MEASUREMENT OF PREDOMINANT ELECTRON SPIN ORIENTATION AT SINGLE CRYSTAL SURFACES OF FERROMAGNETIC NICKEL

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The spin polarization of electrons captured by deuterons scattered from magnetized ferromagnetic nickel is determined via the T(d, n)^{4}He reaction. The predominant electron spin orientation is found parallel to the magnetizing field for electrons in (100)-, (110)-, (111)-, antiparallel in (120)-surfaces.

Deuterons leaving a solid surface can capture electrons becoming neutral atoms. A spin polarization of the captured electron can then be transferred to the deuteron nucleus by hyperfine interaction and thus determined by measuring the asymmetry in the angular distribution of the alpha-emission in the reaction T(d, n)^{4}He. This concept has been proposed by E.K. Zavoiskii [1] in 1956 and recently M. Kaminsky [2] showed its feasibility in transmission experiments of deuterons through thin magnetized single crystalline nickel foils. His findings were essentially verified by L.C. Feldman et al. [3].

Here we report on results utilizing this procedure to measure the dependence of the electron spin polarization on the (*hkl*) of the surface of magnetized nickel samples. We employ a beam of 150 keV deuterons (beam divergence 0.15°) reflected under 0.4° glancing incidence from a surface (*hkl*) of a nickel single crystal placed in a magnetic field of 0.3–1.3 T which is perpendicular to the plane of incidence. After reflection the beam passes through an electric field to extract residual charged deuterons. The neutral deuterium atoms reach the tritium target and the alpha-particles emitted in T(d, n)^{4}He are counted by two solid state detectors A and B positioned in a plane perpendicular to the beam and 90° to each other, A being parallel to the direction of the applied magnetic field in the nickel sample. For details see the legend to fig. 1.

The ratio of the counting rates, Z_A/Z_B, of the two detectors is a measure of the tensor polarization of the deuteron in the deuterium atom. Calibration of the counter symmetry was performed by substituting the nickel sample by a (non magnetized) polycrystalline copper sample of identical dimensions assuming the analyzing power of the T(d, n)^{4}He reaction to be 1. Going through the appropriate formulae [2] yields the required relationship between Z_A/Z_B and the mean polarization of the captured electrons

$$P_{el} = (N\uparrow - N\downarrow)/(N\uparrow + N\downarrow)$$

$$= 12\,(Z_A/Z_B - 1)/(Z_A/Z_B + 2)$$

$N\uparrow$ is the number of electrons with spin parallel to the direction of the magnetic field applied to the nickel crystal. Z_A/Z_B is measured with such an accuracy that P_{el} can be calculated within ± 0.015.

The nickel surface is prepared by wire sawing, grinding, chemical and electrolytical etching, and annealing for five hours at 1280°C in hydrogen. The measured degree of polarization remains constant, if the vacuum in the target chamber is $\lesssim 2 \times 10^{-8}$ torr. Increasing

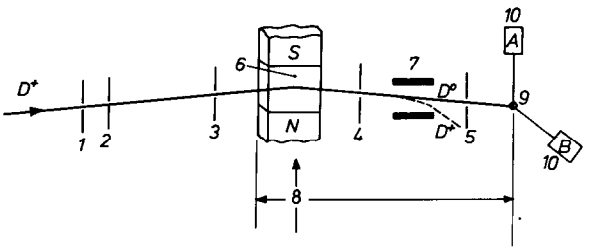

Fig. 1. Experimental arrangement, 1–5: collimating slits; 6: nickel target (12 × 8 × 1.5 mm), magnetized perpendicularly to the beam direction; 7: electrostatic condensor; 8: weak magnetic field (0.8 mT), parallel to the target magnetizing field; 9: T–Ti target; 10: alpha solid state detectors A and B.

Table 1
Electron spin polarisation of nickel single crystal surfaces

Reflection plane	Predominant spin orientation experimental a) sign P_{el} (*hkl*)	Beam direction	Polarisation observed b) %	Predominant spin orientation theory sign P_{el} (*hkl*)					
				Ref.: [4]	[5]	[6]	[7]	[8]	[9]
(110)	+	[110]	32 ± 2	+	+	+	+	+	+
(110)	+	[1$\bar{1}$2]	23 ± 2 c)						
(100)	+	[110]	19 ± 2	+	+		+	+	+
(111)	+	[1$\bar{2}$1]	12 ± 2	+	+	+	+	+	+
(111)	+	[110]	10 ± 2						
(120)	–	[$\bar{2}$10]	9 ± 2	–		–	–	–	

a) + sign: predominant electron spin polarisation parallel (magnetic moment antiparallel) to the direction of the applied magnetizing field in the nickel sample.
b) These values are possibly lowest limits only and subject to experimental conditions. The error limit is taken from repeated experiments with different samples and is not due to counting statistics.
c) measured with D_2^+; all other measurements were performed with D^+.

this pressure to 5×10^{-6} torr gradually deteriorates the polarization to almost zero. The nickel surface has then to be retreated to restore the former polarization.

The magnitude of the measured polarization depends on the preparation of the nickel surface and on scattering parameters inherent in the setup which were beyond control in the present status of the experiments. Therefore, the measured magnitudes of electron polarization (see table 1) can only be considered as lowest limits of the real electron polarization on the surface.

However, the predominant direction of the electron polarization appeared to be a characteristic quantity of the orientation of the nickel surface. In table 1, a summary is given of the measured spin orientations.

Till now no theoretical treatment of the electron polarization at metal surfaces is available. Therefore, we compare the present result with theoretical data on the bulk spin polarization of nickel which has been the subject of several recent investigations [4–9]. Due to screening effects, a passing 150 keV deuteron can only be neutralized in the tail of the electron distribution at the surface [10]. There the available electrons are likely those which are in the highest energy levels. From band calculations of ferromagnetic nickel [4–9] we have deduced the direction of the predominant electron spin polarization, sign P_{el} (*hkl*). The signs thus obtained are listed in table 1, as well. In comparing with the experimental values the correpondence is obvious.

The present results indicate that in general the capture of electrons from solids by passing deuterons (or protons, positrons) and the determination of the spin polarization in the neutral entity thus formed opens a promising field of electron spin spectroscopy on solid surfaces.

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References

[1] M. Kaminsky, Phys. Rev. Lett. 23 (1969) 819.
[2] E.K. Zavoiskii, Soviet Phys. JETP 5 (1957) 378.
[3] L.C. Feldman, D.W. Mingay and J.P.F. Sellschop, Radiation effects 13 (1972) 145.
[4] L. Hodges, H. Ehrenreich and N.D. Lang, Phys. Rev. 152 (1966) 505.
[5] J.W.D. Connolly, Phys. Rev. 159 (1967) 415.
[6] E.I. Zornberg, Phys. Rev. B1 (1970) 244.
[7] B.A. Politzer, Diss. Pennsylvania Univ. (1971).
[8] J. Langlinais and J. Callaway, Phys. Rev. B5 (1972) 124.
[9] G. Meister, Diss. University Munich (1971).
[10] W. Brandt and R. Sizmann, Phys. Letters 37A (1971) 115.