#### PHYSICAL REVIEW B

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# Origin of the Linear Term in the Expression for the Approach to Saturation in Ferromagnetic Materials\*

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There has been confusion for many years over the origin of the a/H term in the expression for the approach to saturation,  $M/M_s = 1 - a/H - b/H^2 + cH$ , observed in many ferromagnetic materials. A calculation is presented which suggests that residual internal strain contributes significantly to this term. Internal strain has previously been thought to contribute only to the  $b/H^2$  term. It is further suggested that the a/H term has been overemphasized and has validity only over a limited region of the H axis. The effect of internal strain is deduced from consideration of a problem concerning nonhydrostatic strains induced in slightly porous magnetic material subject to external hydrostatic pressure. A comparison with recent experimental work supports the calculation.

### I. INTRODUCTION

There has been continued interest for many years in explaining the various terms which occur in the expression for the approach to saturation observed experimentally in many ferromagnetic materials:

$$\frac{M}{M_s} = 1 - \frac{a}{H} - \frac{b}{H^2} + cH .$$
 (1)

The *cH* term has been adequately explained in terms of paraprocesses. The constant in the  $b/H^2$  term has been shown to be

$$b = \frac{8}{105} \frac{K^2}{M_s^2} + \frac{3}{5} \frac{\lambda_s^2 \langle \sigma_i^2 \rangle_{av}}{M_s^2} , \qquad (2)$$

where the first part is due to crystalline anisotropy,<sup>1</sup> and the second part, derived by Becker and Polley,<sup>2</sup> is considered to be the influence of internal strain on the approach to saturation.

The origin of the a/H term is not well understood. Calculations by Brown<sup>3</sup> have shown that dislocation effects can contribute to this term, while Néel<sup>4</sup> has concluded that stray fields due to nonuniform magnetization may bring about forces

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<sup>10</sup>C. Kittel, Rev. Mod. Phys. <u>21</u>, 541 (1949).

<sup>11</sup>This and later results are limiting cases of a general solution attributed to Lamé. See also L. O. Landau and E. M. Lifshitz, *Theory of Elasticity* (Addison-Wesley, Reading, Mass., 1955), p. 20.

<sup>12</sup>See, for instance, R. R. Birss, Proc. Phys. Soc. (London) 75, 8 (1960).

<sup>13</sup>J. P. Hirth and J. Lothe, *Theory of Dislocations* (McGraw-Hill, New York, 1968).

<sup>14</sup>A. H. Morrish, *The Phsical Principal of Magnetism* (Wiley, New York, 1965), p. 395.

<sup>15</sup>E. W. Lee, Rept. Progr. Phys. <u>28</u>, 184 (1955).

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The authory about to thank depresent G. E. David for the induced flammations during the course of this work.

## APPENDIX

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