DICHROISM OF POLARIZED MÖSSBAUER RAYS

D. Barb, M. Rogalski

DICHROISM OF POLARIZED MÖSSBAUER RAYS

D. Barb and M. Rogalski

National Center for Physics, P.O.B. 5207, Bucharest, Romania

Résumé.- On obtient, dans le formalisme de l'opérateur densité, une expression du dichroisme du rayonnement Mössbauer polarisé dans un absorbeur épais. On met en évidence l'influence réciproque entre le dichroisme et les effets dispersifs, en bon accord avec les résultats expérimentaux existants /1/.

Abstract.- We derive, in the density matrix formalism, an expression of the polarized Mössbauer rays dichroism in a finite thickness absorber. The reciprocal influence between the dichroism and the dispersive effects is evidenced, in good agreement with the existing experimental results /1/.

The present investigation was prompted by the fact that the dispersive effects of the polarized Mössbauer rays, measured in finite thickness absorbers /1/, /2/, was theoretically explained /3/ taking into consideration crystals having negligible dichroism (i.e. absorption is isotropic). Because an unisotropic absorption was found in the studied absorbers /1/, it is desired a closer examination of this effect.

We propose ourself to obtain an expression for the dichroism associated with the dispersive effects, assuming an arbitrary polarization state I_o, ξ_o, ϕ_o of the incident Mössbauer ray, done by a density matrix ρ /3/, and an absorber described by the matrix n of his refractive index /4/, in a typical polarimetric experiment (Fig. 1) :

$$n = \begin{pmatrix} n_{11} & n_{12} \\ n_{21} & n_{22} \end{pmatrix} \approx 1 - \frac{\sigma_o}{2k} \sum_{ij} \begin{pmatrix} \rho_{11}^{ij} & \rho_{12}^{ij} \\ \rho_{21}^{ij} & \rho_{22}^{ij} \end{pmatrix} \frac{N_j \; f_i}{(x - x_{ij}) + i} \qquad (1)$$

where $x = 2E/\Gamma$ is connected with the ray energy, and x_{ij} and the ρ_{ij} matrices correspond to the energies and the polarization patterns of the Mössbauer nucleus absorption lines. Using the notation :

$$L = \exp(ikz) = \begin{pmatrix} L_{11} \exp(i\gamma_{11}) & L_{12} \exp(i\gamma_{12}) \\ L_{21} \exp(i\gamma_{21}) & L_{22} \exp(i\gamma_{22}) \end{pmatrix} \qquad (2)$$

we obtain the following expression for the dichroism, defined as the difference of the emergent intensities of two orthogonally polarized beams :

$$D = I_o P \{ \sin 2\xi_o \, (L_{11}^2 - L_{22}^2) - 2L_{12} \cos 2\xi_o [L_{11} \cos(2\alpha + \gamma_{11} - \gamma_{12}) + L_{22} \cos(2\alpha + \gamma_{12} - \gamma_{22})] \} \exp\{-\mathrm{Im}(n_{11} + n_{22})\} \qquad (3)$$

Now we proceed to analyse the dichroism variation as a function of the polarization plane direction α and the wave vector direction θ, making obvious the reciprocal influence between the dichroism and the dispersive effects.

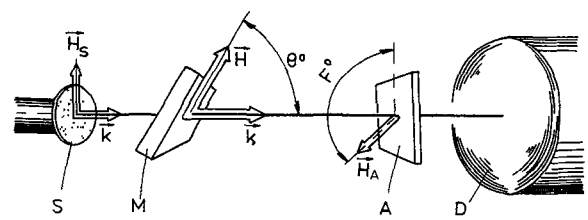

Fig. 1 : Schematic representation of the experiment: S - polarized source, M - transmitter, A - analyser, D - detector.

1.- We first consider the α-dependence of the linear dichroism, which has a simple expression obtained from (3) taking $\xi_o = 0$. The connection between the dichroism and the birefringence is illustrated in the case of an iron foil absorber ($z = 9.4 mg/cm^2$), 92.8% enriched in ^{57}Fe /1/, in an external magnetic field. In figure 2 is represented the α-dependence of the linear dichroism, for the right half of the Mössbauer spectrum. We have the same dichroism for the 10 MHz and 62 MHz lines, which prove that the absorption is saturated, due to the large thickness of the sample. If the incident ray has an energy corresponding to the absorption lines, a significant α-dependence of the dichroism, which influence the birefringence values is observed in figure 2a. Consequently, in the birefringence experiments are used energies corresponding to a negligible dichroism (as an example we considered E = 17.5 MHz /1/).

The connection between the linear dichroism and the Faraday rotation can be putted in evidence for the experiments using an iron foil absorber ($z = 1.94 mg/cm^2$), 91.2% enriched in ^{57}Fe, making an angle $\theta = 25°$ with the wave vector $\vec{k}$ /1/.

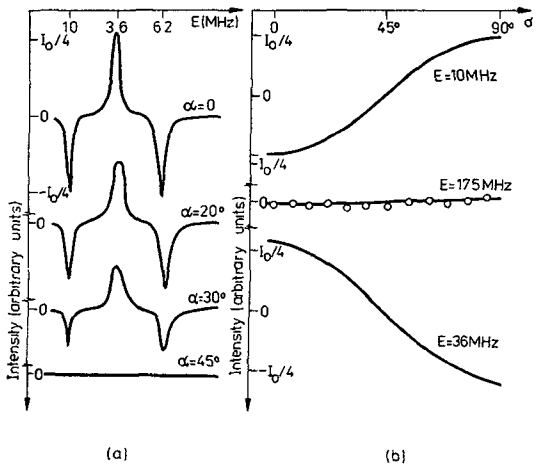

Fig. 2 : Linear dichroism and birefringence (θ=90°): a) linear dichroism for the right half of the spectrum; b) α-dependence of the linear dichroism for different energies of the incident beam; 0 - experimental points /1/.

Although the 10 MHz, 36 MHz and 62 MHz spectrum lines have the same intensities (i.e. the absorption is saturated), we obtain a negligible linear dichroism for the 10 MHz and 62 MHz lines (Fig. 3).

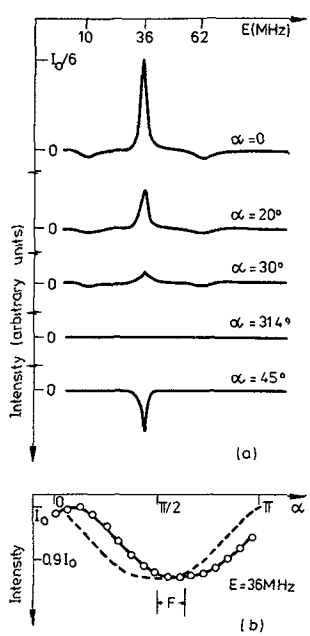

Fig. 3 : Linear dichroism and Faraday rotation (θ=25°) : a) linear dichroism for the right half of the spectrum; b) the Malus curve : 0-experimental points.

This can be explained by the absorption line polarization patterns, which are nearly circular, for these two lines. The dichroism of the 36 MHz line disappears when α = 31.4°, which corresponds to a Faraday rotation F = 13.6°, in good agreement with /1/.

As it is expected, the circular dichroism, done by (3) for $\xi_o = \pi/4$ is α-independent.

2.- The θ-dependence of the absorption was studied for the circularly and linearly polarized beams. Representing this dependence in the case of a circularly polarized ray absorption (Fig. 4) a saturation effect can be observed : the 10 MHz right circularly polarized beam is still completely absorbed by an ellipticaly polarized linè (θ = 30°), in the iron foil (z = 1.94 mg/cm²) previously considered.

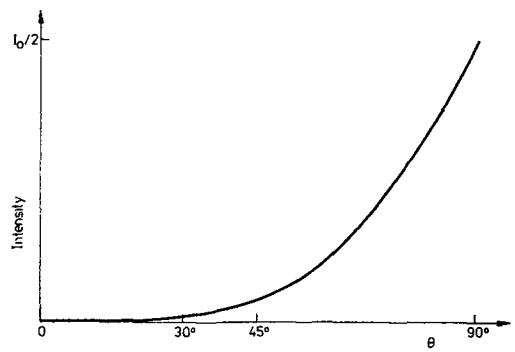

Fig. 4 : The θ-dependence of the 10 MHz right circularly polarized ray intensity.

The θ-dependence study of the absorption evidenced the influence of the dispersion on the linear dichroism. In figure 5 are represented the $I_{\parallel}$ and $I_{\perp}$ intensities of the 36 MHz rays, linearly polarized parallel and perpendicular to the magnetic field direction in the absorber.

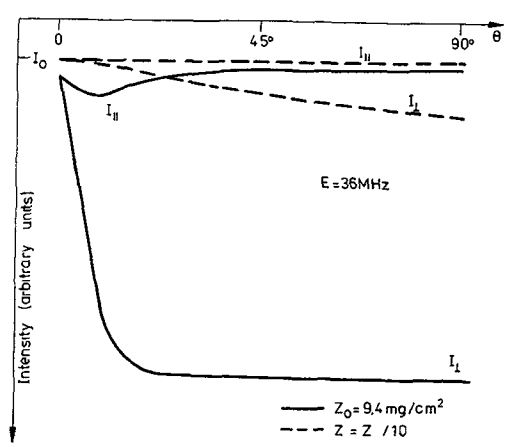

Fig. 5 : The θ-dependence of the 36 MHz linearly polarized ray intensities : $I_{\perp}$ - perpendicular to the magnetic field $\vec{H}$ in the absorber; $I_{\parallel}$ - parallel to $\vec{H}$. Solid line : thick absorber, dotted line : thin absorber.

Because the 36 MHz absorption line is perpendicular linearly polarized, for any θ, we expect a constant $I_{\parallel}$. But a significant absorption, for small θ, was obtained. This can be explained observing that the

parallel linearly polarized ray acquires, for this range of angles, an excentricity $\xi \neq 0$ and a Faraday rotation of 30 - 60°, which makes possible the absorption. For thin absorbers, this effect disappears.

References

/1/ Imbert, P., Thèse (1965), Rapport CEA-R 2925 (1966).

/2/ Housley, R.M., Gonser, U., Phys. Rev. 171 (1968) 480.

/3/ Barb, D., Rogalski, M., J. Physique 38 (1977) 1413.