"SLOW" DEPOLARIZATION OF μ^+ MESONS IN SOME MATERIALS

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Submitted March 25, 1969

Zh. Eksp. Teor. Fiz. 57, 421–431 (August, 1969)

We have used a method of observing the time distribution of $\mu^+ \to e^+ + \nu + \bar{\nu}$ decays in transverse and longitudinal magnetic fields to obtain data which indicate the existence of microsecond depolarization mechanisms for μ^+ mesons in B_4C, LiF, and a number of other materials. We have investigated the effect of temperature and the aggregate state of the material on this phenomenon. It is shown that in a longitudinal magnetic field $H \leq 200$ G the microsecond depolarization is removed. The possibilities are discussed for delimitation of the causes of the fast and slow stages of depolarization, from the point of view of the muonium theory of depolarization of μ^+ mesons in matter.

1. INTRODUCTION

THE present article is a continuation of a series of experimental studies of the possible mechanisms for depolarization of μ^+ mesons in matter.[1-3] A number of theoretical papers[4-6] have discussed various processes leading to loss of the initial polarization of a μ^+-meson beam. The main cause of depolarization is apparently the formation of atoms of muonium (Mu, i.e., μ^+e^-) with successive transitions between the hyperfine structure levels J = 1, m = 0 and J = 0, m = 0. In vacuum the frequency of transitions is $\omega_0 = 2.804 \times 10^{10}$ sec^{-1}.[7] The effect of the surrounding medium on this process is reduced[5,6] to a possible change in the quantity ω_0, and also to the phenomenological introduction of a parameter ν —the frequency of relaxation of the electron spin in the muonium atom, occurring as the result of exchange interaction with the medium.

A competing process which removes this depolarization mechanism is the involvement of muonium in a chemical reaction with the material—formation of a diamagnetic compound.[5,8] Our previous paper[1] was devoted to the experimental verification of the relation arising in this case between the residual asymmetry coefficient of the μ-e decay c′ and the rate constant k_1 of the corresponding chemical reaction.[8] The assumption that the depolarization is cut short with formation of a stable diamagnetic compound has been confirmed experimentally for most materials studied. However, Swanson[9] showed for the first time that the μ^+-meson spin precession amplitude in boron carbide (B_4C) decreases with a relaxation time of $\sim$6.5 μsec, although the precession frequency coincides with the free-meson precession frequency (mesonic precession). This "slow" (microsecond) depolarization, in contrast to the "fast" ($< 10^{-8}$ sec) muonium depolarization, has not been discussed in detail up to the present time. Study of this phenomenon is necessary for a correct interpretation of the results of experiments in which the muonium method is used in different physical-chemical studies.[3,10,11] In the work being published we will present experimental data for a number of materials in which a decrease has been noted in the mesonic precession amplitude during an observation time of $\sim$6.5 μsec, and we will analyze some possible mechanisms for the slow depolarization of μ^+ mesons in matter.

2. EXPERIMENT

We have discussed in earlier papers[1,2] the experimental apparatus and electronic equipment for observation of the precession of μ^+-meson spins (or the system of muonium spins) in a transverse magnetic field.

The moment of stopping of a μ^+ meson in a target of the material being studied was recorded by scintillation counters (an event 1 + 2 – 3, where the numbers designate the number of the counter, and the minus sign corresponds to the anticoincidence channel) and served as the time origin. Emission of a decay positron (an event 3 + 4 – 2) during the next 6.5 μsec could be recorded in one of the channels of an AI-100 pulse-height analyzer corresponding to a given decay time. The time scale (from 5 to 74 nsec/channel) was determined by the operating conditions chosen for the time-to-pulse-height converter. In a transverse magnetic field the distribution of μ-e decay times is modulated as the result of rotation of the μ^+-meson spins. The modulation amplitude is proportional to the residual polarization, determined at the mesonic (or muonic) frequency. In view of the fact that counters 3 and 4 detect decay positrons emitted forward with respect to the initial μ^+-meson momentum direction, it is also possible to study depolarization processes in longitudinal magnetic fields. The decrease in polarization in the latter case will correspond to an increase of the relative fraction of decays recorded. The possibility of comparing the results obtained in transverse and longitudinal fields, under identical experimental conditions, provides a unique analysis of the information obtained in the longitudinal fields.

Magnetic fields of intensity up to 250 G were produced by two pairs of Helmholtz coils. The nonuniformity of the fields did not exceed 0.2–1% over the sample dimensions. In a number of experiments a longitudinal field coil was used with a nonuniformity of $\sim$5%. In these cases it was necessary in analysis of the results to take into account a 10% contribution of meson stoppings in the walls of the coil.

In determination of the depolarization rate occurring

during the entire observation time, appreciable systematic errors can arise because of the nonlinearity of the time analyzer scale and the possible dependence of the accidental coincidence background on time (the method of background measurement has been described in [1]). In the present experiments the differential nonlinearity of the analyzer time scale did not exceed 1%. In order to remove the inconstancy of the accidental coincidence background we used a "guard" system whose action amounts to blocking the analyzer input when a second 1+2 event appears (a particle hitting the target) in the 12 μsec interval before the zero time, or on occurrence of any second 1+2 or 3+4−2 event in a period 8 μsec after the zero time. For a standard μ^+-meson stopping rate in the target of 3000 sec^{-1}, these blocked events amounted to about 20–40% of the total number of counts. The accidental coincidence background values measured experimentally and obtained from analysis of the decay time distribution with a computer (for a minimum χ^2) agree within the accuracy of the statistical errors in determination of the background ($\pm(3-5)$, or $\pm(0.3-0.5)$% of the total number of decays recorded). The constancy of the analyzing equipment channel width was monitored, in addition to the calibration measurements, by the correspondence (within ±0.5%) of the calculated and experimentally measured precession periods.

3. ANALYSIS OF EXPERIMENTAL DATA

The experiments with transverse and longitudinal magnetic fields relative to the initial μ^+-meson spin direction, carried out with various materials at various temperatures, were alternated with control experiments on determination of the coefficient c′ of the μ-e decay asymmetry in a target of bromoform ($CHBr_3$). The values of polarization P listed subsequently are expressed as fractions of the corresponding value for $CHBr_3$ and are related to the measured values of asymmetry coefficients c′ (after introduction of small corrections for the lack of equivalence of the target in ionization loss [1,2]) by the relation $P = c'/c'(CHBr_3)$, where $c'(CHBr_3) = 0.286 \pm 0.004$ is the averaged experimental asymmetry coefficient for bromoform.

Analysis of the experimental data by computer was performed according to the equation

$$N_k' = N_0 e^{-k\sigma/\tau_\mu}[1 - c_0' e^{-\lambda k\sigma}\cos(\omega k\sigma + \delta)] + \Phi, \qquad (1)$$

where N_k' is the number of counts in the k-th channel, k is the channel number counting from the experimentally determined position of zero time, N_0 is the number of counts per channel, extrapolated to zero time, for hypothetically complete depolarization of the μ^+ mesons, τ_μ is the μ^+-meson lifetime, σ is the channel width, λ is the rate of slow depolarization (the reciprocal of the relaxation time), c_0' and δ are respectively the initial amplitude and phase, ω is the precession frequency, and Φ is the accidental coincidence background. For the subsequent discussion it is convenient to convert the experimentally measured number distribution N_k' to a number distribution N_k by subtracting the background and multiplying by the exponential factor corresponding to the k-th channel, which takes into account meson decay. Assigning the designations ⊥ and ∥ to the data of experiments performed with transverse ($H_\perp$) and longitudinal ($H_\parallel$) magnetic fields, we obtain

$$N_k(\perp) = N_0(\perp)[1 - c_0'(\perp)e^{-\lambda k\sigma}\cos(\omega k\sigma + \delta)]. \qquad (2)$$

The quantities determined in the analysis are $N_0(\perp)$, which corresponds to the "average line" of precession in Figs. 1–4, $c_0'(\perp)$, λ, and also the small possible deviations of the parameters ω and δ from the theoretical values. The control experiments in longitudinal magnetic fields showed that the possible lack of correspondence of the directions of the longitudinal magnetic field intensity vector, the initial polarization of the beam, and the axis of the counter system detecting the decay positrons, did not exceed 0.1 radiun. Therefore in this case $\cos(\omega k\sigma + \delta) = 1$ with sufficient accuracy, and in place of Eq. (2) we obtain

$$N_k(\parallel) = N_0(\parallel)[1 - c_0'(\parallel)e^{-\lambda k\sigma}] \qquad (3)$$

or, if we do not postulate an exponential behavior of the depolarization,

$$N_k(\parallel) = N_0(\parallel)[1 - c_k'(\parallel)]. \qquad (4)$$

The parameters $N_0(\parallel)$, which has the same sense as $N_0(\perp)$, and $c_k'(\parallel)$—the μ-e decay asymmetry coefficient at the moment of time corresponding to the k-th channel—cannot be uniquely determined on the basis of the results obtained in a single experiment. However, if we compare the data of two experiments whose conditions differed only in the direction and magnitude of the magnetic field used, we can determine the values of $c_k'(\parallel)$ as

$$c_k'(\parallel) = [N_0(\perp) - N_k(\parallel)]/N_0(\perp). \qquad (5)$$

The equality suggested here for the quantities $N_0(\perp)$ and $N_0(\parallel)$ occurs, generally speaking, only for rather weak fields ($H \lesssim 3-5$ kG), in which the curvature of the decay positron trajectories can be neglected. In fields of higher intensity it is possible to "rotate" the angular distribution of the particles emitted from the target (in a transverse field), or to change the effective solid angle in which the decays are detected, as the result of magnetic focusing of the positrons (in a longitudinal field).

By extrapolation of the series of values of $c_k'(\parallel)$ to

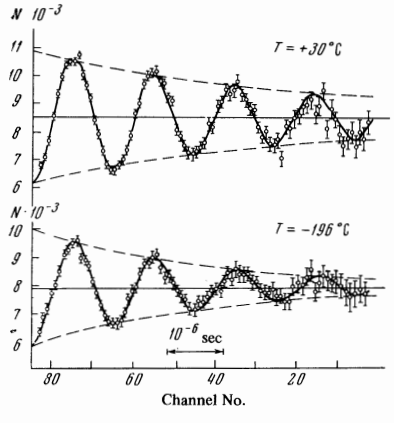

FIG. 1. Damped mesonic precession in B_4C at different temperatures. The abscissa is the channel number (channel width ~73 nsec), and the ordinate is the number of events recorded per channel, corrected for exponential decay of the mesons. The solid curves are plotted from the computer results.

the moment of zero time, the quantity $c'_0(\parallel)$ can be obtained with a high degree of reliability without additional assumptions as to the nature of the time dependence of the polarization. In view of the fact that the coefficients $c'_k(\parallel)$ and also the quantities $c'_0(\parallel)$ and $P_0(\parallel)$ associated with them are calculated on the basis of the data of two different experiments, the errors listed subsequently in determination of the polarization $P_0(\parallel)$ take into account possible random fluctuations of the detection efficiency for the events. The reproducibility of the results obtained was controlled by a systematic alternation of the experiments.

4. RESULTS

In preliminary experiments the phenomenon of slow polarization was observed by us not only in B_4C but in a number of other materials. Later a more detailed study was made of the effect of temperature, external magnetic field intensity, and change of the aggregate state of the target on the processes considered. The results of these studies are presented in the table and in Figs. 1–4.

In the table we have listed for each target the values of the average temperature at the center of the target (determined by means of a thermocouple) and the intensity of the transverse or longitudinal magnetic field at which the experiments were performed. The experimentally measured values of P_0 and λ are given with inclusion of the corrections discussed above, after averaging the results of the individual experiments.

The results obtained for a finely divided powder of technical B_4C are in good agreement with the data of Swanson[9] and Eisenstein et al.[12] The large initial polarization ($P_0 \approx 1$) indicates that fast depolarization processes can be neglected in this case both at room temperature and at low temperature. The dependence of the rate of depolarization on temperature is characteristic. For B_4C (as well as for most materials in which similar experiments have been performed) a reduction of the temperature leads to a significant increase in the rate of depolarization. Figure 2 shows a more complete picture than [9,12] of the "restoration" of the polarization by a weak longitudinal magnetic field (i.e., one which does not affect the value of $P_0(\parallel)$). In a

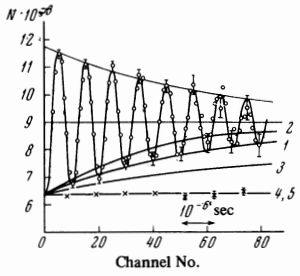

FIG. 2

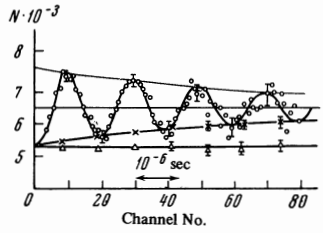

FIG. 3

FIG. 2. "Restoration" of μ^+-meson polarization in B_4C at (room temperature) by a longitudinal magnetic field. The precession curve was obtained in a field $H_\perp$ = 100 G. Curves 1–5 were obtained in longitudinal fields of: 1 – $H_\parallel$ = 10 G, 2 – $H_\parallel$ = 1 G, 3 – $H_\parallel$ = 30 G, 4 – $H_\parallel$ = 70 G, 5 – $H_\parallel$ = 180 G. The statistical errors in the left part of curves 4 and 5 are of the order of the dimensions of the points. The remaining designations correspond to Fig. 1.

FIG. 3. "Restoration" of polarization by a longitudinal magnetic field in LiF. The precession curve (○) was obtained in a transverse field of 50 G; the decay curves were obtained in longitudinal fields as follows: × – 1 G, △ – 180 G. The remaining designations are the same as in Figs. 1 and 2.

transverse field the relaxation time does not depend on the field intensity (see the table). It can be seen from Fig. 2 that in very weak longitudinal fields the rate of occurrence of depolarization processes is greater than the similar quantity observed in a transverse field (curve 2 lies above the lower envelope of the precession curve). When the longitudinal field intensity in increased to 10 G, these rates become equal, and for a further increase of field intensity the "slow" depolarization is absent (curves 4 and 5 are parallel to the axis of abscissas).

A qualitatively similar picture is obtained for a single crystal of lithium fluoride LiF (Fig. 3). Here, however, in the absence of an external magnetic field the depolarization rate is the same as in a transverse field, and the dependence of relaxation time on temperature is the strongest found in any of the materials studied. The essential difference of the μ^+-meson depolarization processes occurring in LiF, in comparison with other ionic crystals,[10] was confirmed by experi-

Material	T, °C	H, Oe	P_0	λ, μsec^{-1}
B_4C	room	50(⊥)	1.03±0.03	0.19±0.02
»	»	100(⊥)	1.00±0.03	0.19±0.02
»	»	400(⊥)	1.03±0.03	0.18±0.02
»	»	180(∥)	0.99±0.05	—
»	−196	50(⊥)	1.00±0.03	0.28±0.03
LiF	room	50(⊥)	0.59±0.03	0.15±0.02
»	»	180(∥)	0.63±0.05	—
»	−196	50(⊥)	0.57±0.05	0.76±0.14
LiH	room	»	0.58±0.04	0.19±0.03
CH_3OH	−196	»	0.54±0.03	0.22±0.05
»	−98 *	»	0.71±0.02	0.03±0.03
$(C_2H_5)_2O$	−196	»	0.39±0.04	0.15±0.05
»	−116 *	»	0.63±0.03	0.02±0.03
SiO_2	room	50(⊥)	0.15±0.01	—
»	»	180(∥)	0.58±0.02 **	—
»	»	7(⊥)	0.43±0.04 ***	2.5±0.5
H_2O	−196	50(⊥)	0.21±0.02	0.10±0.13
»	»	250(∥)	0.65±0.03 **	0.09±0.02
»	»	7(⊥)	~ 0.4 ***	~12

*Liquid phase.

**Sum of mesonic and muonium polarizations.

***Muonium polarization, obtained from the data of ref. 2 with inclusion of the contribution of mesonic polarization.

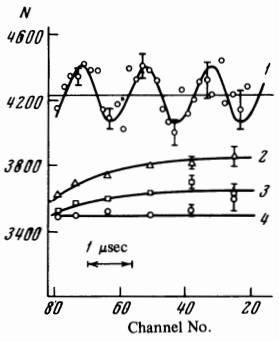

FIG. 4. Simultaneous observation of free and bound μ^+ mesons in SiO_2. Curve 1 – mesonic precession in a transverse field of 50 G; curves 2, 3, 4 were obtained in longitudinal fields of 1, 30, and 70 G. The difference between curves 2–4 and curve 1 corresponds to muonium precession, which is not observed in a transverse field of 50 G because of the small value of the period. The remaining designations are the same as in Fig. 1.

ments in which a longitudinal magnetic field with intensity up to 250 G was used in order to "restore" the polarization of μ^+ mesons in single crystals of NaCl and KBr. The negative result of these experiments apparently indicates that, from the point of view of the behavior of μ^+ mesons in the crystal lattice of a material, these compounds lie much closer to AgBr, which has been well studied by the photoemulsion method,[13] than to LiF.

Another compound containing a lithium ion is lithium hydride, LiH. Measurements made at room temperature with this material have shown that the results observed (see the table) agree with the data obtained for LiF. However, in order to bring out the causes of the difference of compounds of the type LiF, LiH from other ionic crystals, the existing experimental data should be considerably extended.

Experiments with methyl alcohol CH_3OH and diethyl ether $(C_2H_5)_2O$ were undertaken with the purpose of investigating the effect of the aggregate state of the material on the occurrence of the slow depolarization processes. As can be seen from the table, in samples frozen in liquid nitrogen (–196°C) a decrease is observed in the amplitude of mesonic precession, with relaxation times of the order of several microseconds. In the liquid phase at comparatively low temperatures, near the phase transition point for these materials (–116°C for $(C_2H_5)_2O$ and –98°C for CH_3OH), the slow depolarization is absent.

All of the compounds enumerated differ basically from B_4C in the fact that the initial polarization value P_0 in them is considerably less than unity. This is evidence that the slow depolarization processes (at least for the materials considered) occur after a part of the polarization has been lost by much more rapid processes.

The experiments performed with quartz at room temperature served a somewhat different purpose. Previously, a precession had been identified[2] in this material with a frequency corresponding to the frequency of precession of a free muon in the state (J = 1, m = 1). Figure 4 shows the results of experiments with quartz in transverse and longitudinal magnetic fields. The values of transverse field intensity and detecting apparatus channel width used in this case do not allow observation of precession with the muonium frequency (period ~0.2 channel). Thus, curve 1 corresponds to that part of the precessing μ^+ mesons which either did not form muonium or entered into a chemical reaction in the epithermal region, and also to the contribution of "depolarized" μ^+ mesons which have formed muonium. Curves 2–4 show a "recovery" of the polarization in weak longitudinal magnetic fields, similar to that discussed earlier. It is significant that the initial polarization value in these experiments is practically constant. It is apparent that the gap between curve 4 and the average line of curve 1 is proportional to the combined polarization of "free" mesons and mesons bound in the muonium state (J = 1, m = 1) (as has been indicated above, μ mesons occurring in a diamagnetic chemical compound behave like free mesons, from the point of view of the experiments being discussed). The facts that muonium precession[2] and the inhibition of the slow depolarization by a weak longitudinal magnetic field (Fig. 4) are observed permit us to suggest that in quartz there are essentially no electron exchanges between muonium and the medium. In this case the polarization $P_0(\perp)$, which is proportional to the amplitude of the precession with the mesonic frequency, and the polarization $P_0(\parallel)$, measured in a longitudinal field, should be connected by the relation

$$P_0(\perp) + 2[P_0(\parallel) - P_0(\perp)] = 1, \qquad (6)$$

in which the second term takes into account the half-depolarized μ^+ mesons which are part of atomic muonium. Substituting into this expression the experimental data taken from the table, we obtain $2P_0(\parallel) - P_0(\perp) = 1.01 \pm 0.04$, which indicates with rather high accuracy the absence of additional depolarization channels. With further increase of the longitudinal magnetic field intensity, the polarization $P_0(\parallel)$ measured in this field should increase in accordance with the equation

$$P_0(\parallel) = 1 - f/2(1 + x^2). \qquad (7)$$

Here x is the dimensionless field intensity ($x = H/H_{cr}$; $H_{cr} = 1588$ G for vacuum[13]), and the coefficient f takes into account the fraction of mesons occurring in the composition of muonium. In contrast to the "restoration" discussed above of the part of the polarization lost "slowly", in this case there is removal of the main cause of fast depolarization—breaking of the bond between the magnetic moments of the μ^+ meson and the electron in the muonium atom (the Paschen-Back effect[4]). Preliminary experiments performed by us with stronger magnetic fields showed that in the quartz target the increase in initial polarization is in good agreement with Eq. (7) and the value of the critical field intensity is close to that for vacuum.

A series of experiments on the "restoration" of polarization by a weak longitudinal magnetic field were performed with ice cooled to a temperature of –196°C, a material in which muonium precession had also been observed previously. The results, shown in the table, show that a field of intensity $H_{\parallel} \approx 250$ G is insufficient to completely remove the slow depolarization, although the value of $P_0(\parallel)$ agrees satisfactorily with that measured by us previously.[2] The small relaxation time in comparison with quartz ($\tau \approx 0.08$ μsec for ice and $\tau \approx 0.4$ μsec for quartz[2]) is consistent with a possible greater rate of depolarization processes in ice, but an estimate of the contribution of electron exchanges to these processes requires performance of additional experiments.

5. DISCUSSION OF RESULTS

The experimental data accumulated up to the present time regarding the depolarization of μ^+ mesons in matter confirms to a large extent the main conclusions of the muonium theory of depolarization.[5,6] In gases[14] and condensed media a close connection has been established between the residual polarization and the chemical activity of the material. The muonium chemical reaction rate constants calculated on the basis of this theory from measured polarization values are in good agreement within experimental error with the corresponding values obtained for atomic hydrogen by gas kinetic methods.[1]

Study of the processes leading to slow depolarization of μ^+ mesons in matter is particularly desirable for the further development of the theory, because a number of experimental facts, whose explanation is difficult in terms of the formulas and conclusions of Ivanter and Smilga,[6] have much in common with the results being published. Among these facts are the experimental data on "restoration" of polarization by a weak longitudinal magnetic field in plastic scintillator.[15,16] The sharp increase in residual polarization in longitudinal fields of intensity 100–200 G not only indicates an appreciable change in the hyperfine splitting frequency ω_0, but in general is inconsistent with the three-point law obtained by Ivanter and Smilga as characteristic of the muonium theory,

$$(H_2^2 - H_1^2) / (H_3^2 - H_1^2) = (P_2 - P_1)(1 - P_3) / (P_3 - P_1)(1 - P_2).$$

Here P_1, P_2, and P_3 are polarization values measured in longitudinal fields of intensity H_1, H_2, and H_3, respectively. The array of data obtained in semiconductors[3,17] evidently require additional assumptions in order to be reconciled with theory. It is extremely interesting that the slow depolarization of μ^+ mesons in monocrystals of Ge found in our earlier work[3] is accelerated, under certain conditions, with increase of temperature. A change in temperature also has an important effect on the initial polarization value P_0. Probably, for materials with an intermediate density of conduction electrons, in contrast to the materials discussed in the present work, the slow depolarization mechanism is due to other processes.[3]

Possible explanations of the phenomenon of slow depolarization of μ^+ mesons in the materials listed in the table fall into two categories. The first category of causes occurs in the case when, after completion of the muonium stage (i.e., after entry of the muonium into a chemical reaction), chemical equilibrium is not yet achieved. If the chemical compound being formed, which includes muonium, is unstable and breaks up after microsecond time intervals, being converted to a material with paramagnetic properties (of the free radical type), depolarization channels are possible which are similar to the muonium channel. The question of interaction of the μ^+-meson magnetic moments and the unpaired electron belonging to the same molecule in which the muonium is located has not yet been considered theoretically. It is clear that in this case the role of molecular rotation is important, in view of the possible averaging of the interaction. One can, however, assume that in the solid phase the effect of a longitudinal magnetic field on the depolarization of a μ^+ meson in a radical compound will be appreciable in a region of $H_{||}$ values considerably smaller than $H_{cr} = 1588$ G for a free muonium atom. Loss of polarization can result also from charge-exchange processes (the transitions $\mu^+ \rightarrow Mu \rightarrow \mu^+$, and so forth), which are possible in media with high dielectric constants. This depolarization mechanism has been discussed in detail by Yakovleva.[18] All processes involving a change in the chemical state of the μ^+ meson in matter (μ^+ meson, muonium, radical, molecule) have one property in common—an increase in the transition probability with increased absolute temperature of the experiment. The experimentally observed more intense depolarization at low temperatures for the materials listed in the table is inconsistent with the possibilities discussed above.

A second category of causes of slow depolarization does not involve a change in the structure of the molecules containing the muonium atom. Interaction of the μ^+-meson magnetic moment with the local magnetic fields (LMF) in matter also leads to a decrease in residual polarization measured both in transverse and in longitudinal external magnetic fields.[4,12] Without analyzing in detail the causes responsible for the presence of LMF in diamagnets (these may be, for example, the existence of magnetic moments in nuclei, small impurities of paramagnetic compounds, imperfections in the crystal structure of the material, and so forth), we will point out that there is a qualitative difference in the occurrence of depolarization processes in transverse and longitudinal external magnetic fields in this case.

In a transverse field the effect of LMF reduces basically to a change in the frequency of precession (we are considering the case $H_{loc} \ll H_{ext}$, where H_{loc} and H_{ext} are respectively the fields corresponding to LMF and the external field). In the simplest approximation we will replace a spatially isotropic distribution of LMF intensity by a distribution in which half of the μ^+ mesons precess in a transverse field $H_\perp = H_{ext} + H_{loc}$, and the other half in a field $H_\perp = H_{ext} - H_{loc}$. The average precession of the spins $\overline{\sigma}_z(t) = \frac{1}{2}\cos\omega(H_{ext} + H_{loc})t + \frac{1}{2}\cos\omega(H_{ext} - H_{loc})t = \cos\omega(H_{ext})t\cos\omega(H_{loc})t$ (here $\overline{\sigma}_z(t)$ is the average value of the projection of the μ^+-meson spin, and t is time) occurs with an amplitude decreasing with time, the second factor depending on the external field intensity. It is obvious that the harmonic nature of the precession amplitude variation is artificially produced by the assumption made above.) In a longitudinal magnetic field with intensity $H_{ext} \gg H_{loc}$, precession is absent and the depolarization produced by this mechanism is cut short.

Nosov and Yakovleva[5] have discussed the interaction of the magnetic moments of μ^+ mesons and surrounding nuclei. They have remarked that there is a dependence of a depolarization mechanism of this type on the velocity of rotation of the molecules, arising from the fact that in averaging over all possible directions of the vector **n** the corresponding term in the Hamiltonian $\mathcal{H}_a = [\mu\mu_a - 3(\mu n)(\mu_a n)]r_a^{-3}$ goes to zero (μ and μ_a are the magnetic moments of the μ^+ meson and the nucleus, r_a is the distance between the μ^+ meson and the nucleus, and **n** is a unit vector directed along the line joining the nucleus with the μ^+ meson). In the case of rotation of the molecule with a frequency much greater than the quantity $\hbar/|\mathcal{H}|_a$, depolarization resulting from the in-

teraction being considered does not occur. The absence of detailed theoretical calculations hinders a more detailed analysis of the experimental data from this point of view; however, the accelerated occurrence of depolarization processes at low temperatures is qualitatively consistent with the slower rotation of molecules in this case.

The experimentally observed dependence of the rate of slow depolarization on temperature is consistent with other mechanisms for production of LMF in matter, since the effect of LMF on the magnetic moment of a μ^+ meson is determined both by the LMF intensity and by the time of interaction, which increases with reduction of the temperature.

6. CONCLUSION

On the basis of the above remarks we can conclude that the processes leading to slow depolarization of μ^+ mesons in matter do not, in most of the cases studied, appreciably affect the muonium stage of the depolarization. The principal relations obtained previously[1,5,6,8] which relate the characteristics of atomic muonium and the chemical activity of the medium remain in force, if we take for the residual polarization its initial value P_0. Determination of the chemical constants on the basis of polarization values extrapolated to zero time makes sense, however, only when the fast and slow depolarization processes can be clearly differentiated experimentally. Removal of the causes of slow depolarization in weak longitudinal magnetic fields is one of the main criteria for applicability in each specific case of the conclusions and formulas of the muonium depolarization theory. In some cases[3] the fast and slow depolarizations are evidently related organically and explanation of the experimental facts on the basis of the existing models without additional assumptions is not legitimate. We emphasize the value of discussing slow μ^+-meson depolarization processes in matter, since from the experimental data we can in principle obtain information on the interactions of the meson and of muonium with a real crystal lattice.

In many studies made by the muonium method, the slow polarization can be a complicating factor. Inclusion of this factor is important for a correct interpretation of the processes being studied.

The authors extend their thanks to V. I. Kudinov and V. I. Grafutin for assistance in the measurements, and to I. G. Ivanter and V. P. Smilga for helpful discussions.

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Translated by C. S. Robinson
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