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Abstract

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PHYSICS

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CONCERNING THE NOTE BY W. F. BROWN, ON THE THEORY OF MAGNETOSTRICTION OF NICKEL SINGLE CRYSTALS

The calculations of Gans and Harlem do indeed contain an error, and we are grateful to Brown for pointing this out. However, this error has no bearing on our theory or on our calculations, and the objections to the formal method that was applied by Heisenberg remain valid even if one starts from Brown' s corrected calculations.

In the work of Gans and Harlem the basic formulas for magnetostriction given by us are applied correctly; the error they made is connected with an incorrect application of Heisenberg' s method, which shows that the application of this method is not always simple. Although Brown' s formula, based on a more correct application of Heisenberg' s method, agrees better with experiment than the curve of Gans and Harlem, nevertheless the theoretical curve based on the energy method we gave describes the experimental data better than Brown' s formula.

We believe that the agreement of the curve we gave with the experimental data is difficult to explain by experimental errors. However, even apart from the results of comparing theory with experiment, one must note the presence of a certain inadequacy in Heisenberg' s method, which is due to the fact that real crystals always have internal elastic stresses. The method applied by Heisenberg is not physically justified and does not take their role into account.

Work is performed against internal stresses during magnetization. If hysteresis is neglected, this work in the case of domain transitions

$$I_s \parallel [\bar{1}\,\bar{1}\,\bar{1}] \rightarrow I_s \parallel [111]. \tag{1}$$

is equal to zero, in contrast to transitions of the type

$$I_s \parallel [11\bar{1}] \to I_s \parallel [111], \tag{2}$$

where this work is nonzero. Therefore transitions (1) and (2) are not statistically equivalent, as is assumed in Heisenberg' s method. The error arising from this is to a known extent analogous to the error of Gans and Harlem, when they regard as statistically equivalent directions of the type $[\bar{1}11]$ on one side and directions of the type $(\bar{1}\bar{1})$ on the other. As experiment shows, the resulting error in a number of cases may be comparatively small; nevertheless, there is a fundamental inadequacy of the formally statistical method in revealing a number of specific features in the behavior of magnetostriction curves and other effects. Therefore, in a number of cases the energy method for calculating the distribution function of domains over the directions of easy magnetization—which, in various variants, was further developed in the works of other authors—gives better agreement with experiment and is physically better justified.

After the appearance of these two methods (the energetic and the formally statistical), already in 1932 the idea arose of giving their synthesis and justification. This was achieved, in a first approximation, in the energy-statistical method, in which the role of internal stresses (although not completely) is taken into account by introducing into the theory the magnetic susceptibility ($\chi_0 = I/H$) for $I \ll I_s$, which is very sensitive to the magnitude of the internal elastic stresses. The theory of elastically stressed domains based on this method, developed in the works of Akulov and Kondorskii (^{6}), and also in the analogous work of Brown (^{3}), makes it possible to describe satisfactorily a large number of different effects associated with the action of external and internal elastic stresses σ on single crystals and polycrystals (see also (^{9})). In particular, the formulas obtained by Akulov and Kondorskii for various mechano-magnetic effects are in fairly good agreement with experiment. In contrast to Heisenberg' s theory, these formulas include the susceptibility χ_0. An example of this is the formula for the ΔE effect

$$\left(\frac{\Delta E}{E}\right)_s = c\chi_0\lambda_s E_0/I_s^2, \tag{3}$$

where the coefficient c, when averaged according to Reuss, is equal to 3/5. In the literature our formula is sometimes used with larger values for this coefficient (up to 4/5). The experiments of Yamamoto and Taniguchi (^{8}) confirm the validity of formula (3), which they, however, call semi-empirical. In reality it was derived purely theoretically in the works (^{6,3,9}).

For the value of the coefficient c, the authors mentioned, as an average from various experimental data, give the value 0.7, which agrees within the limits of experimental error with the theoretical value. Akulov and Kondorskii carried out the averaging according to Reuss. If one averages according to Voigt, a different value of c is obtained, which, naturally, does not change the fundamental essence of the formula we found. The question of the character of the averaging is, of course, of independent interest and can be finally resolved only on the basis of the accumulation of sufficiently reliable experimental data.

It should be noted that the theory of the mechano-magnetic phenomena discussed in Brown' s note is based on the formulas for magnetostriction

$$\lambda = {}^3/_2\lambda_{100}(\alpha_1^2\beta_1^2 + \alpha_2^2\beta_2^2 + \alpha_3^2\beta_3^2 - {}^1/_3) +$$

$$+3\lambda_{111}(\alpha_1\alpha_2\beta_1\beta_2 + \alpha_2\alpha_3\beta_2\beta_3 + \alpha_3\alpha_1\beta_3\beta_1) \qquad (4)$$

and for the energy of elastic stresses σ

$$E_\sigma = -{}^3/_2\sigma\left[\lambda_{100}(\alpha_1^2\gamma_1^2 + \alpha_2^2\gamma_2^2 + \alpha_3^2\gamma_3^2) +\right.$$

$$\left.+3\lambda_{111}(\alpha_1\alpha_2\gamma_1\gamma_2 + \alpha_2\alpha_3\gamma_2\gamma_3 + \alpha_3\alpha_1\gamma_3\gamma_1)\right]. \qquad (5)$$

These formulas in some cases are given without proper references to the original sources ([7,5]), and are sometimes erroneously attributed to Becker and Döring (see, for example, ([10])).

Heisenberg's work is based on a relation of type (4), as Heisenberg quite correctly notes. In a number of works the relation given by us for the thermodynamic potential of elastic stresses is also used, with additional terms proposed by Gans and his collaborators, as well as by Becker and Döring.

In conclusion, we note that, despite individual exceptions and the need for further justification, the statistical theory of elastically stressed domains, relying on the relations indicated above, gives, as a rule, more universal and accurate results in comparison

with other methods of calculation. In this respect we are in complete agreement with Brown. For a final judgment and for the improvement of the theory, the accumulation of new, more precise experimental data is highly desirable.

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Note: Figure translations are in progress. See original paper for figures.