detector plate current by a logarithmically diminishing current in an electric circuit containing a standard resistance and a standard condenser.

Fig. 9 shows the variation with magnetic field intensity of the decrement of longitudinal vibration in a soft iron rod magnetized parallel to its axis. The curve upon which no points appear is the so-called "reversible" magnetization curve for the iron. It will be noticed that the internal friction remains constant over the entire steep portion of the magnetization curve and then increases to twice its initial value as the magnetization approaches saturation.

The magnitude of the coefficient of internal friction may also be obtained by measuring the electrical resistance of the piezoelectrically excited oscillator at resonance with an ordinary a.c. bridge. The bridge method, while more difficult to handle, has a wider range of application than the decremeter. The two methods supplement one another in a study of the behavior of these composite piezoelectric oscillators.

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BARKHAUSEN EFFECT: ORIENTATION OF MAGNETIZATION IN ELEMENTARY DOMAINS

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SINCE the postulate of the elementary domain by Weiss,[1] and the discovery of the discontinuous nature of the magnetization process by Barkhausen,[2] there have been many investigations attempting to throw more light on the nature of the elementary regions in each of which the magnetization changes as a unit. On the experimental side we are interested in knowing the sizes of the domains, the extent to which the domain is localized in space, the extent to which it is "saturated" in one direction, and the orientation of its magnetization vector before and after the change.

It has been found that all, or nearly all of the change in magnetization takes place in jumps, at least on the steeper portions of the hysteresis loop;[3] and that the volume of a domain varies but little with the condition of the iron, being sometimes thousands of times smaller, and sometimes thousands of times larger than a crystal.[4]

Mr. Dillinger and the writer have obtained some evidence that the elementary domain is a region well localized in space, within the whole of which the elementary magnets reverse. The following experiment is to the point. Two search coils are connected in series opposing to the amplifier. They are placed coaxially with the sample, equidistant from its middle. The distance between them is varied and the intensity of the Barkhausen effect is measured as a function of this distance. The differential effect increases rapidly with the distance between the coils until the distance is greater than about 3 cm. But the attainment of maximum at this distance is not due to the permanent change in magnetization over the 3 cm, but rather to the spread of eddy-currents for about that distance along the wire. This is proved by placing a small coil of wire carrying a small alternating current, around the middle of the specimen and making measurements similar to those of the Barkhausen effect just mentioned. The results,[5] plotted in Fig. 1, show that the measured spreading of a single disturbance due to an alternating field will account for the observed spreading of the Barkhausen discontinuities. As far as the data go they are consistent with a point source of the Barkhausen disturbance, but the accuracy

[1] P. Weiss, Jour. de physique [3] **8**, 542 (1899); Phys. Zeits. **9**, 358 (1908); P. Weiss and G. Foex, Le Magnétisme, Paris, 162 (1926).

[2] H. Barkhausen, Phys. Zeits. **20**, 401 (1919).

[3] R. M. Bozorth, Phys. Rev. **34**, 772 (1922). A similar result has also been obtained by F. Preisach, Ann. d. Physik (5) **3**, 737 (1929) with a different method.

[4] R. M. Bozorth and J. Dillinger, Phys. Rev. **35**, 733 (1930).

[5] Calculated from data already published (reference 4).

merely fixes the length of the domain as less than a few mm. The best assumption now is the simplest, that the group is as compact as possible.

Closely related to the spatial extent of a domain is the question as to its degree of saturation. Is the magnetization always at saturation in some direction, only the orientation changing? Mr. Dillinger and the writer have answered this question to some extent by a study of what may be called the *transverse* Barkhausen effect.[6] The experimental arrangement is shown in Fig. 2. The specimen is in the form of a tube about 2 feet long. Along its axis is a heavy copper wire carrying a current, effecting circular magnetization of the tube. Changes in magnetization perpendicular to the direction of gross circumferential magnetization are picked up by the search coils shown. The longitudinal or ordinary Barkhausen effect is determined in the usual way by magnetizing the tube lengthwise in a long solenoid, with the same search coils.

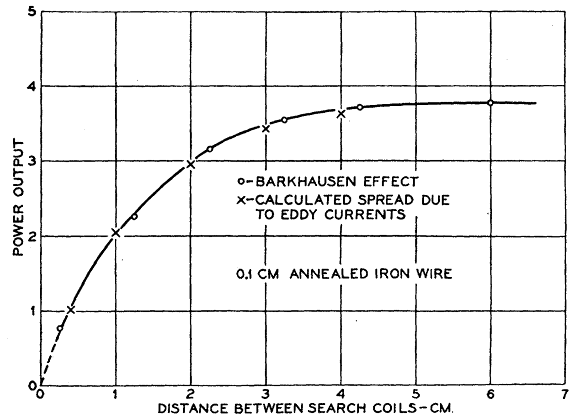

Fig. 1.

The ratios of the average transverse to the average longitudinal change in magnetization for various parts of the magnetization curves[7] are shown in Fig. 3. It is better to plot this ratio as a function of B-H as shown in Fig. 4; here the hysteresis is much less pronounced, and it is seen that the transverse effect becomes relatively much more important at higher inductions. The minimum ratio is 0.05 corresponding to the complete reversal of magnetization in a domain with the direction of magnetization inclined 5° to the direction of the field. At higher magnetizations the ratio increases until it is almost equal to unity when $B-H=15{,}000$ and rises quickly to six when $B-H=16{,}000$.

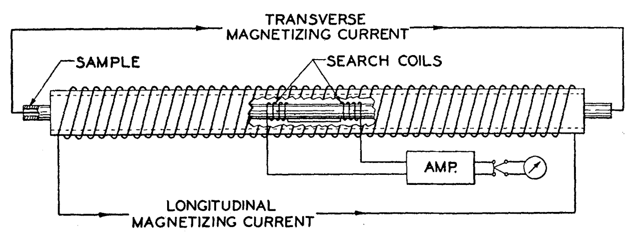

Fig. 2.

These data can be interpreted best in connection with the diagrams of Fig. 5. Some possible modes of change are shown consistent with Akulov's recent theoretical investigations[8] which,

[6] Preliminary note by R. M. Bozorth and J. F. Dillinger, Phys. Rev. [2] 38, 192 (1931).

[7] Magnetization curves were determined for both longitudinal and transverse magnetization and were found to be almost identical.

[8] N. S. Akulov, Zeits. f. Physik **67**, 794 (1931).

in connection with experimental data[9] on single crystals, indicate that the magnetization is directed very closely along one of the six <100> directions in the crystal (parallel to the edges of the crystallographic unit cube), at least until the material is about three-quarters saturated.

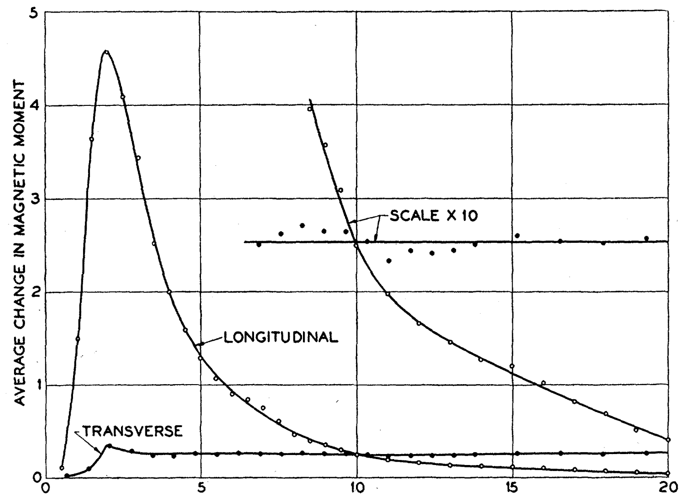

Fig. 3.

In the figure the solid arrow indicates the direction of magnetization before the change, and the dotted arrow the direction after the change. In (a) the direction of magnetization of the crystal which constitutes the greater part of the domain coincides as always with the direction of the

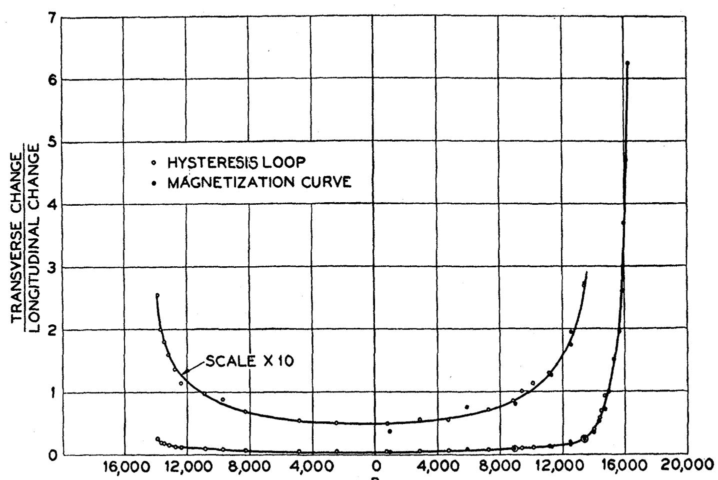

Fig. 4.

cube edge and makes an angle of more than 135° with the direction of the applied field, *H*. By assuming in accordance with Akulov's theory that the magnetization takes up the position of minimum potential energy, the most stable position after the change is that shown, again coincident with a cube edge. If the direction of magnetization, however, happens to lie initially

[9] W. L. Webster, Proc. Roy. Soc. Lond. **107A**, 496 (1925). K. Honda and S. Kaya, Sci. Rep. Tohoku Univ. **15**, 721 (1926).

between 135° and 90° to the direction of H, as shown in (b), the change in its direction will be 90° and not 180° as before. In this case the ratio of the transverse component (T) to the longitudinal component (L) of the change will be much greater than before. This ratio will be still greater as the initial direction of magnetization approaches nearer to that of H, as shown in (c), until the angle between the magnetization and field is 45°. When the direction of magnetization coincides with a cube edge and makes an angle of less than 45° with the direction of the applied field, there will be no other direction of less potential energy to which the magnetization can change and therefore there will be no Barkhausen effect. When the field-strength becomes high enough, of the order of 100 gauss, the direction of magnetization will depart from the <100> direction nearest to that of the applied field, and saturation will be approached. In a more quantitative treatment the two-dimensional diagram must, of course, be abandoned and three dimensions taken into account

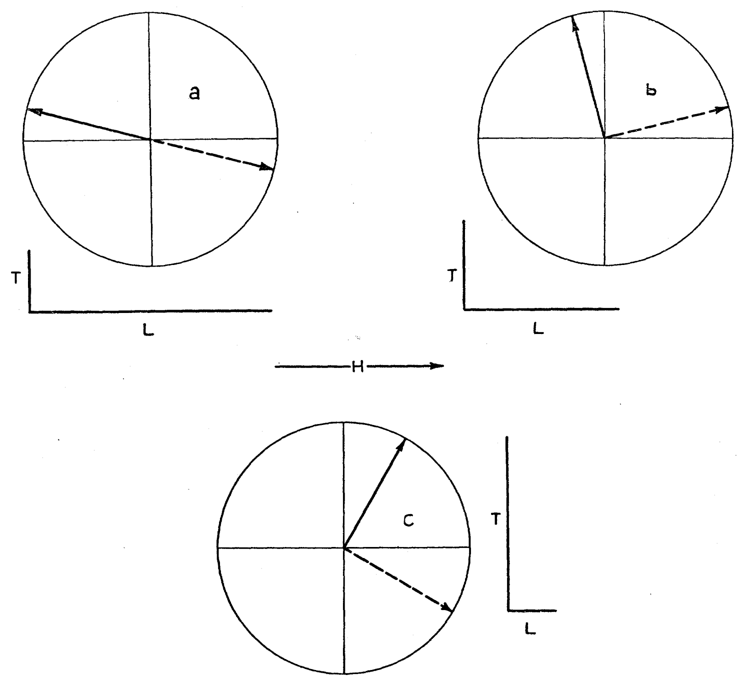

Fig. 5.

In a demagnetized specimen the directions of magnetization in the various domains will be oriented at random. As the field-strength is slowly increased from zero those domains will be first affected in which the direction of magnetization makes the greatest angle with the direction of the field, because the potential energy of those domains will be greatest. The diagram illustrates how the ratio T/L changes as the magnetization of the whole specimen increases according to this scheme; the ratio is small when the magnetization is small, and continually increases as magnetization proceeds, finally becoming much larger than one. Qualitatively, the data support this theory, the ratio of transverse to longitudinal change becoming greater as domains with less potential energy are turned by the field. As $B-H$ increases, the transverse change tends to become constant and the longitudinal change smaller according to both theory and experiment. We should expect the ratio to increase as $B-H$ increases up to that value of $B-H$ beyond which changes from one <100> direction to another cannot increase the magnetization parallel to the applied field. We should expect also that the Barkhausen effect should vanish when the individual magnetization vectors are within 45° of the field vector, that is at about 85 percent saturation, a magnetization attained in ordinary iron at about $H=100$ gauss. It is hoped that more quantitative tests of these ideas can soon be made.