MEASUREMENT OF THE TOTAL MUON CAPTURE PROBABILITY IN He^3

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The total muon capture probability in He^3 is measured with a high pressure diffusion chamber. It is found to be $\lambda_{exp} = 2140 \pm 200\ sec^{-1}$. This result is in agreement with Primakoff's calculations on the basis of the theory of universal weak interaction.

ALONG with measurements of the probabilities of the partial transitions $\mu^- + C^{12} \rightarrow B^{12} + \nu$ [1], $\mu^- + He^3 \rightarrow H^3 + \nu$ [2], which have yielded important information on the capture of muons by nucleons, a large number of investigations have been made by now on the measurements of the total muon capture probability in various complex nuclei (A > 12) in order to check on the correctness of the theory of universal weak interaction [3]. However, a critical review of Primakoff's theoretical estimates [4], with which the experimental data were compared, shows that the calculations are not reliable enough for a comparison with them to lead to the conclusion that the universal theory is valid [5-7]. Many fewer approximations are made in the calculation of the total muon capture probability in the lightest nuclei (D, He^3, He^4) [4], so that one can expect the results of calculations in these cases to be more reliable than corresponding calculations for heavier nuclei. In the case of D (as for capture by hydrogen [8,9]) complications arise because of the mesic-molecule processes, so that great interest is attached to data on capture in He^3. The present investigation was devoted to a measurement of the total muon capture probability in He^3, i.e., the probabilities of the following processes:

$$\mu^- + He^3 \rightarrow H^3 + \nu, \tag{1}$$

$$\mu^- + He^3 \rightarrow d + n + \nu, \tag{2}$$

$$\mu^- + He^3 \rightarrow p + 2n + \nu. \tag{3}$$

In each of these reactions there is emitted one charged particle, and the events have the appearance of single-prong stars. These stars were observed in the high pressure diffusion chamber, which we used previously [2] to measure the probability of reaction (1). The description of the apparatus, the experimental set-up, and a more detailed description of the procedure used to reduce the experimental data can be found in these other papers.

To separate the muon stars from the pion stars (see below), we used the range spectra of secondary charged particles. In Fig. 1 the solid line shows a histogram of the ranges of the secondary particles in the 'muon' exposure (in which 98—99 per cent of the stopped particles are muons and 1—2 per cent are pions). This histogram is constructed for stars with charged-particle ranges which are reliably confined to the sensitive layer of the chamber. It includes 424 stars produced by mesons with track length ≥ 20 mm (starting with which the stopped particle is identified with assurance as a meson).

The spectrum obtained in the 'muon' exposure contains a large number of stars due to pions which are present as an admixture, since each stopping of a pion, unlike the stopping of the muon, is accompanied by a star. In order to obtain the net spectrum of the charged particles from reactions (1)—(3), we have employed a subtraction procedure using the spectrum of the ranges of charged particles from pion capture in He^3, which we have obtained in a 'pion' exposure [10] (where 70 per cent of the stoppings were due to pions and 30 per cent to muons), in which the fraction of the stars due to the muons does not exceed 2 per cent. This spectrum is shown by a dashed line in Fig. 1. It contains 292 stars in the range region 0.5—12 mg/cm^2. The pion spectrum was normalized against the yield of the $\pi^- + He^3 \rightarrow H^3 + \gamma$ reaction, the peak of which at R = 5.6 mg/cm^2 is clearly seen on the spectra of both the 'muon' and 'pion' exposures.

Figure 2 shows the spectra of the charged particles from single-pronged stars, obtained by subtracting the normalized 'pion' spectrum from the spectrum of the 'muon' exposure. On the small

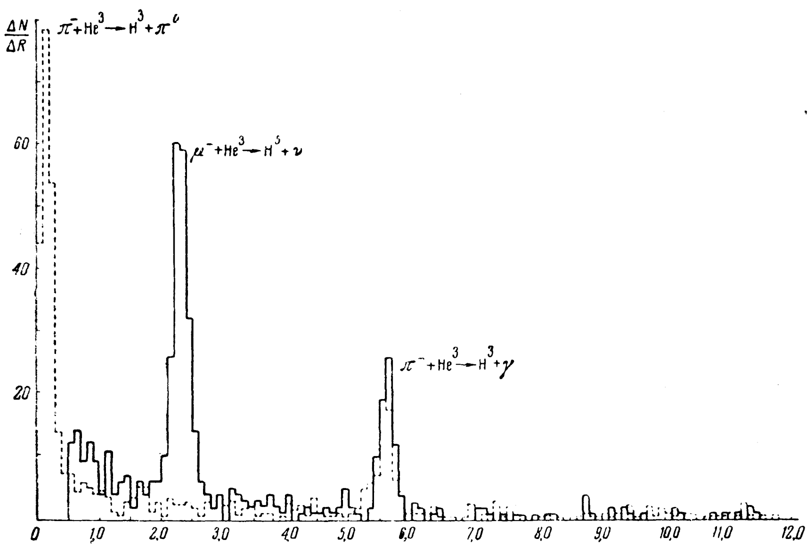

FIG. 1. Spectra of ranges of secondary particles from stars due to mesons stopped in He³. The solid line shows the spectrum obtained in the 'muon' exposure, and the dashed line shows the normalized spectrum obtained in the 'pion' exposure. The spectra are constructed without correction for registration efficiency.

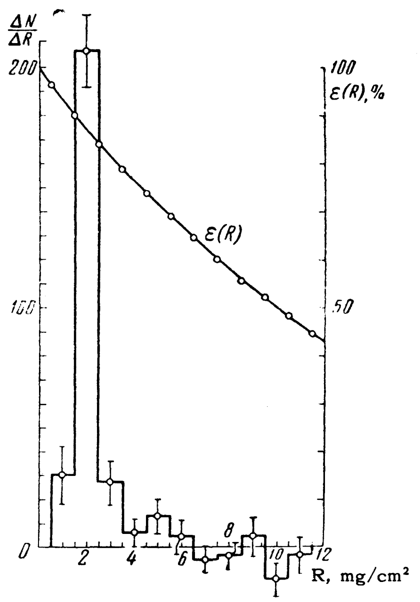

FIG. 2. Spectra of ranges of secondary particles, obtained after subtracting the 'pion' spectrum from the 'muon' spectrum (histogram); the smooth curve shows the dependence of the registration efficiency on the range of the secondary particle. In subtracting the spectra, the registration efficiency for each exposure was taken into account.

range side, the region 0—0.5 mg/cm² was eliminated in which the contribution made to both spectra by the reaction $\pi^- + He^3 \to H^3 + \pi^0$ is very large. More reliable data for this range interval can be obtained by extrapolating the spectrum from the neighboring interval. On the large-range side we have confined ourselves to the quantity R = 12 mg/cm², i.e., the portion of the spectrum where it was possible to obtain reliable data on the star registration efficiency. In constructing the spectrum (Fig. 2) we took account of the variation of the star registration efficiency with length of the prong. This efficiency was calculated for each exposure by the Monte Carlo method using known distributions of stoppings in the chamber volume. One of the calculated curves (for 'muon' exposure) is shown in Fig. 2. A correction was introduced for the contribution to the 'muon' spectrum from false stars which are imitated by electronless stoppings of muons with scattering on the end of the track. The magnitude of this correction was largest in the soft part of the spectrum (range region 0.5—1.5 mg/cm²) where, however, it did not exceed 25 per cent. The spectrum of the ranges due to muon capture shows a peak at $R \sim 2$ mg/cm², corresponding to the reaction $\mu^- + He^3 \to H^3 + \nu$. This spectrum decreases practically to zero at a range $R \sim 6.5$ mg/cm². It thus turns that the charged particles emitted upon capture of a muon in He³ have a fairly soft spectrum.

During the process of the muon capture, a considerable amount of energy, ~100 MeV, is released, and consequently the charged particles could in theory have quite a high energy. Therefore, in order to obtain the total probability it is necessary, strictly speaking, to measure the spectrum of the ranges in a very wide region. However, the rapid decrease of the spectrum which we obtained indicates that for this purpose it is necessary to use a limited region of ranges (to $R \le 6.5$ mg/cm²). We present below arguments in favor of assuming that the total probability λ of the capture of muons in He³ should not differ in practice from the value of $\lambda_{6.5}$, the probability of muon capture in He³ with emission of charged particles with ranges $R < 6.5$ mg/cm².

Indeed, a range of 6.5 mg/cm^2 corresponds to protons and deuterons with energies ~ 2 and ~ 3 MeV, respectively. This agrees with estimates of the 'maximum' energies of these particles, obtained under the assumption that muon capture occurs principally via the direct process $\mu^- + p \rightarrow n + \nu$, and in this case the charged particles are the 'observers.' This point of view is confirmed by comparison of our spectrum with the charged-particle spectrum obtained recently in a study of muon capture in He^4 [11]. The considerable difference in the maximum particle energies observed on capture in He^4 and He^3 agrees qualitatively with what can be expected for the 'observer' particles, if account is taken of the difference in the binding energies of He^3 and He^4.

Integration over the interval 0.5—6.5 mg/cm^2 yields 287.6 ± 25 events. In the range region 0—0.5 mg/cm^2, a correction of 9 ± 5 stars is introduced, obtained by linearly extrapolating to zero the number of events from the neighboring interval 0.5—1.0 mg/cm^2. Thus, in the calculation of the total muon capture probability in He^3 we have taken 296.6 ± 25 events. Summation of the number of stars over the 0.5—6.5 mg/cm^2 interval with elimination of the peak from the reaction $\mu^- + He^3 \rightarrow H^3 + \nu$ yields 91.3 ± 22 events. Using these quantities, i.e., the number of stoppings recorded for muons with initial-track length ≥ 20 mm (67463 ± 1093), and the known lifetime of the muon (2.21×10^{-6} sec), we can calculate $\lambda_{exp} = \lambda_{6.5}$ and the total probability of reactions (2) and (3) $w_{exp} = w_{6.5}$:

$$\lambda_{exp} = (2.14 \pm 0.18) \cdot 10^3 \text{ sec}^{-1},$$

$$w_{exp} = (0.66 \pm 0.16) \cdot 10^3 \text{ sec}^{-1}.$$

In the calculation of the probabilities we introduced a correction of (7 ± 1) per cent to account for the fraction of the events lost in selecting only those events which had clearly visible prong ends.

It must be noted that the experimental data which includes stars with charged particles with $R > 6.5$ mg/cm^2, do not contradict the assumption $\lambda = \lambda_{6.5}$. Indeed, we can estimate the capture probability by including also the charged particles with range $R > 6.5$ mg/cm^2. We have (in units of 10^3 sec^{-1}):

$$\lambda_{12.0} = 2.0 \pm 0.2. \qquad \lambda_{25.0} = 2.3 \pm 0.3.$$

We see that the quantities obtained in this manner are compatible, within the limits of statistical errors, with the value of $\lambda_{6.5}$. We note here that when $R > 12$ mg/cm^2, the errors can exceed the indicated statistical errors, since the efficiency of registration in this region is very small (~ 20 per cent) and has been roughly estimated.

An estimate of λ taking into account all the events, including also the stars with ranges of secondary particles which do not lie in the sensitive layer of the chamber, also gives a value compatible with $\lambda_{6.5}$. However, this estimate is connected with large uncertainties which are not only statistical, but also systematic (the uncertainty in the identification of the stars).

The obtained value $\lambda_{exp} = (2.14 \pm 0.20) \times 10^3$ sec^{-1} agrees with the value for the total probability calculated by Primakoff [4], who obtained on the basis of the universal theory $\lambda_{theor} = 2.5 \times 10^3$ sec^{-1} with an uncertainty of ~ 10 per cent. The probability λ is the sum of quantities w and Λ (Λ is the probability of the partial transition $\mu^- + He^3 \rightarrow H^3 + \nu$, which we measured before in [2]). Thus, all the new information lies in the quantity w_{exp}. From the calculations of Primakoff and Fujii [4,12] we can obtain $\lambda_{theor} - \Lambda_{theor} = w_{theor}$, which is found to be 1.0×10^3 sec^{-1} with an uncertainty of the order of 20 per cent.

The agreement with the calculations of Primakoff was observed also in measurements of the total probability of muon capture in He^4 [11] ($\lambda_{theor}(He^4) = 470$ sec^{-1}, $\lambda_{exp}(He^4) = 450$ sec^{-1}). Thus, in the investigation of the capture of muons in helium we obtained three independent quantities (w, Λ, λ (He^4)), which turn out to agree with the predictions of the universal theory.

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