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ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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Summary

On the basis of the electron asymmetry measurements of (mu-e)-decay the nature of paramagnetism of various mesic atoms has been studied. The results of experiments show that in dielectrics, diamagntic and weak-paramagnetic normal metals paramagnetism of mesic atoms is caused by the magnetic moment of the muon and in paramagnetic transition metals, lantanides and actinides it is caused by the magnetic moment of the electron shell and that of the meson. The possibility has been proved of using polarized mesons as a means of investigating magnetic properties of hydrides of transition metals, actinides and lantanides the atoms of which have zero spin states.

I. Introduction

Studies of fine and hyperfine structure in atomic systems and concerned with them quantum electrodynamic effects are of great interest. A considerable number of investigations is devoted to the study of phenomena in usual atoms and positronium. The investigation of them in such atomic systems as muonium and mumesic atoms is also of importance. Studies are possible due to the fact that muon beams obtained at accelerators are polarized. Unfortunately, at available beam intensities the investigation of muonium and mesic atoms is possible only if they are produced in condensed material. As is known, the presence of medium might complicate the phenomenon. In /1/ the results of investigation in mumesic atoms of hyperfine structure caused by spin coupling of the meson and the nucleus have been reported. In the present paper the general attention is paid to hyperfine structure caused by the coupling of the meson and the electron. As is known, attempts to observe directly this phenomenon in the production of muonium in condensed material have provided a negative result /2/. Attempts to find this phenomenon in mesic atoms with $Z \leq 6$ /2/ were also not successful. Naturally, a question arises on the existence of this phenomenon in mu-mesic atoms with $Z \geq 6$. The use of mesic atoms with $Z \geq 6$ has an essential advantage. Indeed, on the basis of the data on the properties of ion magnetic moments of paramagnetic matters it is possible to find such mesic atoms and matters in which the influence of medium is negligible and, hence there is a possibility of studying heperfine structure in a 'pure' form. There are many reasons which cause practical interest to this phenomenon. Further we shall give some of them.

a) Polarized negative muons are essentially depolarized in matter due to interactions causing fine and hyperfine structure in mesic atoms /1/. A question arises: might meson polarization be either eliminated or restored in mesic atoms ? It is evident that depolarization caused by spin coupling of the meson and the nucleus can be avoided by using matters with zero nuclear spin. It seems that in order to avoid depolarizatinn due to fine and hyperfine structure caused by the spin coupling of the meson and the electron shell, the magnetic field of considerable value might be used. However, the elimination of depolarization by means of magnetic neutralization is concerned with insuperable experimental difficulties. It is also impossible to avoid kinematic depolarization in (π - μ)-decay in flight. The circumstance that the time of depolarization ($\sim 10^{-12}$ sec) is several orders less than the meson lifetime τ, suggests an idea of restoring meson polarization in mesic atoms with zero nuclear spin states by making use of static methods of nuclear polarization. Two methods consisting in applying magnetic fields to a pattern at sufficiently low temperatures are interesting from the point of view of our experiment. The first method is based on the effect of the external magnetic field on the magnetic nuclear moment, the second method is based on the effect of the internal magnetic atoms field caused by uncompensated moments of electrons. The expression for the coefficient of nuclear polarization by the direct effect of the external field has the following form[3]

$$f \approx \frac{1}{3} \frac{I+1}{I} \frac{\mu_N \cdot H}{KT} \qquad (1)$$

where I is nuclear spin, μ_N is the nuclear magnetic moment, K is the Boltzman constant, H is the applied magnetic field and T is the absolute temperature.

If the internal atom magnetic field is used, nuclear polarization is determined by the expressions[3]:

$$f = \frac{1}{3} f_e \frac{I+1}{I} \cdot \frac{J_e}{2J_e+1} \cdot \frac{\Delta W}{KT}, \quad J_e \geq 1 \qquad (2a)$$

$$f \approx \frac{1}{3} f_e \frac{I+1}{2I+1} \cdot \frac{\Delta W}{KT}, \quad J_e \leq 1 \qquad (2b)$$

Here f_e is electron polarization, J_e is their angular momentum, ΔW is the energy of hyperfine spliting.

From expressions (1) and (2) it follows that the greater the values $\mu_N, \Delta W$ and the smaller the value I, the easier it is to obtain the polarization.

If to take into account that muons have spin ½ and the magnetic moment an order higher than the nuclear magneton, the given polarization of mesons in mesic atoms can be obtained by using either temperatures an order higher or smaller magnetic fields than it is in the case with nuclei. It can turn out that already at temperature of liquid helium one can obtain the available effect of restoring meson polarization. Everything depends on the values of J_e and ΔW in mesic atoms. Thus, in order to find out what method of polarization should be used in a given case it is necessary to investigate the nature of mesic atom paramagnetism in various media. The question is what happens to the electron shell of initial atoms in production of mesic atoms and how paramagnetism of isolated mesic atoms changes in medium.

It should be noted that the employment of the external field method can meet with insuperable difficulties due to a long time of relaxation of meson spin comparing to τ. These difficulties arise no longer when internal atoms fields are used. Indeed, electron moments of the pattern atoms can be polarized before meson irradiation. Then the time of the meson spin overturn in the field of the mesic atom shell is determined/1/ 'by the time of interaction' $t' \sim \frac{\hbar}{\Delta W} \sim 10^{-10}$ sec which is several orders less than τ.

b) As is known, at present one of the most effective methods of studying electron configuration of paramagnetic atoms is the investigation of the asymmetry of polarized nuclei irradiation. Evidently, only elements having nuclear spin which is not equal to zero can be treated by this method. The studies of electron asymmetry from polarized muon decay in mesic atoms provides a possibility of investigating the electron structure of atoms of paramagnetic matters having zero spin states.

c) Measurement of gyromagnetic ratio of mesic atoms having only spin electron paramagnetism caused by an uncoupled electron and nuclear spin equal to zero gives a possibility of direct determination of negative muon spin.

d) It is necessary to investigate mesic atom paramagnetism in order to find out the process of negative muon depolarization.

II. Main Theoretical Preconditions

The production of mesic atoms is concerned with the destroy of the electron shell state of the initial atom. The problem is that in cascade meson transitions excitation and ionization of atoms are possible. After the production of mesic atoms the electrons of the shell turn out to be in the nuclear field with the new effective charge $Z-1$. The lifetime t_0 of the shell excited state for free mesic atoms depends on the electron configuration and the degree of excitation. When mesic atoms are produced in medium, the time t_0 greatly depends on the nature of medium atom coupling. If a mesic atom is in metal, the electron shell returns to its ground state in a very short time (less than 10^{-12} sec) comparing to t' and τ. On the other hand in ion crystals and dielectrics the time $t_0 > t'$ and τ. Consequently, at the moment of mesic atom decay the state of the electron shell depends upon the kind of combination which the investigated atom joins, and also upon the aggregate state of the matter.

It should be noted that if the atom is a part of the molecula, the reorganization of the electron shell and the emission of x-rays in mesic atom should lead to the destroy of chemical bindings and to the ejection of a mesic atom in the form of a free atom. One can believe that in view of the so-called phenomena of electron and kinetic activation of mesic atoms their paramagnetic moment is directly concerned with the values of the quantum numbers $\mathcal{J}$, $\mathcal{L}$ and S of the atom. If an isolated mesic atom with zero nuclear spin has the moment of the electron shell, its paramagnetic moment will consist of three parts:

1) muon magnetic moment

$$\mu_\mu = \frac{\sqrt{3}\,\mu_B}{207} \qquad (3)$$

2) electron orbital magnetic moment

$$\mu_L = \mu_B \sqrt{L(L+1)} \qquad (4)$$

3) electron spin magnetic moment

$$\mu_S = 2\mu_B \sqrt{S(S+1)} \qquad (5)$$

In the production of mesic atoms in medium their paramagnetism will be affected by neighbouring atoms and the compensation of one or another moment will be a consequence of it. Everything depends on the fact, electrons of what shells create the magnetic moment. By analogy with the properties of the ion magnetic moments of paramagnetic matters one can expect that if mesic atoms are formed of lantanide or actinide atoms where the magnetic moment is caused by electrons deeply set in atoms and least of all affected by external influence, paramagnetism of such mesic atoms in medium will be caused by the moments μ_L , μ_S and μ_μ . In the case with atoms of transition elements where the magnetic moment of atoms is caused by electrons which are located not deeply and which are more affected by external influence mesic atoms in medium will have only spin moments μ_S and μ_μ (orbital moments of such atoms are, as a rule, compensated). And at last, mesic atoms of diamagnetic matters or of weak-paramagnetic normal metals can have in medium only the moments μ_μ.

The electron shell can influence the polarization of negative muons only in the ground state of mesic atoms. It can be easily proved if one compares the time t of the meson state at lower levels with the time t′ of reorientation of meson spin in the field of the shell. It turns out that the inequality $t' \ll t$, as it was stated in section I, is fulfilled only up to the state IS.

It should be noted that in matters with $J_e \neq 0$, mesic atoms will be formed in two states of hyperfine structure with $F = J_e \pm 1/2$. In the first approximation the energy of interaction ΔW of hyperfine structure in mesic atoms will be of the same order as in muonium

$$\Delta W = -\frac{32\,\mu_\mu \cdot P_{eff}}{3 a_{e\mu}^3} .$$

Here μ_μ is the magnetic moment of a muon, P_{eff} is the effective magnetic moment of the electron shell, $a_{e\mu}$ is the Bohr radius of a hydrogen nucleus. Hyperfine disintegration in the ground state of a mesic atom is considerably greater than $\frac{\hbar}{\tau}$. Therefore, the states with $F = J_e + 1/2$ and $F = J_e - 1/2$ for an isolated mesic atom form incoherent mixture. Each state is characterized by its values of the magnitudes of the gyromagnetic ratio g and the magnetic moment μ. Thus expressions for g and μ have the following form[4]:

$$g_+ = \frac{1}{J_e + \frac{1}{2}} \left(\mu_\mu + P_{eff} \right) \tag{6}$$

$$g_- = -\frac{1}{J_e + \frac{1}{2}} \left(\mu_\mu - \frac{J_e + 1}{J_e} P_{eff} \right) \tag{7}$$

$$\mu_+ = \mu_\mu + P_{eff} \tag{8}$$

$$\mu_- = -\frac{2J_e - 1}{2J_e + 1} \left(\mu_\mu - \frac{J_e + 1}{J_e} P_{eff} \right) \tag{9}$$

If one uses a method[5] of measuring the asummetry of the decay electrons in order to study mesic atom paramagnetism, one obtains the precession curve observed experimentally which is the superposition of precession curves of mesons disintegrating from both the states of hyperfine structure. Evidently, the greater the value J_e, the more difficult it is to treat such a curve. Indeed, let us denote the degree of the muon beam polarization by P_0. According to[4,6–8] the degree of the polarization P of a meson at K-shell averaged by two states of hyperfine structure is

$$P = \frac{1}{6} P_0 \cdot \frac{1}{3} \left[1 + \frac{2}{(2J_e + 1)^2} \right]. \tag{10}$$

From this formula it follows that the value of polarization depends on the total moment of the electron shell J_e. Thus, e.g., for $J_e = 1/2$ the polarization will decrease twice; for mesic atoms with $J_e \gg 1$ it will decrease three times. Evidently, all the abovesaid concerns the case with isolated mesic atoms. The presence of medium can complicate the phenomenon, e.g., it can lead to the appearence of meson transition between the levels of hyperfine structure.

III. Experimental

When choosing matters for investigation it is necessary to take into consideration that matters consisting of atoms of the same sort or hydrogenious matters are of practical interest. The case is that the utilization of matters consisting of atoms of various sorts leads to additional difficulties in the interpretation of experiments due to the lack of knowledge on mesic atom production in various combinations. One can expect that in hydrogenious matters hydrogen does not play any important role in mesic atom production.

As objects for investigation the following matters have been chosen:

1) dielectrics (paraffin, polythene, water and sulfur)

2) diamagnetic and weak-paramagnetic normal metals (graphite, magnesium, zinc, cadmium and lead) and

3) paramagnetic transition metals (chromium, molybdenum, palladium and tungsten).

The results of investigations with H_2O, Mg, S, Zn, Cd and Pb have been already published/12/. In the present paper investigations have been performed for the rest of matters. Chromium, molybdenum, tungsten and palladium have been taken in the form of metals. As media containing carbon nuclei, graphite, polythene and paraffin have been used. They have been chosen on the following basis: as is known, up to now the problem of the helicity of negative muons remains undecided/9/. One of the methods suggested in/10/ in order to settle the question is the investigation of the asymmetry of decay electrons in B^{12} of the reaction $\mu^- + C^{12} \rightarrow B^{12} + \nu$. In the performed experiments/9/ the absence of asymmetry has been found. The reason of it is, evidently, in the depolarization of B^{12} in the employed patterns (hexan, pentan). According to/10/ the depolarization of B^{12} is possible owing to two reasons:

1) due to hyperfine structure caused by the spin coupling of the nucleus and the electron shell of B^{12}, and

2) due to the short period of relaxation of B^{12} nuclear spin in the employed matters in comparison with the lifetime of B^{12}. In order to find out the question on the presence of B^{12} nuclear depolarization mechanism due to hyperfien structure we have taken patterns containing carbon in various combinations. One may expect that carbon mesic atoms will have the electron configuation of the Bohr atom/10/ in such media.

Mesic atom paramagnetism of carbon, chromium, molybdenum, tungsten and palladium in media under study have been investigated by a precession method/5/. Making use of such a method, one can consider the nature of paramagnetism on the basis of measurements of asymmetry of electrons in (mu-e)-decay in the following two ways. In the first method the electronic system is switched to register the frequencies of spin precession of a free meson. As it follows from formulae (6) and (7) in the given magnetic field H the frequency of spin precession of mesic atoms having the electron moment and the meson moment, is several orders higher than the frequency of spin precession of mesic atoms paramagnetism of which is caused by meson spin. Owing to a great difference in frequencies one can consider the nature of paramagnetism basing on the measurements of the number of electrons in (mu-e)-decay N_{max} and N_{min} with two values of the intensity of the field $\pm H$ corresponding to those calculated by the formula

$$t_1 + \Delta t = \frac{T}{2} = \frac{\pi mc}{eH} \qquad (11)$$

where t_1 is the delay time, Δt is 'the gate' width and T is the precession period of a 'free' muon. Indeed, for mesic atoms having the electron moment, the value of the ratio $\xi = \frac{N_{max}}{N_{min}}$ is equal to a unit; mesic atoms paramagnetism of which is caused by meson spin have the value ξ differing from a unit. With such a method of investigation the measurement of the values ξ in hydrides of paramagnetic metals with such a concentration of hydrogen with which paramagnetism of the combination vanishes to zero, as e.g., with $PdH_{0.6}$ might serve as a test experiment directly confirming the existence of electron paramagnetism. Indeed, palladium atoms being in $PdH_{0.6}$ solution, have no magnetic moment. As for hydrogen it will not take part in the process of mesic atom production.

The second way of studying the nature of paramagnetism is the measurement of asymmetry of electrons in (mu-e)-decay in the case when the electronic system is switched to register the precession frequency of mesic atom spin calculated from formulae (6) and (7). However, such an experimental procedure is more complicated. Indeed, in this case the difference from a unit of the value ξ observed experimentally when mesic atoms have the electron moment, as it is seen from formula (10), will be considerably less. Besides, the existence of two states of hyperfine structure and also the presence of meson transition between them (e.g., from $F = 1$ and $F = 0$) will complicate the interpretation of the experiments. The present paper describes the investigation of paramagnetism performed by the first method.

In our experiment the same experimental arrangement has been used as in /11-12/. The conditions of experiments remained the same except the electronic technique. Fig. 1 presents the block-scheme of the apparatus. Negative muons stopped in target 6 were registered with scheme 8 of anticoincidences 1 + 2 − 3. Pulses from scheme 8 amplified in 10 and formed in 12 were delayed by the time t_1. The delayed impulses started trigger 16 which opened simultaneously two identical gating circuits ('gates') 18 and 21 for the time Δt. Electrons from the muon decay and also the background of foreign radiation were fixed by scheme 9 of anticoincidences 3 + 4 − 2. Pulses from scheme 9 amplified in II and formed in 13 divided into two and then moved to the inlet of gating circuit 18 with the delay time $t_2 > t_1 + \Delta t$ and then to the outlet of gating circuit 21 without any delay. Owing to two identical gating curcuits and the delay time t_2 used in our experiment we could register simultaneously the number of pulses from the decay electrons and the background of foreign radiation by scaler 23 and the number of background pulses only by scaler 20. The difference in the number of counts in scalers 23 and 20 is the number of decay electrons. Pulses from trigger 16 were directed through a separate outlet to scaler 17 which registered the number of openings of the gating circuit. Its readings served as a monitor.

The value of the ratio $\frac{t_1}{\Delta t}$ in each experiment was equal approximately to 0.2. The angle at which the electron detector axis and the target were placed relatively to the 'axis' of the meson beam was equal to 90° and 45°, respectively. The targets had the dimensions 15 x 15 cm; the thickness of the targets was equal to $4 \div 6$ gr/cm^2. In the experiments with graphite, polythene and paraffin the thickness of paraffin filter 7 between counters 3 and 4 was equal to 4 gr/cm^2. In the experiment with chromium, molybdenum, tungsten and palladium the alluminium filter 4 gr/cm^2 thick was used instead of paraffin filter 7. Since we made use of an alluminium filter, the value of the registration efficiency of γ-rays with an energy less than 10 MeV emitted from the target as a result of negative muon /13/ absorption was achieved to be less than 10^{-3}.

The obtained values of $\xi = \frac{N_{max}}{N_{min}}$ are enlisted in the second column of the Table.

T a b l e.

M a t t e r	$\xi = \frac{N_{max}}{N_{min}}$	
Graphite	1.10	0.02
Paraffin	1.09	0.02
Polythene	1.10	0.02
Palladium hydride ($PdH_{0.6}$)	1.09	0.02
Palladium	1.00	0.02
Chromium	1.00	0.02
Molybdenum	0.99	0.02
Tungsten	0.99	0.02

The above values of ξ include corrections which take into account the delay time, the width of the gating circuit, the meson decay and the solid angle of the electron detector. The indicated errors are standard statistical deviations.

4. Discussion of the Results

As it follows from the Table, the value of ξ for graphite, polythene, paraffin and palladium hydride $PdH_{0.6}$ were obtained similar within statistical errors. The values of ξ for chromium, molybdenum, tungsten and palladium turned out to be equal to each other as well. However, the absolute values of ξ for graphite, polythene, paraffin and $PdH_{0.6}$ differ from the values of ξ for chromium, molybdenum, tungsten and palladium. It is necessary to note that in the angular distribution $1+a\cos\Theta$ integrated over electron energy the value of the asymmetry coefficient a_0 obtained from the value ξ coincides within experimental errors with the value a_0 obtained in/1,11,12/ on the basis of the measurements of a large number of points at the precession curve. The difference from a unit of the values ξ for graphite, paraffin and polythene and also their equality to each other show that paramagnetism of carbon mesic atoms in such media is caused by the meson magnetic moment. Indeed, let us consider first the case when mesic atoms are produced in metals. Metals including also graphite can be considered in the first approximation as a complex of ions submerged into the electron gas. If a metal belongs to the group of diamagnetic metals or to the group of weak-paramagnetic normal metals its ions have no magnetic moment. Thus, it is probable that in the production of mesic atoms in such metals due to the fact that $t_0 \ll t'$ the electron ion state is not destroyed in the end and the ionization of atoms is followed only by the emission of collectivized electrons of conductivity. If one takes into consideration the constancy of the values a_0 measured in/12/ for metals of this group as, e.g., Mg, Zn, Cd and Pb and also their equality to the value a_0 for graphite, one can say that in the production of mesic atoms in diamagnetic or weak-paramagnetic normal metals, electron paramagnetism does not arise. But there is another situation when mesic atoms are produced in dielectrics where $t_0 \gg t'$. Carbon mesic atoms in paraffin and polythene, and oxygen mesic atoms in water, sulfur/12/ have no electron moment due to two reasons. Firstly, it can occur in the case if mesic atoms are negative ions having the electron configuration of initial atoms. Secondly, it is possible that mesic atom production is concerned with the destroy of the electron shell of initial atoms. Then according to/6/ there will be no electron shell if its total compensation under the influence of neighbouring atoms takes place. Only further investigations can answer the question: which of two suggestions is correct? The results of these experiments provide a possibility of finding out the existence of the depolarization mechanism of B^{12} owing to hyperfine structure caused by the spin coupling of the nucleus and the electron shell of B^{12} produced as a result of the reaction $\mu^- + C^{12} \to B^{12} + \nu$. Indeed, it might seem that carbon mesic atoms in graphite should have the electron configuration of B atoms/10/. However, experimental results show that there is no electron moment. Evidently, B produced in the reaction $\mu^- + C^{12} \to B^{12} + \nu$ in graphite cannot have electron paramagnetism. Consequently, the depolarization mechanism of B^{12} due to hyperfine structure in graphite should not take place. In the production of B in dielectrics this mechanism can take place owing to the abovementioned reasons.

If we compare the values of ξ for graphite, polythene and paraffin, we can get some informations on the probability of mesic atom production in various components of hydrogenious media. Indeed, being equal within experimental errors, the values of polarization for these matters and also the coincidence of spin precession frequency of mesic atoms with the spin precession frequency of a 'free' meson show that mesons in such media do not 'stay' at hydrogen. This circumstance can be explained in the following two ways. Firstly, muons can 'land' in general directly on carbon. This explanation does not contradict 'the law Z' of Fermi-Taylor. Secondly, it is possible that when mesons stop in such media, there is no proportionality between the probability of mesic atom production and the atomic number Z. Then the equality of the residual polarization of mesons in the abovesaid media can occur in the case if jumping of mesons from hydrogen to carbon takes place during a shorter period than the time of meson transition in mesic proton up to the orbits where depolarization takes place. Or in other words, in view of great concentration of carbon in such media, jumping takes place only from the levels of mesic protons having $n \geqslant 3$ /6,7/. Indeed, if, e.g., the probability of capture to mesic atom orbits were proportional to the concentration of atoms in medium and jumping occurred from the IS level of hydrogen, the value of the polarization degree should be

$$P_{CH_2} = \frac{1}{3} P_C + \frac{2}{3} P_H \cdot P_C \approx \frac{1}{3} P_C$$

where $P_H = \frac{1}{6} P_0 \cdot \frac{1}{3}\left[1+\frac{2}{(2I+1)^2}\right] \approx \frac{1}{12} P_0$ is the degree of meson polarization on K-orbit of mesic hydrogen, $P_C \approx \frac{1}{6} P_0$ is the polarization degree on K-orbit of carbon mesic atoms and P_0 is the degree of muon beam polarization. However, the results of experimental data show that mesons in hydrogenious matter 'land' on carbon in such a way that their polarization does not change. The results of experiments with palladium and $PdH_{0.6}$ directly show that paramagnetism of palladium mesic atoms is caused by the magnetic moments of the electron shell and of the meson. And, indeed, ions of the transition metal palladium have the magnetic moment caused by the electrons of internal magnetic active shells 4d. In the combination $PdH_{0.6}$, as it is shown by the results of the measurements of ξ for graphite, paraffin and polythene hydrogen does not influence on the process of meson depolarization.

It is necessary to stress specially that as it is shown by the results of experiments with Pb and $PdH_{0.6}$ there arises a possibility of using polarized negative muons as a means to investigate the magnetic properties of hydrides of transition metals, lantanides and actinides the atoms of which have zero nuclear spins. In the case with Cr, Mo and W a test experiment directly confirming the presence of electron paramagnetism cannot be carried out, unfortunately. The reason is that when hydrogen is dissolved in these metals no hydrides are formed.

The equality to a unit of the values ξ for these transition metals and also their coincidence with each other can be if

1) there is the total depolarization of mesons in such matters and

2) mesic atom paramagnetism is caused by the magnetic moments of the electron shell and the negative muon.

Now consider the problem on negative muon depolarization in various mesic atoms. The measurements /12/ of negative muon polarization degree in the mesic atoms of metals belonging to a group of diamagnetic metals with zero nuclear spin states show that in all the cases polarization remains the same within experimental errors and is ~17%. The degree of meson polarization for graphite, polythene and paraffin obtained from the measured values of ξ is also similar and by its absolute value is equal to the value of the above metals. The independence of the measured depolarization for $Z \geqslant 6$ upon Z, and also its absolute value are in good agreement with theoretical calculations/6,7/ which take into consideration only the mechanism of spin-orbital interaction. It is difficult to imagine that Cr and Mo might differ considerably from the above matters in connection with the process of depolarization of negative muons. In the process of stopping and the capture to the upper mesic atom levels mesons, as is shown in/14/, are not practically depolarized. As is known, the probability of mesic atom production is equal to a unit. The elements Cr and Mo consist within 80–90% of atoms having zero nuclear spin states. The nuclei of these atoms have no special properties which might induce total meson depolarization. Consequently, the existence of other depolarization mechanisms except spin-orbital interaction in mesic atoms with such Z is hardly probable. Cr and Mo differ from the abovesaid matters only by the fact that their atoms have unclosed internal electron shells. Hence, the results of experiments with Pd and $PdH_{0.6}$ with great probability show that in the case with Cr and Mo, ions of which have the magnetic moment differing from zero, caused by electrons of internal magnetic active shells 3d and 4d, respectively, we have hyperfine structure.

The results of experiments with tungsten are of special importance since unlike Pd, Cr and Mo tungsten has mesic atoms with nuclear distortion. As is shown in/15/ the interaction of mesons with quadrupole nuclear distortion can lead to considerable negative muon depolarization. Let us compare the measured values of $\xi_{meas.}$ with $\xi_{theort.}$ predicted theoretically. If the assumption on the connection of the abovesaid negative muon depolarization with quadrupole nuclear distortion is correct, then according to theoretical assumptions/15/ there should be the following ratio between the values of a_o for carbon and tungsten: $(a_o)_W \approx 0{,}4\,(a_o)_C$. Meanwhile the precession frequency of the magnetic field of tungsten mesic atom spin should coincide with the precession frequency of a 'free' meson spin. Making use of the normal law of error distribution one can show that the case $\xi_{theor} = \xi_{meas}$ is not acceptable since $\xi_{meas} < \xi_{theoret.}$ with a 70% probability. This circumstance shows that 'total' meson depolarization observed experimentally is difficult to explain only by the interaction of mesons with quadrupole nuclear distortion. With this aim it is necessary to have another explanation. The results of the experiments for Pd, Cr and Mo with great probability show that in the case with W we have also hyperfine structure caused by meson spin coupling and electrons of the internal unclosed shell 5d. Here we should say that despite the fact that the atoms of the metal tungsten have the magnetic moment which is not very effective, e.g., with respect to Cr, in these experiments it can be as a consequence of rather a high sensitivity of the investigation method. Really, muons have the magnetic moment which is an order higher than that of the nuclear magneton but the time of the meson spin reorientation in the field of mesic atom shell ($\sim 10^{-10}$ sec) is several orders less than its lifetime. Evidently, in order to make the abovesaid conclusions more definite it is necessary to observe directly the precession curves of mesic atom spins of Cr, Mo and W.

On the basis of the performed experiments described in the present paper and in/1,11,12/ one can make the following conclusions concerning the process of negative muon depolarization:

1) interaction of meson magnetic moments with the electron shell influences on meson polarization only in mesic atoms of transition elements, lantanides and actinides, and

2) the degree of negative muon polarization due to spinorbital interaction decreases 6 times. This results is in good agreement with the theoretical calculations made in/6,7/.

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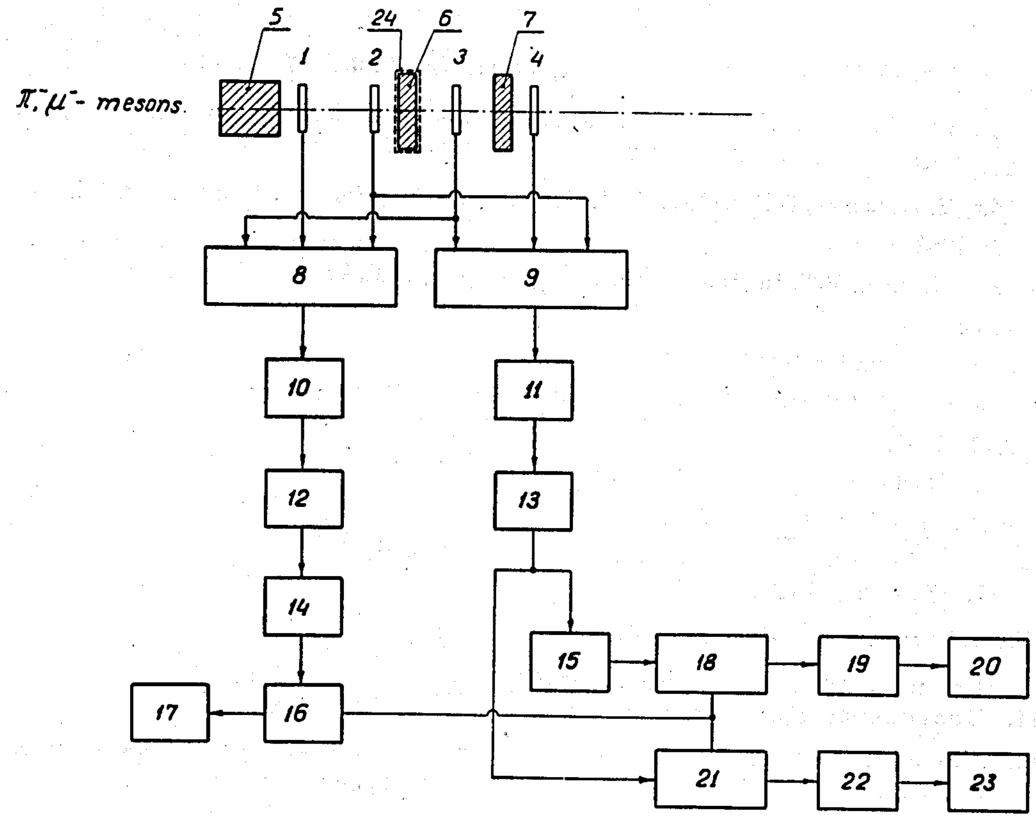

Fig.1. Block diagram of the experimental arrangement.

1,2,3,4 - scintillation counters, 5 - copper absorber, 6 - target, 7 - paraffin absorber, 8,9 - anticoincidence circuits, 10,11 - amplifiers, 12,13 - shaping circuits, 14 - delay line t_1, 15 - delay line t_2, 16 - trigger circuit, 18,21 - gate circuits, 19,22 - discriminators, 17,20,23 - scalers, 24 - magnetizing coil.