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MEASUREMENT OF THE π^- MESON CASCADE TRANSITION TIME IN GASEOUS He^3

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A diffusion chamber in a magnetic field was used to measure the cascade-transition time of negative pions in gaseous He^3, which turned out to be $(1.4 \pm 0.7) \times 10^{-10}$ sec, the same as obtained in liquid helium [2,3].

THE time interval between the capture of a negative pion by an atom and its absorption by the nucleus is closely connected with the cascade-transition mechanism. Experimental studies of this time interval (the cascade-transition time) of pions in liquid helium have been reported in several papers [1–3], where it is shown that the cascade-transition of pions in liquid helium is larger by two orders of magnitude than predicted on the basis of the mechanism proposed by Day [4,5]. Day started from the premise that the Stark effect plays a dominant role in collisions between a charged mesic atom and the atoms of the medium, leading to rapid transitions between sublevels with different orbital quantum numbers. It is shown in [2,3] that the experimental results can be qualitatively reconciled with the theoretical estimates by making only the assumption that the cascade transitions are due to the external Auger effect and radiative transitions.

For a further study of the cascade transition mechanism in helium it is of interest to measure the transition time in gaseous helium. The cascade transition time $T_\pi(\beta_A)$ is defined as the average time that a meson with velocity β_A comparable with the velocity of the orbital electron (0.02–0.03) stays on the atomic orbits prior to the nuclear absorption. The following relation holds:

$$T_\pi(\beta_A) = \tau N_d / N_t,$$

where N_d is the number of pion decays on the atomic orbit, N_t is the total number of pions subjected to the cascade process, and τ is the pion lifetime. To measure the lifetime of the cascade transition it is necessary to register decays of negative pions with velocity $\lesssim \beta_A$.

We present in this communication the result of measurement of the cascade-transition time of π^- mesons in gaseous He^3. A beam of slow negative pions from the JINR synchrocyclotron was stopped in a diffusion chamber filled with He^3 to a pressure 17.5 atm and placed in a magnetic field. The experimental setup and material are described in detail in [6].

The experimental material was obtained in two runs made in different magnetic fields, 12 000 Oe in run I and 6000 Oe in run II. A total of 9798 stopped π^- mesons were registered in both runs. The chamber was also exposed to a beam of π^+ mesons. We registered 455 cases of $\pi\mu e$ decays and 617 $\pi\mu$ decays in the negative-pion beam. To obtain the number of pion decays with velocity $\lesssim \beta_A$ we selected those decays in which the muon was emitted into the rear hemisphere. This selection was used in order to eliminate the kinematic ambiguity in the determination of the pion velocity, and also to exclude the contribution due to scattering. The pion velocity was determined from the measured momentum and emission angle of the muon.

The muon momenta were determined from the curvature of the track or from the range in that case when the muons were stopped in the gas of the chamber. The following selection criteria were used in the measurements: 1) the muon track length should be not less than 5 cm in run I and 7 cm in run II: 2) the track inclination to the plane perpendicular to the direction of the magnetic field must not exceed 30°.

The measured curvature radii were corrected for optical distortion due to the oblique projection, and account was also taken of the nonuniformity of the magnetic field in the chamber. In addition, allowance was made for the deceleration of the muon in the chamber gas. The latter correction was approximately 1.5% for momenta 28–29 MeV/c and 10% for 16 MeV/c. The dispersion in the values of the momenta was determined by measuring the momenta of the μ^+ mesons emitted by the stopped π^+ mesons, and was found to be 1.3 MeV/c.

In accordance with the criteria indicated above, we selected and measured 61 events. Figure 1 shows the results of the measurements of the momenta of the muons p_μ as a function of the emission angle $\theta_{\pi\mu}$. The smooth curves show the results of a kinematic calculation of the functions $p_\mu(\theta)$ as a function of the pion velocity at the instant of decay.

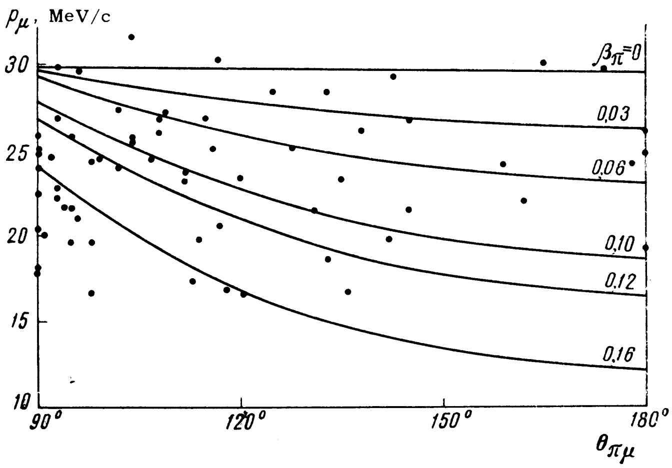

FIG. 1. Measured momenta of muons from $\pi\mu$ decay vs. the emission angle $\theta_{\pi\mu}$. The continuous curves show the kinematically calculated function $p_\mu(\theta)$ as a function of the pion velocity.

It follows from these results that in the region $\beta < 0.03$ there were registered nine cases of $\pi\mu$ decay. This number could include, owing to the measurement in accuracy, decays of pions with velocity exceeding β_A. To estimate the contribution of these decays, we calculated the expected dependence of the number of pion decays in flight on the velocity, with allowance for deceleration losses and measurement errors. The calculated dependence, together with the experimental results, is shown in Fig. 2.

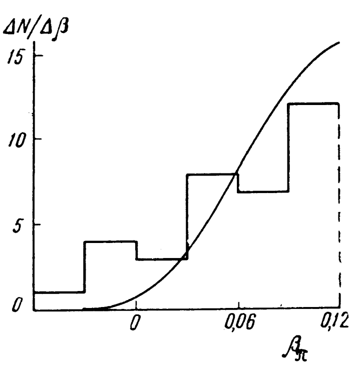

FIG. 2. Histogram of $\pi\mu$ decays per pion velocity interval. The smooth curve shows the calculated relation with account of deceleration losses and dispersion measurements.

As seen from this figure, the sought-for contribution is small and does not exceed two cases. We thus assumed that the number of decaying pions with velocity < 0.03 is 7 ± 2, the error being connected with the uncertainty in the separation of the pions decaying in flight from those decaying at rest. The final result was corrected for the efficiency of selection in accord with the chosen criteria, which was calculated by the Monte Carlo method from the measured topography of the meson stopping, and turned out to be 0.26 ± 0.02.

The time of the cascade transition was found to be

$$T_\pi = (1.4 \pm 0.7) \cdot 10^{-10} \text{ sec}.$$

This is approximately two orders of magnitude larger than the value predicted by Day [4,5], and apparently is evidence of the insignificant role played by the Stark effect in the cascade transition of pions in gaeous He^3.

The obtained value can be compared also with the results of analogous measurements in liquid helium (He^4), where $T_\pi = (3.19 \pm 0.23) \times 10^{-10}$ sec [3], and the density of the medium differs by a factor of approximately 40. We see that both results coincide within the limits of error. Inasmuch as there are no grounds for a noticeable difference between the processes of cascade transition of pions in the helium isotopes, this means that the time of the cascade transition in helium does not depend on the density of the medium.

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