Physical Significance of Certain Apparent Irregularities in the Magneto-Resistance Curves of Nickel

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ABSTRACT.

The change of resistance of nickel in small longitudinal magnetic fields is studied with a view to determine the reality of negative changes and intersections of individual parts of the resistance-hysteresis curves. It is found that the negative change is a physical reality and not an experimental error. It is a record of the previous magnetic treatment of the material, and depends on the maximum field used in a cycle. The negative change is not observed even with a sample possessing residual magnetism at the beginning, if the maximum field to which it is subjected during a resistance-hysteresis cycle is above a certain value. It is suggested that the real " zero state " of a sample is the state corresponding to its minimum resistance in a cycle.

The intersections of parts of the resistance-hysteresis curves are found to be real. As these intersections do not occur in the curves of magnetisation, they seem to be associated with process of electrical conduction in metals. A new field of investigations is thus opened for theoretical physicists. The existing theories of electrical conduction are unsatisfactory. The formulation of a theory, relevant with observed facts, is necessary.

Introduction.

The problem of the change of resistance of metals in magnetic fields, has been studied by innumerable workers.

Nickel attracted a good deal of attention as it presented certain apparent anomalies in low applied fields. Some earlier workers on this subject found that, for low values of the magnetic field, there was a decrease in the resistance of nickel. In this connection the work of Vilbig[1] may be mentioned here. He measured the change of resistance of nickel wire, 0·051 mm. in diameter, over its complete magnetic cycle. Individual parts of the curves so obtained showed frequent intersections. The change in resistance between 0 and 55 gauss was found to be negative. Vilbig also studied a number of samples between 0 and 55 gauss, and found the change of resistance to be negative. He did not give any explanation of these phenomena.

O. Stierstadt[2] working with samples of nickel wire possessing residual magnetism at the beginning, found that the negative change was obtained between 0 and 30 gauss, when the field was first increased to about 150 gauss, and then decreased to zero and subsequently increased in the opposite direction. He considers the state of the sample with residual magnetism at the beginning as the "zero state" and finds that the minimum resistance is smaller than that in the zero state. On the basis of these results he asserts that the incomplete demagnetisation of the sample before each measurement accounts for the reversal in sign of the effect in low fields. He is uncertain as to the reality of the intersections of the resistance-hysteresis curve, obtained by Vilbig. McKeehan[3] found these intersections to occur, when studying the change of resistance of permalloys by tension in the magnetic field. Stierstadt has emphasised the need for further research work on these intersections, specially for nickel.

The object of the present investigations was to determine the conditions in which the negative changes of resistance and

[1] Fr. Vilbig, Arch. f. Elektrotechnik, 194, 1929.

[2] O. Stierstadt, Phys. Rev., (2) 37, 1356, 1931.

[3] L. W. McKeehan, Phys. Rev. (2), 36, 948, 1930.

the intersections are obtained, and to find the physical reality and significance, if any, of these phenomena.

Experimental.

An electromagnet was used for the production of the field. The strength of the field was almost uniform over a length of 4 cms. between the pole pieces. The difference in the values of the field between the ends and the centre of the 4 cm. range was less than three per cent. for a field of 600 gauss. For lower values of the field, the difference was considerably less. Besides, the non-homogeneity of the field can only alter the slope of the magneto-resistance curve for high values of the field. It cannot affect the form or the paths of the curves.

The change of resistance was measured by a sensitive Kelvin Double Bridge. The nickel wire (0·071 cm. in diameter) was formed into a rectangular coil in one plane of 6 or 7 turns, the length of each turn being about 3 cms. An ebonite carriage was mounted on the pole pieces of the magnet and the coil of wire was hung from brass terminals, projecting downwards from the ebonite carrier. The coil was always mounted parallel to the field. Connections to the bridge were taken from the projecting portions of the same terminals above the ebonite plate. Soldering was avoided to ensure the absence of thermo-electic and the thermo-magnetic effects.

It is evident that with the mounting of the coil described above, the field was not exactly parallel to the whole of the coil. Parts of the wire at the bends of the coil were transverse to the field. The total length of the transverse parts was a negligible fraction of the longitudinal parts. The error due to the transverse portions was thus very small and could not possibly affect the results as the transverse effect becomes manifest only in very high fields of the order of thousands of gauss.

The electromagnet, together with the wire mounted as described above, was enclosed in a simple air thermostat. The maximum fluctuation in temperature was about 0°·25 C about the mean constant temperature 32°·5 C.

The samples were not demagnetised before measurements. This was done purposely to see the effect of residual magnetisation on the nature of the curves. The resistance of the sample in zero applied field at the beginning was measured, and the subsequent changes in resistance calculated with reference to this.

Discussion of the Results.

The Negative Change.

Fig. 1 shows the resistance-hysteresis cycle of nickel between 0 and 200 gauss. A negative minimum of resistance

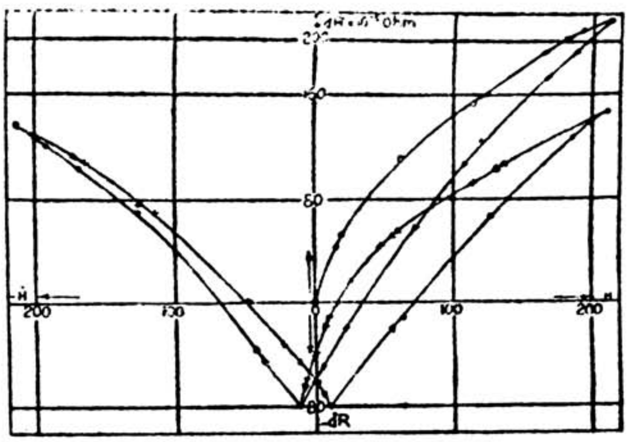

FIG. 1.

is obtained, and the negative change is found to occur between 0 and 60 or 70 gauss. At the start, the curve for decreasing fields is found to be situated below the curve for increasing fields. Fig. 2 is another typical example of negative change. Here also we find the curve for decreasing fields situated below the curve for increasing fields. The change of resistance is found

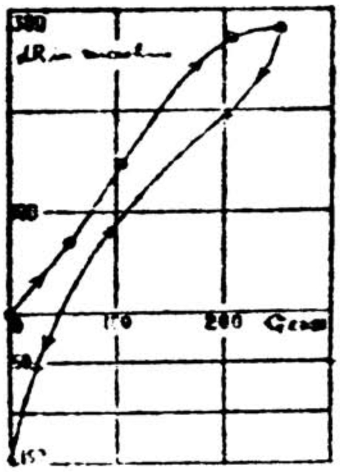

FIG. 2.

to be negative between 0 and 50 gauss. The curve of Fig. 2 was obtained in the following manner. The resistance of a sample of nickel wire being measured, the field was increased to about 250 gauss and then brought back to zero. The resistance of the wire was now measured. This was found to be greater than the original resistance. Taking this resistance in zero field as the starting point, the field was now increased in the opposite direction, and gradually brought back to zero. The resistance of the sample was measured at suitable intervals and the changes in resistance were calculated with reference to the resistance at the starting point, mentioned above. It is clear from this that the negative change depends on the previous magnetic treatment of the material.

Stierstadt, who also observed the negative change under similar conditions, failed to notice the effect of the magnetic history. He believed the negative change to be an error due to the incomplete demagnetisation of the sample before each measurement. This is not true. A sample, possessing residual magnetism at the beginning, gives the negative change only when the maximum field in the cycle is below a certain value. This is at once apparent from the results of Stierstadt, Vilbig and ourselves. But the former workers failed to notice this fact in their own results. The effect of the maximum field on the change of resistance of a sample not demagnetised at the beginning, is shown in Fig. 3. Here the maximum field in the cycle is about 600 gauss and the change of resistance is always positive. All our attempts to get a negative change when the maximum field in the cycle was above 300 gauss, failed.

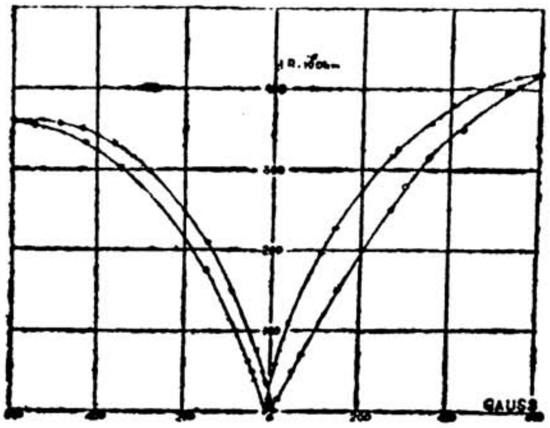

Fig. 3.

It is evident from the above discussions that the negative change depends on the previous magnetic treatment of the material and the maximum field to which it is subjected during a resistance-hysteresis cycle. If we regard the minimum resistance in a cycle as that corresponding to the "zero state," the negative change disappears. This definition of the zero state appears to be plausible. Stierstadt did not get the negative change with a completely demagnetised sample. This was because the sample was in its real zero state. But we should remember that even if we take the state of a sample with some residual magnetism at the beginning as the zero state, the negative change is not obtained if the maximum field in the cycle is above a certain value. This is what the earlier workers failed to consider, and hence they regarded the negative change as an error. They did not notice the physical significance of the apparent negative change of resistance in small magnetic fields.

The Intersections.

Figs. 4 and 5, are examples of the intersections of the individual parts of the resistance-hysteresis curves of nickel.

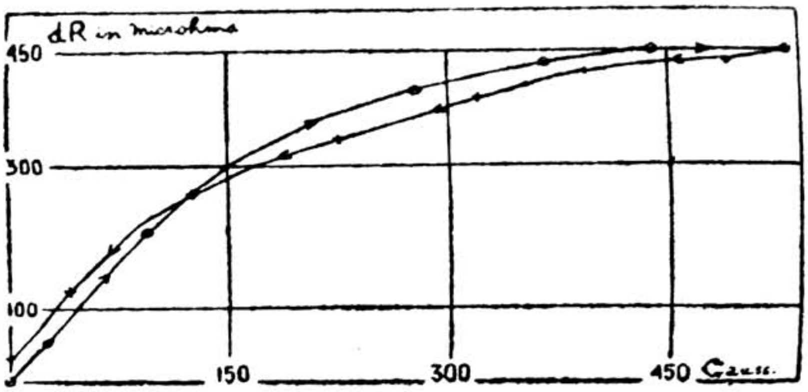

Fig. 4.

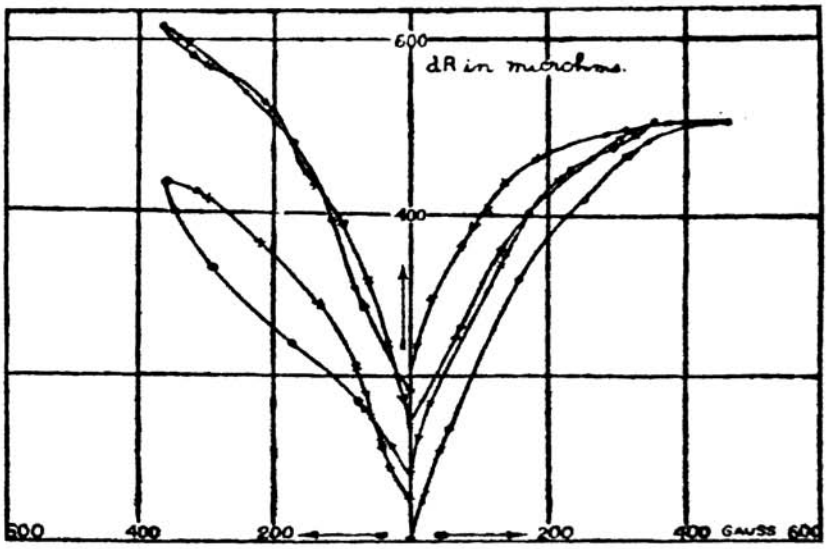

Fig. 5.

Fig. 4 shows half a cycle only. The crossing is marked by the formation of a distinct loop. Fig. 5 gives four successive half cycles. Here we notice that in the 2nd and 3rd half cycles, the intersections occur frequently. Here we have not shown the minimum resistance in any cycle. At the beginning of the 2nd, 3rd and 4th half cycles, the ordinates for zero field have been joined directly to the corresponding ordinates for 75 gauss (nearly). This value of the field was much above that which would have given the minimum resistance. This was done to simplify the curves as our object was to study the higher parts of the cycles for the occurrence of the intersections. The curves of Figs. 4 and 5 give a decisive evidence in favour of the reality of the intersection. In Fig. 5 we notice another interesting fact. The value in zero applied field is gradually going down. In Fig. 1 we can see that the curve is getting stabilized after the first cycle. The curve of Fig. 5 also might have got stabilized after a number of cycles. Stierstadt also noticed the gradual stabilization of the resistance-hysteresis curve after a single or repeated passing of the minimum range. He observed this stabilization for the negative change in low fields. A detailed discussion of the stabilization of the magnetic-resistance curves will appear elsewhere.

Fig. 5 also shows that the intersection may begin to appear when the curve due to decreasing fields is going below that due to increasing fields. If the curve for decreasing fields is going overhead as in the preliminary half cycle in Fig. 5, there is no intersection. This going down of the curve for decreasing fields is just the reverse of hysteresis. Here the fall of resistance with diminishing fields, instead of lagging behind the field is actually going far in advance of it. This is very interesting, and opens a new field of investigation for theoretical physicists.

As the intersections do not occur in the curves of magnetisation, they seem to be associated with the process of electrical conduction in metals. The existing theories of electrical conduction are unsatisfactory. The classical theory can only explain magnetic hysteresis. It cannot explain the change of resistance of metals in longitudinal magnetic fields. Sommerfeld[4] applied the Fermi Statistics to the electrons and found that there should be no change of resistance in longitudinal fields. Thus the existing theories are in direct conflict with observed facts. A theory of electrical conduction to be at all satisfactory, should account for the change of resistance in longitudinal magnetic fields and the intersection of parts of the resistance-hysteresis curves.

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A. Sommerfeld, Zeits. f. Physik, 47, 1, 1928.

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