

$$M = \pm \frac{5}{2} \leftrightarrow \pm \frac{3}{2} : H_{1,5} = H_0 \pm \left\{ 4D - \frac{4}{3}(a-F) \right\} - \frac{20}{27} \frac{a^2}{H_{1,5} \mp 2D},$$

$$M = \pm \frac{3}{2} \leftrightarrow \pm \frac{1}{2} : H_{2,4} = H_0 \pm \left\{ 2D + \frac{5}{3}(a-F) \right\} + \frac{20}{27} \frac{a^2}{H_{2,4} \pm 3D},$$

$$M = + \frac{1}{2} \leftrightarrow - \frac{1}{2} : H_3 = H_0 - \frac{20}{27} a^2 \left( \frac{1}{H_3 + 2D} + \frac{1}{H_3 - 2D} \right),$$

where  $M$  is the electron spin magnetic quantum number,  $H_0 = h\nu/g\beta$  ( $\nu$  is the frequency of the radiation field, and  $h$  is the Planck's constant), and  $D$ ,  $a$ , and  $F$  are expressed in oersteds and are obtained from the corresponding constants in the expression for the Hamiltonian by dividing by  $g\beta$ . These formulas give good agreement with the experimental data for the following values of the constants:

$$g = 2.003 \pm 0.001, |D| = (1801 \pm 3) \text{ Oe}, \quad |a - F| = (357 \pm 2) \text{ Oe}, \quad |a| = (280 \pm 20) \text{ Oe}.$$

The calculated spectrum for the "perpendicular" orientation also gives good agreement between the theoretical and experimental data at the lowest of the frequencies used.

We also investigated the spectrum of a sample enriched in the isotope  $\text{Fe}^{57}$ . No line of the allowed hyperfine structure was observed, which verifies the hypothesis<sup>1</sup> that the nuclear magnetic moment of this iron isotope is small.

<sup>1</sup>B. Bleaney and R. S. Trenam, Proc. Roy. Soc. (London) 223, 1 (1954).

Translated by E. J. Saletan  
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## THE PROBLEM OF PIEZOMAGNETISM

I. E. DZIALOSHINSKII

Physical Problems Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor June 20, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) 33, 807-808 (September, 1957)

IN the recent literature one encounters assertions that piezomagnetic bodies in general cannot exist in nature. This conclusion has been based on the invariance of the equations of mechanics with respect to a change of the sign of time when a simultaneous change is made in the signs of all magnetic fields and spins; from this the inference has been directly drawn that in the expression for the thermodynamic potential of an arbitrary substance, there can be no terms linear in the magnetic field.<sup>1</sup> In actuality, however, such an argument is valid only for paramagnetic bodies, whose magnetic symmetry group contains the transformation (we denote it by  $R$ ) consisting of a change of sign of the magnetic field and the spin. In substances possessing, for instance, the magnetic structure of antiferromagnetics, the magnetic symmetry group does not contain the element  $R$  by itself; this element enters only in combination with other symmetry elements, or else is not present at all. Consequently such substances, in general, are capable of possessing piezomagnetic properties.<sup>2,3</sup> In this note several substances are pointed out that actually occur in nature and that should, on the basis of magnetic symmetry considerations be piezomagnetic.

We consider, for example, the antiferromagnetic crystals  $\alpha\text{-Fe}_2\text{O}_3$  and  $\text{FeCO}_3$ . As has been shown,<sup>4</sup> they have the same magnetic symmetry class, composed of the following elements:

$$2C_3, 3U_2, I, 2S_6, 3\sigma_d.$$

(This refers to that one of the two antiferromagnetic phases of  $\alpha\text{-Fe}_2\text{O}_3$  that exists below  $250^\circ \text{K}$ ). Here the symbols for symmetry elements are the same as in Ref. 4; a rectangular coordinate system is chosen with the  $x$  axis along one of the twofold axes. It is easy to verify that such symmetry permits the presence, in the expression for the thermodynamic potential  $\Phi$ , of two combinations linear in the components of the stress tensor  $\sigma_{ik}$  and of the magnetic field  $H$ :

$$\Phi = -\lambda_1 \{(\sigma_{xx} - \sigma_{yy})H_x - 2\sigma_{xy}H_y\} - \lambda_2 (\sigma_{xz}H_y - \sigma_{yz}H_x).$$

Hence we find at once the expressions for the magnetic moment in the absence of an external field:

$$m_x = \lambda_1 (\sigma_{xx} - \sigma_{yy}) - \lambda_2 \sigma_{yz}, \quad m_y = -2\lambda_1 \sigma_{xy} + \lambda_2 \sigma_{xz}.$$

Other examples are the antiferromagnetics  $\text{MnF}_2$ ,  $\text{CoF}_2$ , and  $\text{FeF}_2$ . In accordance with Ref. 4, their magnetic symmetry class consists of

$$C_2, 2C_4R, 2U_2, 2U'_2R, I, \sigma_h, 2S_4R, 2\sigma_v, 2\sigma'_vR.$$

This symmetry group leaves invariant the following term in the expression for  $\Phi$ :

$$\Phi = -\lambda (\sigma_{xz}H_y + \sigma_{yz}H_x),$$

whence we get for the magnetic moment

$$m_x = \lambda \sigma_{yz}, \quad m_y = \lambda \sigma_{xz}.$$

<sup>1</sup>W. Zocher and H. Török, Proc. Nat. Acad. Sci. U.S.A. **39**, 681 (1953).

<sup>2</sup>B. A. Tavger and V. M. Zaitsev, J. Exptl. Theoret. Phys. (U.S.S.R.) **30**, 564 (1956); Soviet Phys. JETP **3**, 430 (1956).

<sup>3</sup>L. D. Landau and E. M. Lifshitz, Электродинамика сплошных сред (Electrodynamics of Continuous Media), Gostekhizdat, 1957.

<sup>4</sup>I. E. Dzialoshinskii, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 1547 (1957); Soviet Phys. JETP **5**, 1259 (1957).

Translated by W. F. Brown, Jr.

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## THE ROLE OF NUCLEONS IN MULTIPLE PRODUCTION OF PARTICLES

A. A. EMEL'IANOV and I. L. ROZENTAL'

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor June 20, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 808-809 (September, 1957)

**I**N the processes of multipole production of particles in collisions of high-energy nucleons with nuclei, nucleons play a special role compared to mesons.

In addition to the obvious differences caused by conservation of nuclear charge and different masses of nucleons and mesons, one should note a less obvious characteristic which is essential in a hydrodynamical description.<sup>1</sup> For energies of the incident nucleon  $E_0 = 10^{12} - 10^{13}$  ev, the temperature of the system at the beginning of the hydrodynamical expansion is  $1 - 2 \text{ Mc}^2$  (temperature is measured in units of energy;  $M$  is the nucleon mass). At the same time, the condition  $T \gg \mu c^2$  ( $\mu$  is the mass of the  $\pi$ -meson) is satisfied. Therefore, at the energies discussed, during the whole process the probability of production of a nucleon-antinucleon pair is very small; in this respect, nucleons and mesons differ essentially. At the present, it is not possible to unambiguously describe this difference of the nucleons in the process. Here we consider a simplified model of the hydrodynamical development of the system, taking into account the special role of the nucleons taking part in the process.<sup>2\*</sup>

We consider a given collision of two nucleons. In the interaction between nucleons, a meson cloud is formed, which is contracted by them as if by a piston (the contraction proceeds in a non-adiabatic fashion). As a result, a system is produced in which the kinetic energy is divided between nucleons in a very small volume. It is natural, in the spirit of the whole conception, to postulate that the order of magnitude of the volume  $V$  is  $(4\pi/3)(h/\mu c)^3 2\text{Mc}^2/E'$  where  $E'$  is the energy of the nucleons in their center of