Investigation of the post-muonium stage of depolarization of μ^+ mesons in germanium

V. I. Kudinov, E. V. Minaĭchev, G. G. Myasishcheva,
Yu. V. Obukov, V. S. Roganov, G. I. Savel'ev, and V. G. Firsov

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The rate of slow relaxation of the spin of the μ^+ meson in n-type germanium single crystals was measured as a function of the temperature of the medium and of the concentration of the doping impurity. The data are discussed in the framework of the overall picture of the interaction of muonium (μ^+ meson) with germanium.

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The method of observing the Larmor precession in transverse magnetic fields[1] was used to study the slow depolarization (occurring after the completion of the muonium stage)[2] of μ^+ mesons in germanium. The rate of relaxation of the μ^+-meson spin was measured as a function of the temperature of the medium and of the concentration of the doping impurities. The experiments were performed in the strong-focusing channel of the synchrocyclotron of the Nuclear Problems Laboratory of the Joint Institute for Nuclear Research.[3] A beam of polarized ($P_0 \sim 0.86$) μ^+ mesons was stopped in the investigated target and the positrons of the μe decay were registered at an angle $\sim 0°$ relative to the initial momentum of the μ^+ mesons. In a transverse magnetic field ($H_\perp$), the distribution of the registered events in time was modulated because of the spatial asymmetry of the decay at a frequency $\omega = gH_\perp$, where g is the gyromagnetic ratio for the μ^+ meson. The time distribution of the registration probability $W(t)$, after taking into account the background and the exponential behavior of the μ^+-meson lifetime, is given by

$$W(t) \sim [1 - c_0' e^{-\lambda t} \cos(\omega t + \phi)],$$

where c_0' is the experimental asymmetry coefficient in the medium at the instant of time $t = 0$ (the time is reckoned from the instant when the μ^+ meson is stopped in the target), λ is the rate constant of the slow relaxation of the μ^+-meson spin, and ϕ is the meson-precession phase shift due to the presence of the muonium stage. Absolute normalization of the polarization of the μ^+ mesons was carried out in accordance with control experiments with a standard bromoform ($CHBr_3$) target with allowance for the energy spectrum of the registered decay positrons. The principal measured quantity in these experiments is the parameter λ. At the chosen field intensity ($H_\perp \approx 120$ Oe) and observation time ~ 8 μsec, we traced 12—13 periods of the precession at a total statistics of the registered decay events $\sim 2.5 \times 10^5$ in each experiment.

The investigated samples of single-crystal germanium doped with arsenic with concentrations 1×10^{14}, 1.5×10^{15}, and 1.5×10^{17} cm^{-3} (n-type conductivity) were placed in a thermostat, in which the specified temperature was maintained

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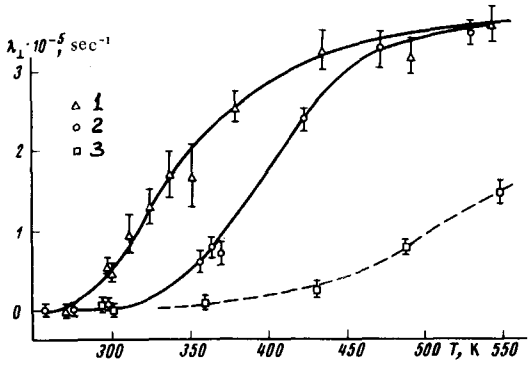

FIG. 1. Dependence of the strength of the post-muonium depolarization of μ^+ mesons (λ) in n-type germanium single crystals with different concentrations of the carriers on the temperature (T) of the medium: 1—1×10^{14} cm^{-3}; 2—1.5×10^{15} cm^{-3}; 3—1.5×10^{17} cm^{-3}.

accurate to ± (1—2)°. A contribution not exceeding 5% from the μ^+ mesons stopped in the thermostat walls was taken into account.

The results of the experiment on the determination of the rate of the rapid depolarization of the μ^+ mesons are shown in Fig. 1. We note two important conclusions that follow from the presented data: first, the depolarization accelerates with increasing temperature; second, the increase of the carrier density produces the opposite effect, i.e., it slows down the process.

The revealed dependence of the depolarization rate on the temperature ($d\lambda/dT > 0$) for μ^+ mesons in n-type germanium (an analogous effect was noted by us[4] also in p-type germanium) distinguishes this process strongly from the mechanism of the dipole—dipole relaxation of the μ^+-meson spin,[2,5] where $d\lambda/dT < 0$. We note that under the experimental conditions considered above, all the germanium samples were nondegenerate, with fully ionized impurity atoms. A comparison of the data for samples with successively increasing concentration of the arsenic atoms shows that the inverse proportionality of the relaxation rate of the μ^+-meson spin and the conduction-electron density have a nonlinear character, and a limiting value of λ may be reached with increasing temperature (for the germanium sample $n = 1.5\times10^{17}$ cm^{-3}—only in the region of higher temperatures).

It was shown in our earlier papers[4,6] that the μ^+ mesons produced in germanium, with a near-unity probability, muonium atoms which subsequently enter in chemical reaction with the crystal-lattice atoms. The resultant diamagnetic coupling produced by a pair of spin-compensated electrons prevents the "rapid" (during the muonium stage) depolarization of the μ^+ mesons on account of the hyperfine interaction in the muonium atoms.[7] The most probable is the formation of a chemical bond of the hydride type Ge—H.[8] Thus, the process of slow (post-muonium) depolarization investigated in the present paper can be regarded as subsequent thermal disruption of the chemical bond, which results in formation of a paramagnetic center that depolarizes the μ^+ mesons.

The foregoing dependences of the rate of depolarization of the μ^+ mesons on the temperature in media other than germanium have not yet been observed. In these cases, the phenomenological theory of depolarization of the μ^+ mesons

with allowance for the possible formation of unstable diamagnetic compounds, which was described in the paper of Ivanter and Smigla,[9] may be quite productive. However, a more detailed analysis of the interaction of the muonium (μ^+ mesons) with germanium calls for additional experiments, particularly at higher temperatures. A determination of the quantitative characteristics of the process of violation of the diamagnetic Ge-Mu bond will undoubtedly reveal the actual mechanism whereby this bond is produced.

[1]A. I. Babaev, M. Ya. Balats, G. G. Myasishcheva, Yu. V. Obukhov, V. S. Roganov, and V. G. Firsov, Zh. Eksp. Teor. Fiz. **50**, 877 (1966) [Sov. Phys. JETP **23**, 583 (1966)].

[2]E. B. Minaĭchev, G. G. Myasishcheva, Yu. V. Obukhov, V. S. Roganov, G. I. Savel'ev, and V. G. Firsov, Zh. Eksp. Teor. Fiz. **57**, 421 (1969) [Sov. Phys. JETP **30**, 230 (1970)].

[3]Yu. M. Grashin, B. A. Dolgoshein, V. G. Kirillov-Ugryumov, A. A. Kripin, V. S. Roganov, A. V. Samoĭlov, and S. V. Somov, At. Énerg. **18**, 384 (1965).

[4]D. G. Andrianov, G. G. Myagishcheva, Yu. V. Obukhov, V. S. Roganov, V. G. Firsov, and V. I. Fistul', Zh. Eksp. Teor. Fiz. **56**, 1195 (1969) [Sov. Phys. JETP **29**, 643 (1969)].

[5]V. G. Grebinnik, I. I. Gurevich, V. A. Zhukov, A. P. Manych, E. A. Meleshko, I. A. Muratova, B. A. Nikol'skiĭ, V. I. Selivanov, V. A. Suetin, Zh. Eksp. Teor. Fiz. **68**, 1548 (1975) [Sov. Phys. JETP **41**, 777 (1975)].

[6]V. I. Kudinov, E. V. Minaĭchev, G. G. Myasishcheva, Yu. V. Obukhov, V. S. Roganov, G. I. Savel'ev, V. M. Samoĭlov, and V. G. Firsov, Zh. Eksp. Teor. Fiz. **70**, 2041 (1976) [Sov. Phys. JETP **43**, 1065 (1976)].

[7]V. G. Nosov and I. V. Yakovleva, Zh. Eksp. Teor. Fiz. **43**, 1750 (1962) [Sov. Phys. JETP **16**, 1236 (1963)].

[8]D. G. Andrianov, Yu. V. Obukhov, V. G. Firsov, and V. I. Fistul', Dokl. Akad. Nauk SSSR **201**, 884 (1971).

[9]I. G. Ivanter and V. P. Smilga, Zh. Eksp. Teor. Fiz. **60**, 1985 (1971) [Sov. Phys. JETP **33**, 1070 (1971)].