MAGNETIC SUSCEPTIBILITY OF SEMIMETALLIC Bi-Sb ALLOYS IN THE ULTRAQUANTUM LIMIT

N. B. Brandt, E. A. Svistova, and M. V. Semenov
Moscow State University
Submitted 10 December 1973
ZhETF Pis. Red. 19, No. 2, 107 - 111 (20 January 1974)

A sharp increase of the constant part of the transverse ($H \perp C_3$) differential magnetic susceptibility was observed in bismuth and in semimetallic bismuth-antimony alloys on going to the ultraquantum region of magnetic fields.

The anomalously large diamagnetism of Bi-Sb alloys and its appreciaible increase [1, 2] in the Sb concentration region from 7 to 21 at.%, where the alloys are semiconducting, have recently found a quantitative explanation [3] on the basis of allowance for the interband contributions, the role of which increases when the alloys go over into the semiconducting state. Less clear is the question of the behavior of the magnetic susceptibility of these alloys in the ultraquantum region of magnetic fields. Although individual aspects of this questions are dealt with in theoretical papers, we know of no special experimental research in this field.

We have investigated the magnetic susceptibility of Bi and of Bi-Sb alloys in the ultraquantum limit of magnetic fields at helium temperatures. The measurements were performed with an induction magnetometer similar to that described in [6]. A magnetic field up to 50 kOe was produced with a superconducting solenoid. The modulating magnetic field, of 20 - 30 Hz frequency and amplitude up to 100 Oe was produced by a superconducting modulating coil fed from a G3-33 oscillator through a UM-50 power amplifier. At these frequencies, the contribution of the skin effect becomes manifest in Bi and in Bi-Sb alloys only in the weakest fields (up to 300 - 400 Oe). The signal is picked off from a pair of measurement coils wound in opposition and containing each several thoudand turns of PEV-0.02 wire. After compensating out the remaining induction from the modulating field, the signal is amplified by a U2-6 narrow-band amplifier and is fed through a synchronous detector to an x-y recorder to plot the $\chi(H)$ curves. When working with sufficiently long samples, the measurement method is absolute [7], viz., when the sample is placed in one of the compensated measurement coils, the deflection at the output of the system is proportional to the differential magnetic susceptibility $\chi = dM/dH$. Since the compensation of the coils is disturbed when the magnetic field is increased, the useful signal is reckoned from a shifted "null point" corresponding to the signal produced by the measuring coils without the sample. If the system is suitably calibrated, the obtained values of χ in weak fields agree well with the published data on the susceptibility of the Bi-Sb alloys [1, 2].

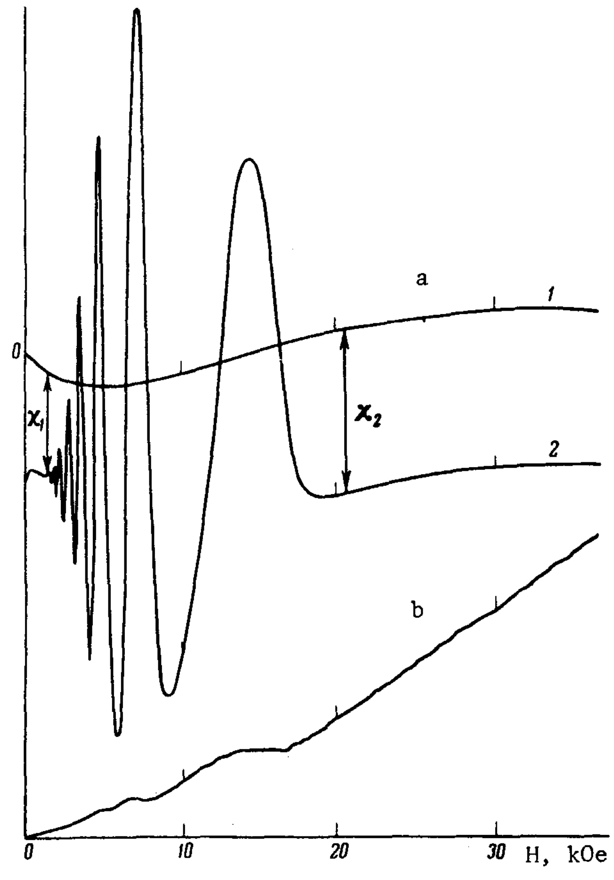

Fig. 1. a) Differential susecptibility (difference between curves 1 and 2) of Bi vs. magnetic field $H \parallel C_2$; b) modulus of magnetic moment of Bi vs. field $H \parallel C_2$.

Figures 1a, 2a, and 2b show the differential magnetic susceptibility of Bi measured at T = 4.2°K with the magnetic field oriented along the binary (C_2) and bisector (C_1) axes of the crystal (the curves were obtained by averaging several repeated plots obtained with the recorder). The abrupt variation of the signal in weak fields is due to the increase of the skin-layer depth in the magnetic field. In strong fields, the signal characterizes the initial suseptibility χ_1, on which de Haas – van Alphen oscillations are then superimposed.

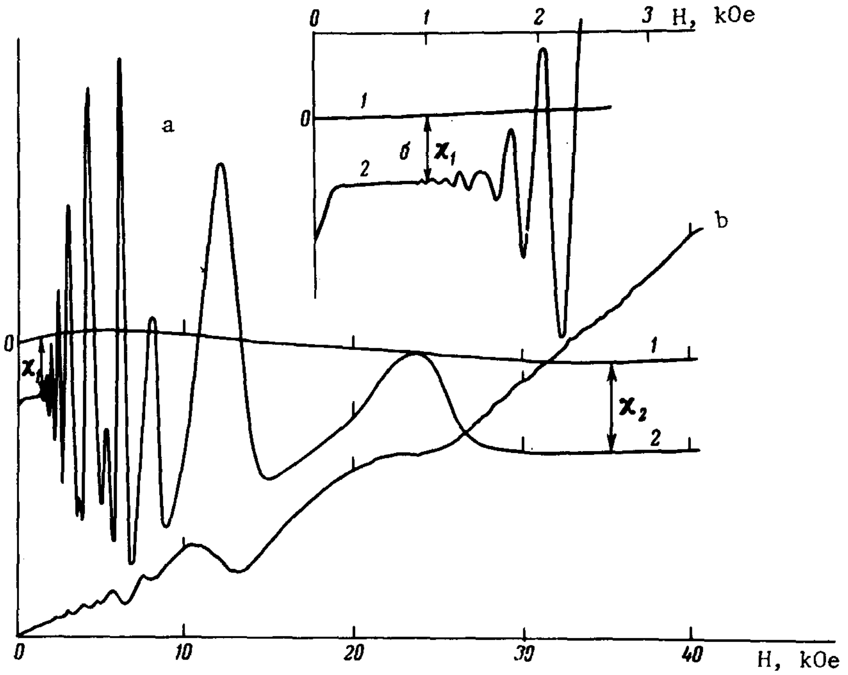

Fig. 2. a) differential susceptibility difference between curves I and.2) of Bi vs. the magnetic field $H \parallel C_1$. b) the same, in enlarged scale, for initial section of the curve. c) Modulus of magnetic moment of Bi vs. the field $H \parallel C_1$.

After emergence of the last Landau level for two (at $H \parallel C_2$) all all three (at $H \parallel C_1$) electron ellipsoids, the ultraquantum region of magnetic fields is reached. A new and rather unexpected fact is that in this region the differential susceptibility χ_2 is much larger than in weak fields. The value of χ_2 does not depend on the orientation of the magnetic field (at $H \parallel C_2$, C_1) and on the temperature (at 2.1 - 4.2°K), and decreases little with increasing magnetic field. The maximum ratio χ_2/χ_1 for Bi is on the average 1.66 ± 0.05. The susceptibility $\chi_2 \approx -3.0\times10^{-6}$ cgs/g is close to the values of χ_1 in the superconducting Bi-Sb alloys (maximum $\chi_1 = -2.5\times10^{-6}$ cgs/g at an Sb concentration 7 - 8 at.%).

As an independent check on the observed phenomenon, we measured the dependence of the magnetic moment M of Bi on the field. An alternating field gradient up to 400 Oe/cm was produced at the center of the solenoid. The alternating force acting on the sample was transmitted to a piezoelectric pickup connected to the sample by a thin quartz tube. The signal from the piezopickup was fed through a cathode follower to the recorder described above. The results of these measurements are shown in Figs. 1b and 2c. There is clearly noted increase of the slope of the M(H) curve following the last oscillation at both field orientations. The slope of the curve (i.e., χ) increases by approximately 1.7 times, in good agreement with the susceptibility data.

Figure 3 shows the measured maximum values of χ_2/χ_1 at G C_2 for semimetallic Bi-Sb alloys. We see that the ratio χ_2/χ_1 decreases with increasing antimony concentration. The decrease of χ_2/χ_1 is due mainly to the increase of the susceptibility χ_1, whereas the absolute value of χ_2 remains of the same order as for Bi, viz. $-(2.9 - 3.1)\times10^{-6}$ cgs/g, for all investigated Sb concentrations. The possible causes of the increase of the diamagnetism of Bi and of the Bi-Sb alloys in the ultraquantum region may be the saturation of the paramagnetic moment of the conduction electrons located at the zeroth Landau level, or else the increase of the diamagnetic interband contribution as a result of the

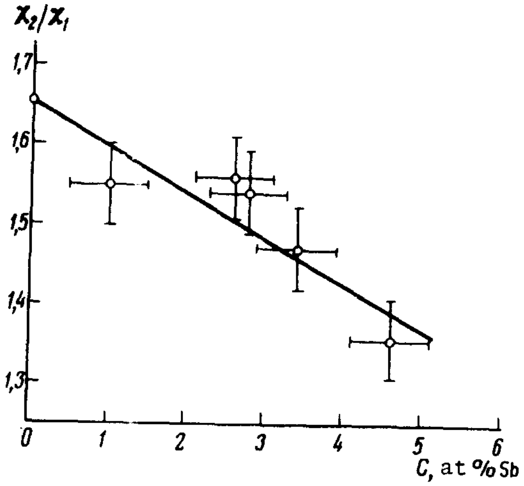

Fig. 3. Ratio of susceptibility χ_2 in the ultraquantum limit to the suseptibility χ_1 in a weak field on the Sb concentration in Bi-Sb alloys.

change of the character of the state density in the conduction band in the ultraquantum region. It should also be noted that a large value of χ_2, close to χ_1, in semiconducting Bi-Sb alloys can make it very difficult to observe the anomalies of the magnetic characteristics of the medium [4] in the case of electronic transitions in strong magnetic fields [8].

We take the opportunity to thank V. S. Zemskoi, V. V. Rozhdestevenskaya, and A. D. Belaya of the Baikov Metallurgy Institute for supplying the samples, G. N. Ronami for analyzing them with the "Cameca" apparatus, and A. S. Borovik-Romanov for a useful discussion of the results.

[1] B. I. Verkin, L. B. Kuz'micheva, and I. V. Svechkarev, ZhETF Pis. Red. 6, 757 (1967) [Sov. Phys.-JETP 6, 225 (1967)].
[2] L. Wehrli, Phys. Kondens. Mater. 8, 87 (1968).
[3] F. A. Buot, J. Phys. Chem. Sol. Suppl. 32, 99 (1971)
[4] M. Ya. Azbel' and S. Ya. Rakhmanov, Fiz. Tverd. Tela 10, 1650 (1968) [Sov. Phys.-Solid State 10, 1304 (1968)].
[5] A. Isihara and J. T. Tsai, Phys. Kondens. Mater. 15, 214 (1972).
[6] A. Goldstain, S. J. Williamson, and S. Foner, Rev. Sci. Instr. 36, 1356 (1965).
[7] L. Pal, Vestnik, Moscow Univ. Phys. Ser. No. 12, 49 (1955).
[8] N. B. Brandt and E. A. Svistova, Usp. Fiz. Nauk 101, 249 (1970) [Sov. Phys.-Usp. 13, 370 (1970)].

METASTABILITY OF LIQUID PHASE UNDER CONDITIONS OF DEVELOPED EVAPORATION OF CONDENSED MEDIA

N. V. Karlov, B. B. Krynetskii, V. A. Mishin, and A. A. Samokhin
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 10 December 1973
ZhETF Pis. Red. 19, No. 2, 111 - 114 (20 January 1974)

We report direct experimental observation of metastability of a superheated liquid phase under conditions of developed evaporation of condensed media by electromagnetic radiation.

When sufficiently intense radiation acts on the surface of an absorbing condensed medium, the temperature of the material in the surface layer can exceed the boiling temperature T_B (developed evaporation). The superheat phenomenon was discussed repeatedly from the point of view of the ratio of the surface to volume evaporation (see, e.g., [1, 2]), but the influence of the metastability of the superheated layer on the dynamics of the evaporation process remains unclear. Some possible manifestations of the metastability of the liquid phase were noted recently in [3 - 5]. We report here the first experimental observation of metastability under conditions of developed evaporation.

A metastable liquid phase has a finite lifetime that depends very strongly on the degree of superheat. This enables us to speak of a limiting superheat temperature T_L that depends on the external pressure p [6]. Under conditions of developed evaporation, p is determined by the surface temperature T_0 and amounts to approximately half the saturated-vapor pressure $p_S(T_0)$. When the radiation intensity I is abruptly decrease, the surface temperature drops, and this leads to a decrease of $p(T_0)$. If $T_L(p)$ is in this case lower than the actual temperature inside the still uncooled liquid layer, then a rapid (explosive) transformation of the metastable liquid into a heterophase system takes place. Estimates of the principal characteristics of this effect are given in [4] for strongly absorbing media (metals).

We consider here the case when the reciprocal absorption coefficient α^{-1} is not small in comparison with the characteristic length of the temperature influence in the stationary regime, χ/v, which is determined by the temperature-conductivity χ and by the velocity v of the evaporation boundary. Under these conditions ($\alpha\chi/v << 1$), the maximum temperature inside the superheated layer can reach values $T_0 + \varepsilon/c$, where ε and c denote respectively the heat of evaporation and the specific heat per unit volume [7]. This quantity, however, usually exceeds the critical temperature T_c, so that a stationary regime of developed evaporation is actually not realized in this form. If the radiation pulse is long enough, the metastable state should decay as soon as the temperature inside the superheated layer reaches T_L. If the initial liquid temperature is T(0), then the time needed to attain T_L is $t_0 \approx c\Delta T/\alpha I$, where $\Delta T = T_L - T(0)$.

However, even before the temperature inside the layer rises to T_L, the temperature on the