with the Bernstein modes as has been suggested by Canobbio and Crocci.[7]

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ELECTRON SCATTERING BY NEUTRALIZED ACCEPTORS IN GERMANIUM

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Based upon the hydrogenic model suggested by Pearson and Bardeen,[1] Erginsoy[2] has developed a formula for the electron scattering by neutralized impurities:

$$1/\tau_I = 20\hbar a^* N_I/m^*. \quad (1)$$

Here a^* is the effective Bohr radius for the impurity electron, N_I is the impurity concentration, and $m^{*-1} = \frac{1}{3}(m_1^{-1} + 2m_t^{-1})$. Though this formula has been widely used for many kinds of neutral impurity in semiconductors, its validity should in reality be confined to the pentavalent donors in Ge or Si. Through the cyclotron resonance work by Fukai et al.,[3] it has been verified experimentally that electron scattering by neutralized group-V impurities in Ge or Si is surprisingly well explained by the Erginsoy's formula. So in this Letter we shall focus our attention on the next typical impurities—the group-III elements.

Neutralized trivalent acceptors in Ge or Si should be compared to antihydrogen in the framework of the effective-mass approximation. Electron scattering by antihydrogen, however, is equivalent to positron scattering by a hydrogen atom apart from the charge relation which does not affect the cross-section calculation. Theoretical treatments of positron scattering by hydrogen atoms have been developed by several authors,[4-7] and the phase-shift calculations for various energies of the incident positron are available. Combining the most recent results by Schwartz[6] and Rotenberg,[7] which are very close to each other (Fig. 1), one obtains the inverse collision time

$$1/\tau_A = 3.5\hbar a_A^* N_A/m^*, \quad (2)$$

where a_A^* is the effective Bohr radius for the acceptor hole, N_A is the acceptor concentration, and m^* is the same as that in (1). This is only

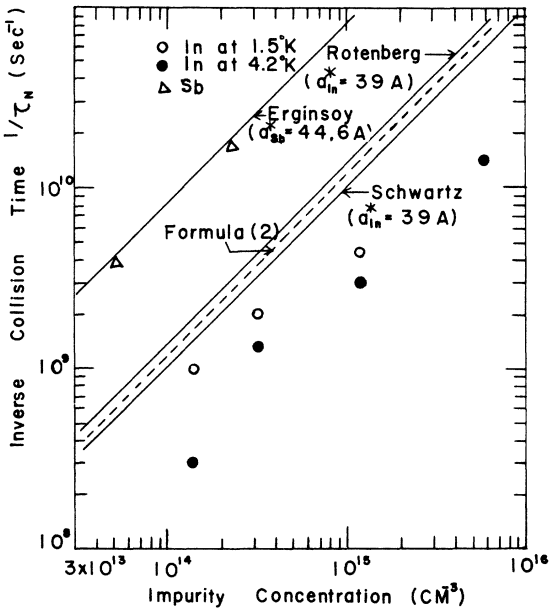

FIG. 1. Inverse collision time due to neutralized impurities is plotted against the impurity concentration. The straight lines give theoretically expected values: "Erginsoy" for Sb with the e^-H scattering model and others for In with the e^+H scattering model. The effective Bohr radii have been adjusted by the method of quantum defect.[3]

approximately valid between 1.5°K and 4.2°K, on account of the energy dependence of τ_A.

A cyclotron resonance experiment has been performed at 8-mm wavelength, using Ge doped with In. In Fig. 1 is shown the inverse relaxation time due to In versus In concentration obtained through measuring the electron-resonance linewidth. Values both at 4.2°K and at 1.5°K are plotted. The lattice scattering has been subtracted through the procedure described in reference 3, and use has been made of the relation

$$1/\tau_L = 3.5\times 10^8 T^{3/2}, \quad (3)$$

which has been obtained with our pure Ge specimen. The possible effects of the accompanying donors are neglected, since their concentrations are suppressed by about two orders of magnitude. This is not strictly justifiable, however, because of the much larger cross section of the donor for electrons. Hence the $1/\tau_{In}$ obtained here gives merely the upper limit for electron scattering by neutralized In. Nevertheless, the experimental points come somewhat below the theoretical lines. One may further note that $1/\tau_{In}$ is larger at 1.5°K than at 4.2°K for the first three samples, thus indicating the existence of a slight temperature dependence in the relaxation time. With the heaviest doped sample, the resonance signal has failed to appear at 1.5°K, though there remains a strong photoconductance signal. For comparison, the experimental values for electron scattering by Sb in Ge by Fukai et al.[3] are also plotted along with the nearly coinciding Erginsoy's formula. One may conclude from these results that the simple Erginsoy's formula for electron scattering utterly fails for the neutralized acceptors; a modified expression based on the e^+H scattering model certainly explains the experimental results much better, but there still remains some discrepancy.

Detailed account of this work and its extension as well as the effects of various other neutralized impurities will be reported in later papers.

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GERMANIUM TELLURIDE: SPECIFIC HEAT AND SUPERCONDUCTIVITY*

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According to Cohen's[1] theoretical predictions, certain many-valley semiconductors and semimetals may be superconductors at experimentally accessible temperatures. Hein et al.[2] have examined germanium telluride containing a large number of carriers. They find that it does indeed show those changes in magnetic susceptibility with temperature to be expected of a superconductor. However, susceptibility (and resistivity) measurements do not exclude the possibility of the superconductivity being confined to unrepresentative regions of the sample.[2] The heat-capacity measurements presented here show that at least the major part of the germanium telluride sample was superconducting and, hence, that the superconductivity observed by Hein et al. is a true bulk effect.

A germanium telluride sample of the type used by Hein et al. was kindly supplied to me by Dr. J. K. Hulm. It was a specially prepared large (one gram-mole) cylinder of nominal composition $Ge_{0.950}Te$, annealed for 10 days at 485°C. Attached to the sample were a carbon (painted colloidal graphite) resistance thermometer, Manganin heater, copper, varnish, and a negligible amount (<0.001 mole) of lead in a superconducting heat switch. Tha apparatus was that described by O'Neal and Phillips.[3] For each series