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MEASUREMENT OF THE $\mu^- + He^3 \to H^3 + \nu$ REACTION RATE

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In our previous paper [1] an experiment has been described in which the reaction

$$\mu^- + He^3 \to H^3 + \nu \qquad (1)$$

was observed and its rate was estimated roughly. By analysing 14 events of reaction (1), the H^3 recoil energy was accurately determined, so that it was possible to give quite a low (< 8 MeV) upper limit for the mass of the neutral particle emitted in the muon capture by the nucleon. This result showed that in the muon-nucleon interaction a neutrino is emitted and that the relevant process is, in fact,

$$\mu^- + p \to n + \nu . \qquad (2)$$

Recently, Hildebrand [2], as well as Blaser et al. [3] observed reaction (2) in liquid hydrogen.

Here are given the results of an investigation of reaction (1) which is based on a statistical material an order of magnitude better than that obtained earlier. The rate of reaction (1) was measured in order to study the question of the muon-electron symmetry in the interaction of these particles with the nucleon.

The same experimental technique as in [1] was used. A "magnetic" diffusion chamber (H = 5000 Oe) filled with He^3 at 20 atmospheres was placed in the 217 MeV/c meson beam of the Dubna 680 MeV synchrocyclotron. The mesons were slowed down by a copper moderator placed in front of the chamber. A typical photograph of an event corresponding to reaction (1) is shown in fig. 1. All the experimental material (about 10^5 photos) was scanned twice. Since stopped mesons could be identified with great confidence if their lengths L_0 were $\geq$ 20 mm, only such stopped particles were considered in the further analysis. It was established that the scanning efficiency for stopping mesons is close to unity and practically independent of the character of the event at the end of the track.

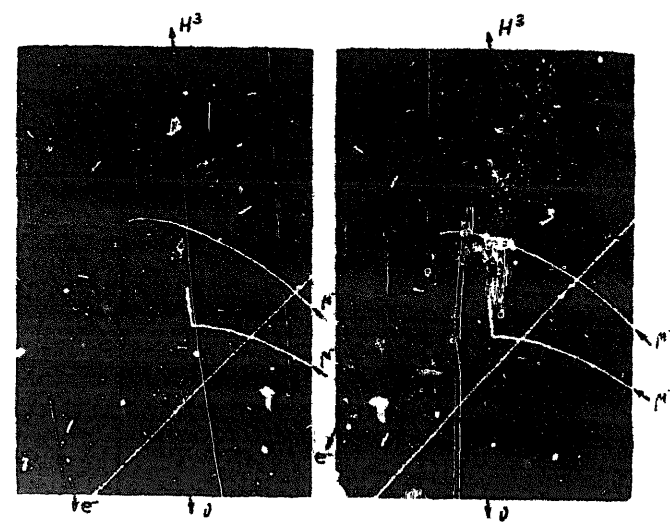

Fig. 1. Photograph of an event of the reaction $\mu^- + He^3 \to He^3 + \nu$. A muon stopping and decaying in the chamber is also visible.

The absolute capture probability is determined in terms of the well-known muon lifetime (2.21 × 10^{-6} sec), if one measures the ratio of the number of capture events to that of (μe)-decays from the He^3 mesic atom state. Since the tritium produced in reaction (1) has a definite energy (1.897 MeV), the problem of identifying events of reaction (1) (tritium stars) consists in selecting a group of one-prong stars with the corresponding range from the background due to other processes. The number obtained in this way must be then corrected for the recording efficiency, i.e., it is necessary to take into account the fraction of stars in which the tritium leaves the sensitive region of the chamber. Such a procedure requires that the stopping of secondary particles be reliably identified in all cases, including those when the range ends in the vicinity of the insensitive region of the chamber. To avoid this difficulty we used the two following methods.

First, the total number of events (1) was determined from the spectrum of the visible tracks of the secondary particles belonging to all the stars with the exception of those which on the basis of the ionization character obviously could not be tritium stars (fig. 2).

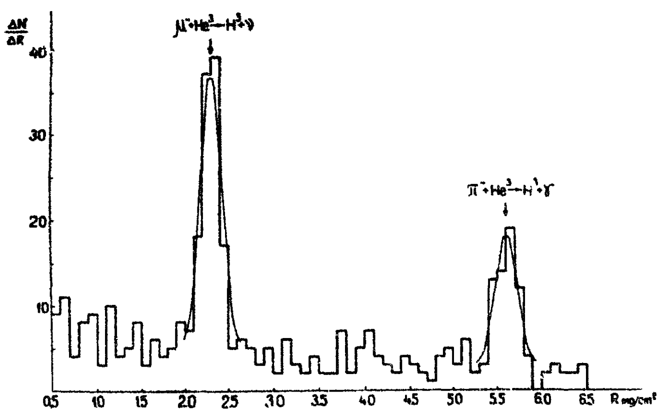

Fig. 2. Spectrum of the visible track lengths of secondary particles from all the stars produced by stopping mesons.

Second, such a number was determined from the range spectrum of the secondary particles, the stopping of which was certain (fig. 3). In this case, an additional correction is necessary, taking into account the tritium stars in which the H^3 stops, but the track end character of which is unclear.

Two peaks can be clearly seen in both the spectra. One peak in the range interval (2.0 - 2.6) mg/cm^2 corresponds to the reaction (1) and the other one in the interval (5.3 - 5.9) mg/cm^2 corresponds to the radiative capture of pions in He^3 ($\pi^- + He^3 \rightarrow H^3 + \gamma$). Solid lines in figs. 2 and 3 are resolution curves.

The background level was determined by linear interpolation between the regions of the spectrum close to the peak on the left and on the right sides. It should be noted that if the interpolation interval is extended from 2.0 mg/cm^2 to the left and from 2.6 mg/cm^2 to the right, the changes in the number

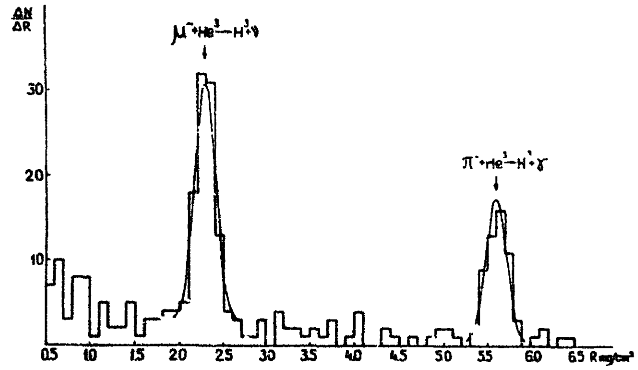

Fig. 3. Range spectrum for secondary particles which undoubtedly are brought to rest.

of tritium stars we are determining are small and do not exceed the statistical fluctuations of the background.

First, the recording efficiency for the tritium stars was calculated, the real topography of the meson stoppings in the chamber being taken into account. Secondly, the efficiency was found experimentally from the analysis of all the stars. The two estimations are in good agreement, and the efficiency was taken to be 0.90 ± 0.02. In the second method an additional correction to the efficiency was made on the basis of the fraction of (μe)-decays with unclear end points and was found to be (6.5 ± 1.5)%.

The experimental results relevant to the number of tritium stars are presented in the left side of table 1.

Table 1
Data on muons stopping in He^3.

Method	Number of reaction (1) events ($L_0 \geq$ 20 mm)		Number of (μe)-decays ($L_0 \geq$ 20 mm)			
	Recorded	Corrected for efficiency	With visible electron	Without visible electron	Corrected for C and O mesic atoms	Final value
I	95.5 ± 11.9	106.0 ± 13.1	24 861 ± 157	10 963 ± 440	- 358 ± 121	35 466 ± 615
II	88.3 ± 10.4	105.2 ± 12.7				

In the right side of table 1 are given the experimental data on the number of (μe)-decays from the states of He^3 meso-atom.

The final results for the rate of reaction (1) is

$$(\Lambda_{H_e^3})_{exp} = (1.36 \pm 0.18) \times 10^3 \text{ sec}^{-1} .$$

This is to be compared with the theoretical value of Wolfenstein [4] $(\Lambda_{He^3})_{theor} = 1.54 \times 10^3$ sec^{-1}. The calculation of $(\Lambda_{He^3})_{theor}$ is based on the theory of the universal vector and axial-vector interaction with account of virtual pion corrections, under the assumptions that the vector current is conserved. Statistical population of the hyperfine structure levels in the He^3 mesic atom is assumed.

The absence of an effective mechanism for the transition between the hyperfine structure levels in the He^3 mesic atoms and the insensitivity of $(\Lambda_{He^3})_{theor}$ even to extreme deviations from a statistical population of the levels make one think that from this point of view the He^3 experiment can be interpreted unambiguously. The uncertainty in $(\Lambda_{He^3})_{theor}$ due to the inexact knowledge of the root-mean-square radius of the nucleus and to the error in the ft value of the H^3 β-decay, is 5% [4]. The uncertainty in the calculations of the pseudoscalar constant $g_p{}^\mu$ is difficult to estimate, but it turns out to be essential only in the region $g_p{}^\mu \leq + 8\, g_A{}^\mu$, where $g_A{}^\mu$ is the axial-vector constant in the μ-capture. The experimental magnitude of the rate of the reaction (1) definitely shows that $g_p{}^\mu$ and $g_A{}^\mu$ have equal signs and that the absolute value of $g_p{}^\mu$ cannot be small $(5\, g_A{}^\mu < g_p{}^\mu < 35 g_p{}^\mu)$ *. Therefore, the uncertainty in the calculated value of $g_p{}^\mu$ cannot play an important role.

Thus, it should be emphasized that the rate of reaction (1) predicted by the universal theory agrees with the experiment within the theoretical and experimental inaccuracies. This implies that the muon-electron symmetry in lepton capture by nucleons, which is at the basis of the universal theory, does not contradict our 13% accuracy experimental result.

Below we shall discuss the problem of the Fermi interaction, the very presence of which in the process of muon capture by nucleons is still to be proved. Reaction (1) is a mixed transition, the rate of which depends on two parameters, the Fermi G_F and the Gamow-Teller G_G phenomenological constants $(\Lambda_{He3} \sim (G_F{}^2 + 3G_G{}^2))$.

It is desirable to get information on G_F without making any "a priori" assumption on the form of the four-fermion interaction.

This is possible, if the analysis is made of both our experimental results and those on the rate of the reaction

$$\mu^- + C^{12} \to B^{12} + \nu\,, \qquad (3)$$

which is a pure Gamow-Teller transition. Unfortunately, there is a considerable discrepancy among different measurements of the reaction (3) rate. It seems reasonable to consider only the more recent measurements of Moyer et al. [6] $(\Lambda_{C12} = (6.31 \pm 0.24) \times 10^3$ sec$^{-1})$. Then we get that $|G_F| = (0.8 {}^{+0.4}_{-0.8})\, |G_G|$. The error indicated takes into account the experimental inaccuracies and the uncertainty in the nuclear matrix elements of reactions (1) and (3). According to Wolfenstein [4], the latter amounts to 20% and is the main one.

Another possibility of getting information about the Fermi constant is to use our He^3 result together with the result of the experiment with hydrogen [3]. The ratio of the muon capture rates from the hydrogen mesic molecule and He^3 mesic atom states $\Lambda_{p\mu p}/\Lambda_{He3}$ turns out to be sensitive to the G_F/G_G ratio[4]. Of course, the result will depend on the not very well known accuracy in the calculation of $\Lambda_{p\mu p}$. If only experimental errors are taken into account, we get that $G_F/G_G < -0.1$. The final value of the Fermi constant is taken to be

$$G_F = -(0.8 {}^{+0.4}_{-0.7})\, G_G\,.$$

This result, confirming the presence of the Fermi interaction in the muon capture, excludes the possibility that G_F exceeds considerably G_G, and is quite compatible with the value predicted by the universal (V-A)-interaction theory.

Of course, the existence of the vector interaction follows from our measurements much more evidently if it assumed that $g_A{}^\mu = g_A{}^\beta$ [4] and $g_p{}^\mu = 8 g_A{}^\mu$ [7]. Indeed, if the vector interaction were absent, the reaction (1) rate would be expected to be 0.93×10^3 sec^{-1}, i.e., essentially smaller than the measured value. However, the above values of $g_A{}^\mu$ and $g_p{}^\mu$ cannot be equally well justified.

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* An analogous conclusion follows also from the analysis of the asymmetry of the neutrons emitted in muon capture by complex nuclei [5].

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