

Magnetic Domains on Silicon Iron by the Longitudinal Kerr Effect*

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USE of the normal Kerr magneto-optic effect to observe domain patterns in ferromagnetic substances having free surface poles has been described by Williams, Foster, and Wood.¹ Since plane polarized light reflected normally from a polished magnetic surface is not affected by magnetization in the plane of the surface, oblique reflection using the longitudinal Kerr magneto-optic effect² has been investigated as a means of observing domains in a single crystal of silicon iron where the magnetization is in the plane of the crystal surface. The plane of polarization of the reflected light suffers a positive or negative rotation depending upon the direction of magnetization. For magnetic saturation this rotation amounts to about 4 minutes at an angle of incidence of 60°. Ambiguity with the transverse Kerr effect is avoided by polarizing the light at right angles to the plane of incidence, for which direction the transverse Kerr effect is zero.³

Two methods have been used to observe domain structure on the (100) surface of the silicon iron crystal. Observations of Kerr effects over local portions of the surface have been made by illuminating the surface with a small optical probe, passing the reflected beam through a nicol analyzer set about 2° from extinc-

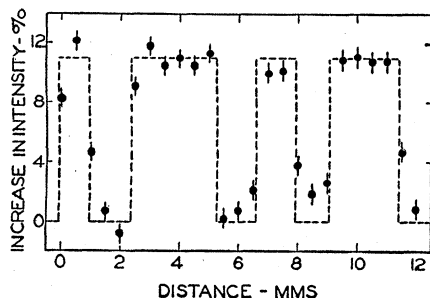


FIG. 1. Percentage increase in transmitted light with magnetization of silicon iron crystal along a line through the center of the crystal in the [001] direction. The broken line indicates the domain configuration suggested and substantiated in (b) of Fig. 2.

tion, and measuring the intensity of the transmitted light with a sensitive multiplier phototube circuit. A traverse of the crystal in an unmagnetized state with a 0.5-mm probe of light, when compared with a similar traverse after application of a small external field, indicates those regions in which there has been a change in surface magnetization. Figure 1 is the result of such analysis for traverses in the [001] direction across the central portion of the (100) surface.

Since the contrast between regions magnetized in antiparallel directions is about 10 percent, photographic observations are possible with a suitable optical system. Figure 2 shows oblique photographs of the crystal with the same domain arrangement as that scanned photoelectrically. (a) and (b) differ 180° in the position of the crystal, resulting in the reversal of the relative intensities of adjacent domains. (c) is the result of magnetizing the crystal along the direction of the original domains, namely the [010] direction. This is the long dimension of the crystal although it appears otherwise because of the angle at which the picture was taken. While the crystal was electro-polished to a mirror surface, oblique photography and the need for increasing the contrast in development and printing have magnified surface imperfections and resulted in its rough appearance.

It is interesting to note that a particular domain pattern is generally quite stable and persists indefinitely under normal conditions of handling. Magnetization and subsequent demagnetization generally result in different domain bands, always parallel to the

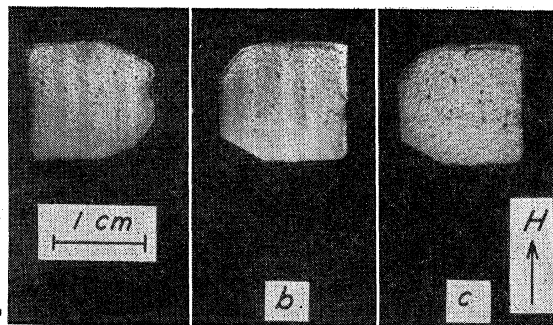


FIG. 2. Oblique photographs of the (100) surface of the crystal. In (a) and (b) the crystal is unmagnetized. An external field in the direction shown was applied in (c).

long side of the crystal surface. There is some evidence, however, that patterns may eventually reoccur.

Results seem comparable with the magnetic powder patterns obtained by Williams, Bozorth, and Shockley⁴ although we have not yet employed their method on this particular crystal.

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* Supported by the ONR.

¹ Williams, Foster, and Wood, *Phys. Rev.* **82**, 119 (1951).

² *International Critical Tables* (McGraw-Hill Book Company, Inc., New York, 1929), first edition, Vol. VI, p. 438.

³ L. R. Ingersoll, *Phys. Rev.* **35**, 312 (1912).

⁴ Williams, Bozorth, and Shockley, *Phys. Rev.* **75**, 155 (1949).

⁵ H. J. Williams, *Phys. Rev.* **52**, 747 (1937).

The Occurrence of Heavy Mesons in Penetrating Showers*

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IN the course of a cloud chamber study of penetrating showers, two events have been observed which probably represent the decay in flight of τ -mesons,¹ and one event which probably represents the decay in flight of a κ -meson.²

One of the τ -meson decays is shown in Fig. 1. The particle enters the chamber at the top, traverses the 2.5-cm lead plate with no detectable deflection, and decays in the lower section of the chamber into three charged particles. All of the tracks except that of the left-hand secondary are at, or very near, minimum ionization; the ionization of the latter secondary is estimated to be 1.4–2.2 times minimum. The momentum of the τ -meson, based upon its curvature in the 5000-gauss magnetic field, is 600 ± 100 Mev/c, and the momenta of the three secondary particles are, from the left to right, 155 ± 30 , 350 ± 75 , and 210 ± 50 Mev/c. The masses of the secondaries are therefore $350 \pm 75 m_e$, less than $600 m_e$, and less than $300 m_e$, respectively, and are thus all consistent with π -mesons, but none can be a proton. Charge is conserved, and the measured momenta are consistent with conservation of momentum in the decay. The mass of the τ -meson, calculated from the above momenta, is about $975 m_e$, which corresponds to an energy release of about 75 Mev.¹ It would be extremely difficult to interpret this event as a collision phenomenon.

The second τ -meson decay is similar in appearance to the above one, but the momenta are higher, making the mass limits on all of the particles less sharp. Both of these τ -mesons, which are the only ones we have so far observed to decay, travel much farther inside the chamber before decaying than do V -particles; this suggests that their mean life is considerably longer than that of V -particles—perhaps 10^{-9} sec or even longer.

The κ -meson decay is shown in Fig. 2. The particle (heavily ionizing) enters the upper chamber from the right, proceeds downward toward the left, and decays above the plate, producing a single charged particle (which travels upward toward the left) and presumably one or more neutral particles. The momentum of the κ is 185 ± 20 Mev/c, and its ionization, estimated visually, is 6–10 times minimum. Thus its mass is $1200 \pm 300 m_e$. The momentum of the secondary particle is 150 ± 15 Mev/c, and its ionization is about 1.2–1.6 times minimum, indicating a mass of $250 \pm 50 m_e$, a value consistent with either a π - or μ -meson. The kinetic energy of the meson (assumed to be a μ) in the center-of-mass system is 82 Mev.

This event might alternatively be interpreted as the decay of a V^0 or V^- particle. However, the absence of a nearby origin from which either of these particles could have come suggests, rather, a longer-lived particle which can decay at a great distance from its point of origin, even though it is moving slowly. Furthermore, if the event were to represent the decay of a V^0 -particle, the latter

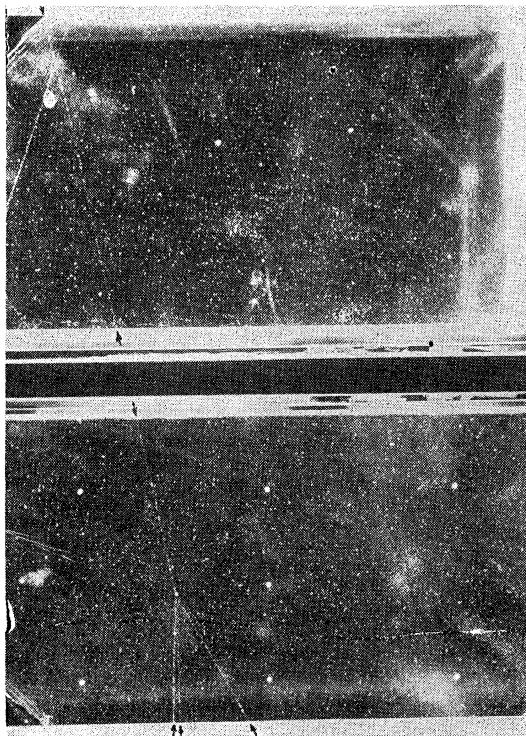


FIG. 1. The decay of a τ -meson.

would have to be traveling upward, and would thus be the only one to do this out of more than 150 observed V^0 -particles.

The presence of both τ - κ -mesons in penetrating showers is also indicated by direct estimates of the masses of heavily-ionizing particles in these showers. Preliminary results suggest that the flux of τ - and κ -mesons may be rather great—perhaps much greater than that of V -particles.

In addition to several τ - and κ -meson tracks, this preliminary survey has also yielded three tracks which may indicate the existence of a particle whose mass lies in the range 400–650 m_e . The momenta of these particles are 180 ± 20 , 100 ± 15 , and 135 ± 15 Mev/c, and their ionizations, estimated visually by comparing them with time-coincident protons, mesons, and electrons on the same photographs, are 2–3, 3–6, and 4–8 times minimum, respectively. These measurements indicate masses of $550 \pm 150 m_e$, $450 \pm 150 m_e$, and $750 \pm 150 m_e$, respectively. Only with great difficulty can the first two tracks be reconciled with those of

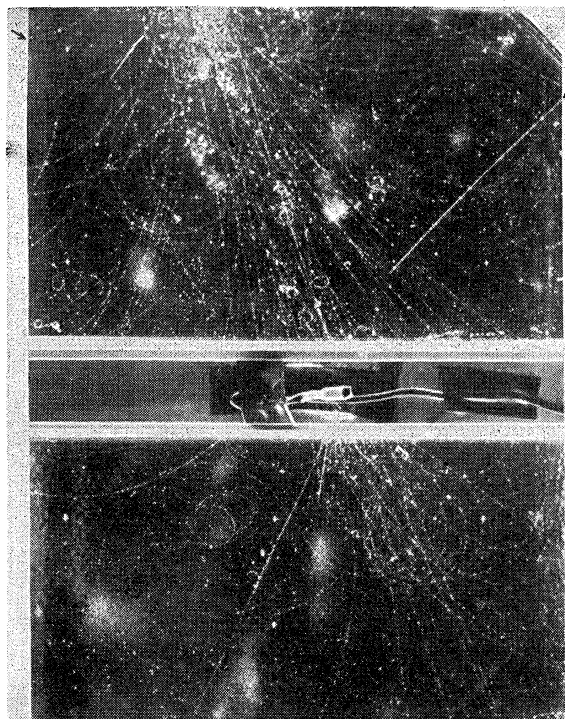


FIG. 2. The decay of a κ -meson.

either π - or τ -mesons; the third cannot be a π -meson, but might conceivably be a τ -meson.

It should perhaps be mentioned that there are indications, mainly from the division of momentum between V^0 -particle secondaries, that particles of mass 500–700 m_e are sometimes produced in V^0 decay.

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¹ Brown, Camerini, Fowler, Muirhead, Powell, and Ritson, *Nature* **163**, 82 (1949).

² C. O'Ceallaigh, *Phil. Mag.* **42**, 1032 (1951).

Motion of an Electron in a Perturbed Periodic Potential

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IN a previous publication¹ (referred to as I) a generalized multi-band form of Wannier's theory² was derived and used to establish the region of validity of Luttinger's³ generalization of the one-band theory. In the presentation of the theory a logical gap was overlooked, so it was necessary to note in proof that the diagonal part of the operator ξ^μ , which represents the μ -component of the electron coordinate, need not have the form used throughout the last half of the paper. Accordingly, it was stated that the equations of (I) were to be modified so that the part of ξ^μ in the n th band became $x^\mu + \xi(p)_{nn}^\mu$ instead of x^μ , $\xi(p)_{nn}^\mu$ being some periodic function of p . Now such a form for ξ^μ is not objectionable for the formal structure of the theory. However, it is a great inconvenience in a calculation because of the additional complexity which it introduces into the commutation rules as a result of the p dependence of ξ_{nn}^μ . For this reason, one would want to simplify the form of ξ_{nn}^μ as much as possible. It will be shown that in every case ξ_{nn}^μ can be made independent of both p and x , and hence is a constant which will be called X_n^μ . X_n^μ has a simple significance.

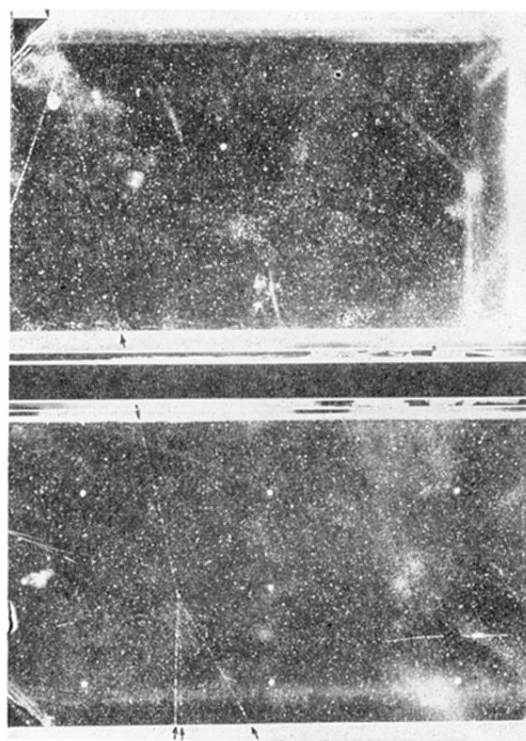


FIG. 1. The decay of a τ -meson.

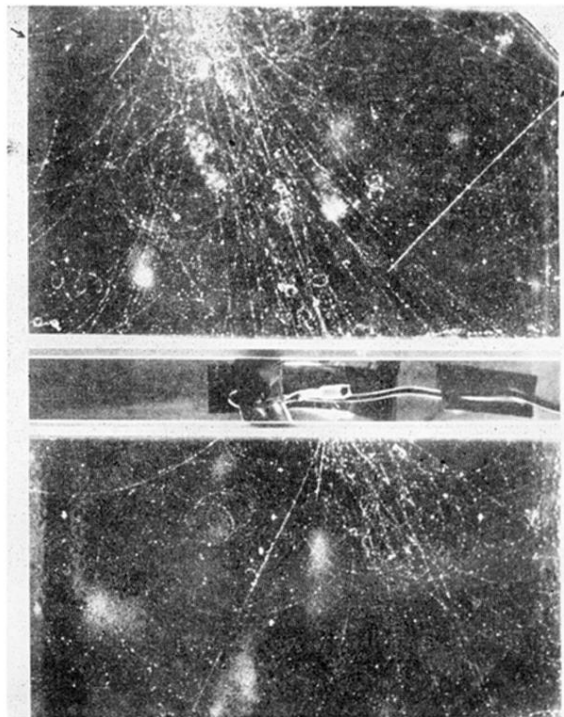


FIG. 2. The decay of a κ -meson.