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SEARCH FOR AXION ON IBR-2 PULSE REACTOR

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In this note we give the results of the search for a new particle-axion, which was introduced by S.Weinberg/1/ and F.Wilczek/2/ to cope with the contradiction connected with the P- and CP-violation when uniting electroweak and strong interaction theories. Paper/3/ provides minutely calculated characteristics of the axion and the probability of its production in various processes, for instance, at nuclear transitions. The axion possessing properties /3/ is usually called as a "standard" axion.

Among many negative papers the papers of H.Faissner et al./4,5/ stand out, which report on the observation of the axion under various conditions. However, the latest one/5/ strictly contradicts the negative results of A.Zehnder et al./6/ obtained also at the nuclear reactor though with a considerably higher sensitivity. Our results agree with those of ref./6/.

The search for the axion has been performed on IBR-2 pulse reactor which is putting now into operation. The mean power of the reactor in our case was 1 MWt; the duration of burst, 230 μs (FWHM); frequency, 25 Hz. The pulse mode of the reactor operation allows to considerably reduce the influence of the background from cosmic rays and natural radioactivity, which is a main difficulty in the axion search for. In this experiment we used a strobe 400 μs long (95% of the reactor burst intensity). Thus, the duty cycle of the installation was 100.

The installation consisted of two counters 17x17x40 cm^3 each with polystyrene-base scintillators, adjusted for coincidence between each other, and an anticoincidence counter 40x36x1 cm^3 in size designed to reduce the background from cosmic rays (Fig.1). In front of the counters there were six meters of free space where the axion was supposed to decay into two photons.

Counters of the above-mentioned sizes have ~50% efficiency in the photon energy range from tenth parts to several MeV; their amplitude spectra allow judgements on the energy spectrum of the detected photons. The threshold on energy, liberated in each counter, was $E_t = 100$ keV in one part of exposure and $E_t = 300$ keV - in another part. The counters were calibrated with the help of a set of standard γ-sources. During this procedure a considerable excess of counting rate was discovered, as compared with the estimated one, due to photon scattering in the substance around the counters. The counting rate of coincidences from the source of ^{60}Co exceeded the estimated one by 1.6 times with $E_t = 100$ keV and by 1.3 times with $E_t = 300$ keV.

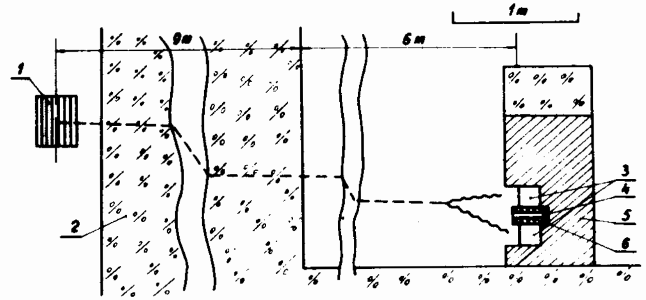

Fig.1. Schematic diagramme of the installation. 1 - reactor core, 2 - reactor shielding, 3 - scintillation counters, 4 - anticoincidence counter, 5 - iron shielding, 6 - lead.

For additional reduction of the background from the cosmic rays the limit was imposed on the sum energy release in the counters: $E_1 + E_2 < 10$ MeV.

The experiment consisted in measuring the number of coincidence signals from the scintillation counters during the power pulses of the reactor. The sum energy release in the counters was registered. The experimental conditions were variable: the detection thresholds of the counters were changed as well as, counters' arrangement, shielding configuration, strobe duration. The total time of measuring was ~3.6 days. During this time 429±21 events were detected with the sum energy release $E_1 + E_2 < 5$ MeV. The corresponding number of background events measured between the bursts was 429±14. Thus, no photon pairs from reactor core were found behind the reactor shielding.

In order to determine limitations on the axion production we followed Zehnder et al. and analyzed the most powerful potential sources of axions with the well-known properties. They include the excited states of deuteron and ^{7}Li, which occur during the capture of a neutron by hydrogen and boron respectively. Both states pass into ground state through M1-transition. The transition of deutron ($E = 2.23$ MeV) is an isovector transition, the transition of ^{7}Li ($E = 0.48$ MeV) is a single-proton transition.

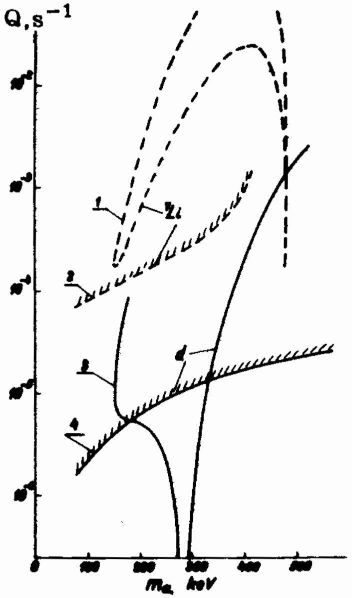

Fig.2. The relative probability of axion production Q from excited states of ^{7}Li* (curves 1,2) and d* (curves 3,4). Curves 2 and 4 show the upper limit at 95% CL from this experiment; curves 1 and 3 are calculated theoretically.

Around IBR-2 reactor core there is a water moderator where a capture of $0.35\cdot 10^{16}$ thermal neutrons.$s^{-1}\cdot MW^{-1}$ takes place. The total intensity of the reaction $n+p\to d$ is noticeably higher, as there is much water in cooling systems and concrete around the core. Besides, fast neutrons also take part in the capture reactions. But, these additions being difficult to take into account, we considered only the above-mentioned intensity of the reaction $n+p\to d$. Intensity of ^{7}Li production in the boron-containing shielding of the reactor equals $10^{16}\,s^{-1}\,MW^{-1}$ (taking account of thermal neutrons only).

To determine the efficiency of axions detection their decay and photons getting into the detectors were modelled with the Monte-Carlo method. The counters efficiency to photons depending upon their energy and detection threshold was taken into consideration. The increase of the effective aperture of the counters due to scattering of photons in the surrounding substance was partly taken into account. During the data handling the value of the sum energy liberated in the counters was taken into consideration, and the limits corresponding to the studied source of axions were imposed in accordance with the results of calibration measurements.

The results of the data handling are shown in Fig.2 as a function $Q(m_a)$ determined by the model independent method through the experimental values:

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

where n is a difference of the installation counting rate with the reactor on and off; R_γ is the intensity of the production of the investigated excited state of the nucleus; Ω is the solid angle of the installation; ℓ is the decay length; v is the speed of the axion; ϵ is the efficiency of the installation, including the probability of photons getting into the detectors and their detection, this value depends upon the energy and mass of the axion; k is a factor taking account of losses due to the limited duration of the strobe and due to the limits imposed on the total energy release. On other hand Q can be expressed as a ratio of the probability of an axion transition of a nucleus ω_a/ω_γ to the lifetime of the axion in the laboratory coordinate system $\gamma\tau_a$:

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

Curves 2 and 4 in Fig.2 show the upper limits of Q (95% CL) when the excited states of ^{7}Li* and d*, respectively, are assumed to be the source of axions. Estimations of the lifetime and irradiation probability of the axion through formulae[3,5] lead to the behaviour of $Q(m_a)$ shown by curve 1 (Li) and curve 3 (d).

It follows from the comparison of the theoretical and experimental curves that the data on ^{7}Li exclude the axion with the mass $m_a<400$ keV, and the data on d exclude its existence in the range 330 keV $< m_a <$ 2.2 MeV (the upper limit is predetermined by the energy of the transition E = 2.23 MeV). Our work confirms in this way the conclusion of Zehnder et al.[6] on the absence of the standard axion in the Nature.

At the same time our results strictly contradict the observation of the axion at the reactor in Julich. The set of characteristics of the axion given in ref.[5] (production probability in case of np-capture $\omega_a/\omega_\gamma = 3\cdot 10^{-5}$, $\tau_a = 10$ ms and $m_a \sim 250$ keV) allows the calculation of $Q = 3.4\cdot 10^{-4}\,s^{-1}$, which exceeds our upper limit by more than an order of magnitude.

If we avoid a detailed analysis of the potential souces of axions in the reactor and assume according to[3] that the probability of the axion production for one γ-transition is 10^{-8} and the spectrum of axions corresponds to the spectrum of γ-quanta in the reactor, then our data will provide the following limit: $m_a < 325$ keV.

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Алексеев Г.Д. и др. E1-82-387

Поиск аксиона на импульсном реакторе ИБР-2

На импульсном реакторе ИБР-2 проведен поиск аксионов с помощью пластических сцинтилляционных счетчиков. За защитой реактора фотонных пар обнаружено не было, что противоречит данным Файснера о наблюдении аксионов на реакторе в Юлихе и согласуется с выводом Зендера об отсутствии в природе "стандартного" аксиона.

Работа выполнена в Лаборатории ядерных проблем и Лаборатории нейтронной физики ОИЯИ.

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Alekseev G.D. et al. E1-82-387

Search for Axion on IBR-2 Pulse Reactor

A search for axions with plastic scintillation counters has been performed on IBR-2 pulse reactor. Behind the reactor shielding no photon pairs have been observed, what contradicts the data of Faissner on observing axions at the reactor in Julich and agrees with the conclusion of Zehnder et al. on the absence of the "standard" axion in the Nature.

The investigation has been performed at the Laboratory of Nuclear Problems and the Laboratory of Neutron Physics, JINR.

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