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Optical Faraday-Rotation Studies of Spin-Lattice Relaxation Time in NdES (*).

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The Faraday effect is very large, in general, in paramagnetic salts at very low temperatures (~ 1 °K). The rotation of the plane of polarization of light passing through the material in a magnetic field has been found to be proportional to the magnetic moment of the salt ([1,2]).

The Faraday rotation can then be used to measure the spin temperature of a sample of one of these paramagnetic salts under the influence of disturbing factors. This procedure was suggested by KASTLER ([3]) and was firstly used by DANIELS and WESEMEYER ([4-6]) to estimate the spin-lattice relaxation time for neodymium ethylsulphate. The spin system in this case was perturbed by a pulse of microwave radiation at the electron paramagnetic-resonance frequency. Measurements were made of the relaxation time as a function of the field up to values of 2500 G. Outside this range the absorption of microwaves was so small that is was not possible to disturb the population of the spin level sufficiently with the power available.

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(1) J. VAN DEN HANDEL: *Handb. der Phys.*, vol. **15** (Berlin, 1956), pp. 1-37.
(2) J. BECQUEREL, A. DE HAAS, J. VAN DEN HENDEL: *Physica*, **5**, 753 (1938).
(3) A. KASTLER: *Compt. Rend.*, **232**, 953 (1951).
(4) J. M. DANIELS and H. WESEMEYER: *Can. Journ. Phys.*, **36**, 405 (1958).
(5) H. WESEMEYER and J. M. DANIELS: *Zeits. f. Phys.*, **152**, 591 (1958).
(6) J. M. DANIELS and K. E. RIECKHOFF: *Can. Journ. Phys.*, **38**, 604 (1960).

Other experiments employing optical Faraday rotation for the observation of microwave resonance and relaxation have been reported ([7-10]).

In the present letter we describe an optical Faraday-rotation technique for the determination of spin-lattice relaxation times. Here the crystal is subjected to a pulsed magnetic field. The shape of the first part of the pulse assumes the form of a quarter of a sine wave whose time duration is fixed (30 ms). The decay time may be adjusted from 30 ms up to 1 s using a crow bar system with variable resistance.

The relaxation time is derived from the delay with which the magnetization (detected by the Faraday effect) follows the magnetic-field pulse. Such method turns out to be particularly suited to relaxation time measurements with high magnetic field (10^5 G) whereas conventional methods cannot reach such values ([11]).

To obtain the spin-lattice relaxation time τ from the experimental results we start from the equation

$$\frac{\mathrm{d}M(t)}{\mathrm{d}t} = \frac{M - M_0}{\tau}, \tag{1}$$

where $M(t)$ is the istantaneous magnetization and $M_0(t)$ is the equilibrium magnetization in a static field equal in magnitude to the value of the field at the instant t.

As the rotation angle $\theta(t)$ is proportional to the magnetization $M(t)$ an equation similar to (1) holds for $\theta(t)$:

$$\frac{\mathrm{d}\theta(t)}{\mathrm{d}t} = \frac{\theta(t) - \theta_0(t)}{\tau}. \tag{2}$$

The relaxation time τ is thus derived from rotation angle measurements performed in dynamic and static fields.

The experimental arrangement (*) used in illustrated in Fig. 1.

The crystal sometimes was held inside a bath of He, or inside a sealed plexigas box and care was taken that the exagonal axis was parallel to the direction of propagation of light. The magnetic pulse was obtained by the discharge (130 kJ) of a bank of condensers in a coil cooled by liquid nitrogen.

The light source was an He-Ne laser operating at a wavelength of 6328 Å. The high intensity, the small beam cross-section, and the lack of appreciable beam divergence of this type of source minimize scattering and alignment problems. The temperature of the helium bath was obtained from the measured vapour pressure above the liquid helium. The error on the temperature is estimated to be less than 1 per cent.

The pulsed magnetic field acting on the sample was measured by means of a coil

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([7]) S. C. CHANG and J. Q. BURGESS: *Journ. Appl. Opt.*, **1**, 329 (1962).

([8]) J. MORT, F. LÜTY and F. C. BROWN: *Phys. Rev.*, **137**, A 566 (1965).

([9]) Y. HAGASHI, M. FUKUI and H. YOSHIOKA: *Journ. Phys. Soc. Japan*, **23**, 312 (1967).

([10]) K. E. RIECKHOFF and D. J. GRIFFITHS: *Can. Journ. Phys.*, **41**, 33 (1963).

([11]) A. A. MANENKOV and R. ORBACH: *Spin-Lattice Relaxation in Ionic Solids* (New York, 1966).

(*) A detailed description is found in ref. ([12,13]).

([12]) G. SACERDOTI: *A technique for the measurement of Faraday effect in pulsed magnetic fields at low temperatures*, to be published in *Proc. Phys. Sol.* (New York).

([13]) R. BRUZZESE, F. FRAZZOLI, M. MANCINI, G. SACERDOTI, G. TORALDO DI FRANCIA and F. UCCELLI: INFN/FM-66/2 (1966).

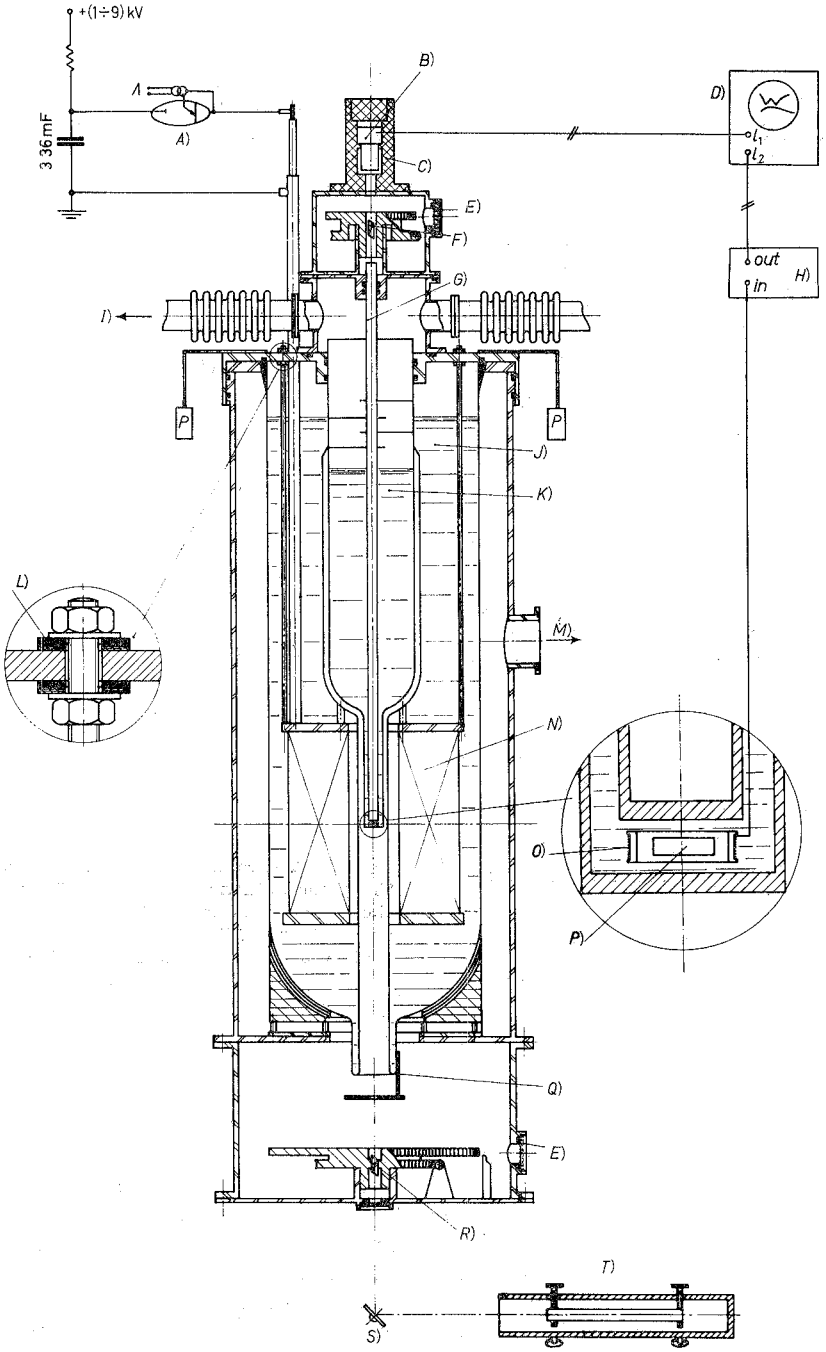

Fig. 1. – Diagram of the experimental apparatus: *A*) discharge ignitron; *B*) photomultiplier; *C*) magnetic shield; *D*) double-trace CRO; *E*) windows; *F*) rotable analyser; *G*) vacuum-closed tube; *H*) integrator; *I*) He recovery; *J*) liquid N_2; *K*) liquid He; *L*) rubber; *M*) high vacuum; *N*) pulsed magnet; *O*) coil; *P*) sample; *Q*) cold shield; *R*) rotable polarizer; *S*) optical deflection system; *T*) orientable laser.

having a known cross-section placed around the sample. The output from the coil was sent to a C.R.O. In some cases an integrator was placed in between.

The error by which the photomultiplier output is affected comes only from the 5 per cent inaccuracy of the C.R.O. This error is carried over to the angle determination through the function $\cos^2\theta$. An error varying with angle thus follows, which is practically negligible at the maxima and minima, reaching 6 per cent in the worst cases.

A typical experimental pulse shape is illustrated in Fig. 2. The upper trace represents the output signal from the photomultiplier. The lower trace represents the time derivative of the magnetic field.

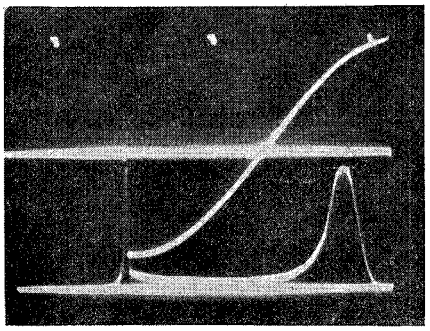

Fig. 2. – Typical experimental pulse shape. The upper trace represents the output signal from the photomultiplier. The lower trace represents the time derivative of the magnetic field.

The time evolution of the Faraday rotation angle $\theta(t)$, for two different temperatures, and of the magnetic field are reported in Fig. 3.

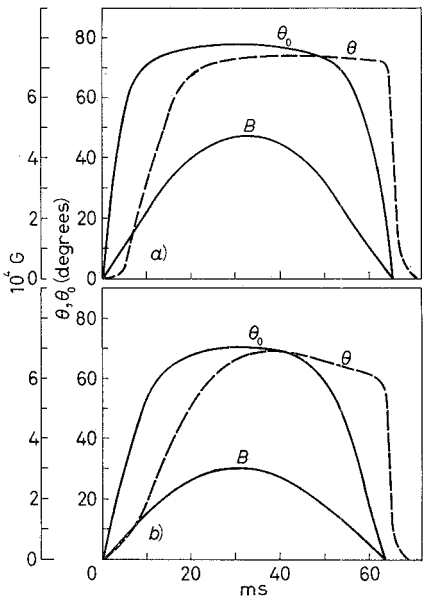

Fig. 3. – The rotation angle θ_0 of the polarization plane at thermodynamic equilibrium conditions, the time evolution of the Faraday rotation angle $\theta(t)$ and of the magnetic field are reported for two different temperatures: *a*) $T = 1.67$ °K; *b*) $T = 2.10$ °K.

Figure 3 shows also the curve of the rotation of the polarization plane θ_0 at thermodynamic equilibrium conditions. Experimentally this curve was obtained by measuring the rotation of the polarization plane both by using a superconductor magnet and with a quasi-static field. The results obtained by the two methods were in good agreement (better than 10 per cent).

Starting from (2) through the knowledge of $\theta(t)$, θ_0, $\mathrm{d}\theta/\mathrm{d}t$ the field dependence of τ, for a given temperature, is easily obtained.

In Fig. 4 the experimental results derived in the first part of the pulse (rising field) are compared with the theoretical ones, as obtained by one of the authors (ref. [14]). It is seen that the agreement is good for low magnetic-field values, the difference being within an order of magnitude up to 10 kG. For field strengths higher than 10 kG the present theory is inadequate to explain the experimental results.

The fact is peculiar that the time evolution of the magnetization for decreasing magnetic field is extremely fast: it is not yet understood whether this phenomenon

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([14]) F. FRAZZOLI and M. MANCINI: *Nuovo Cimento*, **53**, 471 (1968).

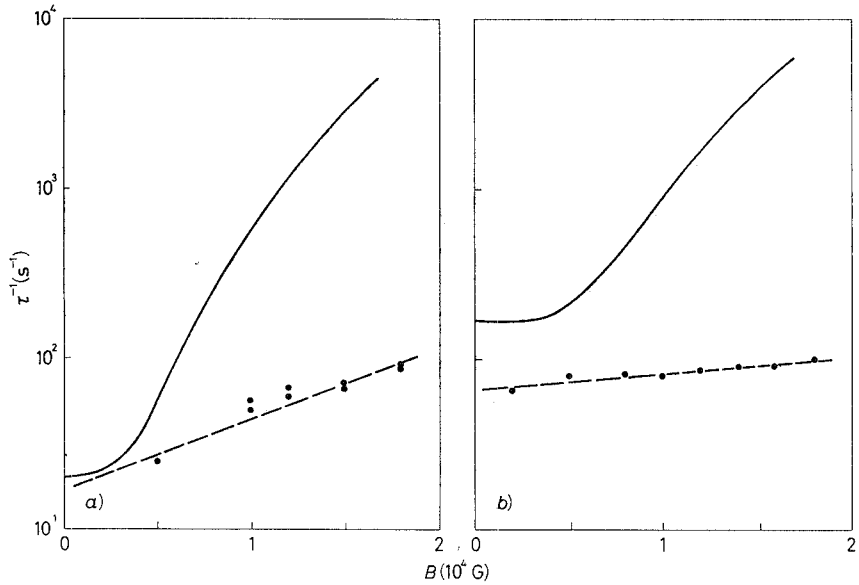

Fig. 4. – Relaxation time as a function of magnetic field. The experimental results (broken line) are compared with the theoretical ones (solid line) for two different temperatures: *a*) $T = 1.67$ °K; *b*) $T = 2.10$ °K.

arises from some mechanism different from that postulated, or from eq. (2) being not sufficient to describe the facts. Preliminary tests with a superconducting bias field seem to indicate that for a field greater than 1000 G the rapid descent disappears.

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