PANOFSKY RATIO FOR He^3 AND THE MEAN-SQUARE RADIUS FOR THE $He^3 \to H^3$ TRANSITION

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The capture of π^- mesons stopping in He^3 has been observed for the first time. The $\pi^- + He^3 \to H^3 + \pi^0$ and $\pi^- + He^3 \to H^3 + \gamma$ reactions have been singled out, and the Panofsky ratio for He^3 (the ratio of the probabilities of the above-mentioned reactions) has been determined. Its value is used to estimate the mean-square radius for the $He^3 \to H^3$ transition.

THE capture of stopping π mesons in He^3 was investigated theoretically by Messiah[1] and Struminskiĭ.[2] The conservation laws permit the following processes:

I.	$\pi^- + He^3 \to p + n + n$	(55.5%)	— absorption
II.	$\pi^- + He^3 \to n + d$	(27.8%)	— absorption
III.	$\pi^- + He^3 \to H^3 + \pi^0$	(9.4%)	— charge exchange
IV.	$\pi^- + He^3 \to H^3 + \gamma$	(4.8%)	— radiative capture
V.	$\pi^- + He^3 \to d + n + \gamma$	(2.0%)	— radiative capture
VI.	$\pi^- + He^3 \to p + n + n + \gamma$	(0.5%)	— radiative capture

The relative probabilities of these processes, given in the parentheses, were calculated by Messiah[1] in the impulse approximation using the available data on π meson capture in hydrogen and deuterium.[1)] It was also assumed that the capture occurs in the S state of the mesic atom. Struminskiĭ[2] has shown that the ratio of reactions (III) and (IV), which we shall denote by P and call the Panofsky ratio for He^3, can be directly related with the value of the mean-square radius of the $He^3 \to H^3$ transition by a radiative process. We have the following relation:

$$P = \frac{P_H}{1 - {}^1/_3 k^2 r^2 + {}^1/_{18} k^4 r^4} \frac{\omega + M}{\omega_H + m} \frac{\omega_H}{\omega} \left[\frac{E}{E_H} \frac{M}{m} \left(\frac{\mu + m}{\mu + M}\right)^3\right]^{1/2}, \quad (1)$$

where P_H is the Panofsky ratio, r is the mean-square radius, k is the wave number of the photon in IV, ω is its energy, ω_H is the energy of the photon in the π^--meson capture in hydrogen, m is the neutron mass, μ is the π^0-meson mass, M is the mass of tritium, E is the energy released in process III, and E_H is the energy released in the process $\pi^- + p \to n + \pi^0$ (the masses of the particles and the energies are given in MeV). An experimental determination of the mean-square radius for the transition is of great interest, especially for the interpretation of data on muon capture in He^3.

An experimental study of the π^- meson capture in He^3 has been attempted for the first time in the present experiment.

The mesons were stopped in a diffusion chamber filled with He^3 at a pressure of 20 atm.[4] The chamber operated in a magnetic field of 6000 Oe. On the average, one stopping π^- meson was observed every four pictures. The admixture of stopping μ mesons amounted to 32% of all events. About 8500 photographs were taken in two exposures. All the material was scanned three times. The results of the scanning are as follows (the figures refer to the number of events of each type);

Single-prong stars:	
track ending in the chamber	805
track traversing the chamber	1567
total number of stars	2372
μ–e decay:	
decay electron visible	700
decay electron invisible	353
Multi-prong stars	21
π–μ decay or scattering	1423
μ–e or star (not identified)	61
π–μ or star (not identified)	33

π^- mesons produce single-prong stars only when captured in He^3. For this reason we have to regard the detected multi-prong stars as π^- capture in the carbon or oxygen nuclei contained in the methyl-alcohol vapor.

In reactions II—IV the energy of the emitted particles is strictly fixed and, consequently, they

1)The above values are corrected according to the latest, most accurate measurement of the Panofsky ratio for hydrogen $P_H = 1.533 \pm 0.021$.[3]

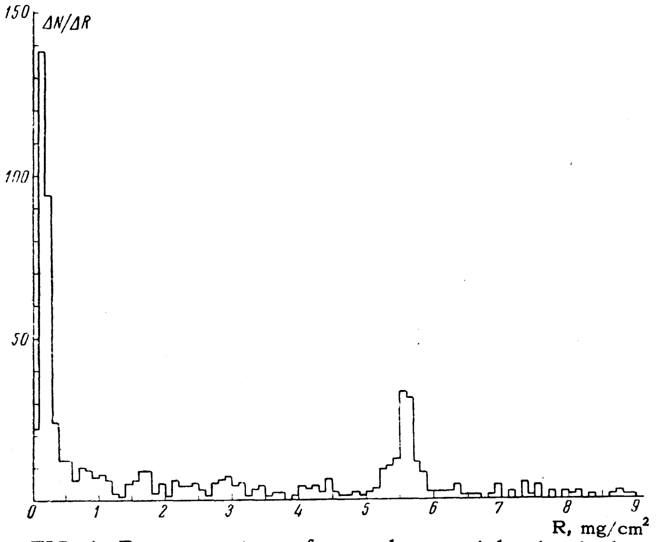

FIG. 1. Range spectrum of secondary particles in single-prong stars due to the π^--meson capture in He^3.

can be easily identified by measuring either their range or momentum. In the remaining processes, the energy is distributed among three or more particles. Our main concern in the present experiment was to single out the reactions III and IV. As shown above, the number of stars satisfying the selection criterion and representing, in the majority of cases, the π meson capture in He^3, amounted to 2372. It was established that with triple scanning the detection efficiency of a π meson stopping in the chamber is independent of the nature of the event visible at the end of the meson track, and is close to 100%.

The selected events were measured with a reprojector. The range spectrum of secondary particles from single-prong stars is shown in Fig. 1. Two maxima corresponding to two monoenergetic particle groups are clearly visible at $R \sim 0.2$ mg/cm^2 and at $R \sim 5.5$ mg/cm^2. The energy of tritium in reactions III and IV is 0.19 and 3.28 MeV, respectively. The expected values of the range of tritium having such energies correspond to the values for which the maxima have been observed in the spectrum. This indicates that the peak near 0.2 mg/cm^2 is related to the exchange process III, and the peak in the vicinity of 5.5 mg/cm^2 to the radiative capture process IV. Photographs of stars corresponding to the two processes are shown in Fig. 2. The range of the deuteron from reaction II is so large that the events could not be recorded as a star with a prong ending in the chamber. The approximately uniform background of the spectrum is partly due to reactions I, V, and VI. In selecting the charge-exchange and radiative-capture events it was assumed that the background is monotonic in the region of the peaks.

In the following we present the data concerning reaction III:

Range interval, mg/cm^2	0–0.5
Number of events	382 ± 20
Background from stopping μ mesons	23.3 ± 4.2
Background from other reactions	43 ± 7
Number of H^3 + π^0 events	316 ± 21

It can be seen from the spectrum that the secondary particles in reaction III have very small ranges. In order to achieve a high selection efficiency in the scanning we have therefore included into this group of stars, in addition to the obvious events with a short prong, also all events in which any singularity was evident at the end of the meson track, such as a kink or another non-uniformity. The background of false stars was then determined by the background of μ-meson events (scattering and others). In order to estimate the background we have used the results of the scanning of a μ meson exposure[5] where mainly μ mesons stopped in the chamber. In that case, practically all events with a singularity at the end of the track are imitations of short-range stars because of the low π^--meson contamination (< 2%) and the small yield of stars from μ-meson capture in He^3.

In some cases, because of a disadvantageous spatial orientation of a prong, it was impossible to measure its length (for $R < 0.3$ mg/cm^2), and some of the events (93 events) were included therefore in the range interval 0—0.5 mg/cm^2 which was not measured. The range measurements on the secondary particles from the capture reaction of thermal nucleons $n + He^3 \rightarrow H^3 + p$ and also from reaction IV showed that the deviation from the mean range ie ≤ 0.3 mg/cm^2. We can assume therefore that the majority of events representing reaction III will be contained in the range interval 0—0.5 mg/cm^2. The detection efficiency in the chamber of prongs with such length (i.e., the probability that the prong will not be cut off by the limits of the sensitive layer) was assumed to be 100%. It was also assumed that in the range interval 0—0.5 mg/cm^2 the background from other reactions was the same as in the adjacent interval 0.5—1 mg/cm^2.

The results concerning reaction IV are as follows:

Range interval, mg/cm^2	5.2–5.9
Number of events detected	114 ± 11
Background from other reactions	14.2 ± 1.7
Number of H^3 + γ events divided by efficiency	146.6 ± 16.5

The detection efficiency of a prong with a length of 22 mm (5.5 mg/cm^2) was found from the analysis of the visible range spectrum of secondary particles in all stars. Its mean value (for both exposures) was found to be (68 ± 2)%. The background from

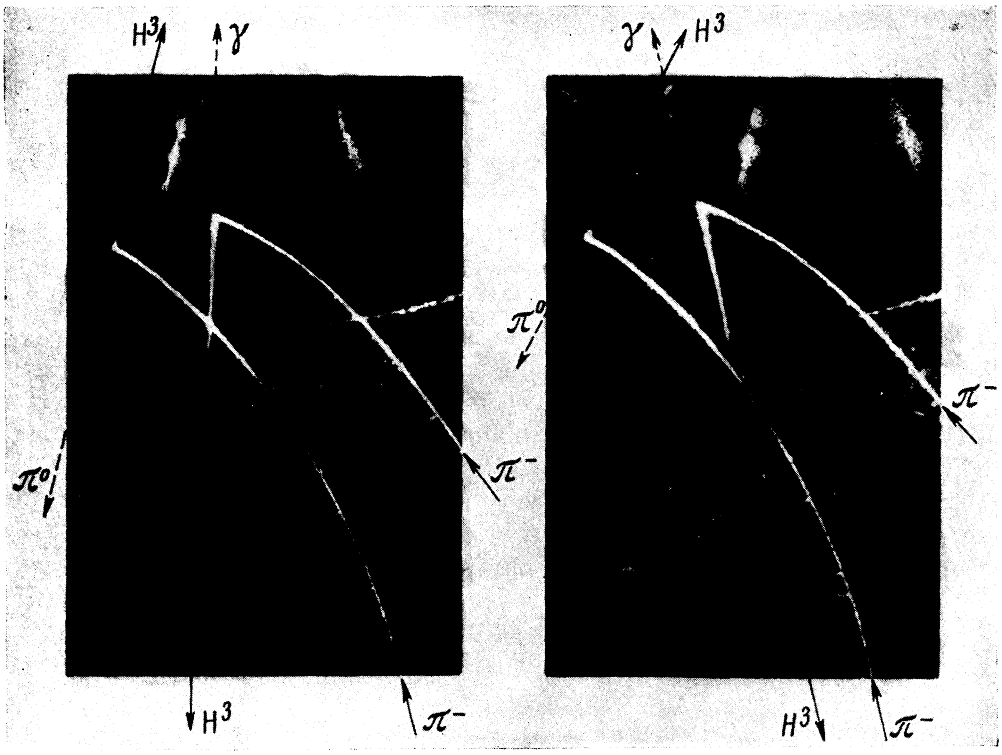

FIG. 2. Stars representing the processes $\pi^- + He^3 \to H^3 + \pi^0$ and $\pi^- + He^3 \to H^3 + \gamma$.

other reactions was determined from the intervals adjacent on the right and left of the peak associated with reaction IV. The mean range of tritium in reaction IV was found to be 5.55 ± 0.05 mg/cm^2.

Using the data on reaction III and IV we find the Panofsky ratio in He^3:

$$P = 2.16 \pm 0.28.$$

The error given is statistical only, and we have neglected the errors due to the assumptions underlying the method used to single out the charge-exchange reaction. The relative probabilities of reactions III and IV are as follows:

$$W_3 = (13.5 \pm 0.9)\ \%, \qquad W_4 = (6.2 \pm 0.7)\ \%.$$

The calculation of the mean-square radius for the $He^3 \to H^3$ transition based on Eq. (1) and on the experimental value of P gives

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

This value of the mean-square radius is in better agreement with the value of 1.56×10^{-13} cm calculated by Werntz [6] using the known value of the binding energy of He^3 and taking the repulsive-core potential for the nucleon-nucleon interaction into account, than with the value 1.78×10^{-13} cm given by Fuji and Primakoff. [7]

The yield of processes III and IV is found to be somewhat larger than that predicted by Messiah.[1]

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