17\times17\times40$ cm in size, connected in coincidence, and an anticoincidence counter $40\times36\times1$ cm in size, used to suppress the cosmic-ray background (Fig. 1). In front of the counters we left a free space $\sim$6 m long for the axion to decay into two gammas. At these dimensions, the counters have an efficiency $\sim$50% for gamma energies from a few tenths of an MeV to several MeV, and the pulse-height spectra from the counters can be used to determine the energy distribution of the gammas detected. The energy-evolution threshold in each counter was $E_{th} = 100$ keV in one part of the exposure and $E_{th} = 300$ keV in the other. The total measurement time was $\sim$3.6 days. Over this time we detected 429 ± 21 coincidence signals with a total energy evolution $E_1 + E_2 < 5$ MeV. The corresponding number of background counts, measured in the pauses between the reactor pulses, was 429 ± 14. Accordingly, no gamma pairs were observed outside the reactor shielding.

In order to infer a limitation on the axion production probability, we followed Zehnder *et al.*[4] and analyzed the most intense potential sources of axions whose properties are well known. Among these sources are the excited states of the deuteron and ^{7}Li, which are produced when neutrons are captured by hydrogen and by boron, respectively. In each case, there is an *M* 1 transition to the ground state. The transition

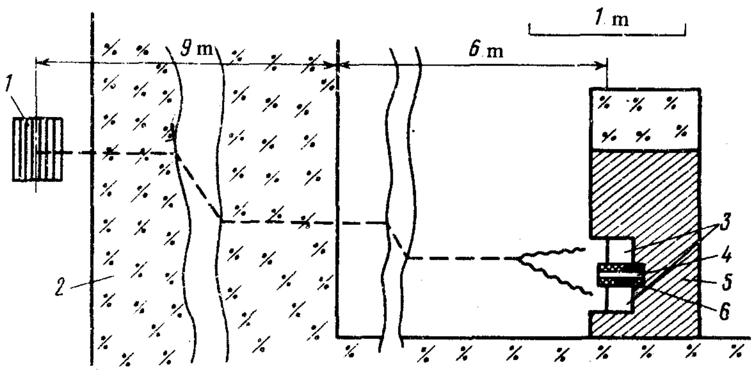

FIG. 1. Experimental arrangement. 1—active zone of reactor; 2—concrete shielding of reactor; 3—scintillation counters; 4—anticoincidence counter; 5—iron shielding; 6—lead.

in the deuteron ($E = 2.23$ MeV) is an isotopically vector transition, while the ^{7}Li transition ($E = 0.48$ MeV) is a purely proton transition.

The IBR-2 reactor core is surrounded by a water moderator, in which thermal neutrons are captured at 0.35×10^{16} s^{-1} MW^{-1}. The rate of ^{7}Li production in the boron-loaded shielding is 10^{16} s^{-1} MW^{-1}. (Only the capture of thermal neutrons is taken into account.)

The results of the analysis are shown in Fig. 2 as the function $Q(m_a)$, which was determined from the experimental results in a model-independent manner:

$$Q = \frac{n}{R_\gamma \,(\Omega/4\pi)(l/v)\epsilon k},$$

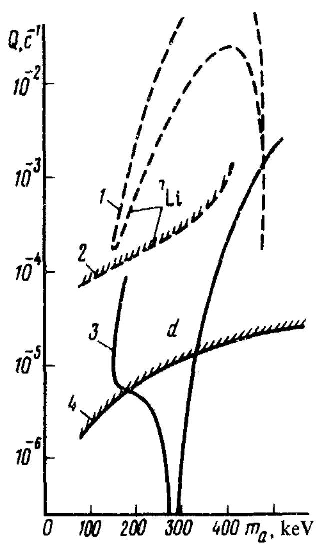

FIG. 2. Relative probability, Q, for axion production during the decay of ^{7}Li* (curves 1 and 2) and d* (3 and 4). 2, 4—upper limit at the 95% confidence level according to the present experiment; 1, 3—theoretical values.

where n is the difference between the count rates in our apparatus with the reactor on and off; R_γ is the rate at which the excited nuclear state of interest forms; Ω is the solid angle of the apparatus; l is the decay length; v is the axion velocity; ϵ is the efficiency of the apparatus, which includes the probability that the gammas will reach the detectors and the probability that they will be detected (this efficiency depends on the energy and mass of the axion); and k is a factor which reflects the loss of counts due to the limitations imposed by the gating pulse and the restriction on the total energy evolution. The quantity Q represents the ratio of the probability for an axion transition of the nucleus, ω_a/ω_γ, to the axion lifetime in the laboratory frame of reference, $\gamma\tau_a$:

$$Q = \frac{\omega_a/\omega_\gamma}{\gamma\tau_a} .$$

Curves 2 and 4 in Fig. 2 show upper limits on Q (at the 95% confidence level) calculated under the assumption that the source of the axion is the excited state of ^{7}Li and the excited state of d, respectively. Curves 1 and 3 (for ^{7}Li and d, respectively) are calculated from the equations for the lifetime of the axion and for the probability of its emission from Refs. 4 and 5.

A comparison of the theoretical and experimental curves shows that the data on ^{7}Li eliminate an axion with a mass $m_a < 400$ keV, while the data on the deuteron eliminate an axion in the region 330 keV $< m_a <$ 2.2 MeV (the upper limit is set by the transition energy, $E = 2.23$ MeV). Our study thus supports the conclusion reached by Zehnder *et al.*[4] that the "standard axion" (one with the properties corresponding to Ref. 5) does not occur in nature.

At the same time, our results strongly contradict the observation of an axion at a reactor in Jülich.[6] From the axion characteristics given in Ref. 6 (according to which, the probability for production in np capture is $\omega_a/\omega_\gamma = 3\times 10^{-5}$; $\tau_a = 10$ ms; and $m_a \sim 250$ keV) we can calculate Q: $Q = 3.4\times 10^{-4}\ \mathrm{s}^{-1}$. This value is more than an order of magnitude above our upper limit.

If we skip a detailed analysis of the potential sources of axions in the reactor and assume, following Donnely *et al.*,[5] that the probability of axion production per γ transition is 10^{-8} and that the axion distribution corresponds to the γ distribution in the reactor, then our data yield the limit $m_a < 325$ keV.

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