the weak-field anomaly of an apparent increase in carrier concentration with decreasing temperature in the extrinsic region.

Extrinsic-carrier concentrations were determined for p-type specimens of germanium (55, 50, and 2.2 ohm-cm at 300°K) using the strong-field approximation at −196°C. Mobilities were then calculated from resistivity data. Results are plotted in Fig. 2.

The values obtained from the strong-field calculations are compared with those resulting from the usual weak-field determinations and with drift-mobility data[2] in Table I.

By carrying out measurements in strong magnetic fields and using the equations valid in the limiting cases of such fields, we have found that the calculated mobilities did show good agreement with the results of drift measurements. Also, the ratio of electron to hole mobility at 27°C was approximately 2, the value obtained by Hunter from careful studies on resistivity data. These experiments suggest that differences between mobility values as computed from Hall coefficient and conductivity, and those computed from drift experiments may, for the most part, result from the inadequacies of the weak-field Hall equations in giving the correct values for carrier concentrations in extrinsic p-type germanium. In addition, the extrinsic Hall coefficients determined from strong-field asymptotic behavior were seen to remain relatively constant with decreasing temperature. Hence, there is no anomalous apparent increase in carrier concentrations at the lower temperatures.

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Electron Spin Resonance in Metals at Low Fields[*]

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Kip, Kittel, and co-workers have observed electron spin resonance in sodium[1] and in lithium[2] metal at microwave frequencies and at 300 Mc/sec.[3] Measurements on these metals at lower frequencies have been made by Carver, Holcomb, and Slichter.[4] We wish to report the results of some independent observations, at frequencies near 25 Mc/sec, of the absorption line shapes for lithium from 77° to 300°K and for sodium from 77° to 385°K.

The apparatus was identical to that employed for broad nuclear magnetic resonance lines[5] except for two concentric pairs of Helmholtz coils which provided the main magnetic field (0 to 25 gauss) and the field modulation. The system was calibrated by means of the electron spin resonance in α, α-diphenyl β-picryl hydrazyl. The lithium and sodium samples were dispersions prepared by high-speed stirring of the molten metal in mineral oil; particle sizes ranged from 1 to 50μ, averaging 15μ.

The observed derivatives of the absorption lines were recorded automatically as a function of applied magnetic field at a fixed radio-frequency. They are Lorentzian in shape but distorted somewhat on the low-field side. This distortion can be attributed in part to the use of a resonance frequency less than the total half-width of the absorption. Thus, there is still absorption at zero applied field; moreover, absorption occurs from each of the opposing circularly polarized components of the oscillating rf field. Becker and Eisner[6] have reported similar detailed results for the narrower hydrazyl resonance at frequencies less than 3 Mc/sec. Feher and Griswold[3] have pointed out the possible importance of skin effects in distorting the line shape.

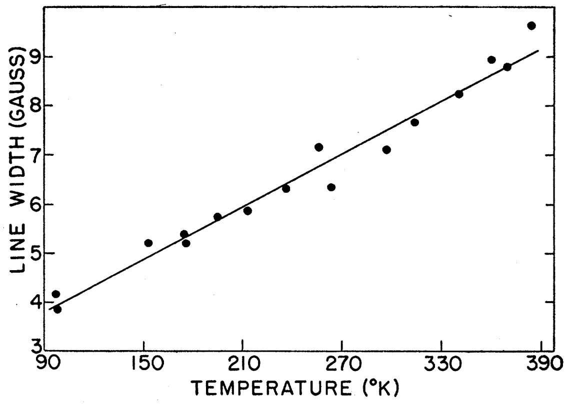

FIG. 1. The temperature dependence of the electron spin resonance absorption in sodium metal dispersed in mineral oil. The line width is defined as the separation between points of maximum slope.

In lithium, the resonance at room temperature has a width of 4.4 gauss between the maximum and minimum of the derivative. Widths of 5 gauss have been reported by Feher and Griswold[3] and by Slichter.[4] The Lorentzian line shape suggests that spin-lattice relaxation processes determine the width, which corresponds to a T_1 of 7.5×10^{-9} sec. This relaxation time is shorter by a factor of 10^2 than Overhauser's theoretical prediction.[7] Feher and Griswold[3] have mentioned that the line width increases at lower temperatures; in our sample at 77°K the width was 4.5 gauss, only slightly greater, if at all, than at room temperature.

On the other hand, the width of the resonance in sodium exhibits a pronounced, reasonably linear dependence upon temperature, as shown in Fig. 1. The width decreases from 9.7 gauss at 385°K to 3.6 gauss at 77°K. The slope of 0.018 gauss deg^{-1} gives a width of about 2 gauss when extrapolated to 0°K. The results were independent of the resonance frequency between 20 and 30 Mc/sec. Feher and Griswold[3] reported a width of 10 gauss at room temperature and noted a temperature dependence as well. The different temperature effects for lithium and sodium present an unresolved problem. Overhauser's analysis[7] predicts an increase in T_1 and therefore a decreasing line width with decreasing temperature. The experimental results suggest that T_1 includes a temperature-dependent and a temperature-independent term, the former increasing with nuclear charge. Holcomb and Norberg[8] have found that nuclear relaxation in the metals is sensitive to impurities and imperfections, which could contribute to the electron relaxation.

Electron spin resonance was observed at 77°K in a sample of high-surface sodium prepared by mixing molten sodium with surface-active alumina (Alcoa F–20; 160 meter^2 g^{-1}). The proportions of sodium and alumina were such that if the sodium film was uniform it was 10A thick. The line shape observed is identical with that for the dispersion in mineral oil, confirming that the resonance is from the sodium and not the supporting medium. Unsuccessful attempts were made to detect the electron resonance in K, Rb, Cs, Cu, Be, Mg, Al, Ta, Nb, and V at 30 Mc/sec at room temperature and in K, Rb, Cs, and Mg at 77°K.

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