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PRESSURE DEPENDENCE OF THE MAGNETIC ANISOTROPY ENERGY OF NICKEL BETWEEN 300 K AND 4.2 K

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The effects of hydrostatic pressure on the magnetic anisotropy energy of nickel have been studied between 300 K and 4.2 K with pressures up to 6 kbar, with special attention for the complicated angle dependence of this energy at low temperature. The relative change with pressure (in 10^{-2} /kbar) of the first anisotropy constant varies between 300 K and 4.2 K from -0.75 to -0.15. Experiments in the (100) -plane do not show any influence of pressure on the higher order contributions to this energy.

TORQUE experiments on the magnetic anisotropy energy of a ferromagnetic single crystal with cubic symmetry can be described in the (100) -plane by the expression:

$$L_A^{100}(\nu) = -\sin 2\nu \times \cos 2\nu$$

$$(B_1 + B_2 \sin^2 2\nu + B_3 \sin^4 2\nu + ..) \qquad (1)$$

where ν is the angle between $\vec{M}$ and the [001]- direction, $B_1 = K_1$, $B_2 = \frac{1}{2}K_3$, etc., with K_1, K_3, etc., the anisotropy constants, defined in the usual way.[1] The extrema in expression 1, denoted by L_{ex}, are found for $\nu = \pi/8, 3\pi/8, ..$ and are equal to $\pm\frac{1}{2}(K_1 + \frac{1}{4}K_3 + ...)$.

In addition to previous experiments at 77 K and 296 K,[2] these extrema have now been studied under pressure between 4.2 K and 300 K. The torque measurements were performed on a pure nickel sphere (diameter 7.6 mm) in nearly the same manner as described in reference 2. By using a capillary tube with an outer diameter of 1 mm and a length of 700 mm, the connection between the high pressure vessel and the pressure generating system is sufficiently weak to permit an accurate study of the magnetic torque in nickel.

Between 77 K and 300 K helium gas was used as the pressure transmitting medium. At the 4.2 K we made use of the solid helium technique. To get at this temperature the pressure as hydrostatic as possible the helium gas was frozen from the bottom of the vessel under constant pressure in a way as described by Schirber.[3] The pressure was measured with a manganine cell and checked by strain gauges on the outer side of the high pressure vessel. At 4.2 K the pressure was determined directly with these strain gauges.

The effect of pressures on the extrema in the torque curve is purely linear as is shown in Fig. 1, where the decrease in the maximum torque with pressure at 77 K is demonstrated as an example. In Fig. 2 we present the relative and the absolute changes of the extrema under pressure as a function of temperature. At 77 K two results are shown, one with a more accurate technique that was needed in order to perform the experiments at 4.2 K. From the four extrema at 77 K we found for the relative change with pressure of the maximum torque: $(-0.20 \pm 0.005) \times 10^{-2}$/kbar. Literature data at room temperature[2,4,5] at 77 K[2] and between 260 K and 300 K[6] are in agreement with the data of Fig. 2.

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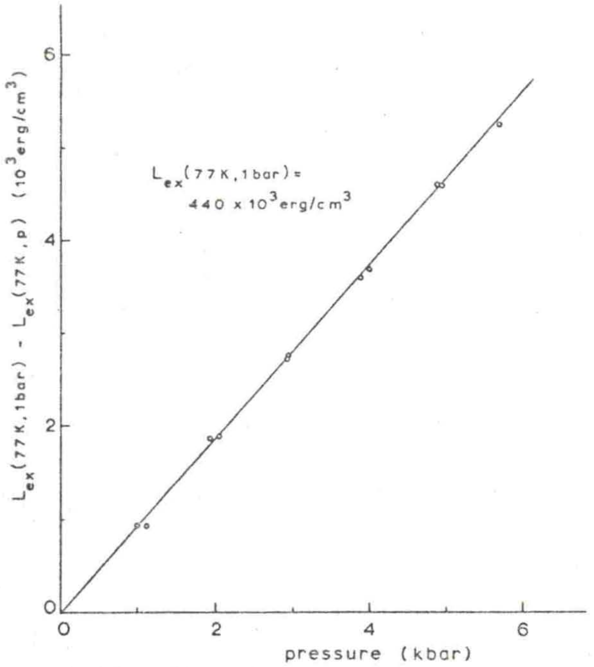

FIG. 1. The effect of pressure on the extremum (L_{ex}) of the magnetic torque curve in the [100]-plane of nickel at 77 K.

At low temperature we were especially interested in the effect of pressure on the higher order contributions to the magnetic anisotropy energy. To study these higher order contributions as a function of pressure we measured accurately the magnetic torque at 60 bar and at 6 kbar over the full range of orientations in the [100]-plane.;The analysis of these torque data at 4.2 K is rather complicated, as has been discussed earlier.[1,7]

The constants B_1, B_2, etc. of equation (1) are a bad choice for giving a unique representation of the magnetic torque measurements at this temperature. These constants are, however, very sensitive to small changes in the complicated angle dependence of the anisotropy energy. For that reason we present in Table 1 the constants $B_1, \ldots, B_4$ at 4.2 K and B_1 and B_2 at 77 K at the two pressures. Using these constants we have at 4.2 K a rather good, and at 77 K a very good description of the experimental data. From the data in this table it must be concluded that the effect of pressure is only observable for the first anisotropy constant.

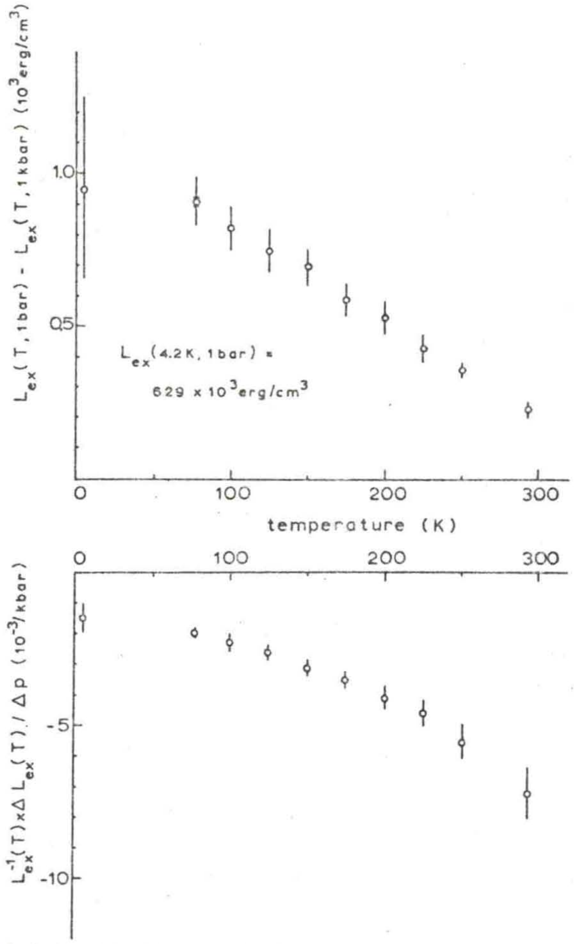

FIG. 2. Absolute and relative change with pressure of the extremum of the magnetic torque curve of nickel as a function of temperature. These data can be interpreted as the absolute and the relative change with pressure of the first anisotropy constant K_1.

In investigating the behaviour of the magnetic anisotropy energy of nickel at low temperature, experiments have now been performed on this energy as a function of temperature below 4.2 K[7,8] as a function of the external magnetic field with fields between 10 and 20 koe,[7] as a function of pressure with pressures up to 6 kbar, and as function of impurity concentrations, with Cu, Co and Fe concentrations between 0.1 and 1 per cent.[7,9] Only in these latter experiments changes in the complicated angle dependence of the magnetic anisotropy energy of nickel could be observed

Table 1. The constants B_1, B_2, etc., defined in equations (1) *and the energy differences between the* [001] – *and* [011] – *directions, at different pressures* (*in* 10^3 erg/cm³).

		B_1	B_2	B_3	B_4	$E_A[100] - E_A[110]$
77 K	60 bar	–833 ± 1	–100 ± 2	–	–	220.4 ± 0.5
	6 kbar	–823 ± 1	– 99 ± 2	–	–	217.9 ± 0.5
4.2 K	60 bar	–1203 ± 3	–320 ± 20	540 ± 50	–250 ± 30	311.3 ± 1
	6 kbar	–1189 ± 3	–322 ± 20	550 ± 50	–260 ± 30	307.6 ± 1

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On a étudié l'anisotropie magnétique sous pression hydrostatique entre 300 K et 4.2 K avec des pressions jusqu'à 6 kbar, accordant beaucoup d'attention aux structures compliquées de l'énergie anisotropique à basse température. Le changement relatif sous pression (en 10^{-2} /kbar) de la première constante anisotropique varie entre 300 K et 4.2 K de –0.75 à –0.15. Les expériences dans le plan (100) a'indiquent pas un effet de la pression sur les constantes anistropique d'une ordre plus haute.