Magnetic oscillations of the lifetime of electron-hole drops in pure germanium

A. L. Karuzskiĭ, K. W. Betzler,[1)] B. G. Zhurkin, and B. M. Balter

P. N. Lebedev Physics Institute, USSR Academy of Sciences

(Submitted May 7, 1975; resubmitted June 9, 1975)
Pis'ma Zh. Eksp. Teor. Fiz. 22, No. 2, 65–68 (July 20, 1975)

A new oscillatory effect is observed, namely the oscillations of the lifetime of electron-hole drops in pure germanium in magnetic fields up to 32 kOe. The observed effect confirms the Keldysh-Silin theory regarding oscillations of the density of the electron and hole Fermi liquids in the drops following application of a magnetic field.

PACS numbers: 75.80., 71.20.

Bagaev and co-workers[1] have observed magnetic oscillations in the intensity of the luminescence from electron-hole drops (EHD) and have advanced the hypothesis that they are due to oscillations of the electron-hole binding energy in the drops. Keldysh and Silin have shown[2] that in a magnetic field the free energy of the Fermi liquid of electrons and holes in the EHD has an oscillating part that leads to oscillations of the equilibrium carrier density n in the drops. The main contribution to the oscillating part is made by the exchange energy rather than by the kinetic energy, as would be the case for a Fermi gas.

We have observed experimentally a new oscillatory effect—the oscillations of the lifetime τ of EHD in a magnetic field (Fig. 1). It is precisely this effect which determines the oscillations of the intensity (quantum yield) of the EHD emission. The oscillations of τ prove that the interactions in the liquid phase determine not only its thermodynamic characteristics (binding energy), but also its recombination kinetics, i.e., its lifetime. It is important to note that the lifetime and quantum yield in EHD exceed by an order of magnitude these values for the excitons and free carriers. The results of the present study lead to the unequivocal conclusion that the mechanism of carrier recombination in EHD is different from that of the excitons and free carriers, and is determined by the equilibrium carrier density, i.e., in final analysis, by the interparticle interaction in the liquid phase.

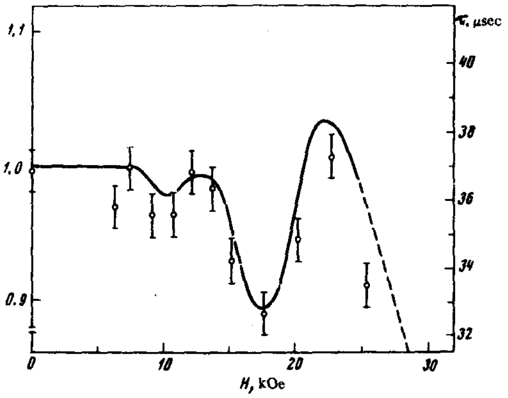

FIG. 1. Lifetime τ of EHD as a function of the magnetic field H (the experimental points were taken from the data represented in Fig. 2). The solid curve is the plot of $\tau(H)$ calculated from the magnetic oscillations of $n(H)$ of[4].

The experiments were performed at $T = 1.5$ °K on pure Ge samples with impurity density $\lesssim 10^{12}$ cm^{-3}, in a magnetic field $H = 0$ to 32 kOe produced by a superconducting solenoid. The field H was parallel to the [100] axis of the sample. The details of the experimental setup are described in[3,4]. The dependence of τ on the magnetic field, shown in Fig. 1, was obtained from direct measurements of the kinetics of the EHD decay at a given constant magnetic field. Figure 2 shows plots of the logarithm of the intensity of LA-709 meV IR line of the EHD against the delay time relative to the exciting pulse of a GaAs laser (the pulse duration was 2 μsec, the repetition frequency 1 kHz, the light flux on the sample ≈5 W/cm²). The upper straight line corresponds to $H = 0$ and the lower to $H = 32$ kOe. As seen from Fig. 2, the EHD decay is well described by an exponential in the entire investigated magnetic-field range. For small H we obtain $\tau \approx 36$ μsec, in good agreement with data by others.[5,6]

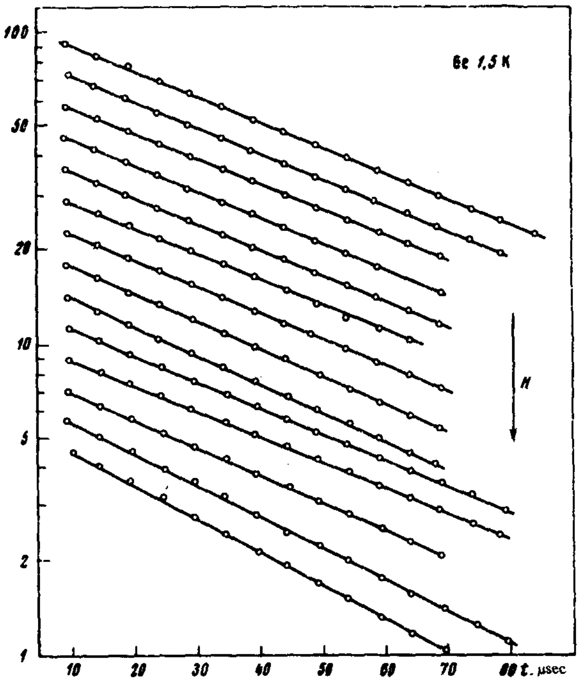

FIG. 2. Time dependence of the luminescence intensity of EHD for various magnetic field (the field increases from zero for the upper curve to 32 kOe for the lowest curve).

The magnetic oscillations of τ can be explained on the basis of the kinetic equations for the EHD considered in[4], where the following relation was obtained for the lifetime

$$\tau^{-1} = A + Bn + Cn^2. \tag{1}$$

The term A gives the contribution to the recombination due to the impurities; Bn is the contribution of the radiative recombination in the EHD, while Cn^2 is a term due to nonradiative Auger recombination. The coefficients A, B, and C are constant for any given temperature. It is seen from (1) that if the carrier density n in the EHD oscillates, then τ also oscillates, in counterphase with n, i.e., a minimum of n should correspond to a maximum of τ. From (1) we can obtain the connection between the relative oscillations of n and τ:

$$\frac{d\tau}{\tau} = (Q - 2)\left(\frac{dn}{n}\right), \tag{2}$$

where $Q = Bn/(A + Bn + Cn^2)$ is the quantum efficiency of the recombination in the EHD.

The solid curve of Fig. 1 represents the values of τ calculated from formula (2), using the data of[4] on the oscillations of the density n in the EHD. The agreement with the experimental values of the oscillations of τ is good.

In conclusion, the authors are grateful to L.V. Keldysh and A.P. Silin for a discussion of the results.

[1)] Visitor from the Physics Institute of Stuttgart, W. Germany.

---

[1] V.S. Bagaev, T.I. Galkina, N.A. Penin, V.B. Stopachinskiĭ, and M.N. Churaeva, ZhETF Pis. Red. 16, 120 (1972) [JETP Lett. 16, 83 (1972)].
[2] L.V. Keldysh and A.P. Silin, Fiz. Tverd. Tela 15, 1532 (1973) [Sov. Phys.-Solid State 15, 1026 (1973)].
[3] V.B. Ginodman, P.S. Gladkov, B.G. Zhurkin, N.A. Kazakov, and N.A. Penin, Preprint No. 90, FIAN SSSR, Moscow, 1974.
[4] K.W. Betzler, B.G. Zhurkin, and A.L. Karuzskiĭ, to be published in Solid State Commun.
[5] R.M. Westervelt, T.K. Lo, J.L. Staehli, and C.D. Jeffries, Phys. Rev. Lett. 32, 19, 1051 (1974).
[6] C. Benoit a la Guillaume and M. Voos, Solid State Comm. 11, 1585 (1972).