deposit is pale yellow by reflected light and gray by transmitted light. It is exceedingly soft and loses in reflectivity rapidly when exposed to air.

Magnesium

(Figure 6) Like cadmium and zinc, magnesium must be deposited over a film of chromium. Fresh magnesium surfaces are extremely brilliant and have a very high reflectivity in the near ultraviolet. They tend to tarnish, however, and in the course of a month show definite signs of aging.

Chromium

(Figure 6) This metal forms extremely hard tenacious films which are brown by transmitted light. Its reflectivity is fairly high throughout the near and far ultraviolet. Although it has a tendency when molten to dissolve tungsten, it is not unduly difficult to evaporate.

Antimony

(Figure 6) Films of antimony are very easy to produce, but are exceedingly soft. It is grayish blue by transmitted light and is quite lasting. The reflectivity down to 1200A is fairly good.

Copper

(Figure 6) The evaporation of copper is very easy. It forms bright reddish films which are green by transmitted light. They are soft and tarnish after a week or so in air.

A number of other metals have been attempted unsuccessfully. In general, the difficulty has been either that the film was destroyed rapidly by standing in air, or that it was impossible to evaporate it with the apparatus here described. In the first class fall the alkali metals, calcium, gallium, indium, thallium, and tin, in addition to zinc and cadmium which have been discussed above. The other group consists of cobalt, columbium, iridium, rhodium, silicon, tantalum, uranium, and vanadium.

In conclusion, the author wishes to express his indebtedness to Professor R. C. Gibbs whose constant encouragement and friendly advice have made it possible to bring the work to a conclusion. He is also heavily indebted to Drs. J. E. Ruedy and R. C. Williams for advice in carrying out the evaporation work, and to Dr. H. M. O'Bryan for his generous aid in connection with designing the vacuum spectrograph for determining reflectivities in the far ultraviolet.

JUNE 1, 1939 PHYSICAL REVIEW VOLUME 55

The Magnetoresistance of Nickel in Large Fields

C. W. HEAPS
The Rice Institute, Houston, Texas
(Received April 13, 1939)

The magnetoresistance of a nickel foil has been measured in fields up to 24,000 gauss. A drop of the curves in large fields is found, in disagreement with Alocco's results on similar material, but in agreement with Gerlach's theory that a resistance decrease is produced proportional to the square of the increase of spontaneous magnetization. The constant of proportionality is shown to be dependent on the temperature. It is concluded that spontaneous magnetization may be increased by a magnetic field without saturation appearing, even up to fields of 200,000 gauss as produced by Kapitza.

A FERROMAGNETIC material, unmagnetized in the technical sense, is supposed to consist of randomly oriented domains all magnetized spontaneously to saturation. An external field changes the orientations of these domains and thereby alters the electrical resistance of the material. Furthermore, it appears to be a well established fact that if the spontaneous magnetization of the domains is increased the resistance is decreased. Two obvious ways of changing the spontaneous magnetization consist in (1) varying the temperature of the material,

and (2) varying the strength of a field which is always sufficiently large to maintain technical saturation, or complete alignment of domains.

There is considerable lack of agreement between the various experiments made at room temperature which use method (2) and attempt to detect resistance changes. Some of the earlier experiments[1] on longitudinal magnetoresistance in nickel show a definite maximum followed by a decrease in magnitude of the effect as the field is increased. The cause of this downward drop in the magnetoresistance curve was usually attributed to non-uniformity of field or to a transverse component of magnetization. Later measurements by G. Alocco[2] on thin square films of nickel do not show the drop of the curve. The data collected and shown graphically by McKeehan[3] give no evidence of this effect, perhaps because insufficiently strong fields were used. The results of Potter[4] and of Englert,[5] however, show a decided decrease of longitudinal magnetoresistance in nickel wires as the saturation field is increased.

Since a magnet capable of producing large uniform fields was available it seemed worth while to repeat the experiments with nickel in the form of a thin film as used by Alocco. This film was made by electrodeposition from a nickelous sulphate solution (containing ammonium chloride and boric acid) on to a stainless steel knife blade (kept in continuous rotation) after the manner of Bosworth.[6] A current density of 10 ma/sq. cm was used. The nickel film, about 2.4μ thick, was easily peeled off of the stainless steel with a razor blade. It was uniform and without holes. A section of dimensions 0.90×0.95 cm was cut out, mounted on a flat Bakelite plate, and provided with heavy copper terminals along opposite edges. These terminals were soldered on with Wood's metal.

The specimen was mounted on a holder similar to that used by Jones and Malam so that accurate adjustment of orientation could be made with respect to the magnetic field. For measuring the resistance change a special Wheatstone bridge with low resistances was constructed, and a galvanometer of low resistance and high sensitivity was used.

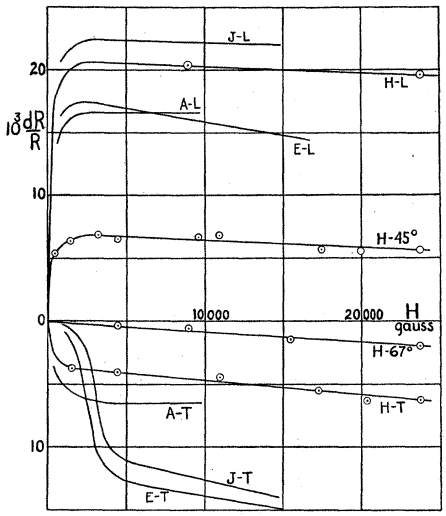

FIG. 1. Magnetoresistance of nickel as a function of magnetic field. Curves from various authors are indicated as follows: *J*, Jones and Malam; *H*, Heaps; *A*, Alocco; *E*, Englert. The letters *L* and *T* indicate longitudinal and transverse fields, respectively.

The magnetic field was supplied by a large water-cooled electromagnet, wound with copper tubing and having a current capacity of 600 amperes. The poles were 18.7 cm in diameter and 1.9 cm apart. For large fields there was approximately a 0.2 percent difference in field strengths between a point centered between the pole faces and a point halfway out along a radius of a pole. The field was therefore very uniform over the specimen which was placed at the central position.

In Fig. 1 are plotted the results obtained for various orientations of the specimen; also curves obtained by other experimenters are given. The two points on the down-sloping curve *H–L* were determined with considerable care, the specimen being oriented so as to produce a maximum value of dR/R. The second point was determined by making repeated measurements of the resistance change produced when the magnetic field was varied over the range between the two points.

It appears from the present experiments that for all orientations of the specimen there is produced approximately the same decrease of

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resistance by a given increase of the magnetic field beyond the saturation value. This conclusion is in general agreement with the results obtained by Englert, but Englert's data indicate a larger effect than is found in the present experiments. It is not clear why Alocco failed to find a drop in his curve for large fields; his curves are definitely at variance with those of other experimenters in this respect.

As regards the relative magnitudes of magnetoresistance found by different observers Fig. 1 indicates considerable diversity. It appears probable that polycrystalline material as used by different experimenters is widely different with respect to preferred orientations of crystallites. Kaya's results[7] on single crystals indicate, especially for the transverse effect, that magnetoresistance is decidedly sensitive to crystalline orientation.

It is interesting to note that the curve H–T of Fig. 1, if continued as a straight line up to fields of 200,000 gauss, gives the value of dR/R as found experimentally by Kapitza[8] in this field. Kapitza's results are not sufficiently accurate in themselves to detect a small slope such as that of H–T. Taken in conjunction with the curve H–T, however, Kapitza's data show that even in fields up to 200,000 gauss there is still no evidence of saturation of the spontaneous magnetization.

The work of Gerlach[9] and his collaborators, and of Potter, indicates that the change of resistance is proportional to the change in the square of the intensity of magnetization. Accordingly we may write $dR/R=aI^2$, where a is a constant and I is the specific intensity of spontaneous magnetization. From this equation we get $d(dR/R)/dH=ad(I^2)/dH$. The value of the left-hand side of this equation may be calculated from the drop of the H–L curve in Fig. 1. The work of Weiss and Forrer[10] on nickel gives $d(I^2)/dH=2.9\times10^{-3}$. Accordingly a is calculated to be -1.75×10^{-5}.

Suppose now that the spontaneous magnetization is reduced to zero by heating the nickel to a temperature above the Curie point. There will then be an increase of resistance given by the first of the above equations, this increase being superposed on any increase arising from the ordinary temperature coefficient. Gerlach and Schneiderhan[11] have determined the resistance-temperature curve of nickel through the Curie point, and find the resistance decrease (which arises from the disappearance of spontaneous magnetization of domains) to be accurately proportional to the square of the intensity of spontaneous magnetization. Their results give $a=-1.7\times10^{-4}$.

The discrepancy between these two values of a, obtained by the different methods, is large. A factor of 10 is not likely to be due to differences in the purity of the specimens used in the different experiments. If the constant a were independent of the temperature T we would have

$$\frac{d}{dT}\left[\frac{d}{dH}\left(\frac{dR}{R}\right)\right]=a\frac{d}{dT}\left[\frac{d(I^2)}{dH}\right].$$

From the work of Gerlach and Schneiderhan the value of the left-hand side of this equation may be calculated over the range 325° to 340°C. The data of Weiss and Forrer enable the value of the differential factor on the right-hand side to be calculated. As determined in this way a is found to decrease from -2.1×10^{-3} at 340° to -4.9×10^{-4} at 325°. Apparently, therefore, a depends upon the temperature, and the two methods used above for determining a cannot be expected to give the same result.

In summary it may be said that spontaneous magnetization is increased by an increase of a large magnetic field, and the resulting resistance decrease shows no saturation effect in the largest fields so far obtained in the laboratory. There is no satisfactory theory as to why the resistance decrease should be proportional to the square of the spontaneous magnetization. However, the constant of proportionality appears to be a function of the temperature, so that a given change of spontaneous magnetization, made at a high temperature, has a larger effect on the electrical resistance than the same change made at a lower temperature.

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