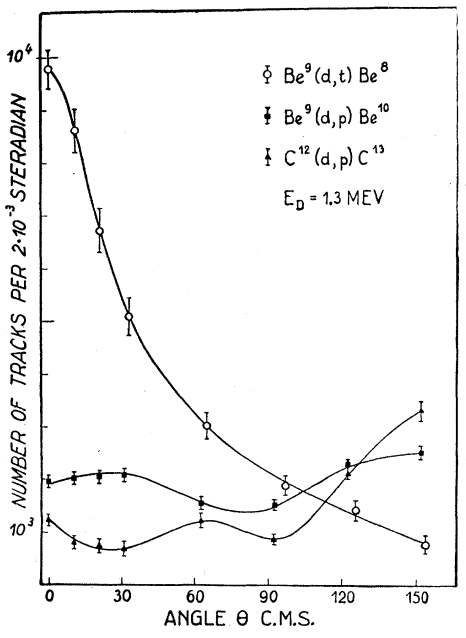

FIG. 2. Angular distributions in the c.m. system. $E_d = 1.3$ Mev. The ordinates give the numbers of measured tracks reported in the c.m. solid angles.

barding energy well below the neutron binding energy, the forward distribution of tritons is striking; it is then possible, taking account of a substantial amount of pick-up, to give a less complex analysis than Resnick and Hanna at low energy. Results at 1 Mev and at more angles, showing still a substantial effect, will be published later. The pick-up process for light elements seems to be more frequent even at low energy that we would expect according to the Bohr model. Its extensive study will certainly give interesting results concerning the possibility of substructures. Similar experiments are in progress with $C^{13}+d$ and are planned with $O^{17}+d$ and Be^9+He^3.

We wish to thank Dr. W. D. Allen and Dr. R. H. V. M. Dawton of Harwell for kindly supplying Li^6, B^{10} and C^{13}, and Professor S. Gorodetzky for facilities granted during the many exposures at the high tension set of Strasbourg. Thanks are due to Mr. Liess for the mechanical device.

* Some consequences of these results relating to substructures for light elements have been presented at the Mainz colloquium, Germany, March, 1952 (unpublished).

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Microwave Observation of the Collision Frequency of Electrons in Germanium

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THE effective mass m^* and relaxation time τ, caused by collisions, for electronic conduction in crystals can be deduced indirectly from such combinations as the drift mobility and the Hall mobility.[1] In germanium, however, at temperatures between 298°K and 160°K the mobility rises from 3800 to 10 000 cm²/volt-sec. At microwave frequencies $\omega\tau$ becomes an appreciable fraction of one radian of phase of the microwaves, and it becomes possible to observe the carrier (electron) contribution to the dielectric constant.[2] A measurement of this contribution then leads in a fairly direct way to the determination of m^* and τ.

Let us assume that germanium can be considered a lossless continuum characterized by a dielectric constant κ_0 to which is added N noninteracting carriers (electrons) per unit volume. These electrons are assumed to have a fixed relaxation time τ and effective mass m^*. The equation of motion for the electrons under the influence of a sinusoidal electric field is given (in MKS units) by

$$\dot{I}+\frac{I}{\tau}=\frac{Ne^2}{m^*}E_0\exp(i\omega t). \tag{1}$$

The electron current is therefore

$$I_0\exp(i\omega t)=\frac{Ne^2\tau}{m^*}\left(\frac{1}{1+i\omega\tau}\right)E_0\exp(i\omega t). \tag{2}$$

The dielectric constant[3] is then given by

$$\kappa=\kappa_0-\frac{Ne^2\tau^2}{\epsilon_0 m^*[1+(\omega\tau)^2]} \tag{3}$$

and the conductivity by

$$\sigma=\frac{Ne^2\tau}{m^*[1+(\omega\tau)^2]}. \tag{4}$$

The dc conductivity is $\sigma_0=Ne\mu=Ne^2\tau/m^*$, where $\mu=e\tau/m^*$ is the mobility of the carriers. The dielectric constant may therefore be written

$$\kappa=\kappa_0-\frac{Ne^2}{\epsilon_0 m^*[(e/m^*\mu)^2+\omega^2]}. \tag{5}$$

It is seen that if the number of carriers and the mobility are known, a measurement of the dielectric constant will yield a value of the effective mass. Over the temperature range 298°K to 160°K the number of carriers for relatively pure germanium remains essentially constant[1] and the mobility[4] varies approximately as $T^{-\frac{3}{2}}$.

The samples were prepared by doping intrinsic germanium with arsenic in order to obtain enough carriers to make the effect observable. Measurements were made of the attenuation and phase shift resulting from a 0.016-inch transverse sample which completely filled the rectangular wave guide of a 1.24-cm microwave bridge. From these measurements the dielectric constant

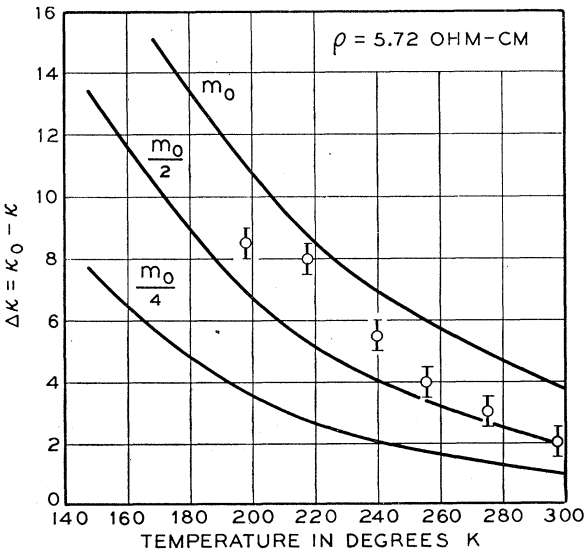

FIG. 1. Plot of $\Delta\kappa=\kappa_0-\kappa$ *vs* absolute temperature for germanium ($\rho=5.72$ ohm cm).

was determined by numerically evaluating the complex transmission coefficient[5] (including multiple reflections in the sample).

For a very pure specimen ($\rho=40$ ohm cm) the contribution of the carriers to κ is negligible at room temperature and for these conditions a value of 16.0±0.5 was obtained. This value was used for κ_0 in Eq. 5 and is in good agreement with infrared data for the index of refraction[6] which leads to $\kappa=16.55$ for $\lambda=2.60$ microns.

The results of the measurements are given in Figs. 1 and 2 where $\Delta\kappa=\kappa_0-\kappa$ is plotted as a function of temperature for samples with room temperature dc resistivities of 5.72 ohm cm

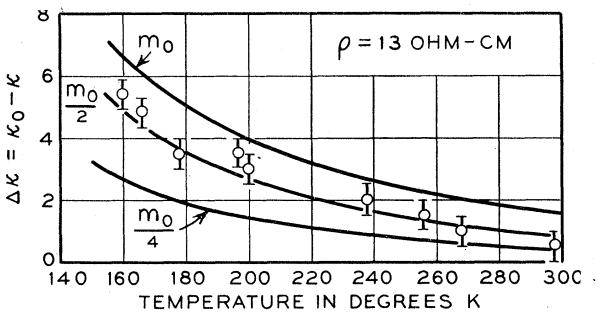

FIG. 2. Plot of $\Delta\kappa=\kappa_0-\kappa$ *vs* absolute temperature for germanium ($\rho=13.0$ ohm cm).

and 13.0 ohm cm. The solid curves are the theoretical curves predicted by Eq. 5 for various effective masses. It is seen that both sets of measurements predict an effective mass of about 0.6 times the free electron mass. It also is seen that the simple theory presented here predicts the proper temperature dependence from which we obtain $\tau=6.6\times10^{-9}T^{-\frac{3}{2}}$ sec for the relaxation time.

The authors wish to thank G. L. Pearson for preparing the samples and M. B. Prince for providing the mobility data prior to publication.

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The Hall Coefficient of Calcium

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IN the course of other investigations regarding the Hall effect, we have measured the Hall coefficient of calcium which seems not to have been determined before.[1] A sample of calcium was kindly put at our disposal by the Metallurgical Laboratory, Technical University of Denmark. The purity was not specified but was supposed to be high. As it seems rather laborious to analyze calcium for small impurities (e.g., CaO), we have measured the electric resistivity, the density, and the lattice constant in order to give a specification of our calcium.

The resistivity was found by passing a known current through a rod of the material and measuring (with a potentiometer) the potential difference between two probes placed over various lengths of the rod. The density was found by weighing a cylinder of known dimensions. The lattice constant was determined with cobalt K_α radiation in a Debye-Scherrer camera calibrated with copper.

The results were, at room temperature:

Resistivity	$(3.60\pm0.03)\times10^{-6}\Omega$ cm.
Density	1.543 ± 0.004 g cm^{-3}.
Lattice constant	$(5.59\pm0.01)\times10^{-8}$ cm (face-centered cubic).

For comparison we may quote:[2]

Resistivity	$4.3\times10^{-6}\Omega$ cm.
Density	1.542 g cm^{-3}.
Lattice constant	5.57×10^{-8} cm.[3]

The density found corresponds well with the ordinarily accepted values of density and lattice constant, whereas the lattice constant found by us is a little too high. The resistivity found is very low, however, and as one would hardly expect the resistivity to decrease as a consequence of impurities, we think we can be pretty sure that our calcium was of high purity, say at least 99 percent.

For measurement of the Hall coefficient the material was rolled down to a thickness of (0.203±0.002) mm. The rolling was carried out at room temperature and in the atmosphere, but the material was protected by an oil film; one annealing (by heating in a very good vacuum) was necessary. The specimens were cut out in rectangular shape, 48 by 17 mm, and measured in air, still being protected against oxidation by an oil film. Immediately

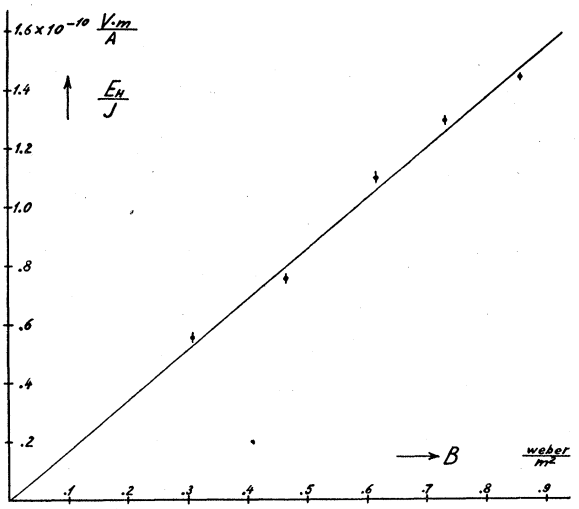

FIG. 1. Ratio E_H/J as a function of magnetic induction B.

before measuring, the surface was scraped clean under oil; no change in the measured Hall potential difference was noticeable for hours afterwards.

The dc was supplied through two circular contacts (2 mm diameter) placed symmetrically at a distance of 40 mm between centers. Reversal of the current direction did not influence the results. Each measurement was performed by measuring the change in Hall potential difference caused by reversal of the magnetic field while the current through the specimen was kept constant.

The two points on the edges of the specimen between which the Hall PD was measured were situated on the same equipotential of the current-field in the absence of the magnetic field. (This was secured in the usual way by connecting one of the leads not to the edge but to a copper wire connected to two points of the edge, and sliding the lead along the copper wire until no change in PD between the two leads appeared on reversal of the current. To minimize thermoelectric forces, this copper wire and all connecting wires were taken from the same piece of wire).

Figure 1 shows the ratio of the measured Hall-field strength E_H to the current density J as a function of the magnetic induction B. Each point is the result of several measurements with different current densities, and the standard deviation ("root mean square error") is indicated. As will be seen, the Hall-coefficient (slope of