

VII. RELATIONS BETWEEN THE HALL EFFECT AND RESISTANCE IN SPUTTERED GOLD FILMS

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Inasmuch as the classical electromagnetic theory appears time after time in the application of quantum mechanics to the atom, where its validity is questionable, it is pertinent, before a general revision of electromag-

netic theory is made, to investigate any and all of the peculiar electromagnetic effects. As Professor Richtmyer has put it, pushing the accuracy of results to the next decimal place frequently results in new developments of importance. So likewise, observing and listing the various aspects of each type of physical phenomena is a necessary prerequisite to future developments.

Sputtered and evaporated films of metals offer convenient material for the investigation of magnetic effects, since their thickness and state of aggregation may be partially controlled, and since they exhibit properties present but scarcely observable in the bulk metal. Starting with "thick films" in which the various magnetic effects are the same as in the bulk metal, it is possible by using thinner and thinner films to trace the changes in each property as other factors are varied. Thin films are particularly well adapted to measurement of the Hall Effect since the Hall e. m. f. is given by the formula

$$e = \frac{R I H}{d}$$

where d is the thickness of the film, R the Hall Constant which is characteristic of the metal, I the current flowing from one end of the film to the other, H the magnetic field placed at right angles to the film, and e the transverse potential difference which appears between the edges of the film upon the addition of the field H . The Hall e. m. f. is known as e . The thinner the film the larger is e , the other factors being maintained constant, until the film is so thin that the current must be made proportionately smaller to avoid overheating.

Previous experiments have shown that: (1) the resistance in films decreases rapidly while the film ages after being sputtered, due to combination or coalescence of the particles; (2) this aging is hastened by heat treatment and by removing the surrounding air; (3) the Hall Effect is independent of change in resistance of gold films by aging at room temperature; (4) a film having a negative temperature coefficient of resistance (explained tentatively by assuming the number of electrons taking part in conduction is increased by heating) may be made by continued heat treatment to acquire the positive temperature coefficient of resistance, as in the bulk metal; and (5) in tellurium films the Hall Effect is directly proportional to the resistance both when the temperature coefficient of resistance (and of the Hall Constant) is negative and when it is positive, and also that during the change from negative to positive coefficient by heat treatment, the plot showing the variation of Hall e. m. f. with resistance is a smooth curve.

The present problem undertaken was to find if the relation of Hall e. m. f. to resistance found in (5) was a general one or only a peculiarity of the metal tellurium which has a Hall Constant that is positive at room temperature, but which changes sign at higher temperatures. The Hall Effect in sputtered films of gold which has the normal (negative) Hall Constant R was observed while the film was heated and cooled between room temperature and 110° C. The observations were taken on freshly sputtered films of gold, and in all the films the Hall e. m. f. decreased rapidly with decrease in resistance on the first heating; in one film a decrease of both Hall e. m. f. and resistance to ten percent of the original values. After the first heating the changes in the Hall e. m. f. and the resistance were much smaller. The Hall e. m. f. temperature curves were very similar to the resistance-temperature curves, and the Hall e. m. f. plotted against resistance shows this resemblance in a smooth curve. For the larger values of Hall e. m. f. and resistance, obtained during the initial heating, this curve is nearly

a straight line, indicating proportionality. It was very difficult to procure the data on freshly sputtered films because of the liberation of gases from the film while being heated, which made the data quite erratic. By a long series of measurements repeating readings of the Hall e. m. f., the irregular disturbing effect of the gases was largely reduced.

There is thus a direct relation between the Hall e. m. f. and resistance when the changes in both Hall e. m. f. and resistance are caused by heating.

If the explanation of the reproducible decrease in resistance upon heating, described in (4), as due to the increase in the number of electrons taking part in conduction—an increase in the number of so-called "free electrons"—be correct, then the simultaneous decrease in the Hall Effect indicates that the more slowly moving electrons are deflected in the magnetic field still less as compared to the faster moving electrons than electro-dynamics predicts; since in the same current I , composure of more electrons, these electrons must move with a smaller average velocity. The amount of deflection (transverse motion) of the electrons in a given magnetic field depends on the atomic restoring forces, hence on the crystal structure. The Hall Constant of various metals might be taken in part as indicative of the number of electrons taking part in conduction and in part as indicative of the crystal structure.

The rapid initial decrease of resistance of a film on heating, which is not reproduced in the same film does not mean, however, an increase in the number of electrons taking part in conduction, but a coalescence of particles. Such a coalescence would reduce the work necessary to move an electron across the film and result in a smaller Hall e. m. f. as this investigation shows.

If we consider that the electrons taking part in conduction are never very free from the atoms (i. e., the attractions to the various nuclei do not cancel out); then the reproducible decrease in resistance upon heating indicates that due to the increased heat motions the electrons find it easier to pass from one atom to another, and as e. m. f. is work per electron the Hall e. m. f. should be proportional to the resistance both in the initial non-reproducible decrease of resistance and Hall e. m. f. upon heating and in the changes while the film has the negative temperature coefficients of resistance and of Hall e. m. f. The Hall e. m. f. should also be proportional to resistance when the film has acquired the positive temperature coefficient of resistance, where heating increases the obstructions to the drift of electrons from atom to atom as the nuclei get more and more in their way.

It has been predicted that if there exist cavities in the metal, the Hall e. m. f. should be the sum of the potential differences in the metal exclusive of the cavities, and the experiment method in (3) bears this out. Reduction of resistance (aging) by heating is then probably not so much an elimination of actual cavities as a reduction only of the difficulty an electron has in passing from one atom to another.

References

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