LETTERS TO THE EDITOR

Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the twentieth of the preceding month; for the second issue, the fifth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

Surface Magnetization in Ferromagnetic Crystals

Deposits of a magnetic powder on a polished surface of a ferromagnetic crystal form under certain conditions a complicated pattern of lines related in some way to the crystalline space-lattice. Bitter, who published the first pictures of such patterns,[1] preferred a suspension in ethyl acetate of Fe_2O_3 particles about 1μ in diameter. Akulov and Degtiar[2] obtained more sharply defined patterns ("*S*-lines") with an alcohol suspension of the same material. Their Figs. 5 and 7 are particularly good. Becker and Freundlich[3] used a propyl alcohol suspension described as "almost colloidal" and show several photographs of the same region with different patterns depending upon the intensity of the applied magnetic field. All these observers applied magnetic fields parallel to the surface and report that the conspicuous lines of the patterns have different directions for different azimuths of the applied field. The spacing of parallel lines is different in different cases. In Bitter's Fig. 2 several horizontal lines near the lower right corner are spaced at about 100μ. Akulov and Degtiar report spacings of the order of 40μ. Becker and Freundlich's photographs show a few clearly resolved vertical lines, near the left of their Fig. 3, spaced at about 50μ. More conspicuous lines are farther apart, from 100μ upward.

We have improved the technique for observing such superficial heterogeneities of magnetization by using true sols of Fe_2O_3 in water (with a little KOH) which do not precipitate on iron.[4] The concentration of Fe_2O_3, however, is so much increased in regions where H is very non-uniform, that temporary swarms of particles in such regions can be photographed with ease. The mobility of the particles is a help rather than a hindrance, for in photographs with exposures of the order of a minute the sharpness of boundaries is not much affected by the size of individual particles. Furthermore, any change in the field-distribution is immediately followed by a migration of the swarms to new regions of highly non-uniform H. By these means we have been able to observe a new effect which throws some light on the distribution of magnetization to which the patterns are due.

In a particular experiment, a mono-crystal silicon iron[5] disk 0.6 cm in diameter and 0.04 cm thick was carefully polished on one side and mounted polished side up on the ground end surface of a vertical soft-iron bar 1.3 cm in diameter forming the core of a small electromagnet. A small rubber washer, a brass clamp with a hole in it, and a cover glass to cover the hole, formed the sides and top of the colloid cell. The cover glass had to be inclined to the horizontal to avoid troublesome reflections under vertical illumination. With this arrangement the applied magnetic field is normal to the surface and may easily be reversed in direction. Its magnitude can only be estimated as of the order of 1000. Fig. 1 shows the appearance of the same region for the two directions of the applied field. The time of exposure in each case was one minute and several minutes were allowed for the pattern to become stable before photographing it. It will be observed that the black lines on one pattern occupy the centers of the white spaces on the other. The spacing of adjacent parallel lines is about 4μ.

It was further observed (and photographed) that a very faint pattern, obtained after demagnetizing the core by reversals, comprised both of the patterns for large vertical applied fields. Moreover, a colloid containing smaller concentration of Fe_2O_3 gives patterns of the same dimensions but with narrower lines. There are in this specimen, two directions parallel to which lines run. These directions, nearly at right angles, agree in azimuth with the traces on the surface of the two planes of form {100} most nearly perpendicular to the surface. These traces were located by the analysis of a Laue diagram with about 30 fairly intense spots showing little internal strain in the disk. The lines are definitely not in the directions of the projections on the surface of $<100>$ axes, which would require exchange of the acute angles, 86°, with the obtuse angles, 94°. Over considerable areas both sets of lines are equally developed and of the same average spacing. Where they are unequally developed the better developed set have the closer spacing. The longer lines are unequally black, blacker regions occurring at intervals of about 2μ. (This is particularly evident where lines are faintest, such lines appearing beaded.) As already reported by Akulov and Degtiar, ells and tees occur, but no crosses. We also note that H-patterns with cross-bars of minimum length are very unusual.

These findings seem to agree best with the hypothesis that the surface layer is composed of roughly cubical blocks

[1] F. Bitter, Phys. Rev. **41**, 507 (1932).
[2] N. [S.] Akulov, M. Degtiar, Ann. d. Physik **15**, 750 (1932).
[3] R. Becker, H. F. W. Freundlich, Zeits. f. Physik **80**, 292 (1932).
[4] We are indebted to Dr. L. A. Welo, of this laboratory, for the preparation of these sols in various concentrations.
[5] From a larger piece furnished by Dr. W. E. Ruder and more fully described by L. W. McKeehan and R. F. Clash, Jr., Phys. Rev. **45**, 839 (1934).

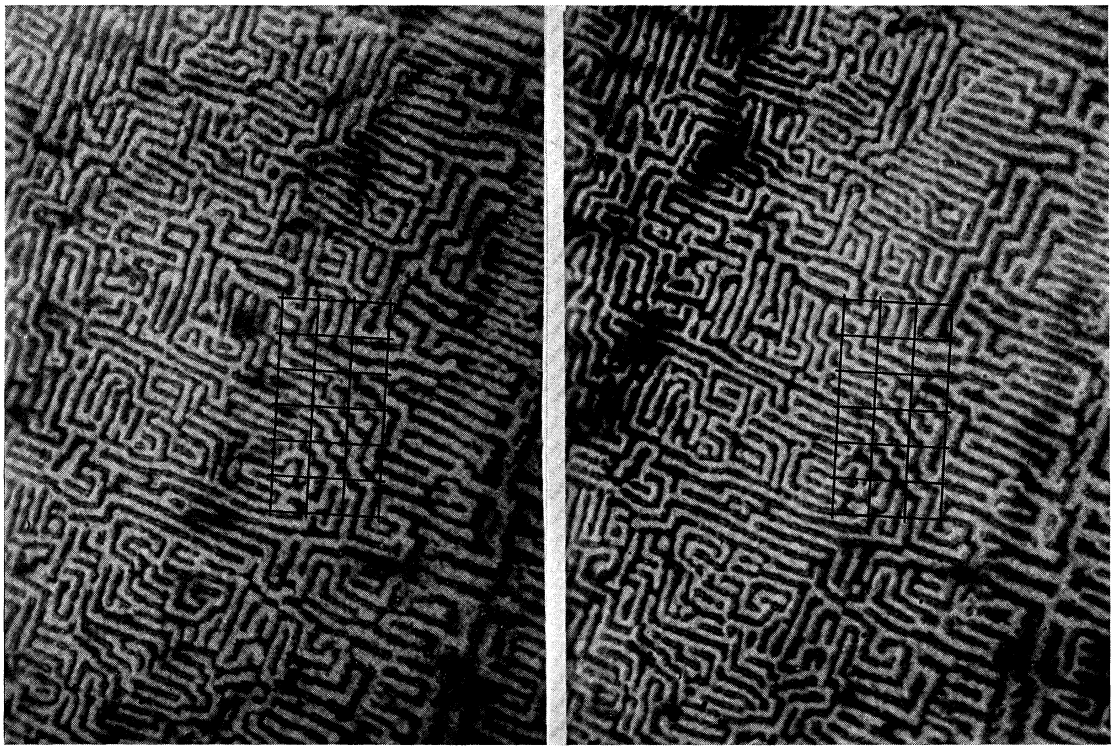

FIG. 1. Powder patterns with H normal to the surface. The group of 6 squares is about $70\mu \times 35\mu$.

about 2μ on each edge magnetized parallel to the surface either along a <100> direction or along a <110> direction. These blocks are so magnetized that the average magnetization over any small region is as small as possible. This requires opposing magnetizations normal to about half the block boundaries. In the absence of any applied field the stray field at these boundaries can produce some concentration of the colloid, producing a faint pattern with 2μ spacing. In the presence of a normal field half these boundaries have their stray field increased by the inclinations of the magnetizations in the adjacent blocks. The other half of the boundaries have stray field decreased by the same inclinations, as indicated in vertical cross section in Fig. 2. One of the denser patterns with 4μ spacing is then observed. A normal field in the opposite sense selects the other half of the original no-field pattern for enhancement. The blocks must be about as thick as they are wide to make these enhancements so striking.

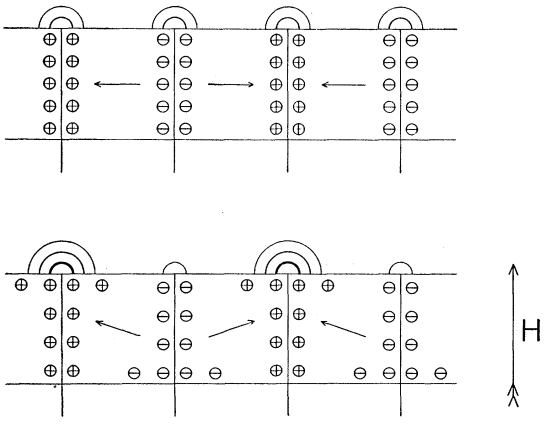

FIG. 2. Schematic diagram of magnetization in a plane perpendicular to the surface and of powder swarms at block boundaries, without H, and with H as indicated.

The particular scale of the patterns here shown seems to be accidental, for we have observed double spacings (in a normal field) as small as 1μ, and, as noted in the introductory paragraph, nearly rectangular patterns with much larger spacings have previously been observed by others.

More irregular streaks of much greater spacing are also observed on our specimens. Streaks of this sort may just be recognized in Fig. 1 and are seen to be parallel to one set of closely spaced lines. They are conspicuous at lower magnifications. These streaks also migrate when the normal field is reversed, so that light and dark regions interchange, as may be appreciated to some extent by studying the two photographs in Fig. 1. We attribute these also to variations in normal induction through the surface. The reversal of deeper lying layers with magnetic axes normal to the surface in both cases would account for the effect.

We are proceeding to study patterns in oblique applied fields by combining with the vertical bar electromagnet a larger electromagnet (Du Bois type) producing horizontal fields. The exchange of lines for spaces with change in the direction of the normal component persists as long as the fine lines are observable. In agreement with previous observers we find that the fine line pattern itself changes as the field parallel to the surface increases and may be made very nearly invisible.

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July 7, 1934.

Progression of Nuclear Resonance Levels with Atomic Number

In a recent letter to the *Physical Review*[1] one of us pointed out that the resonance levels for alpha-particle disintegration seem to vary linearly with the atomic number. A tentative explanation was given in terms of standing waves within the potential barrier. In the present note we offer a more adequate explanation in terms of particle interaction.

For the six elements Be, B, N, F, Mg, Al, resonance levels are found with energies differing by increments proportional to the change in nuclear charge. The mean increment for an increase in charge of two units (a difference of an alpha-particle) is $1.1\pm0.3\times10^{-6}$ ergs. A second series of levels is found with approximately the same increment although the experimental data are less complete. The straight lines joining the values of the resonance energies in each series plotted against nuclear charge are roughly parallel to the line joining the minimum penetration energies (or barrier heights) which are much harder to define and measure than the resonance energies themselves. The linear increase of barrier height with nuclear charge implies that the radius of the inside of the potential wall is at least approximately a constant.

Resonance levels correspond to energies of unoccupied alpha-particle states inside the nucleus. For approaching alpha-particles of these energies the penetration probability rises to unity. There is as yet no theoretical method of determining the actual positions of the virtual alpha-particle levels for a given nucleus. This is, however, not necessary if the *change* in energy of a particular level from nucleus to nucleus is considered. We make the suggestion that the difference between the energies of corresponding alpha-ray resonance levels in elements of atomic numbers Z and $Z+2$ is in general due to the interaction of two alpha-particles: (1) the alpha-particle added to the nucleus in passing from the first element to the second, (2) the alpha-particle, the virtual presence of which gives rise to the resonance. Since the radius of the inside of the barrier is sensibly constant for these elements, this interaction accounts very simply for the approximately linear increase in the resonance energy as we pass from, say, boron to nitrogen.

It is also possible, on the basis of simple assumptions, to explain the order of magnitude of the energy differences. Let us assume that one alpha-particle is localized near the center of the nucleus while the other is bound in one of the stationary states of the nucleus. If the latter is regarded as a barrier of infinite height and radius r_0, the radial part of the ψ-function for any one of the stationary states has the form

$$R=Ar^{-\frac{1}{2}}J_{l+\frac{1}{2}}(kr)$$

where k is determined by the condition that $J_{l+\frac{1}{2}}(kr_0)=0$. Let us assume the interaction to be of the Coulomb type. We then obtain for ΔE, the energy difference in question,

$$\Delta E=4e^2k\int_0^{\xi}J^2{}_{l+\frac{1}{2}}(x)dx/\int_0^{\xi}J^2{}_{l+\frac{1}{2}}(x)\cdot xdx,$$

where ξ is a root of $J_{l+\frac{1}{2}}(x)$. If we assume the alpha-particle to be bound in the lowest S-state ($l=0$, ξ is the first root) the result is: $\Delta E=2.3\times10^{-6}$ ergs, if it is in the lowest P-state ($l=1$, ξ is the first root) $\Delta E=1.7\times10^{-6}$ ergs. For higher states the results are somewhat smaller. The value for r_0 here chosen is 10^{-12} cm. This is probably not too high because the finite actual height of the barrier causes the charge of the alpha-particle to penetrate into the walls of the barrier.

The significant fact seems to be that the Coulomb energy alone produces the correct order of magnitude for ΔE, but that the results are numerically too high. This is in line with the known circumstance[2] that the deviations from Coulomb interaction between alpha-particles diminish the repulsion. As is seen, the correction here amounts to about 50 percent of the Coulomb energy itself.

The change in the position of the resonance level from one element to the next, e.g., from beryllium to boron, is to be understood in a similar manner. The increment in energy is here due to the interaction between a proton and an alpha-particle, and this should be approximately half the ΔE calculated above. A general linear progression in the position of nuclear resonance levels with atomic number is thus explained.

It is to be expected that the resonance level of B^{10} lies higher than that of B^{11}, for the latter contains one neutron more than the former, and a "free" neutron should produce a negative energy of interaction with an alpha-particle. The experimental results so far indicate that this is actually the case but are not sufficiently accurate to permit more than a speculative value for the difference.

The suggestions here presented may be of guidance in the absence of a correct nuclear theory. The similarity of this explanation with that of the progression of atomic resonance states is of course evident.

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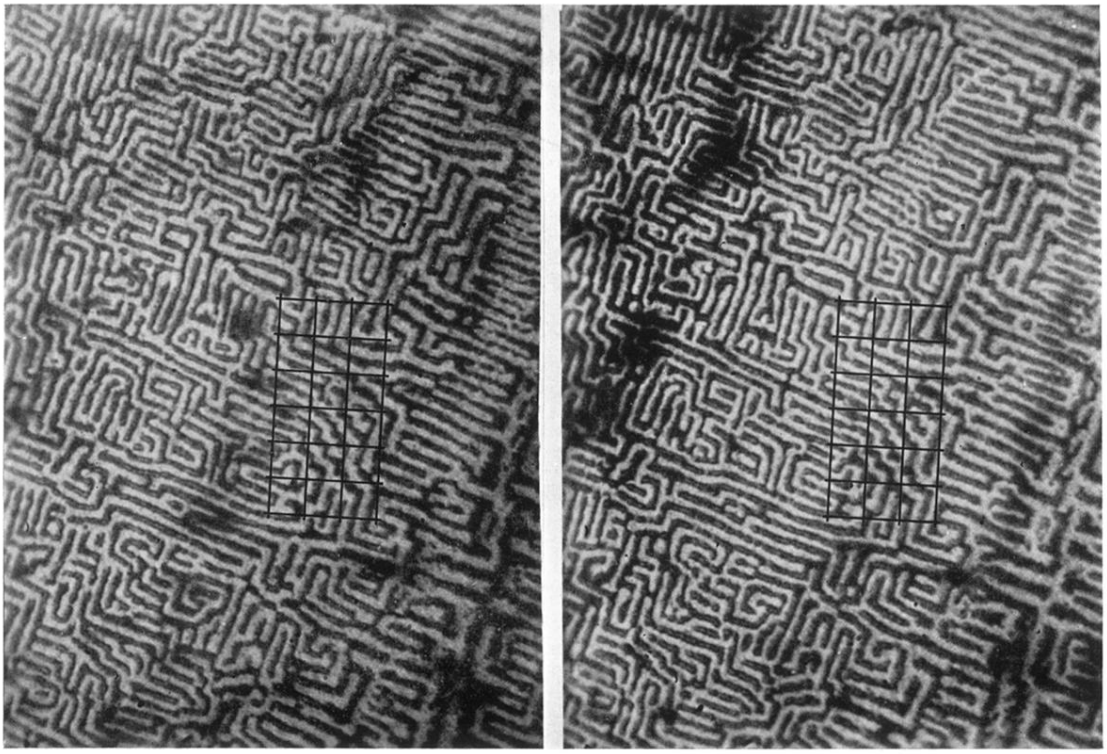
June 13, 1934.

* Sterling Fellow.

[1] E. Pollard, Phys. Rev. **45**, 218 (1934).
[2] H. M. Taylor, P.R.S.A. **134**, 113 (1931).



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