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Laboratory of Nuclear Problems

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MEASUREMENTS OF NEGATIVE μ - MESONS POLARIZATION IN MESIC ATOMS OF CARBON, OXIGEN, MAGNESIUM, SULFUR, ZINC, CADMIUM AND LEAD

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Объединенный институт
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БИБЛИОТЕКА

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Abstract

The angular distributions of electrons from μ^--meson decay in mesic atoms of C, O, Mg, S, Zn, Cd and Pb were measured by means of the scintillation counters. μ^- - meson polarization was determined on the basis of measurements. In mesic atoms of Mg, Zn, Cd and Pb polarization equals to (19 ± 7)%; for C, O and S mesic atoms polarization equals (14 ± 4)%. μ^- - meson depolarization in matters with zero nuclear spins, are explained mainly by spin-orbital interaction in process of mesic atom production; depolarization is partially connected also with interaction of the magnetic field of the electron atom shell on μ^--meson during its life-time on K-orbit.

* * *

I. Introduction

As is known, under moderation in matter the negative μ^--mesons are subjected to nuclear absorption and this process takes place through intermediate stage producing mesic atoms. It is considered, that this absorption process is due to the reaction: $\mu^- + p \to n + \nu$. The investigation of neutron angular distribution due to capture of polarized μ^- - mesons in liquid hydrogen is one of the methods of determination of weak μ - meson interaction with nucleons [1,2]. However, as the experimental results [3] on determination of μ^-- meson polarization in the liquid hydrogen show, this method is unsuitable because of the full μ^- - meson depolarization. The theoretical consideration of the polarized μ^-- meson capture by light nuclei shows [2] that the measurement of angular distribution of neutrons with energy in upper spectrum part, may allow to determine the type of interaction. Neutron angular distribution is described by the formula:

$$W(\theta) = 1 + a\beta\gamma\cos\theta \qquad (1)$$

where β - is assymetry coefficient in neutron angular distribution, the value and sign of which depend upon the type of interaction, θ - angle between theneutron emergence direction and μ^-- meson spin, a - coefficient, taking into account degree μ^- - meson polarization in mesic atoms and γ - coefficient, depending on the neutron depolarization inside the nucleus.

Formula (1) runs as follows: the measurement of μ^- - meson depolarization in mesic atoms as well as the investigation of neutron depolarization in nuclear matter should precede the experiment on neutron angular distribution. This work deals with μ^- -meson polarization in different matters.

* * *

II. The basic theoretical Ideas

We have proceeded from the following ideas of μ^- - meson depolarization process at heir moderation and stopping in the matter. From the works [4,5] follows that the depolarization does not take place till their capture on mesic atom orbits under μ^- -meson moderation. Due to the fine interaction and under the effect of magnetic fields on electron shell and nucleus of atoms depolarization at mesic atom production is further possible. Depolarization due to spin-orbital interaction will take place if the time τ_e of μ^- - meson stay at given level $\ell \neq 0$, is greater as the time τ_2 of meson spin reorientation in magnetic field to be produced by its orbital motion. The time τ_e can be calculated from the formulas, given in work [6]. The time τ_2 can be estimated from relation $\Delta E \cdot \tau_2 \sim h$ where ΔE the level spacing of fine mesic atom structure [7]; It turns out that τ_e is in some orders greater than τ_2. Depolarization due to the effect of the magnetic fields of electron shell and nucleus in the process of meson capture on K-orbit will be neglible. In fact for the case $\tau_e < \tau_2'$, with $\tau_2' \doteq \frac{h}{\Delta E'}$ (Here $\Delta E'$ - hyperfine structure level spacing).

Thus, we may say that meson depolarization in mesic atom production will be mainly due to fine and hyperfine interaotions. After μ^- - meson was placed on k-orbit, where it stays until its decay or capture by nucleus, depolarization can proceed in magnetic field of electron shell*.

One can avoid depolarization due to hyperfine interaction with applying matters with nuclear spin equal to zero. In this way one cannot avoid depolarization in electron shell field because mesic atom production is always accompanied by changing over electron shell of the initial atom. Hence, the basic depolarization mechanizms should be in the stopping of μ^- - mesons in such matters the spin-orbital interaction and the interaction between the magnetic fields of atom electron shell and μ^- - meson for the time of their life on K-orbit. Proceeding from these ideas we have measured μ^- - meson polarizations for the numbers of matters, 85-95% of which consist of atoms, with zero nuclear spins, namely for C, O, Mg, S, Zn, Cd and Pb.

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* I.M. Shmushkevich. Private communication.

III. Experiment

μ^- - meson polarization was investigated by measurement of anisotropy in the angular distribution of the electron decay. Figure 1 shows experimental equipment. For π^- - and μ^- -meson moderation the aluminium filters were used. Going through the filters μ^- - mesons met the target from the investigating matter, where they stopped. The target size was 15 x 15 cm; the thickness was 2 ÷ 6 g/cm^2. The angle under which the target was installed respectively to the "axis" of meson beam was equal to 45^o. Copper wire coil was wound on the target for the magnetic field production necessary for μ - meson precession. The detailed description of the experimental conditions, scintillation counters and electronic equipment is given in our paper |3| published previously in the present experiments. The thickness of the polyethilenic filter between the counters 3 and 4 was equal to 4 ÷ 8 g/cm^2.

For carbon, oxigen, magnesium and sulfur asymmetry coefficient a in the angular distribution of the electron decay $J(\theta) = 1 + a\cos\theta$ was obtained from investigation of electron number dependently upon the value of the magnetic field H , in which the target was set up. In case of zinc, cadmium and lead the value a was found by the measurement of electron number with field terms H_{max} and H_{min} corresponding maximum and minimum of the electron intensivity on the precession curce, calculated to the formula:

$$J(H)=\int_{t_1}^{t_2} e^{-\frac{t}{\tau}}\left[1+a\cos(2\pi ft+\theta_0)\right]dt$$

with delay time t_1, the width of "gate" t_2-t_1 and life time of μ^- - mesons τ |8,9|.

In the experiments with C,O,Mg and S the width of "gate" was equal approximately τ ; in these with Zn, Cd and Pb accordingly $(2 + 3)\tau$. The value of the ratio $\frac{t_1}{t_2-t_1}$ was equal in every experiment approximately 0,3. In experiments, for instance, with carbon the rate of the electron count with H = 0 was usually equal about 120 per minute; in these with lead - accordingly about 8 per minute. In these experiments the background level made up 3 counts per minute and did not depend upon field H. The background was obtained from the expression $N_B=\frac{N_1+N_2}{2}$ with N_1 - counts number of electron detector, measured without target and magnetizing coil, N_2 - electron detector data, registered with coil but without target.

As the results of the experiments the value of the coefficients of the asymmetry a for electrons with the range greater than $X^{g}_{\mathrm{g/cm^2}}=x_1+\frac{1}{2}x_2+x_3$ was obtained (here X_1 -

filter thickness between counters 3 and 4, X_2 -target thickness, X_3 - scintillation counter thickness in the electron detector). Then, using the energetic asymmetry dependence in $\mu^+ - e^+$ -decay obtained in (10), we got values of a_0 - asymmetry coefficients for the all integral spectrum, it means with $x=0$. The values of a_0 are given in the second column of Table I.

T a b l e I.

M a t t e r	V a l u e ($-a_0$)	Polarization P in %
C	0,040 ± 0,005	$10 \leq P \leq 18$
$O(H_2)$	0,043 ± 0,005	$11 \leq P \leq 19$
Mg	0,058 ± 0,008	$15 \leq P \leq 26$
S	0,042 ± 0,006	$11 \leq P \leq 19$
Zn	0,056 ± 0,011	$13 \leq P \leq 26$
Cd	0,055 ± 0,012	$12 \leq P \leq 26$
Pb	0,054 ± 0,013	$12 \leq P \leq 26$

The corrections were made in the mentioned values, taking into account delaying time, the width of "gate", μ^- - meson decay and solid angle of electron detector. The mentioned errors are usual statistical deviations.

* * *

IV. Discussion of the obtained Results

Assuming that CP is invariant, the polarization value P_- of μ^--meson in mesic atoms can be determined from the equation $\frac{a_0^-}{P_-} = \frac{a_0^+}{P_+}$ where a_0^- and a_0^+ are asymmetry coefficients, accordingly for μ^- and μ^+ - mesons, and P_+ polarization degree of μ^+ - mesons before their decay. Let us consider that μ^+ - meson beams, obtained from the internal targets of the synchrocyclotrons have approximately the same polarization degree independently of the energy of the accelerated protons [10]. If we assume that the μ^- - meson beam, used by us, has the same polarization degree as the μ^+ - meson beams, the polarization value P_- can be obtained from an inequation $3a_0^- \leq P_- \leq 4a_0^-$ given in the work [11], where asymmetry coefficient value for all integral spectrum, that is with X = 0. The limits of the P value, obtained in such way, are plotted in the third column of Table I. Only errors in the value a_0 were taken into account in the calculation. As is seen from Table I polarization in mesic atoms of magnezium, zink, cadmium and lead makes up (19 $\pm$ 7)%, and for these carbon, oxigen and sulfur - (14 $\pm$ 4)%. If one compares the maximum polarization, observed for μ^- - mesons and μ^+ - mesons it may be said that sharper depolarization for μ^- - mesons takes place. The strong depolarization can be explained by spin-orbital interaction in process of mesic atom production. Depolarization is partially connected also with the interaction of the magnetic field of the electron shell on μ^- - meson for its life time on K-orbit.

The question arises: is it not possible to reproduce by any way μ^- - meson polarization in mesic atoms? As to avoiding the depolarization due to the spin-orbital interaction it is quite evident that it simply cannot be done. As for depolarization due to the effect of the electron shell it would be probably possible to avoid it. Placing the target in the longitudinal magnetic field ~ 10000 ersted it seems to be possible to observe the polarization effect of "partial reproduction", because of the coupling between electron shell and μ^- - meson would be broken.

In conclusion the authors thank Prof. B. Pontecorvo for his fruitfull remarks.

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Signatures to the figures

Fig. I. Scheme of the experiment.

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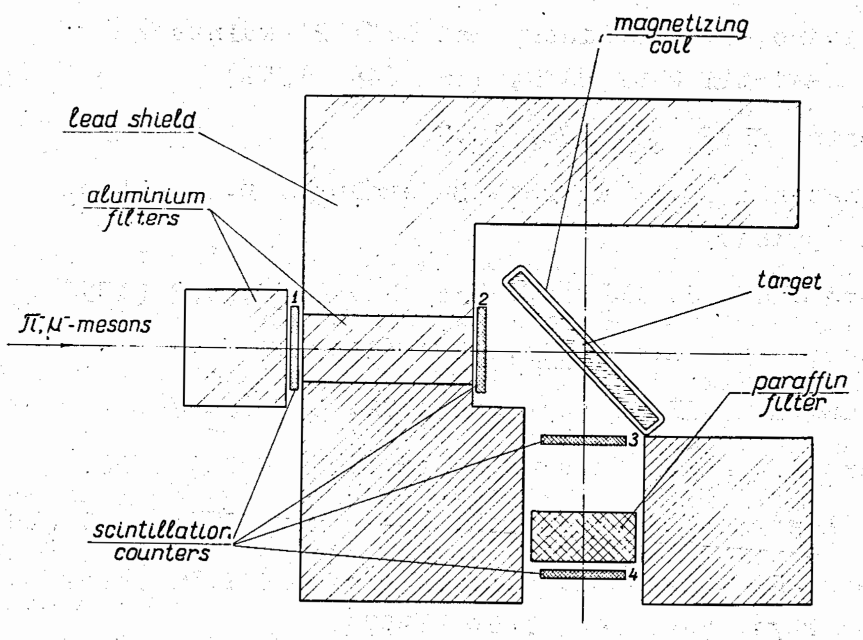
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fig. 1.