J O I N T I N S T I T U T E F O R N U C L E A R R E S E A R C H

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ЖЭТФ, 1958, т 35, в 4, с 894-898.

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Summary

Angular distribution of electrons from μ^- meson decay in liquid hydrogen measured by a scintillation counter method was found to be isotropic within the experimental errors. Polarization of μ^- - meson in mesic hydrogen determined from the results of an electron angular distribution was found to be equal $(2,9 \pm 2,9)\%$. The total depolarization of μ^- - meson observed is mainly connected with a suggested by Ya.B. Zeldovich and S.S. Gershtein mechanizm of jumping of a muon from one proton to another with simultaneous transition into the lower state of the hyperfine structure. Due to this mechanizm the transformation of orthohydrogen and parahydrogen molecules into each other is possible.

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I. Introduction

Investigation the capture of polarized μ^- - mesons in hydrogen makes it possible to obtain data on the type of weak interaction of μ - mesons with nucleons |1,2,3|. It is usually considered that the process of μ^- - meson absorption by protons in mesic hydrogen goes on through the reaction $\mu^- + p \rightarrow n + \nu$. Investigation of the angular distribution of neutrons from this reaction is one of the way for determining the type of interaction. Angular distribution of neutrons is described by the formula:

$$W(\theta) = 1 + a\beta \cos\theta \qquad \text{(I)}$$

where β is the coefficient of asymmetry in the angular distribution of neutrons, the value and sign of which depend upon the type of interaction, θ is the angle between the direction of neutron path and μ^- - meson spin, a is the coefficient depending on polarization of μ^- - meson in mesic hydrogen.

From (I) follows that the experiment on investigation of the angular distribution of neutrons must be preceeded by measuring the polarization of μ^- - mesons in mesic hydrogen. The present paper deals with experimental investigation of μ^- - meson polarization in liquid hydrogen, carried out at the Joint Institute for Nuclear Research synchrocyclotron.

II. Main Theoretical Conceptions

We shall consider the probable mechanizms for depolarization of μ^- - mesons while slowing down or coming to rest in liquid hydrogen.

In [4,5] was shown that when μ - mesons slow down in the matter until the velocities comparable with those of electrons in atoms, they are not depolarized. Depolarization does not apparently occur if μ^- - mesons keep on slowing down until the zero velocity that it until they are capture on mesic atom orbits. Further, in producing a mesic atom there is a possibility of depolarization due to spin-orbital interaction, which is not however completed [6]. Mesoproton has two states of hyperfine structure: the main one is a singlet (F = 0) and the first - is the excited tryplet (F = 1). In case F = 0 a meson "forgets" about original direction of its spin (it is depolarized). In a state F = 1 a meson "remembers" the direction of its spin (it is not depolarized). It is not difficult to see that for isolated mesic atom there is no μ^- - meson transition from one level of hyperfine structure into another during its lifetime. Indeed, because of the fact that the excited state is 0.2 ev higher than the ground one the probability of radiative transition turns out to be many orders of magnitude lower ($\tau_{rad} \sim 10^{6}$ sec) than that of μ - meson decay ($\tau \sim 10^{-6}$ sec)[7]. We shall consider now what is going on with mesic proton when it is produced in liquid hydrogen. If mesic hydrogen is produced when μ^- - mesons stop in liquid hydrogen, the following processes are possible: 1) Capture of μ^- - meson by a deuteron presenting in liquid hydrogen as a contamination:

$$\mu H + D \rightarrow \mu^- D + H + 135 \text{ eV},$$

2) scattering $\mu^- H + H \rightarrow \mu^- H + H$, $\mu^- D + H \rightarrow \mu^- D + H$,

3) production of mesic-molecular ions: $\mu^- H + H \rightarrow \mu^- HH$, $\mu^- H + D \rightarrow \mu^- HD$, $\mu^- D + H \rightarrow \mu^- DH$.

Theoretical consideration of probabilities for such processes was given in[7-11]. One of the interesting results of these works was that the cross-section for process (2) is two orders higher than that of the rest processes. Zeldovich and Gershtein[7] showed that in the process of scattering due to the neutrality of mesic proton there exists an effective mechanizm of "jumping" of μ^- - meson from one proton to another with simultaneous transition into a lower state of hyperfine structure. Due to the fact that the probability of this "jumpings" ($\sim 10^{9}$ sec^{-1}) is three orders higher than that of μ^- - meson decay into ($W_{dec} = 0.5 \times 10^{6}$ sec^{-1}), mesic protons will transit into the ground state of hyperfine structure during the lifetime of μ^- - mesons. The total depolarization of μ^- - mesons is the result of such transitions.

III. Experiment

Polarization of μ^- - mesons stopped in liquid hydrogen was investigated by measuring the anizotropy in angular distribution of decay electrons [6].

The beam of negative π^- - mesons with the energy ~ 150 MeV and intensity of ~900 π /cm^2 sec was directed into the experimental arrangement (fig.1). For slowing down μ^- - mesons and "purification" of the beam of π^- - mesons aluminium filters 32 cm thick were used. A part of μ^- - mesons having passed through the filters stopped in the target of liquid hydrogen. A glass Dewar flask 30 cm high and 15 cm in inside diameter was used as a target. The flask was wound with a copper wire to induce a magnet field necessary for μ - meson precession. In order to detect μ^- - mesons incident on the target two scintillation counters 1 and 2 in coincidence were used. Electrons from μ^- - meson decayed in the target were registered by scintillation counters 3 and 4 connected also in coincidence. Resolution time of the coincidence circuit was equal to 5.10^{-8} sec. As scintillators a plastic was used (2% of p-terfenil in polystyrol + 0.1 LNPO). Scintillators were 100 mm in diameter and 6 mm thick. Paraphine filter 6 g/cm^2 thick was placed between counters

3 and 4.

To electronic operated in the following way: an impulse from the coincidence circuit 1 + 2, delayed 0.5 μ sec., opened the gating circuit ("gate") for 1.5 μ sec. Impulses from the coincidence circuit 3 + 4 passed through "the gate" and were fed into the scalar and registered by a mechanical numerator. As a monitor the coincidence circuit 1 + 2 were used. Thus, the system registered electrons with a range of more than 8 g/cm^2, which are produced in the time region 0.5 to 2 μ sec after μ^- - mesons stopped in hydrogen. Angulaŕ distribution of electrons was investigated by measuring the number of electrons as a function of magnetizing current in a coil. The region of alteration of the magnetic field strength in which the target was placed corresponded to that calculated for the mesic proton precession in a triplet state. In this state mesic proton has a magnetic moment equal approximately to that of μ - meson and angular moment $F = 1/2 + 1/2 = 1$. It is not difficult to show that the precession frequency of mesic protons in the field H will be half the frequency of precession of free μ - mesons. To reduce the background the counters and a target were surrounded by a lead shield 20 cm thick. Usually in experiments the counting rate of electrons was about 20 per min. The background was 4 counts per min and did not depend upon field H. Such a "low" background was reached because a Duwar-target, shield and magnetizing coil used, were made of a material with relatively large Z, the probability of μ^- - meson decay in which is small. In experiment there was not found the dependence of electron counting rate as a function of the current of magnetizing coil. The value of asymmetry coefficient a in angular distribution of decay electrons $I(\theta) = 1 + a\cos\theta$ was found to be $a = -0.01 \pm 0.01$. In a value corrections were introduced taking in account the delay time, "gate" width, μ^- - meson decay and a solid angle of electron detector. The indicated error is a standard statistical deviation.

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IV. Interpretation of the Results

As is seen from value a angular distribution of electrons turned out to be isotropic within the experimental errors.

From the results of measurements of a it is possible to determine polarization P of μ^- - mesons in mesic hydrogen using the energy dependence of electrons asymmetry in $\mu^{\pm} - e^{\pm}$ decay |12|. We shall consider that μ^+ - meson beams obtained from the inner targets of synchrocyclotron have nearly the same polarization independently of proton beam energy |12|. Assuming that the μ^- - meson beam used has the same polarization as μ^+ - meson beams it is possible to determine P from $3a_0 \leq P \leq 4a_0$ obtained in |13|. Here a_0 is the asymmetry coefficient for the all integral spectrum. From the inequality follows that P = (2,9 ± 2,9)%.

As iwas shown in §1 depolarization of mesons due to fine and hyperfine interaction in the process of mesic proton production is not completed. Depolarization of mesons in the process of mesic proton scattering in the magnetic fields of atoms will be negligible due to a small number of collisions necessary for μ^- - meson to jump into the lower state of hyperfine structure |14,15|. Thus, apparently the total depolarization observed is mainly connected with the suggested by Ya.B. Zeldovich and S.S.Gershtein mechanizm of jumping of μ^- - meson from one proton to another with simultaneous transition into a lower state of hyperfine structure. This result is of fundamental importance. It shows that determination of the type of μ - meson-nucleon interaction by measuring angular distribution of neutrons from the reaction $\mu^- + p \to n + \nu$ in liquid hydrogen is not possible due to the total depolarization of mesons.

A question arises: isn't it possible to avoid depolarization of μ^- - mesons ? As for the elimination of depolarization due to the fine and hyperfine interaction, it is clear that it can't be done. It would seem however, that in order to avoid the depolarization due to the mechanizm of "jumping" one can use hydrogen gas where the number of collisions of mesic protons with hydrogen atoms and, thus, the number of "jumping" will be lower. However, it is not reasonable to reduce polarization in this way becuse the probability of the above transitions is so high that "jumping" goes on immediately after first collisions [7,14].

It should be noted [14], that to avoid depolarization of μ^- - mesons due to the mechanizm of "jumping" as well as due to the hyperfine interaction is possible only if one succeeds in polarizing completely the medium (hydrogen) in the direction of polarization of μ^--meson beam.

We considered above the problem of what is going on with mesic protons when colliding with hydrogen atoms. We shall consider now what will happen to molecules of hydrogen in collisions with mesic protons. As is known hydrogen consists of 75 per cent of ortho hydrogen molecules with parallel nuclear spins and 25 per cent of parahydrogen molecules with antiparallel spins. Since the spontaneous transitions between ortho and paramolecules are not possible, the ratio 3:1 is conserved in liquid hydrogen also; only in presence of certain catalysts (e.g. activized carbon) there is a certain possibility of transformation of ortho-molecules into paramolecules. It is not so difficult to see that in presence of mesic protons due to mechanizm of "jumping" transformation of ortho and para molecules into each other is possible. Therefore if hydrogen is radiated by μ^-- meson beam of a sufficient intensity, the ratio 3:1 changes for 1:1.

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C o n c l u s i o n s

1) Angular distribution of electrons from the decay of μ^- - mesons stopped in liquid hydrogen was measured by means of scintillation counter technique and was found to be isotropic within the experimental errors.

2) From the results of measurements of angular distribution of the decay electrons polarization of μ^- - mesons in mesic hydrogen was found to be (2.9 ± 2.9)%.

3) The total depolarization of μ^- - mesons is apparently connected with suggested by Ya.B. Zeldovich and S.S. Gershtein mechanizm of "jumping", of μ^- - meson from one proton to another with simultaneous transition into the lower state of hyperfine structure.

4) Determination of the type of interaction of μ - mesons with nucleons by measuring the angular distribution of neutrons from the reaction $\mu^- + p \to n + \nu$ in liquid hydrogen is not possible due to the total depolarization of μ^- - mesons.

In conclusion the authors wish to thank Ya.B. Zeldovich and S.S. Gershtein for prepublication copy of their paper and discussion of the results obtained.

The authors are grateful also to B. Belyaev and B. Zaharjev for numerous discussions and constant interest to the work.

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Signatures to the figures

Fig. 1 - The scheme of experiment.

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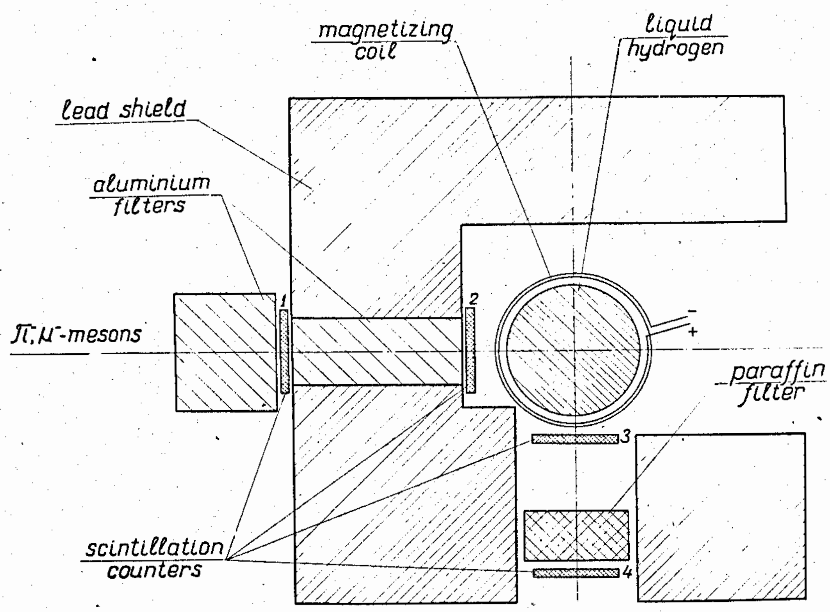
magnetizing coil
liquid hydrogen
lead shield
aluminium filters
π, μ⁻-mesons
1
2
3
4
paraffin filter
scintillation counters

fig. 1.