NEW DATA ON THE PANOFSKY RATIO IN He^3 AND NUCLEAR FORMFACTORS IN μ-CAPTURE

O. A. Zaimidoroga, M. M. Kulyukin, B. V. Struminskii, R. M. Sulyaev, I. V. Folomkin, A. I. Filippov, V. M. Tsupko-Sitnikov, Yu. A. Shcherbakov

Joint Institute for Nuclear Research
Laboratory of Nuclear Problems, Dubna, USSR
(Presented by R. M. SULYAEV)

The study of π^--meson capture by He^3 from a mesic atom state was continued using a high-pressure diffusion chamber in a magnetic field [1]. In the present communication new data on the following two reactions will be presented:

$$\pi^- + He^3 \rightarrow H^3 + \pi^0; \quad (1)$$

$$\pi^- + He^3 \rightarrow H^3 + \gamma. \quad (2)$$

The Panofsky ratio in He^3 was measured, i.e. the ratio between the probabilities of charge exchange (reaction (1)) and radiative capture (reaction (2)) of pions stopping in He^3. Since the energy of the outgoing particles in both reactions is fixed, they can be identified by measuring the range of the tritium nucleus. The energies of the tritium nuclei in these reactions are equal to 0.19 and 3.28 MeV, respectively.

The experimental material contained over 33,000 photographs. About 10,000 one-prong events due to pions stopping in He^3 were analyzed. The reactions (1) and (2) were separated in two experiments: one at a high He^3 pressure in the chamber (17.5 atm), the other at a low pressure (6.5 atm). The spectrum of secondary charged particles from pion capture in He^3 at high pressure is shown in Fig. 1. The spectrum has maxima at ranges of 0–1 mg/cm^2 due to tritium nuclei from reaction (1) and at 5–6 mg/cm^2 due to reaction (2).

The Panofsky ratio in He^3 obtained from the analysis of the experimental range distribution is

$$P_{He^3} = 2.28 \pm 0.18.$$

The relative probabilities of the two reactions are

$$W(H^3\pi^0) = (15.8 \pm 0.8)\,\%,$$

$$W(H^3\gamma) = (6.9 \pm 0.5)\,\%.$$

Our value of the Panofsky ratio in He^3, together with Hofstadter's data [2] on electron scattering by

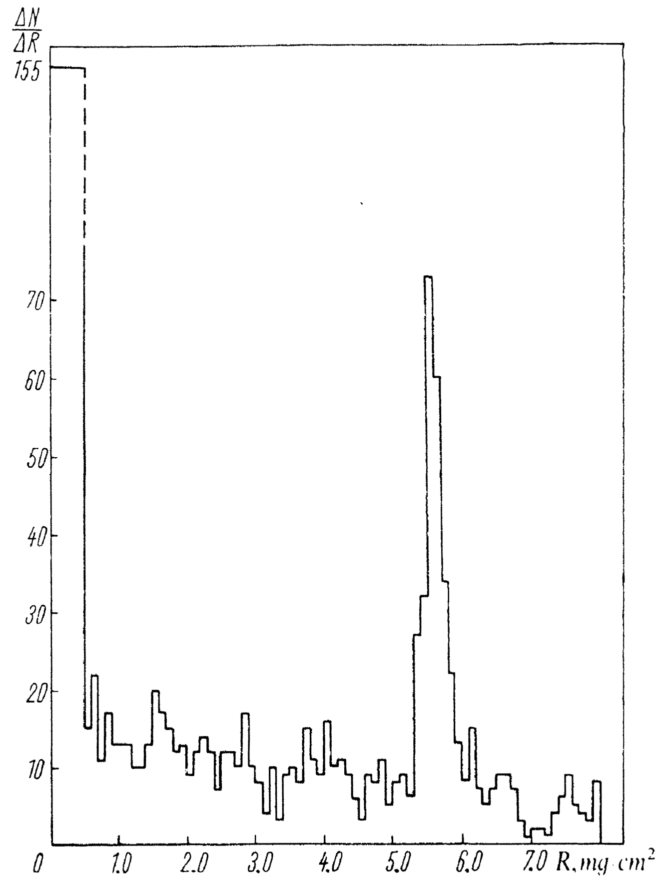

Fig. 1.

He^3 and H^3 were used to improve the nuclear formfactors for the reaction

$$\mu^- + He^3 \rightarrow H^3 + \nu. \quad (3)$$

The matrix element of this reaction can be expressed in terms of the formfactors F_1 and F_2 introduced by Schiff [3]. Using for the matrix element the expression from [4] we obtain

$$|M^{\mu}_{He^3 \rightarrow H^3}| = (G^{\mu}_V)^2 \left(F_1^2 - \frac{8}{3} F_1 F_2\right) + + [3(G^{\mu}_A)^2 + (G^{\mu}_p)^2 - 2G^{\mu}_p G^{\mu}_A] F_1^2.$$

We have assumed that the s-state is the dominant state in the wave function of the nucleus,

$$\psi = \varphi_0 u + \varphi_2 v_2 - \varphi_2 v_1.$$

The formfactors F_1 and F_2 are functions of the momentum transfer q and can be expressed in terms of the wave functions in the following way:

$$F_1(q) = \langle u \,|\, e^{i\mathbf{qr}} \,|\, u \rangle; \quad F_2 = -3\langle u \,|\, e^{i\mathbf{qr}} \,|\, v_1 \rangle;$$

where $\mathbf{r}$ is the radius-vector of the nucleon.

The same formfactors can be introduced to describe the radiative capture of pions by He^3 and electron scattering by He^3 and H^3 nuclei. In this way we can determine the values of F_1 and F_2, and use them to calculate the matrix element of reaction (3). However, in the experiments under discussion, the formfactors are not known for the required values of momentum transfer.

Electron scattering by He^3 and H^3 nuclei was measured for 1 fermi$^{-2} \leqq q^2 \leqq 5$ fermi^{-2}; momentum transfer in radiative capture of pions by He^3 was $q^2 = 0.47$ fermi^{-2}, and in reaction (3) $q^2 = 0.27$ fermi^{-2}. Therefore the experimental results have to be extrapolated into the region of interest. In order to perform the extrapolation we require the explicit expression for the formfactors F_1 and F_2, which depends upon the choice of the one-particle wave functions. It follows from the analysis of the electron scattering data that the experimental results can be adequately described making two alternative assumptions concerning the shape of the one-particle wave function: assuming a Gaussian, we get

$$F_1 = \exp\left(-\frac{q^2 r^2}{6}\right);$$

$$F_2 = \left(\frac{P}{6}\right)^{1/2} \frac{q^2 r^2}{2} \exp\left(-\frac{q^2 r^2}{6}\right);$$

and for an Irving function

$$F_1 = \left(1 + \frac{q^2 r^2}{21}\right)^{-7/2};$$

$$F_2 = \left(\frac{P}{21}\right)^{1/2} q^2 r^2 \left(1 + \frac{q^2 r^2}{21}\right)^{-9/2}$$

with the following values for the root-mean-square nuclear radius corresponding to the distribution of the nucleon centers:

$r = (1.5^{+0.2}_{-0.1})$ fermi for a Gaussian,

$r = (1.7 \pm 0.1)$ fermi for an Irving function.

The parameter P gives the weight of the mixed symmetry state; according to the estimate of [3] and our estimate it is equal to 0.03. Extrapolating the electron scattering by He^3 and H^3 nuclei to $q^2 = 0.27$ fermi^{-2}, we obtain for the formfactor F_1^2 (including the uncertainty due to the choice of the wave function)

$$^{(I)}F_1^2(0.27) = 0.80 \begin{array}{l} +0.03 \\ -0.05 \end{array},$$

and for the formfactor F_2

$$F_2(0.27) = 0.023 \pm 0.005.$$

The Panofsky ratio in He^3 can be expressed in terms of the Panofsky ratio in hydrogen P_H and the nuclear formfactor F_1:

$$P_{He^3} = \frac{P_H k}{F^2},$$

where k is a kinematic factor.

Using the experimental value of P_{He^3} we obtain

$$F_1^2(0.47) = 0.75 \pm 0.06.$$

At a momentum transfer of $q^2 = 0.47$ fermi^{-2}, corresponding to radiative capture of a pion by He^3, the different one-particle wave functions give the same result for the rms radius within 2%:

$$r = (1.4 \pm 0.2) \text{ fermi}.$$

The extrapolated value of the formfactor F_1^2 at $q^2 = 0.27$ fermi^{-2} is equal in this case to

$$^{(II)}F_1^2(0.27) = 0.84 \pm 0.04.$$

The weighted average of the extrapolation results $^{(I)}F_1^2$ and $^{(II)}F_1^2$ is finally

$$F_1^2(0.27) = 0.82 \pm 0.03.$$

The partial probability of muon capture by He^3 in reaction (3), calculated using the universal weak interaction and the extrapolated values of the formfactors F_1 and F_2, is equal to

$$\Lambda_{He^3}^{theor} = (1.55 \pm 0.06) \cdot 10^3 \text{ sec}^{-1}.$$

The error includes only the uncertainty of the nuclear formfactors. This value agrees well with the weighted average of the results of the three known

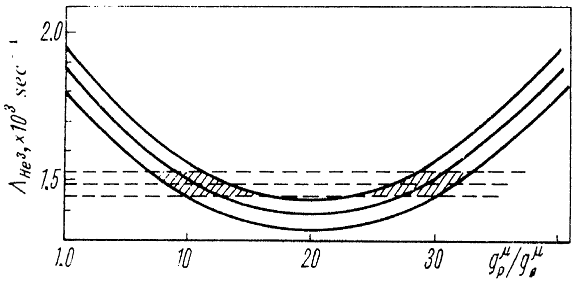

Fig. 2.

experiments on muon capture by He^3 [5–7]:

$$\Lambda_{He^3}^{exp} = (1.49 \pm 0.04) \cdot 10^3\ sec^{-1}.$$

Using the improved value of the nuclear matrix element of reaction (3) together with its experimental probability, one can calculate using the universal weak interaction the pseudoscalar coupling constant g_p^μ, which is otherwise hard to compute. The dependence of the probability of reaction (3) upon the ratio g_p^μ/g_A^μ is given in Fig. 2. The uncertainty includes both the errors in the nuclear matrix element and in the experimental probability. The minimum value of the pseudoscalar constant is

$$g_p^\mu = +\left(11\ {}^{+4}_{-3}\right) g_A^\mu.$$

This result agrees with other estimates of this constant [8–10], and does not contradict the emerging conclusion that the experimental value is slightly higher than the one calculated by Goldberger and Treiman [11] ($g_A^\mu \approx 8 g_A^\mu$).

REFERENCES

1. Zaimidoroga O. A. et al. JETP **44,** 1180 (1963); International Conference on High-Energy Physics at CERN, Geneva, 1962, p. 14.
2. Collard H. et al. Phys. Rev. Lett., **11,** 132 (1963).
3. Schiff L. I. Phys. Rev., **133,** 802 (1964).
4. Fujii A., Primakoff H. Nuovo Cimento, **12,** 327 (1959).
5. Zaimidoroga O. A. et al. JETP **44,** 389 (1963); Phys. Lett., **3,** 229 (1963).
6. Auerbach L. et al. Phys. Rev. Lett., **3,** 23 (1963).
7. Edelstein R. et al. International Conference on Fundamental Aspects of Weak Interaction. Brookhaven, 1963.
8. Cohen R. C. et al. Phys. Rev. Lett., **11,** 134 (1963).
9. Conversi M. et al. International Conference on Fundamental Aspects of Weak Interaction. Brookhaven, 1963.
10. Rothberg J. et al. Phys. Rev., **132,** 2664 (1963).
11. Goldberger M. L., Treiman S. B. Phys. Rev., **111,** 355 (1958).