plane wave combinations of the given symmetry will decrease rapidly. This is most easily seen by considering a particular example. Suppose that $\chi_1^- = (2/\Omega)^{\frac{1}{2}} \sin \mathbf{k}\cdot\mathbf{r}$ is a plane wave combination of the given symmetry type (this occurs for some of the lithium eigenfunctions mentioned above). The matrix element of H connecting χ_1^- with $(1/\Omega)^{\frac{1}{2}} \exp [i(\mathbf{k}+\mathbf{K})\cdot\mathbf{r}]$ will be the difference of two Fourier coefficients of the potential; for very large K it will be of order $1/K^3$, since $U[\mathbf{K}]$ is of order $1/K^2$, and even for smaller K's it will be much less than either Fourier coefficient alone. The second-order perturbation series will thus converge extremely rapidly. This in itself is of course no guarantee that this series gives a good approximation to the eigenvalue: if we were to consider functions of the symmetry type of $\chi_1^+ = (2/\Omega)^{\frac{1}{2}} \cos \mathbf{k}\cdot\mathbf{r}$, the second-order perturbation series would converge—less rapidly than above, but still fairly rapidly—to an energy value far below that of the valence electron eigenfunction of the same symmetry type (because χ_1^+ is not orthogonal to the core functions of the 1s band). However, it is likely that when we are working with functions of the symmetry type of χ_1^- the off-diagonal matrix elements in the secular determinant will decrease so rapidly to zero that we can set a very small upper bound to the difference between the true eigenvalue and the energy yielded by the second-order perturbations.

In conclusion I wish to thank Professors J. C. Slater and E. P. Wigner for reading and discussing this manuscript.

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Optical and Magnetic Properties of Magnetite Suspensions

Surface Magnetization in Ferromagnetic Crystals

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A magneto-optic effect discovered by W. R. Grove in 1845 is suggested as explaining, in part, at least, peculiarities of ferromagnetic colloid patterns on ferromagnetic crystal surfaces.

C. W. HEAPS[1] has recently investigated the optical transparency of a suspension of magnetite in oil, as modified by magnetic fields applied parallel to the light path or at right angles thereto. He explains the effects as due to changes in the area obstructed by rectilinear rows of particles, magnetically linked, when these are turned from random directions so as to lie parallel with the applied field. A field intensity of only a few oersteds produced nearly maximal effect.

The increase in transparency of a suspension of magnetite in water when a magnetic field is applied parallel to the light path was first demonstrated by W. R. Grove at a social meeting of the Royal Institution, in London, on January 8, 1845. Since the report is short, relatively inaccessible, and ignored for so long a time, it is quoted in full.[2]

"Jan. 8, 1845.—Prof. Grove communicated to the proprietors at this their first *soirée* for the season, some of the leading discoveries in physical science during the past year. Of electrical subjects, M. Matteucci's researches were described; with experimental illustrations; as also the magnetic note. In reference to the latter, Mr. Grove detailed a curious experiment that had occurred to him, and which bore greatly on the subject. A glass tube open at the ends, but protected along its length with a copper jacket, was filled

[1] C. W. Heaps, Phys. Rev. **57**, 528–531 (1940). See also Q. Majorana, Accad. Lincei, Rendiconti [6a] **29**, 11–14 (1939) January; Ricerca Scient. **10**, 783–789 (1939), September.

[2] C. V. Walker, Elec. Mag. **1**, 601 (1845), April.

with water, in which was suspended powdered magnetic oxide of iron. On looking through the tube at distant objects a considerable portion of the light was intercepted by the heterogeneous arrangement of the particles of the oxide; but on passing a current through a coil placed round the tube, these particles assumed a symmetrical character, and much more light was transmitted. This experiment was alluded to as an illustration of the molecular polarization and vibration that is attributed to the particles of an iron rod when a musical note is obtained under the influence of the current."

Grove does not seem to have gone any further, and if interest was aroused it was soon forgotten in the furor which followed Faraday's announcement, to the same group, on November 3, 1845, of the rotation of the plane of polarization of light in traversing a transparent medium parallel to an applied magnetic field.[3] Grove alluded to his own magneto-optic effect twice more,[4] and then gave up.

The magneto-optic effect discovered by Grove and systematized by Heaps may be of value in explaining the relatively opaque bands in a ferromagnetic colloid close to the smooth surface of a ferromagnetic crystal when the normal component of the magnetic field is altered by external means.[5] The shifting of these bands when a considerable normal field is reversed was at first interpreted as a bodily transport of colloid particles from boundaries where local block magnetizations were *vis-à-vis* to boundaries where they were *dos-y-dos*, or vice versa. More recently, Elmore[6] has argued that a sufficiently dilute colloid would not be so concentrated at block boundaries because field gradients, though adequate in magnitude for sufficiently rapid transport, have relatively small components parallel to the surface along which the motions seem to occur. He prefers to explain rapid concentration by invoking interparticle magnetic fields once the particles have been properly aligned by fields of more remote origin. We now suggest that the transparent regions are not actually free from colloid particles but are merely more transparent because, in them, long chains of particles have suitable directions.

The conditions of illumination favor this explanation. The light used comes through the microscope objective, which has a relatively great numerical aperture, so that a divergent magnetic field, with approximate symmetry about a line (or plane) normal to the surface, is well adapted to align chains for easy illumination and easy seeing of a reflecting surface beneath the colloid layer. It will also be noticed that convection currents along the surface would not be observable if the chains in the drifting suspension turned as they were bid by the nonmoving field which they traversed. The fact that drift is actually not as troublesome as it was expected to be therefore favors the present hypothesis.

A test of the idea would seem to require a change in type of illumination, perhaps involving a complete blackout of the underlying metallic surface, and I cannot yet see how to manage this without losing the pattern under observation. A good nonoptical method of estimating particle density, which would also serve, seems equally difficult to devise. I am therefore publishing this note in the hope that someone more actively interested in these matters can devise and conduct a crucial experiment.

[3] The date given is that of a meeting of the Council of the Royal Institution, as reported in the Athenaeum, No. 941, of November 8, 1845, on page 1080. The public presentation, before the Royal Society of London was on November 27, 1845.

[4] First, on May 24, 1849, in presenting a paper on another subject before the Royal Society of London. This was briefly abstracted: Phil. Mag. [3] **35** 153–154 (1849); Ann. d. Physik [2] **78**, 567–568 (1849); Proc. Roy. Soc. London, **5**, 826–827 (1851). Second, in 1850, in the second edition of his *Correlation of Physical Forces*, on pages 72–73.

[5] L. W. McKeehan and W. C. Elmore, Phys. Rev. **46**, 226–228 (1934).

[6] W. C. Elmore, Phys. Rev. **51**, 982–988 (1937). Data on the magnetic properties of colloid particles are to be found in his more recent paper, Phys. Rev. **54**, 1092–1095 (1938).