dicated by the curves of Fig. 1 are consistent with the spectral sensitivity data of Fig. 2. Utilizing the short-circuit photocurrents, found by extrapolation to zero external resistance, and the corresponding measured intensities it was possible to calculate the effective quantum efficiencies for both the monochromator measurements and the direct-radiation measurements. The peak response region between 1.65 μ and 1.70 μ corresponds to approximately 0.3 electron-hole pairs produced per incident photon. If approximate values for the optical constants of germanium[4] are applied to the data of Fig. 2 the general shape of the response curve is not appreciably altered, but the peak response then corresponds to an effective quantum efficiency of approximately 0.5 electron-hole pairs per absorbed photon and the 1.0 μ region to approximately 0.3. These effective quantum efficiencies, although verified on several occasions, are decidedly less than the value of unity generally accepted for the photovoltaic process at a *p-n* junction.[5] The discrepancy can be attributed to excessive recombination of the generated charges at the crystal surfaces and to an effective series ohmic resistance at the electrode contacts on the crystal.

The relatively small effective quantum efficiency does not affect the validity of the results reported; it does, however, restrict the magnitudes of the power efficiencies observed. Had an effective quantum efficiency of approximately unity been observed in the peak response region the curves of Fig. 1 would indicate power efficiencies from $2\frac{1}{2}$ to four times those shown. This would correspond to efficiencies of conversion of *absorbed* power five to eight times those indicated in Fig. 1. For the white radiation of curve *A* this would mean a maximum power efficiency of approximately two percent. For the infrared radiation of curve *B* an efficiency of three percent or more is indicated, since there is no evidence of a maximum in the intensity range shown. It appears not unreasonable to presume that efficiencies of seven or eight percent could be realized with a junction better suited to this application.

* This investigation was described, in slightly different form, in a paper presented at the Rochester, New York, meeting of the American Physical Society on June 18, 1953. See Ralph P. Ruth and James W. Moyer, Phys. Rev. **92**, 846 (1953).

† Operated by the General Electric Company for the U. S. Atomic Energy Commission.

[1] H. Y. Fan, Phys. Rev. **75**, 1631 (1949); M. Becker and H. Y. Fan, Phys. Rev. **75**, 1631 (1949); **78**, 301 (1950).

[2] The junction used for this work was supplied by Dr. R. N. Hall of the General Electric Research Laboratory.

[3] A theoretical development of these empirical relationships is contained in a study of the photovoltaic effect in *p-n* junctions made by R. L. Cummerow of this laboratory [Phys. Rev. **95**, 16 (1954)].

[4] W. H. Brattain and H. B. Briggs, Phys. Rev. **75**, 1705 (1949); K. Lark-Horovitz and K. W. Meissner, Phys. Rev. **76**, 1530 (1949); H. B. Briggs, Phys. Rev. **77**, 287 (1950); M. Becker and H. Y. Fan, Phys. Rev. **76**, 1530 (1949); D. G. Avery and P. L. Clegg, Proc. Phys. Soc. (London) **B66**, 512 (1953); H. B. Briggs, J. Opt. Soc. Am. **42**, 686 (1952).

[5] F. S. Goucher, Phys. Rev. **78**, 816 (1950). See also B. J. Rothlein, Sylvania Technologist **4**, 86 (1951).

Magnetic Domains in Cobalt by the Longitudinal Kerr Effect*

CHARLES A. FOWLER, JR., AND EDWARD M. FRYER
Department of Physics, Pomona College, Claremont, California
(Received May 24, 1954)

THE longitudinal Kerr effect was recently employed by the authors to successfully photograph the magnetic domains in a single crystal of silicon iron.[1] The domains in that specimen were unusually large (1–3 mm wide) and the question remained as to how applicable the technique would be for examining the very much smaller domains usually encountered in ordinary ferromagnetic crystals. Partly to answer this question, we have undertaken to photograph the domains in a (10·0) surface of a single crystal of hexagonal cobalt, which was known from powder pattern evidence to contain antiparallel domains lying in the direction of the *c* axis, the direction of easy magnetization.

No data on the longitudinal Kerr effect in cobalt were available, but the normal polar case in cobalt is reported to rotate the plane of polarization by about 20 minutes, which is about the same magnitude as for the normal polar case in iron.[2] The polar effect in cobalt had been employed by Williams, Wood, and Foster to photograph the mottled structure characteristic of the end-on view of domains terminating in a basal plane normal to the *c* axis.[3] We therefore first sought to measure the longitudinal Kerr rotation for the cobalt specimen by using the photoelectric technique previously described.[1] The rotation, a maximum when the light is incident at about 60°, measured 3.5

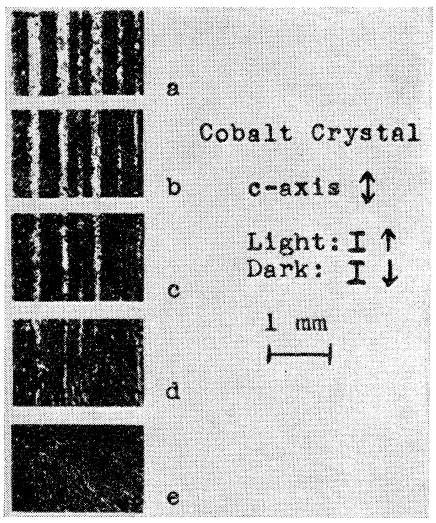

FIG. 1. Photographs of the domain behavior in a (10·0) surface as the applied field is increased from zero in (a) to a value sufficient to produce saturation in (e). The direction of the field is toward the bottom of the page.

minutes at saturation. This value is sufficiently close to the 5 minutes found in silicon iron to assure enough contrast for photographing antiparallel domains.

Employing essentially the same experimental arrangement that was described for our silicon iron investigation,[1] we have succeeded in obtaining reasonably satisfactory photographs of the domain structure in a (10·0) surface of the hexagonal cobalt crystal. Figure 1 is a series of such photographs of a small portion of the surface, taken as the originally demagnetized specimen is subjected to a gradually increasing field. The photocell monitor indicated that the domain changes were characteristically discrete and sporadic, and the pictures reveal that certain domains tend to persist while others are changing. The figure shows that these cobalt domains are a small fraction of a millimeter wide, at least an order of magnitude smaller than those we had photographed in silicon iron.

Certain of the domains appear unsharp and fuzzy at the edges, and this results directly from inability to perfectly superpose the correcting "reversed flat" on the domain negative in order to reduce the photographic "surface noise," a problem first encountered in the silicon iron work.[1,4] Whereas the troublesome small surface imperfections only partially obscured the large silicon iron domains, they practically obliterate the very much smaller cobalt domains. Thus the negative-positive superposition technique that was so useful in the silicon iron work becomes absolutely essential in obtaining satisfactory photographs of the cobalt domains. Figure 2 shows uncorrected photographs of the demagnetized and the saturated specimen, the "reversed flat" corrector, and the same two photographs after correction. It is to be emphasized that the surface was electrolytically polished to a mirror smoothness, and that the rough appearance results simply from the unusual conditions of photography, conditions that cause even the smallest pit, wave, or depression to

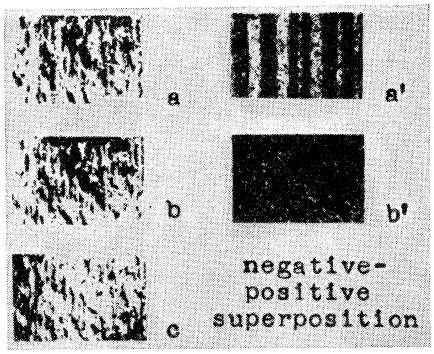

FIG. 2. Reduction of "surface noise" by negative-positive superposition. Uncorrected photographs of domain structure when the crystal is (a) demagnetized and (b) saturated. (c) is the "reversed flat," a positive of (b). Photographs (a′) and (b′) are corrected pictures made by superposing (c) on (a) and (b), respectively.

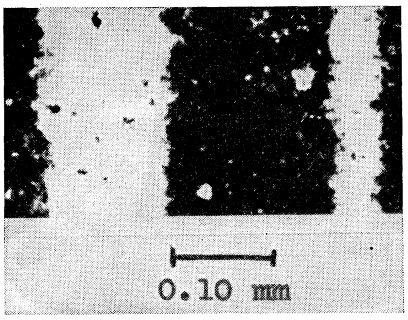

FIG. 3. Further enlargement of a domain photograph, permitting estimate of resolution limit.

stand out in the uncorrected photograph with a contrast that rivals or exceeds the contrast between adjacent domains.

Some estimate of the resolution limit can be made from Fig. 3 which is a further enlargement of one of the photographs. The light domain at the right measuring less than 0.05 mm is well resolved, and an examination of the walls themselves suggests that a width of approximately 0.01 mm is about the limit in this photograph. The sharpness is somewhat improved if the surface area to be corrected by the superposition technique is limited, for the smaller the area the more nearly perfect can be the matching.

This investigation is continuing with the objective of observing the interesting cobalt transition at about 275°C where the *c* axis ceases to be the axis of easy magnetization and becomes the direction of most difficult magnetization.[5] The authors are indebted to R. J. Williams and R. M. Bozorth for the loan of the cobalt crystal and for helpful discussions concerning the work.

* Supported by the Office of Naval Research.

[1] C. A. Fowler and E. M. Fryer, Phys. Rev. **94**, 52 (1954).
[2] *International Critical Tables* (McGraw-Hill Book Company, Inc., New York, 1929), first edition, Vol. VI, p. 435.
[3] Williams, Foster, and Wood, Phys. Rev. **82**, 119 (1951).
[4] C. A. Fowler and E. M. Fryer, J. Opt. Soc. Am. **44**, 256 (1954).
[5] R. M. Bozorth, *Ferromagnetism* (D. Van Nostrand Company, Inc., New York, 1951), p. 555.

Ultrasonic Measurements in Magnetically Cooled Helium*

C. E. CHASE AND MELVIN A. HERLIN
Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received May 19, 1954)

MEASUREMENTS have been made of the absorption of ordinary "first" sound in liquid helium at a frequency of 12.1 Mc/sec and at temperatures down to 0.1°K. A pulse technique similar to that employed earlier by one of the authors[1] was used. The results of one demagnetization are shown in Fig. 1.

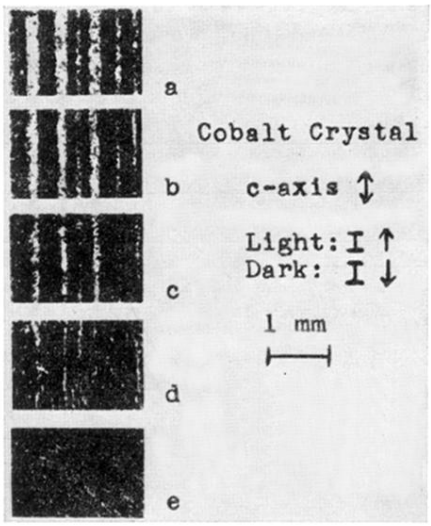

FIG. 1. Photographs of the domain behavior in a (10·0) surface as the applied field is increased from zero in (a) to a value sufficient to produce saturation in (e). The direction of the field is toward the bottom of the page.

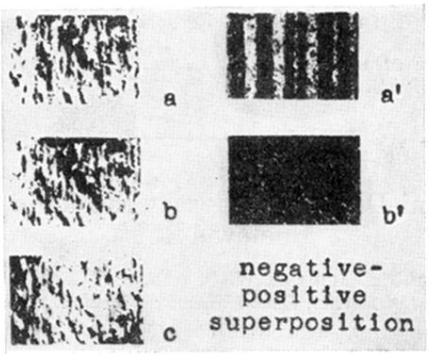

FIG. 2. Reduction of "surface noise" by negative-positive superposition. Uncorrected photographs of domain structure when the crystal is (a) demagnetized and (b) saturated. (c) is the "reversed flat," a positive of (b). Photographs (a′) and (b′) are corrected pictures made by superposing (c) on (a) and (b), respectively.

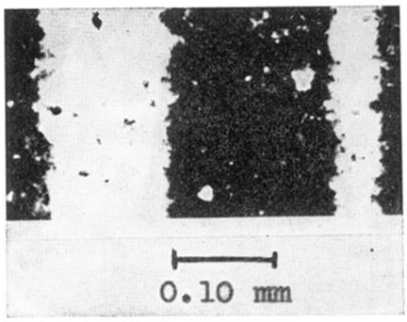

FIG. 3. Further enlargement of a domain photograph, permitting estimate of resolution limit.