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A NEW THERMAL λ-ANOMALY IN IRON GROUP FERROMAGNETICS

Kh. Sh. Borlakov and E. I. Nesis

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The differential thermal analysis method is used to detect a new phase transition in iron group ferromagnetics. Assuming that this transition is caused by relativistic interactions, a thermodynamic theory is constructed to describe the transition.

The anisotropic magnetic properties of iron, nickel, cubic cabalt, and a number of their compounds show a common feature which has yet to be explained theoretically. In such ferromagnetics, below the Curie point T_C there exists a temperature interval $T_1 < T < T_C$, within which no nonzero magnetic anisotropy constant exists. Since the direction of the easy magnetization axis is defined by nonzero values of the magnetic anisotropy constant [1], in this interval there exists an isotropic, absolutely magnetically soft, magnetic phase, with no easy or difficult magnetization axes. With consideration of this, such technical concepts as magnetically soft or magnetically hard ferromagnetics take on a precise theoretical meaning. The goal of the present study is construction of a phenomenological thermodynamic theory which will permit derivation of the temperature dependence of the magnetic anisotropy constant at high temperatures, close to the Curie point. Results will also be presented from thermal experiments which confirm the existence of a transition from an isotropic magnetic phase to an anisotropic one in iron group ferromagnetics and magnetite (Fe_3O_4).

A thermodynamic description of the transition from a paramagnetic phase to an isotropic magnetic phase in ferromagnetics was presented in [2], and we will concentrate our attention on the transition from the isotropic to the anisotropic phase. The ferromagnetics we are dealing with are cubic, with point octahedral symmetry. Below the Curie point a spontaneous

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magnetic moment M, develops, the orientation of which relative to the crystallographic axes is arbitrary — this is the isotropic phase. In the isotropic phase the cubic asymmetry of the crystalline lattice is maintained. Below the temperature T_{LS} of transition to the anisotrophic phase this arbitrariness in the orientation of the vector M is lost — easy magnetization axes appear. The relativistic transition to the anisotropic phase is described by a pseudovector order parameter $C = C \cdot m$, where m is a unit vector directed along the spontaneous magnetization vector in the anisotropic phase. The absolute value of the order parameter C is the contribution to the magnetization produced by the cooperative effect of relativistic interactions. To describe all the single parameter anisotropic phases a sixth order Landau potential is sufficient [3]:

$$\Phi(\mathbf{C}) = A_1C^2 + A_2C^4 + A_3C^6 + DC^6m_x^2m_y^2m_z^2 + (B_1C^4 + B_2C^6)(1-2s), \quad (1)$$

where $s = m_x^2m_y^2 + m_y^2m_z^2 + m_z^2m_x^2$.

By comparison of potential (1) with the magnetic anisotropic energy

$$U_{an} = K_1s + K_2m_x^2m_y^2m_z^2$$

we obtain the temperature dependence of the magnetic anisotropy constant

$$K_1(C) = -2C^4 \cdot (B_1 + B_2 \cdot C^2); \; K_2 = D \cdot C^6 \quad (2)$$

for a known temperature dependence C(T).

From equilibrium and stability conditions $\partial\Phi/\partial C = 0$, $\delta^2\Phi \geq 0$ for potential (1) we find the following single parameter phases: C = (C, C, C); C = (C, C, 0); C = (C, 0, 0). The temperature dependence of C^2 has a form typical of Landau theory: $C^2 \sim (T_{LS} - T)$. If we consider the presence of deformations of the cubic lattice accompanying the relativistic phase transition, the magnetic anisotropy constants can be renormalized in the usual manner (see [4], p. 779), but their temperature dependence $K_1 \sim (T_{LS} - T)^2$, $K_2 \sim (T_{LS} - T)^3$ does not change.

The solution (C, C, C) corresponds to trigonal distortion of the cubic crystal and the axis of easiest magnetization along the space diagonal of the cube, while (C, 0, 0) corresponds to tetragonal distortion of the cubic cell with axis of easiest magnetization along an edge of the cube, and (C, C, 0) corresponds to rhombic distortion of the crystal and axis of easiest magnetization along a face diagonal of the cube.

Qualitatively Eq. (2) agrees with the behavior of experimental $K_1(T)$, $K_2(T)$ curves for iron group ferromagnetics. As an example, Fig. 1 shows $K_1(T)$, $K_2(T)$ curves for nickel. At the point of transition from the isotropic to the anisotropic phase, which according to the proposed theory, is a phase transition of the second sort, a thermal anomaly should appear. Differential thermal analysis (DTA) was chosen as the means of detecting this anomaly. Polycrystals of iron, nickel, and cobalt and a magnetite single-crystal were studied. Aside from the λ-anomaly at the Curie point, the DTA curves of these ferromagnetics showed new λ-anomalies of opposite sign. The temperatures of the new λ-anomalies were somewhat below the temperatures at which the first magnetic anisotropy constants vanished. This can apparently be explained by the effect of the external magnetic field required for measurement of the magnetic anisotropy constant. A strong external magnetic field shifts the phase transition point [6]. As is evident from Fig. 1, the difference between the tempera-

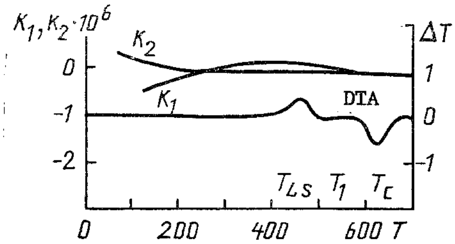

Fig. 1. Temperature dependence of first K_1 and second K_2 magnetic anisotropy constants and DTA curve for nickel. Thermal effect ΔT expressed in relative units. K_1, K_2, J/m³.

tures of phase transition and vanishing of the first anisotropy constant may be significant.

To summarize, it can be said that in 3d-ferromagnetics and a number of compounds of the 3d-metals there exists an isotropic magnetic phase, the thermodynamic properties of which are fully defined by exchange interaction. Relativistic (spin-orbital, dipole-dipole) interactions manifest themselves in a cooperative manner, leading to appearance of magnetic anisotropy and distortion of the crystal at temperatures T_{LS} which do not coincide with the Curie temperature. The above is supported by the behavior of $K_1(T)$, $K_2(T)$, and DTA curves of the ferromagnetics studied.

A number of questions related to theoretical group analysis of relativistic transitions and construction of phase diagrams are beyond the scope of the present study, but will be examined in another effort.

NOTATION

T_C, Curie temperature; T_1, temperature at which first magnetic anisotropy constant vanished; T_{LS}, temperature of relativistic (spin-orbital) phase transition: M, spontaneous magnetization vector; C, pseudovector order parameter; C, absolute value of pseudovector order parameter; Φ, Landau thermodynamic potential; A_1, A_2, A_3, B_1, B_2, coefficients in expansion of thermodynamic potential; m, unit vector directed along spontaneous magnetization vector; m_x, m_y, m_z, components of unit vector m; K_1, K_2, first and second magnetic anisotropy constants of cubic ferromagnetic; Fe_3O_4, chemical formula of magnetite.

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TEMPERATURE FIELD INHOMOGENEITY ON THE SURFACE OF AN ELECTROLYTIC HYGROMETER

V. N. Cherin'ko

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Determination of the temperature field on a hygrometer surface is reduced to measurement of electrical quantities by solution of the thermal conductivity problem for the hygrometer body. Differences in results from direct experimental data on surface temperature obtained by other authors using hygrometer models are analyzed.

Electrolytic heated hygrometers have now been widely used for almost three decades to measure parameters characterizing the moisture content of gases [1]. Their advantages over other sensors for use as primary sensors in automated data collection and control systems are well known. A large number of publications dedicated to analysis of operation of these devices have studied their basic static and dynamic characteristics and offered mathematical models [2, 3]. However the fact remains that the known literature still lacks a detailed quantitative analysis of certain basic well known unique features of these devices.

Komsomol'-on-Amur State Pedagogical Institute.

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