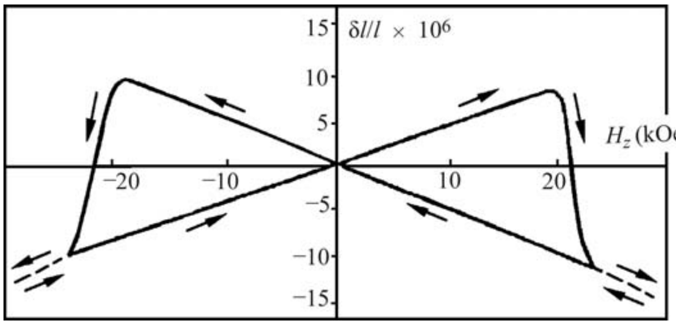

Fig. 1.5.7.2. Linear magnetostriction of CoF_2 (Prokhorov & Rudashevskii, 1975).

The values of these components are one order of magnitude smaller than for CoF_2.

The temperature dependence of the components is similar for the piezomagnetic tensor and the sublattice magnetization. This means that the magnetoelastic constants λ_1 and λ_2 (as well as the constants B and d) in the relations (1.5.7.7) and (1.5.7.8) depend only slightly on temperature.

1.5.7.2. *Linear magnetostriction*

From expression (1.5.7.3), it follows that a deformation of the sample may occur in a magnetic field. This deformation is linear with respect to the field. By its linear dependence, this effect differs essentially from ordinary magnetostriction, which is quadratic in the magnetic field. Most substances display such quadratic magnetostriction. The linear magnetostriction may be observed only in those ordered magnetics that belong to one of the 66 magnetic point groups that allow piezomagnetism and are listed in Table 1.5.7.1. The distinctive feature of linear magnetostriction is the dependence of its sign on the sign of the magnetic field and on the sign of the antiferromagnetic vector **L**. The sign of **L** characterizes the domain state of the specimen. Thus, observation of linear magnetostriction gives information about the domain state. In some materials, it has been observed that a sudden transition from one domain state to the opposite may occur in strong magnetic fields.

Linear magnetostriction (LM) was observed in CoF_2 by Borovik-Romanov & Yavelov (1963) in a magnetic field applied parallel to the fourfold axis. The relations for the LM in CoF_2 can be obtained by differentiating the expression of the thermodynamic potential Φ [(1.5.7.7)]. If the magnetic field is applied along the y axis, a deformation S_{xz} appears:

$$S_{xz} = -\partial\Phi/\partial T_{xz} = 2L_z \frac{d\eta_1 - a\lambda_1}{a(B+b) - d^2} H_y = 2\Lambda_{yxz} H_y = \Lambda_{25} H_2. \qquad (1.5.7.15)$$

A similar formula holds for S_{yz} if the magnetic field is applied parallel to the x axis (with Λ_{14}, which is equal to Λ_{25}).

If the magnetic field is applied parallel to the fourfold axis, the S_{xy} component of the deformation appears:

$$\begin{aligned} S_{xy} &= -\partial\Phi/\partial T_{xy} = -2L_z(\lambda_2/B)H_z = -2L_z\lambda_2\chi_\parallel H_z \\ &= 2\Lambda_{zxy} H_z = \Lambda_{36} H_3. \end{aligned} \qquad (1.5.7.16)$$

If the relations (1.5.7.15) and (1.5.7.16) are compared with (1.5.7.8)–(1.5.7.10), it is apparent that in accordance with theory the components of the tensors of the piezomagnetic effect (PM) and LM are identical.

Prokhorov & Rudashevskii (1969, 1975) extended the investigation of LM in CoF_2. They discovered that if the applied field becomes larger than 20 kOe, a jump in the magnetostriction occurs and it changes its sign (see Fig. 1.5.7.2). This jump is the result of a transition of the magnetic structure from one domain state ($\mathbf{L}_+$) into the opposite state ($\mathbf{L}_-$). To explain such a transition, one has to take into account the term of third power in the expansion of the magnetic energy (Scott & Anderson, 1966),

$$U_m = A_i H_i + \tfrac{1}{2}\chi_{ij} H_i H_j + C_{ijk} H_i H_j H_k. \qquad (1.5.7.17)$$

C_{ijk} is an axial time-antisymmetric tensor, the sign of which depends on the sign of the domain. This term defines the dependence of the magnetic energy on the sign of the antiferromagnetic domain.

To date, CoF_2 and MnF_2 are unique in that LM and PM occur without rotating the antiferromagnetic vector **L** if the magnetic field is applied along the fourfold axis (or pressure along a ⟨110⟩ axis). In all other cases, these effects are accompanied by a rotation of **L** and, as a result, the creation of new components L_i. To the latter belongs the LM in the low-temperature modification of α-Fe_2O_3, which was observed by Anderson *et al.* (1964) (see also Scott & Anderson, 1966; Levitin & Shchurov, 1973). This compound displays PM, therefore it is obvious that LM will also occur (see Table 1.5.7.1).

LM has been observed in some orthoferrites. One of the orthoferrites, $DyFeO_3$ at low temperatures, is a pure antiferromagnet, the vector **L** of which is aligned along the y axis. Its magnetic point group ($\boldsymbol{D}_{2h} = mmm$) allows PM and LM. The latter was observed when a magnetic field was applied parallel to the z axis by Zvezdin *et al.* (1985). There it was shown that $\Lambda_{zxy} \neq 0$ if $0 < H < H_c$. At $H_c \simeq 4$ kOe, a first-order phase transition into a weakly ferromagnetic state with magnetic point group $\boldsymbol{D}_{2h}(\boldsymbol{C}_{2h}) = m'm'm$ ($\mathbf{L} \parallel Ox, \mathbf{M}_D \parallel Oz$) occurs.

Many orthoferrites and orthochromites that possess weak ferromagnetism belong to the same point group, which possesses an ordinary centre of symmetry. Thus PM and LM are allowed for these phases of orthoferrites. If the magnetic field is applied parallel to Ox, they undergo a reorientation transition at which both vectors, **L** and $\mathbf{M}_D$, being orthogonal, rotate in the xz plane. These intermediate angular phases belong to the magnetic point group $\boldsymbol{C}_{2h}(\boldsymbol{C}_i) = 2'/m'$.

LM was observed by Kadomtseva and coworkers (Kadomtseva, Agafonov, Lukina *et al.*, 1981; Kadomtseva, Agafonov, Milov *et al.*, 1981) in two such compounds, $YFeO_3$ and $YCrO_3$. The Λ_{xxz} components of the LM tensor were measured, which are allowed for the $\boldsymbol{D}_{2h}(\boldsymbol{C}_{2h}) = m'm'm$ state.

The experimental data obtained to date for PM and LM are summarized in Table 1.5.7.2. The values of the components $\Lambda_{i\alpha}$ can be converted to SI units using 1 $\text{Oe}^{-1} = 4\pi \times 10^{-3}$ m A^{-1} $= 4\pi \times 10^{-3}$ T Pa^{-1}.

Table 1.5.7.2. *Experimental data for the piezomagnetic effect (PM) and for linear magnetostriction (LM)*

a: antiferromagnetic phase; *w*: weak ferromagnetic phase.

Compound	$\Lambda_{i\alpha} \times 10^{10}$ (Oe^{-1})	T (K)	PM or LM	Reference†
MnF_2	$\Lambda_{14} \simeq 0.2$	20	PM	(1)
CoF_2	$\Lambda_{14} = 21$	20	PM	(1)
	$\Lambda_{36} = 8.2$	20	PM	(1)
	$\Lambda_{36} = 9.8$	4	LM	(3)
$DyFeO_3$	$\Lambda_{36} = 6.0$	6	LM	(8)
$YFeO_3$	$\Lambda_{15} = 1.7$	6	LM	(6)
$YCrO_3$	$\Lambda_{15} \simeq 1$	6	LM	(7)
α-Fe_2O_3 (*a*)	$\Lambda_{22} = 1.9$	78	LM	(4)
	$\Lambda_{22} = 3.2$	77	PM	(2)
	$\Lambda_{22} = 1.3$	100	LM	(5)
	$\Lambda_{14} = 0.3$	78	LM	(4)
	$\Lambda_{14} = 1.7$	77	PM	(2)
	$\Lambda_{14} = 0.9$	100	LM	(5)
α-Fe_2O_3 (*w*)	$\Lambda_{23} = 2.5$	292	PM	(2)

† References: (1) Borovik-Romanov (1959*b*, 1960); (2) Andratskii & Borovik-Romanov (1966); (3) Prokhorov & Rudashevskii (1969, 1975); (4) Anderson *et al.* (1964); (5) Levitin & Shchurov (1973); (6) Kadomtseva, Agafonov, Milov *et al.* (1981); (7) Kadomtseva, Agafonov, Lukina *et al.* (1981); (8) Zvezdin *et al.* (1985).