



ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Лаборатория ядерных проблем

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**THE PANOFSKY RATIO FOR He^3 AND THE ROOT-MEAN-SQUARE
RADIUS OF THE TRANSITION $He^3 \rightarrow H^3$**

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The capture of stopped negative pions in He^3 has been considered theoretically ^{/1,2/}. The following processes are allowed by the conservation laws:

- | | | | |
|--|--------------|---------------------|-----------------|
| 1. $\pi^- + He^3 \rightarrow p + n + n$ | (55.5 %) * | } absorption | |
| 2. $\pi^- + He^3 \rightarrow n + d$ | (27.8 %) | | |
| 3. $\pi^- + He^3 \rightarrow H^3 + \pi^0$ | (9.4 %) | | charge exchange |
| 4. $\pi^- + He^3 \rightarrow H^3 + \gamma$ | (4.8 %) | } radiative capture | |
| 5. $\pi^- + He^3 \rightarrow d + n + \gamma$ | (2.0 %) | | |
| 6. $\pi^- + He^3 \rightarrow p + n + n + \gamma$ | (0.5 %) | | |

The relative rates of these processes have been calculated in ref. ^{/1/} in terms of impulse approximation, the known data on meson capture in hydrogen and deuterium being used. The capture was also considered to take place from the S-state of the mesic atom. It has been shown ^{/2/} that the ratio of the rates of reactions (3) and (4) which we shall call the Panofsky ratio in He^3 and denote by P , may be directly related to the value of the root-mean-square radius of the transition from He^3 to H^3 in radiative processes. The following equation takes place:

$$P = \frac{P_0}{1 - \frac{1}{3} k^2 r^2 + \frac{1}{18} k^4 r^4} \frac{\omega + M}{\omega_H + m} \frac{\omega_H}{\omega} \left[\frac{E}{E_H} \frac{M}{m} \left(\frac{\mu + m}{\mu + M} \right)^3 \right]^{1/2}, \quad (1)$$

where P_0 is the Panofsky ratio, r is the root-mean-square radius, cm, k is the photon wave number in process (3), cm^{-1} , ω is the photon energy in process (4), ω_H is the photon energy in π^- - meson capture in hydrogen, m is the neutron mass, μ is the π^0 - meson mass, M is the tritium mass, E is the energy released in process (3), E_H is the energy released in the process $\pi^- + p \rightarrow n + \pi^0$. The particle masses and the energies are given in MeV.

The experimental determination of the root-mean-square radius is of great interest at present, for instance, for the interpretation of the results on muon capture in He^3 .

In the present investigation the experimental study of π^- - meson capture in He^3 was undertaken for the first time.

Pions were brought to rest in the diffusion chamber, filled with helium-3 at 20 atm pressure ^{/4/}. The chamber was in the magnetic field $H = 6000 \theta e$. One π^- - meson stop on average occurred per 4 pictures. The contamination of muon stops was 32 % of the total number of stops. During two runs ~ 8500 photographs were obtained. The whole material was scanned three times. The results of scanning are given in Table I where the number of events of each type is indicated.

Table I

One-prong stars			$\mu - e$ decay		Many - prong stars	$\pi - \mu$ or pion scattering	Events not identified	
Prong end visible	Prong end not visible	Total number of stars	Electron visible	Electron not visible			$\mu - e$ decay or a star	$\pi - \mu$ decay or a star
805	1567	2372	700	353	21	1423	61	33

* The value quoted in ref. ^{/1/} have been corrected according to the recent, most accurate measurements of the Panofsky ratio, $P_0 = 1.533 \pm 0.21^{/3/}$.

π^- - mesons captured in He^3 provide only one-prong stars. Due to this the registered many-prong stars should be related to the capture in carbon or oxygen nuclei belonging to the vapour of methyl alcohol.

In reactions (2), (3) and (4) the energy of secondary particles is strictly fixed. Therefore, they can be easily identified by measuring the ranges or momenta of secondary particles. In all other processes energy is distributed between three or more particles. In this investigation the main attention was paid to reactions (3) and (4). As seen from Table I, the number of stars satisfying the selection criteria and related in the overwhelming majority to meson capture in He^3 amounted to 2372. It was established that on scanning three times the observation efficiency for π^- - meson stops in the chamber was independent of the event type at the end of the meson track and was close to 100 %.

The selected events were measured with a stereo-projector. The range spectrum of secondary particles from one-prong stars is shown in Fig.1. Two peaks with $R \sim 0.2 \text{ mg/cm}^2$ and $R \sim 5.5 \text{ mg/cm}^2$ corresponding to the two monoenergetic particle groups are well seen in this spectrum. The tritium energy in the reactions $\pi^- + He^3 \rightarrow H^3 + \pi^0$ and $\pi^- + He^3 \rightarrow H^3 + \gamma$ is 0.19 MeV and 3.27 MeV. The expected values of tritium ranges with such energies correspond to the range values of the peaks in the spectrum. This indicates that the peak in the region of 0.2 mg/cm^2 refers to charge exchange process (3), while in the region of 5.5 mg/cm^2 - to process of radiative capture (4). Fig. 2 presents two photographs showing stars related to these processes. The deuteron range length from reaction (2) is too great to be registered as a star with a track ending in the chamber. The approximately smoothly distributed background which is present in the spectrum is formed by a part of events from reactions(1),(5),(6).

In separating the events, due to charge exchange and radiative capture, it was supposed that the behaviour of the background in the region of peaks is monotonous. In the left side of Table II there are data on reaction (3).

Table II

Reaction (3)				Reaction (4)				
Range interval, mg/cm^2	Number of events	Back-ground of muon events	Back-ground due to other reactions	Number of events $H^3 \pi^0$	Range interval mg/cm^2	Number of events	Back-ground due to other reactions	Number of events $H^3 \gamma$ corrected for efficiency
0 - 0.5	382 ± 19.5	23.3 ± 4.2	43 ± 6.5	315.7 ± 21	5.2 - 5.9	114 ± 10.7	14.2 ± 2.7	146.6 ± 16.5

As seen from the quoted spectrum, secondary particles from reaction (3) have very short track lengths. Therefore, to assure a high selection efficiency in scanning not only obvious short prong events were considered to be stars but also all the events when the meson track end had any peculiarity (distortion, inhomogeneity). The background of false stars in this case is determined by the muon background (muon scattering, etc.). In order to evaluate this background the results of scanning the material obtained during the μ^- - exposure were used ^{1/5/}. Due to a small pion contamination (< 2%) and an inconsiderable yield of stars from muon capture in He^3 practically all the events with a peculiarity at the end are false imitations of short track length stars.

Because of possible unfavourable space orientation of star prongs their length (if $R < 0.3 \text{ mg/cm}^2$) was not measurable in all the cases, therefore a fraction of events was included in the range interval (0 - 0.5 mg/cm^2) indicated in Table II without measuring (93 events). The performed measurements of secondary particle track lengths from the capture of thermal neutrons $n + He^3 \rightarrow H^3 + p$, and also from the reaction $\pi^- + He^3 \rightarrow H^3 + \gamma$ show that in measurements the deviation from the mean path length does not exceed 0.3 mg/cm^2 . Therefore, it can be considered that the overwhelming majority of events from

reaction (3) will be included in the region of track lengths from 0 to 0.5 mg/cm^2 . The detection efficiency in the chamber for the prongs of such a length (i. e., the probability that a prong is not cut off by the edges of the sensitive layer) was taken to be equal to 100%. It was assumed that in the track length interval from 0 to 0.5 mg/cm^2 the background due to other reactions remained the same as in the neighbouring interval from 0.5 to 1 mg/cm^2 .

The results of detecting the reaction $\pi^- + \text{He}^3 \rightarrow \text{H}^3 + \gamma$ are shown in the right side of Table II. The detection efficiency of a prong 5.5 mg/cm^2 long was derived by analysing the prong distribution of all the stars. The mean value of the efficiency (for both the exposures) turned out to be $(68.2 \pm 2)\%$. The background due to other reactions was determined from the nearest zones to the right and to the left of the peak $\text{H}^3 \gamma$. The mean range of tritium in this reaction was $(5.55 \pm 0.05) \text{ mg/cm}^2$.

Using the data of Table II, we find the Panofsky ratio in He^3 to be:

$$P = 2.16 \pm 0.28.$$

The relative rates of reactions (3) and (4) prove to be the following:

$$W_3 = (13 \pm 0.9)\%, \quad W_4 = (6.2 \pm 0.7)\%.$$

The evaluation of the root-mean-square radius of the transition from He^3 to H^3 , made on the basis of relation (I) and the experimentally obtained value P, gives

$$r = (1.24 \pm_{-0.46}^{+0.30}) \cdot 10^{-13} \text{ cm}.$$

This value of the root-mean-square radius is in better agreement with the value $1.56 \cdot 10^{-13} \text{ cm}$ calculated in ref. /6/ on the basis of the known magnitude of He^3 binding energy and on taking into account a hard core potential for nucleon-nucleon interaction, than with $1.78 \cdot 10^{-13} \text{ cm}$ quoted by Fujii and Primakoff /7/.

The yield of the processes $\pi^- + \text{He}^3 \rightarrow \text{H}^3 + \pi^0$ and $\pi^- + \text{He}^3 \rightarrow \text{H}^3 + \gamma$ turns out to be somewhat larger than it was predicted in ref. /1/.

Finally, it should be noted that further augmentation of experimental material will make sufficiently accurate ($\sim 10\%$) determination of the transition radius $\text{He}^3 \rightarrow \text{H}^3$ possible.

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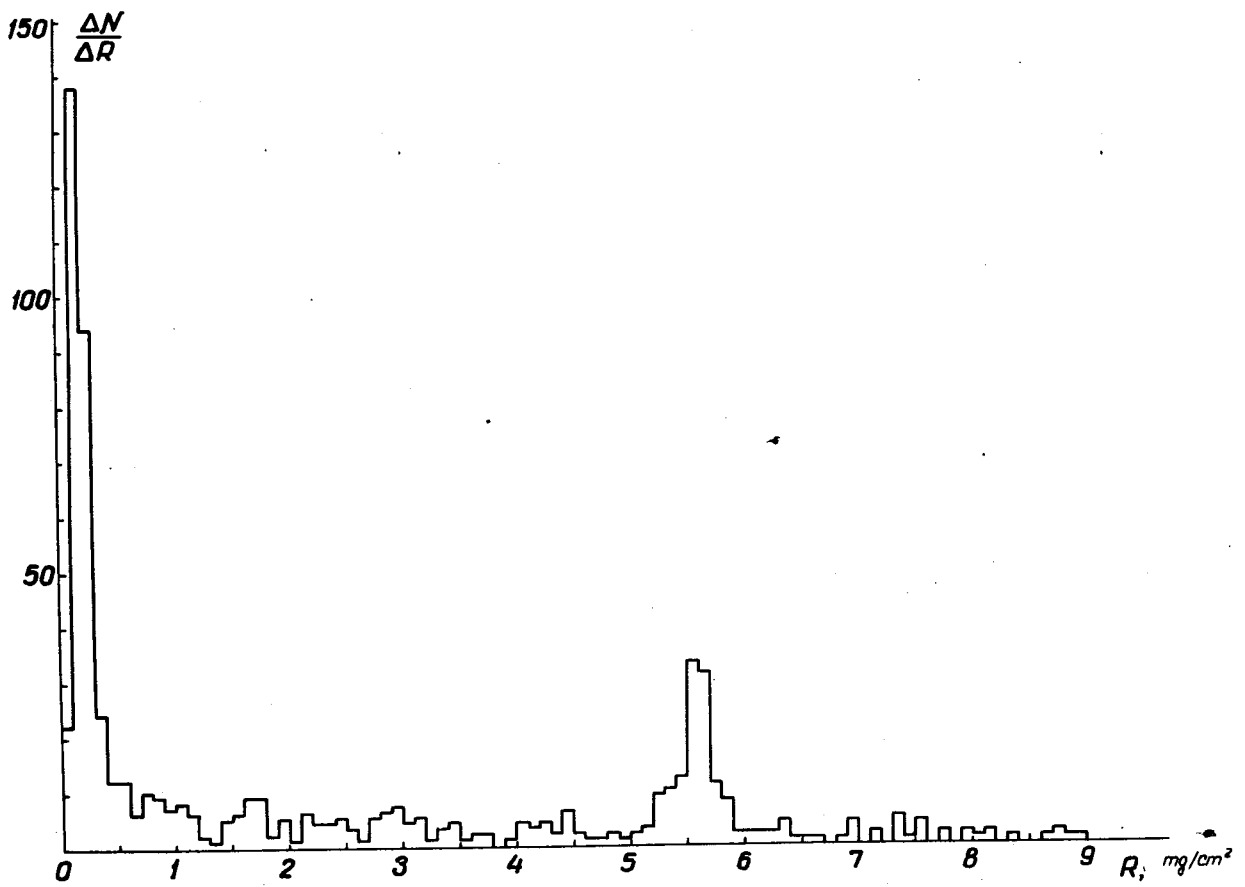


Fig. 1. The spectrum of secondary particle ranges from one-prong stars in π^- - meson capture in He^3 .

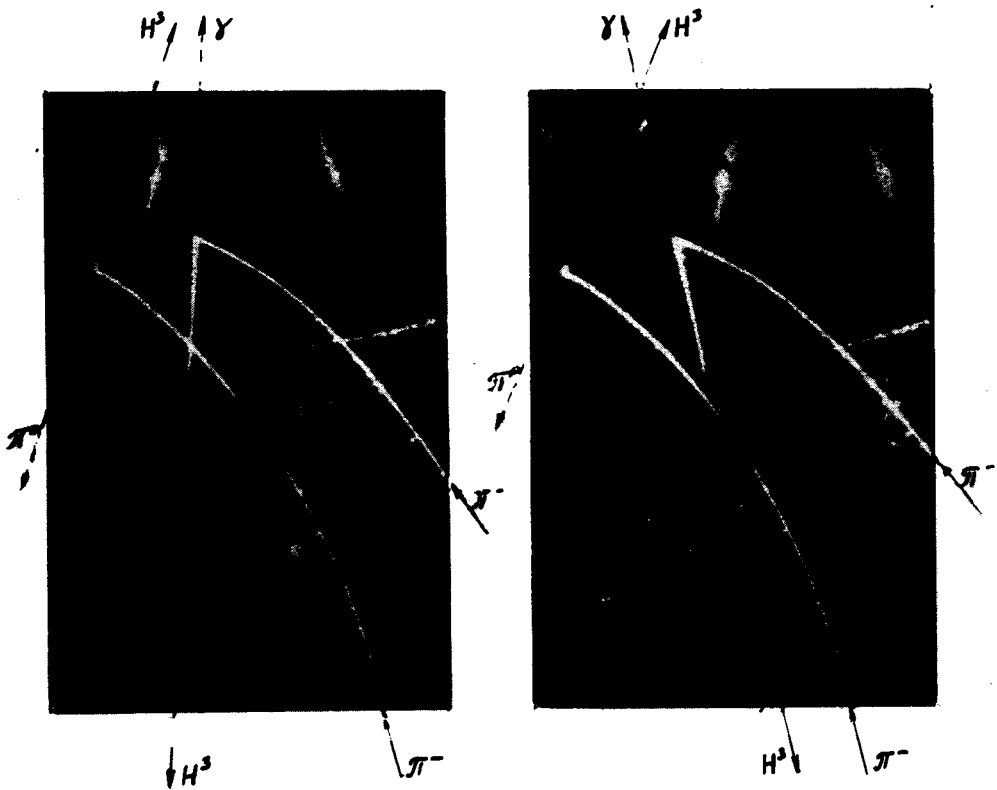


Fig. 2. The stars from the processes $\pi^- + He^3 \rightarrow H^3 + \pi^0$ and $\pi^- + He^3 \rightarrow H^3 + \gamma$.