ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
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ДУБНА

E3 - 11989

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RADIATIVE NEUTRON CAPTURE BY ^{3}He IN THE ENERGY RANGE FROM 1 TO 70 KEV

Submitted to "Письма в ЖЭТФ"

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Радиационный захват нейтронов гелием-3 в интервале энергий 1-70 кэВ

Сообщается о первом наблюдении радиационного захвата нейтронов ядрами ^3He в интервале энергий нейтронов 1-70 кэВ. Измерения выполнены методом времени пролета на бустерной системе реактор ИБР-30 + ускоритель ЛУЭ-40 с применением мишени жидкого гелия-3 и детектора NaJ(Tl). Регистрировались амплитудные спектры и спектры по времени пролета гамма-лучей под углами 90° и 45°. Полученные величина и энергетический ход эффективного сечения радиационного захвата в исследованном интервале энергий интерпретируются как p-волновой захват нейтронов и сопоставляются с теоретическими расчетами в четырехнуклонной проблеме ядерной физики.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1978

Alfimenkov V.P. et al. E3 - 11989

Radiative Neutron Capture by ^3He in the Energy Range from 1 to 70 keV

This paper reports the first observation of the radiative neutron capture by ^3He in the energy range from 1 to 70 keV. The measurements were performed at the IBR-30 reactor working in booster mode of operation by the time-of-flight method using ^3He liquid target and NaI(Tl) detector. Amplitude and time-of-flight spectra of γ-rays were registered at angles of 90° and 45°. The value and energy dependence of the neutron capture cross section obtained were interpreted as a p-wave neutron capture and compared with theoretical calculations made in the frame of the four-nucleon problem.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1978

Radiative neutron capture by ^3He is closely connected with a four-nucleon problem. Many theoretical papers are devoted to this or inverse (α-particle photodisintegration) processes, but experimental data for it is very poor. Differential cross section at an angle of 90° $\sigma(90°)=5^{+2}_{-1}\ \mu b/sr$ for 4 *MeV* neutrons was determined in paper /1/, only. In a short contribution /2/ the cross section value $\sigma_{n\gamma} = 60\pm30\ \mu b$ for thermal neutrons is given, the experiment remains still unpublished. It is rather difficult to measure such a small cross section. But the fact that the energy of γ-quanta is high, i.e., 20.58 *MeV* (equal to the neutron binding energy in ^4He), is helpful from the experimental point of view.

Our measurements were carried out by the time-of-flight method at the pulsed reactor IBR-30 working with the 40 *MeV* Linac in a booster mode. The NaI(Tl) detector of dimensions ⌀ 10 *cm* x 10 *cm* was used at angles of 90° and 45° with respect to the neutron beam at a distance of 33.2 *m* from the reactor. The time analysis was carried out for the pulses with a level of discrimination of 16 *MeV* and at the same time the amplitude spectrum (in the time window corresponding to an energy interval from 4 to 70 *keV*) was registered. The liquid ^3He target of 30 cm^2 surface and $3\times10^{22}\ cm^2$ thickness was prepared in the Al-container placed in the cryostat. Shielding of the detector from the target side was composed of paraffin with boron (10 *cm*), boron carbide (4 *cm*) and lead (1 *cm*). The effect and background measurements followed each other with an 8 *hrs* period. The amplitude spectrum given in *fig. 1* illustrates the observation of γ-rays of neutron radiative capture by ^3He in the measured neutron energy interval.

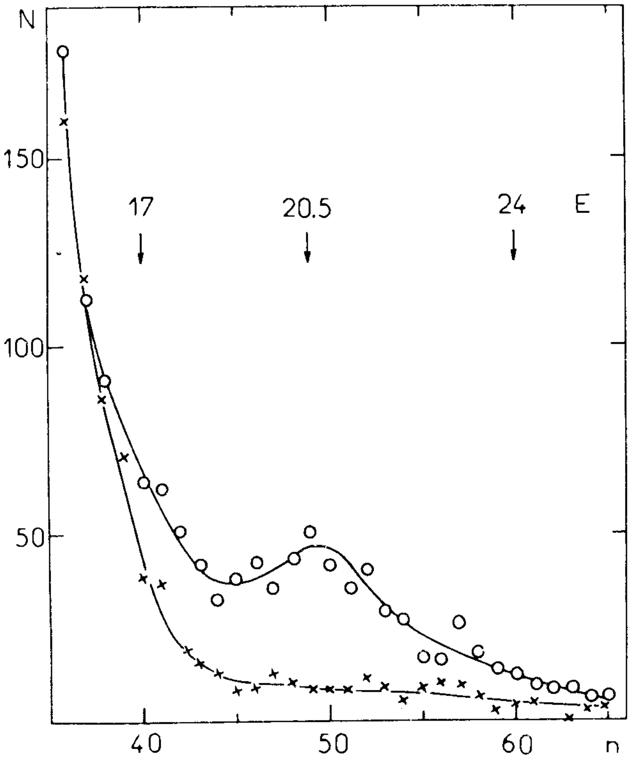

Fig. 1. Points - the γ-ray spectrum in the He(n,γ) reaction obtained with the NaI(Tl) crystal at an angle of 90° with respect to the beam, N - the number of counts per channel after 48 hrs of measurements, n - the channels of the amplitude analyser. Crosses - the background spectrum, ^{3}He sample being replaced by the graphite one equivalent to the former in scattering. Figures stand for the energy of γ-rays in MeV.

The cross section $\sigma(\theta)$ and its energy dependence were determined by using formula for a thin target:

$$N(E_i, E_f) = \sigma(90°, \bar{E})\, \Pi(\bar{E})\, \epsilon_\gamma\, n\, B[1 + \alpha(E_f, \infty)]\, \Delta\Omega$$

Here $N(E_i, E_f)$ is the number of counts in the interval (E_i, E_f), $\bar{E}$ is the average energy in the interval (E_i, E_f), $\Pi(\bar{E})$ is the neutron beam intensity during the measurements, taken with the help of calibrated boron and helium counters, ϵ_γ is the detector efficiency, n is the target thickness, B is the shielding attenuation factor for γ-rays, α is the correction term describing the contribution of faster neutrons in $N(E_i, E_f)$.

In our case this formula is correct with an accuracy better than 15% at energies E $\geq$ 10 *keV*. The α-term was calculated using: the experimental resolution function of the spectrometer, the known energy dependence of the neutron flux and supposed $\sqrt{E_n}$-dependence of the cross section $\sigma_{n\gamma}(^3He)$. The calculation of ϵ_γ was made and experimentally proved earlier in /1/ and we confirmed them in calibrating measurements of the known partial width of the 9 *MeV* direct transition in nickel. The accuracy of our measurements is mainly dependent on the uncertainty of ϵ_γ value. The radiative capture cross section given in *fig. 2* was obtained using formula $\sigma_{n\gamma} = \frac{8}{3}\pi\sigma(90°)$, which is valid for the angular distribution proportional to $\sin^2\theta$. The value 1.8 ± 0.2 obtained for the ratio of γ-rays intensities at 90° and 45° points out to such a distribution.

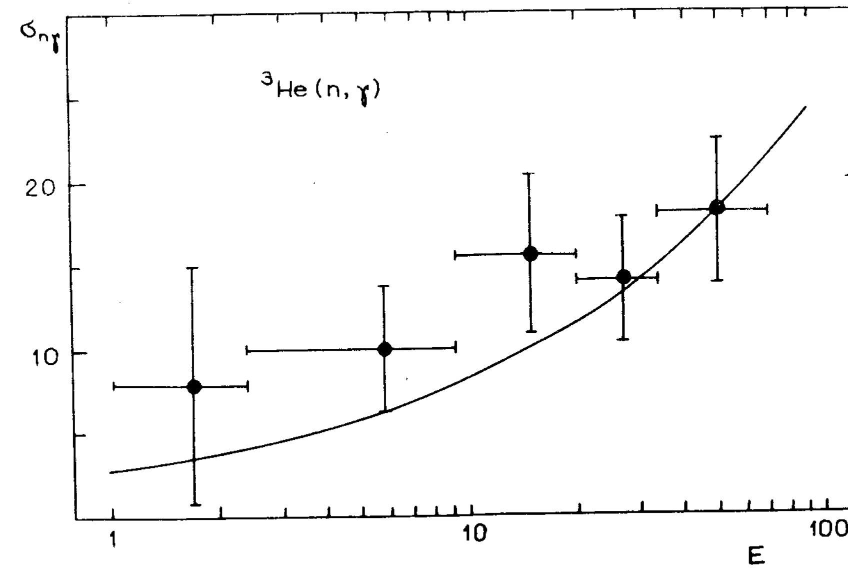

Fig. 2. The energy dependence of the effective cross section $\sigma_{n\gamma}(^3He)$: points - experiment, curve - theoretical prediction discussed in the text, E - the energy of neutrons in keV, σ - cross section in μb.

Results given in this paper are the first ones in this energy region. Discussing our results one must not forget that the first excited 0^+ level of ^4He does not participate in this process because the $0^+ - 0^+$ transition is forbidden. The direct capture in the triplet channel for s-neutrons (M1 -transition) also cannot be taken into account because of its $1/v$ energy dependence. So the most probable interpretation of the results is a p-wave capture where the E1 -transition is possible. Theoretical calculation [3] for the direct reaction with E1 -transition made in the first order perturbation theory with central force approximation gives the following energy dependence for $\sigma_{n\gamma}$:

$$\sigma_{n\gamma} \sim \sqrt{E_n} (E_0 + 3/4E_n)^3 \exp(-3E_n/4\epsilon),$$

where the parameter $\epsilon \approx 6$ *MeV* of the order of the binding energy per nucleon in α-particle and E_0 is the binding energy. In our energy interval this dependence transforms into a more simple form $\sqrt{E_n}$. We made an absolute normalization of the theoretical curve in *fig. 2* using the results of the continuum calculation of photonuclear reactions [4]. The detailed balance relation of the form $\sigma_{n\gamma} \approx \sigma_{\gamma n} 4E_\gamma^2 / 9mc^2E_n$ was used in this normalization. Experimental results are in agreement with the theoretical curve obtained in this way.

Of course one needs a more precise measurement to be performed in the future as well as a direct theoretical calculation in this energy interval. It is desirable to repeat the measurements for thermal neutrons because the results of measurements [2] with a target placed in the reactor core could be in principle influenced by fast neutrons.

ACKNOWLEDGEMENT

The work was initiated by Professor I.M.Frank and we gladly dedicate this paper to him on his 70th birthday. We are also grateful to V.I.Luschikov, A.B.Popov and Yu.P.Popov for useful discussions, to N.T.Khot'ko and A.I.Ivanenko for their help during the measurements and A.D.Rogov for calculating the neutron spectrum of IBR-30 reactor.

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Received by Publishing Department on October 30 1978.