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Длины рассеяния нейтрона на ядре ^{3}He

Измерено полное сечение рассеяния нейтронов ядром ^{3}He в интервале энергий 20 мэВ - 2 эВ. Полученное значение вместе с известной величиной когерентной амплитуды позволило определить два набора длин рассеяния нейтрона ядром ^{3}He.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

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Neutron Scattering Lengths of ^{3}He

The total neutron scattering cross-section of ^{3}He has been measured in the 20 meV - 2 eV neutron energy range. Together with the known value of coherent scattering amplitude it leads to the two sets of n-^{3}He scattering lengths.

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

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The neutron scattering lengths of the simplest nuclear systems (p, D, T, He) have always been of considerable interest for nuclear physicists. Recent progress in the experimental study of n-D scattering[1),2)] allowed us to make the next step and face the problem of neutron scattering on trinuclon systems.

In ref.[3)] this problem was considered and solved on strictly microscopic level by using four-nucleon integral equations of the Faddeev-Yacubovsky type with separable two-nucleon potentials. In particular, the neutron triplet- and singlet- scattering lengths of free nuclei of ^{3}He were obtained for the first time:

$$a_t = 3.07 \text{ fm} , \qquad a_s = 7.52 \text{ fm} \qquad (1)$$

The fact that $a_t < a_s$ shows that along with the (3+1) channel the (2+2) channel begins to play an important role for the system in the state with isospin $\mathcal{T} = 0$ and total spin $S = 0$.

A considerable difference in a_t and a_s values means for ^{3}He an existence of a noticeable (~ 0.5 b) incoherent scattering neutron cross-section ($\sigma_{inc} = 3/4\,\pi\,(a_t - a_s)^2$, a question of which was raised in ref.[4)]. The incoherent scattering cross-section may be essential for a number of experiments, e.g., thermal neutron scattering experiments on ^{3}He-^{4}He mixtures.

Now experimental values of n-^{3}He scattering lengths - two alternative sets - can be obtained by measuring the neutron coherent scattering length and total thermal scattering cross-section. The measurements, however, are complicated by the large absorption cross-section due to the negative resonance discovered in ref.5), which appears to be connected with the first excited 0^+ state of ^{4}He at 20.2 MeV. The choice of the right set requires the presence of polarized neutrons and polarized ^{3}He nuclei.

The first step in this direction had already been made in ref.[6)], where the coherent scattering amplitude on ^{3}He was measured. In the present work we undertaken the total scattering cross-section measurements. It was done by comparing n-^{3}He scattering with n-^{4}He scattering in the same geometry using the gaseous samples.

The intensity (N(E)) at 90° is connected with the total scattering cross-section σ by the relation:

$$N(E) - N_B(E) = K n \sigma A(E) \iint \frac{d^2\sigma}{d\Omega\, dE'} f(E,E') d\Omega\, dE', \quad (2)$$

where $N_B(E)$ is the background, K is the constant depending on the experiment geometry and neutron flux ; n is the thickness of the sample, A(E) is the absorption correction for the transmission of the neutron in gas before and after scattering; $f(E,E')$ is the detector efficiency. The expression for $d^2\sigma/d\Omega dE'$ is of the conventional type (see for example ref.[7)]) but for σ which is taken out of the integral. It is evident that a comparison of the scattering intensities of ^{3}He and

^{4}He involves a calculation of integrals in eq.(2). According to our calculations, the difference between the integrals for ^{3}He and ^{4}He is small (2 ÷ 5 %)depending on energy) and depends mainly on the factor $f(E,E')$.

Figure 1 shows the experimental arrangement. The circular detector consisted of 50 helium counters at a distance

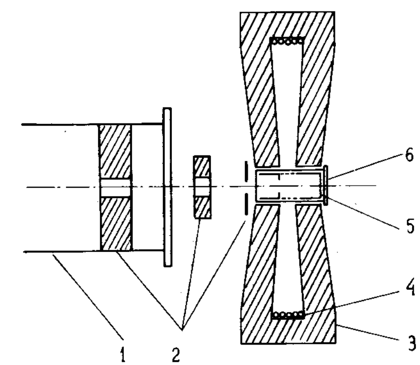

Fig. 1. Experimental lay-out:
1. - vacuum neutron guide; 2.- collimators, 3. - shielding; 4 - helium counters; 5. - cadmium cylinder with diaphragma; 6. - containers for the samples under investigation.

of 40 cm from the sample. The counters had a view for a 4 cm distance along the beam. Pyrexglass or aluminium counters of dimensions ϕ 12 x 20 cm^2 were installed in the opening. The neutron beam was collimated to ϕ 6 cm. The gaseous samples at different pressures were used : 850±10 and 650±10 torr ^4He and 258±10, 50±0.5, 30±0.5 torr ^3He. Helium-4 and helium-3 of high purity were additionally purified while filling the containers using cryosorption trap. Beforehand, the containers were pumped out up to high vacuum during the 150 °C heating, so that the leakage was less than 2 x 10^{-3} torr per 24 hour.

The measurements were carried out at the pulsed reactor IBR-30 by the time-of-flight method at 35 m flight path and using the analyzer with 80 μsec channel width. The examples of the time-of-flight spectra for ^4He, ^3He and background are shown in fig.2. The background was measured after the gas evacuation under continuous cryopumping with the help of the cryosorption trap providing vacuum better than 10^{-4} torr. This procedure was conducted without any displacement of the container.

In the first runs of measurements where the glass containers were used a background was observed. Its intensity for ^4He was nearly 85% of the total scattering intensity at 1 eV and 60% at 50 meV. The background consisted of a small constant component due to the fast delayed neutrons and of a large variable component dependent on the energy of incident neutrons. It was shown that the background was mainly due to the double scattering from the front (or back) wall through the side wall to the detector. In such a case our procedure of background measurements for ^3He leads to the in-

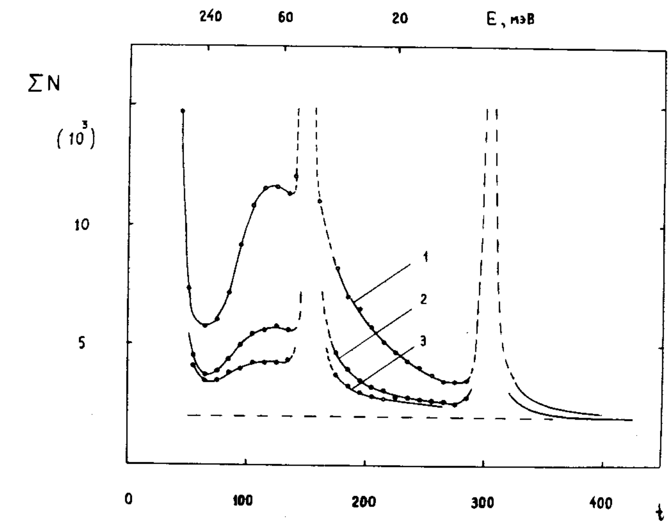

Fig. 2. Neutron scattering intensity $\sum N$ versus channel number t :

1. – ^4He , 850 torr
2. – ^3He , 50 torr
3. – background $N_B(E)$.

$\sum N$ is the number of counts during 4 hour measuring time.

crease in background intensity because of the ceasing of absorption after the scattering on the walls. Therefore, we applyed the background correction$(1-A)$, which was 10% at 40 meV and less at higher neutron energies (^3He sample at 50 torr).

Further runs were done using aluminium container with cadmium diaphragms inside. Thanks to this the background variable component was decreased by a factor of 4 and only half of the remained variable background resulted from double scattering.

The reactor power was monitored during the measurements by two monitors. The detector efficiency was checked in "satellites" which are the fast neutron background peaks specific for the pulsed reactor. The calculated cross section errors were mainly due to the one per sent of monitoring accuracy in the measurements of the effect-background difference. Fig.3 presents the scattering cross sections of ^{3}He obtained (using σ ^4He) = 0.8 b) as a function of energy. From it follows that the weighted mean value is:

$$\sigma(^3\text{He}) = 3.16 \pm 0.20 \text{ b} .$$

The measured value σ (^{3}He) is a little less than the theoretically predicted σ =3.5 b in ref.[8] obtained from the charge-invariant phase-shift analysis of experimental data in different nucleon - ^{3}A reactions.

The quantities a_{coh} and σ are connected with neutron scattering lengths a_t and a_s for ^{3}He by the known relations:

$$\sigma/\pi = 3 a_t^2 + a_s^2 , \qquad 4a_{coh} = 3 a_t + a_s .$$

The experimental data for a_{coh} [6] and σ (present work) in the a_s , $\sqrt{3}$ a_t plane are shown in fig.4 along with their errors. Two alternative experimental sets of mean scattering lengths on ^{3}He follow from fig.4 :

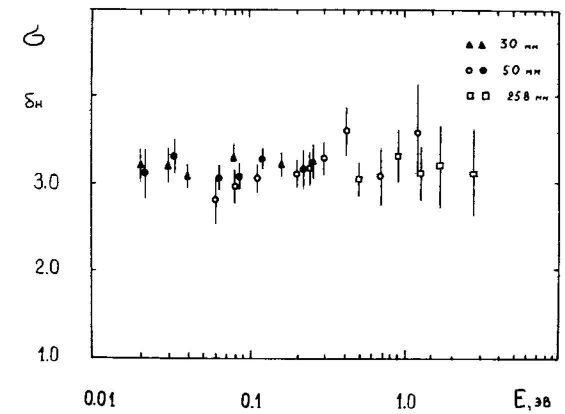

Fig. 3. Total scattering cross section of ^{3}He versus energy of incident neutrons. Open and full points represent the results of measurements with glass and aluminium container, respectively.

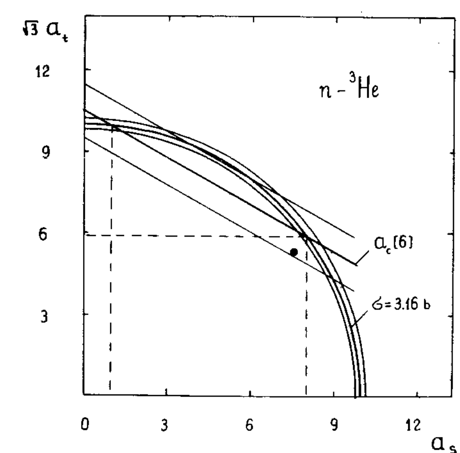

Fig.4. The experimental data for the coherent length [6] and n - ^{3}He scattering cross-section σ (present work) in the a_s,$\sqrt{3}$ a_t plane; ⊗ - theoretical result [3] .

a_t = 5.8 fm   or a_t=3.4 fm
a_s = 1.0 fm a_s=8.0 fm

The second set is consistent with theoretical estimation (1). Uncertanties in scattering length values for every set are rather great and mainly depend on the a_{coh} error. Further improving of the a_{coh} value is desirable. The other way of improving the scattering length values is connected with polarization experiment. It defines the line $a_t = ka_s$, intersecting the circumference at right angle, the true set of the scattering length being chosen simultaneously.

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References

1. V.P.Alfimenkov, V.I.Luschikov, V.G.Nikolenko, Yu.V.Taran, F.L.Shapiro. Phys.Lett.,24B,151 (1967).
2. W.Dilg, L.Köster, W.Nistler. Phys.Lett.,36B, No.3,208(1971).
3. V.F.Kharchenko, V.P.Levashov. Preprint ITR-75-107E (1975),Kiev.
4. V.F.Sears, F.C.Khana. Phys.Letters.,56B, 1 (1975).
5. А.А.Бергман, А.И.Исаков, Ю.П.Попов, Ф.Л.Шапиро. ЖЭТФ,33, 9 (I957)
6. T.A.Kitchens, T.Oversluizen, L.Passell and R.I.Schermer. Phys.Rev.Lett.,32, No.14, 191 (1974).
7. И.И.Гуревич, Л.В.Тарасов."Физика нейтронов низких энергий", Москва (I965).
8. I.Ya.Baritand V.A.Sergeyev. Yad.Fiz., 4, 712 (1966).

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