INVESTIGATION OF μ^+-MESON DEPOLARIZATION IN SCINTILLATING PLASTICS IN DIFFERENTLY ORIENTED MAGNETIC FIELDS

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The dependence of μ^+-meson polarization on the intensity of a longitudinal, transverse, or 45° (135°) magnetic field was studied experimentally in samples of a characteristic structure. A qualitative description is proposed of the behavior of muonium interacting with substances capable of forming molecular and radical products via independent interaction channels. The obtained data are analyzed within the framework of the picture of chemical interactions of muonium.

THE dependence of the experimentally observed polarization of the μ^+ meson in scintillating plastics on the magnetic field intensity is different in a transverse magnetic field than in a longitudinal one[1,2]. In longitudinal fields, the polarization increases appreciably with increasing magnetic field intensity (200–400 Oe), and an important factor is that this result cannot be explained on the basis of simple assumptions with respect to the Paschen-Back effect[3,4], since the fields required to realize the latter are of the order of several kOe (H_{cr} = 1580 Oe in vacuum and is larger in the presence of electronic exchanges[5]). It is possible that the causes of such a dependence may be clarified by determining whether the restoration of the polarization in longitudinal fields is due to the magnetic field vector or to an appropriate component of the magnetic field vector.

We measured the polarization of the μ^+ meson in scintillating plastics of various compositions and in materials of similar structure, as functions of the magnetic field intensity. The angles between the magnetic field and the initial preferred direction of the μ^+-meson spin was 90° (perpendicular field), 0° (180°) (longitudinal field), or 45 (135°) ("oblique" field). The apparatus and experimental procedure were described earlier[6,7]. The results are expressed as percentages of the polarization of bromoform, which was used as a standard[8]. The experimental value of the asymmetry coefficient of the bromoform in this series of experiments was 0.286 ± 0.004. We used scintillating plastics based on polystyrene $[-CH(C_6H_5) - CH_2 -]_n$, polyvinyl xylol $[-CH(C_6H_3(CH_3)_2) - CH_2 -]_n$, and polymethylmethacrylate (plexiglass) $[-CH_2 - C(CH_3) \cdot (COOCH_3) -]_n$.

An example of the use of an oblique field is illustrated by the control experiment in which bromoform was used (Fig. 1). The precession frequency, naturally, is determined by the magnitudes of the vectors of the 90° and 45° fields, but the amplitude of the precession in the latter case is smaller by a factor of approximately 2. The deviation from the coefficient 2 is connected with the geometrical extension of the scintillation counters. It is clear that the minima of both precession curves should coincide, since the recording e-telescope was located at an angle 180° relative to the initial meson spin direction (naturally, at a zero degree geometry the maxima of the curves should coincide,

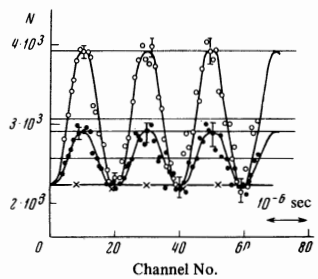

FIG. 1. Precession curves of μ^+ meson in bromoform in a transverse magnetic field (light points; $H_\perp$ = 49.9 Oe, $H_\parallel$ = 0) and a 45° field (filled points; $H_\perp$ = 35.3 Oe, $H_\parallel$ = 35.3 Oe). The numbers of the counts were corrected for the exponential decay of the μ^+ meson. The curves were obtained at equal numbers of stopped mesons in the target and at a constant geometry of the experiments. T = 25°C.

and at a 90° geometry, the center lines should coincide), and in the case of bromoform there is no dependence of the polarization on the intensity of the longitudinal magnetic field.

The resultant plots obtained in oblique fields contain information of two kinds. First, there is the proper "transverse" polarization defined as $(N_{max} - N_{min})/(N_{max} + N_{min})$, where N_{max} and N_{min} are the numbers of the counts at the proper maximum and minimum. This quantity is trivial from the geometrical point of view. In the subsequent reduction of the results, for the comparison of the data obtained in transverse and oblique fields, this quantity was multiplied by the experimental ratio of the corresponding polarizations (with allowance for the absolute value of the polarization). Second, there is a proper "longitudinal" polarization, the amplitude of which is defined as the difference between the numbers of the counts corresponding to the average precession line in the transverse field and to the minimum of precession in the oblique field. If the polarization is independent of the intensity of the longitudinal field, the result obtained in this case equals the polarization in the transverse field.

Detailed results for plastics based on polystyrene are given in Fig. 2. We note first that good agreement is observed with other experimental results in both longitudinal[2] and transverse fields[5]. In oblique fields, the values of the "transverse" polarization are

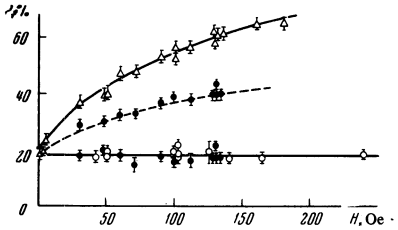

FIG. 2. Dependence of polarization (percentage of polarization of μ^+ mesons in bromoform) in a scintillating plastic based on polystyrene, on the magnetic field intensity: ○ – transverse field, △ – longitudinal field, ● – 45° (135°)-field relative to the meson spin direction (upper and lower points–respectively at the given longitudinal and transverse components of the magnetic field vector). The dashed curve was drawn at an equal distance from the upper curve and the lower straight line.

in satisfactory agreement with the results obtained in a transverse field. The values of the "longitudinal" polarization at a given value of the longitudinal component of the vector of the oblique magnetic field lie well on a curve (dashed line of Fig. 2) representing the arithmetic mean value of the polarization in transverse and longitudinal fields. Thus, experiments in oblique fields show that restoration of the polarization is due to the longitudinal component of the magnetic field vector. We note that alternation of 45° and 135° fields was used in many experiments, and the results practically coincide.

Data on the dependence of the polarization of the μ^+ mesons on the magnetic field in plastics based on polyvinyl xylol and in polymethylmethacrylate, at certain values of the transverse, longitudinal, and 45° fields, are shown in Fig. 3. We note that for both types of scintillating plastics, the polarization varies in similar fashion as a function of the longitudinal field. It is typical that the polarization in the transverse field, which does not depend on the magnitude of the field, increases insignificantly on going over from polystyrene (no methyl groups in the phenyl ring) to polyvinyl toluene (plastic NE 102, used in[1]—one methyl group) and polyvinyl xylol (two methyl groups). A similar effect is observed in monomer compounds following successive methylization of the aromatic rings[9]. It must be indicated that in longitudinal fields a weak time dependence of the polarization is observed (decrease of the asymmetry coefficient during the observation time).

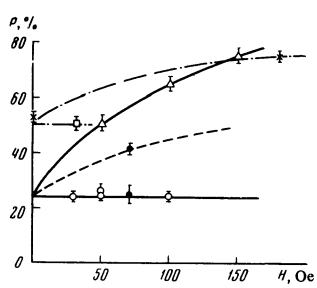

FIG. 3. Dependence of the polarization (percentage of the polarization of the μ^+ mesons in bromoform) on the magnetic field intensity. For a scintillating plastic based on polyvinyl xylol (lower curves), the symbols are the same as in Fig. 2. For polymethylmethacrylate (upper curves), □ – – transverse field, × – longitudinal field.

The causes of the sharp growth of the polarization in relatively weak longitudinal magnetic fields are apparently connected with the complicated mechanism of interaction between muonium and the organic compounds capable of forming radical products. An attempt to describe the effect on the basis of the assumption that the energy of the hyperfine splitting changes as a result of interaction with the medium, leads to violation of the criterion of the functional dependence of the polarization on H^2.[10] It is possible to assume, however, that the constant component of the polarization, which does not depend on the transverse magnetic field intensity, is due to the interaction of muonium with the side groups of the aromatic rings (for plastics) and the methyl groups (for polymethylmethacrylate), at which the molecular products are formed (predominately MuH, i.e., molecules equivalent to molecular hydrogen). At the same time, the polarization component that depends on the intensity of the longitudinal magnetic field is connected with the reaction of radical formation with the unpaired electron (sticking of the muonium to the aromatic ring for plastics, the interaction with the carbonyl group for polymethylmethacrylate) in which a complicated system of spin interactions is realized between the magnetic moments of the electron, which is delocalized in the general case, the meson, and the neighboring nuclei (protons) in the molecule. A quantum-mechanical calculation for such complicated systems is quite difficult, and all that can be done is to introduce certain averaging effective characteristics that agree satisfactorily with the overall picture of the interactions.

There is a qualitative agreement between the experimental data and the described picture. Indeed, the constant component of the polarization increases with increasing ratio of the number of methyl (methylene) groups and functional groups, the interaction with which leads to the formation of the radical products. In this connection, it is natural to have a weaker growth of the polarization as a function of the longitudinal field for polymethylmethacrylate, and also a similar variation (with a certain parallel shift) for both types of plastics. The asymptote to which the polarization tends with increasing longitudinal magnetic field intensity corresponds to the summary rate of chemical interaction between the muonium and the given compound. It must be noted, however, that observation of the latter phenomenon is complicated by conjugation with the effect of the growth of polarization in strong fields, owing to the breaking of the bond between the magnetic moments and the impossibility of depolarization of a muonium atom with antiparallel meson and electron spin directions. The separation of both effects is possible only at an appreciable difference between the critical magnetic fields.

Since the process of interaction of the free atoms (hydrogen, muonium,) with the unsaturated bonds of the organic molecules occurs without an activation energy[11], it is clear that investigations of the temperature dependence of the polarization at a given intensity of the longitudinal magnetic field can yield valuable information concerning the nature of this interaction. It is important that direct measurements in scintillating plastics, at the precession frequency of

the atomic muonium[2], have shown that there is no polarization of triplet muonium even at a temperature −196°C.

The mechanism of radical depolarization of muonium calls for the development of a theory that combines a quantum-mechanical description of the spin interactions in the molecule and an allowance of the specific nuclear-physical characteristics of the behavior of the μ^+ meson in muonium. Investigations in this direction are of undisputed interest, in view of the possibility of experimentally analyzing the delocalization of the electron density in molecules and radicals, the spin interactions of nuclei with magnetic moments in a molecule (analogy with the hyperfine structure of the EPR spectrum), etc.

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