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On Improper Ferromagnetism

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It has been shown that the phase transitions of the second order to an antiferromagnetic state can be accompanied by the appearance of magnetization due to exchange effects.

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As was shown by Indenbom (see [1]), the phase transitions of the second order through representations that do not enter into the content of the vector representation can be accompanied by the appearance of electric polarization. A similar phenomenon should exist in magnetism.

Indeed, let us consider, for example, a magnetic transition through the representation E ($\mathbf{k} = 0$) in crystals of the C_{3v} symmetry class in the exchange approximation. A pair of antiferromagnetic vectors $\{\mathbf{L}_1, \mathbf{L}_2\}$ constitutes the order parameter. The first terms of the expansion of the Landau–Dzyaloshinskii potential have the form

$$a(T - T_c)\eta^2 + B\eta^4 + C\mathbf{Z}^2\mathbf{Z}^{*2}, \quad (1)$$

where $\mathbf{Z} = \mathbf{L}_1 + i\mathbf{L}_2$ and $\eta^2 = (\mathbf{Z}\mathbf{Z}^*) = \mathbf{L}_1^2 + \mathbf{L}_2^2$. In terms of the angle φ between the vectors $\mathbf{L}_1$ and $\mathbf{L}_2$ and the angle θ defined by the relation $\tan\theta = |\mathbf{L}_2|/|\mathbf{L}_1|$, the last term in potential (1) is expressed as

$$C\eta^4(1 - \sin^2 2\theta \sin^2\varphi). \quad (2)$$

The appearing structures are represented by means of the sublattices (see Fig. 1). At $C > 0$, the triangular antiferromagnetic structure, $|\mathbf{L}_1| = |\mathbf{L}_2|$, $\mathbf{L}_1 \perp \mathbf{L}_2$, is realized (see Fig. 1a). At $C < 0$, the minimization of contribution (2) provides only possible values $\varphi = 0, \pi$. To determine the parameter θ, it is necessary to take into account the invariant $(\mathbf{Z}^2)^3 + (\mathbf{Z}^{*2})^3$:

$$D\eta^6(\cos^3 2\theta - 3\cos 2\theta \sin^2 2\theta \cos^2\varphi). \quad (3)$$

At $D > 0$, the structure $\{0, \mathbf{L}_2\}$ (see Fig. 1b) is realized. At $D < 0$, the structure shown in Fig. 1c is realized: $\{\mathbf{L}_1, 0\}$ plus equivalent structures with the cyclic permutations of the sublattices corresponding to the element of the C_3 symmetry of the paramagnetic phase.

Owing to the exchange symmetry element $\sigma_v R$, which is the product of the permutations of atoms under the space reflection σ_v and time reversal R, magnetization in the first sublattice in the structure shown in Fig. 1b is absent and the magnetizations of the second and third sublattices are opposite to each other.

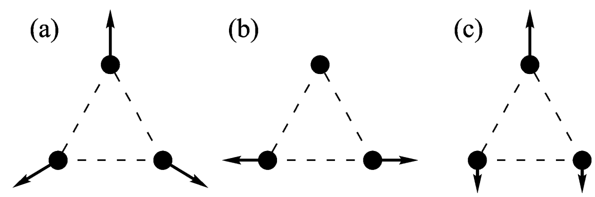

Fig. 1.

The compensation of the sublattices in the structure shown in Fig. 1c is approximate, because there is no transformation relating the sublattices with polarizations different in absolute value. The magnetization $M \propto (T_c - T)^{3/2}$ oriented along the vector $\mathbf{L}_1$ appears in this case due to the existence of the exchange invariant

$$\mathbf{Z}^2(\mathbf{Z}\mathbf{M}) + \mathbf{Z}^{*2}(\mathbf{Z}^*\mathbf{M}).$$

Note that, since this invariant is cubic in the main order parameter $\mathbf{Z}$, the transition becomes a transition of the first order in an external magnetic field.

In contrast to weak Dzyaloshinskii ferromagnetism, improper ferromagnetism, which has an exchange nature, should obviously be small only near the transition point.

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