INHOMOGENEOUS MAGNETIZATION OF NICKEL NEAR THE CURIE POINT

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An investigation of the phase transition in nickel with the aid of polarized neutrons has shown that near the Curie point the polarization of the neutrons passing through the sample is inhomogeneous and depends on the place where the beam intersects the investigated sample [1]. This character of the polarization can be attributed to depolarization of the neutrons by the critical fluctuations of the magnetization and to the shift of the Curie point by the local inhomogeneities of the sample material. Since one measures in the experiment only the polarization-vector component directed along the leading magnetic field, another way of explaining the observed phenomenon is to assume inhomogeneous magnetization of the sample when $T \lesssim T_c$ and rotation of the neutron-polarization vector in the magnetic fields of these inhomogeneities. We present in this article the results of experiments on the state of magnetization of nickel near the Curie point.

The measurement setup was similar to that described earlier [1]. A beam of polarized neutrons with a cross section from 0.3 to 1 mm^2 was passed in succession, in steps of 0.4 or 0.8 mm, through the entire area of the investigated samples. The wavelength of the incident neutrons was about 4 Å and the degree of polarization was $P_0 \simeq 75\%$. The temperature was maintained constant within ±0.01°C. The magnetic field in the region of the sample was <0.1 Oe. Phase-shifting magnets placed near the sample were used to study the depolarization and the rotation of the neutron polarization vector $\vec{P}$ in the interior of the sample. We investigated samples of single-crystal and polycrystalline nickel with various shapes — rectangular plates, discs, and rings.

An analysis of a large number of measurements leads to the following conclusions: regardless of the sample shape or heat treatment, the depolarization of the neutron beam increases with decreasing temperature. This depolarization of the neutron beam increases with decreasing temperature. This depolarization is uniform over the cross section of the sample, down to temperatures corresponding to a decrease of P to values $P/P_0 \simeq 0.6 - 0.7$. No rotation of the polarization vector in the sample was observed. With further decrease of the temperature, the polarization becomes inhomogeneous over the cross section of the sample, and even regions with negative P are produced. This indicates that the inhomogeneous polarization is due to the rotation of $\vec{P}$ in the magnetic field of the sample itself. Thus, the occurrence of magnetization at $T < T_c$ is revealed by rotation of the vector $\vec{P}$, unlike the depolarization at $T > T_c$. The temperature below which $\vec{P}$ begins to rotate determines the phase-transition point. This point agrees with our earlier determination of T_c from the depolarization curve P(T) [1].

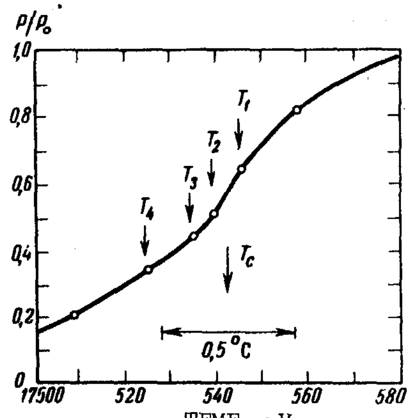

Fig. 1

By way of an illustration we present some experimental data for a ring and a disc cut from

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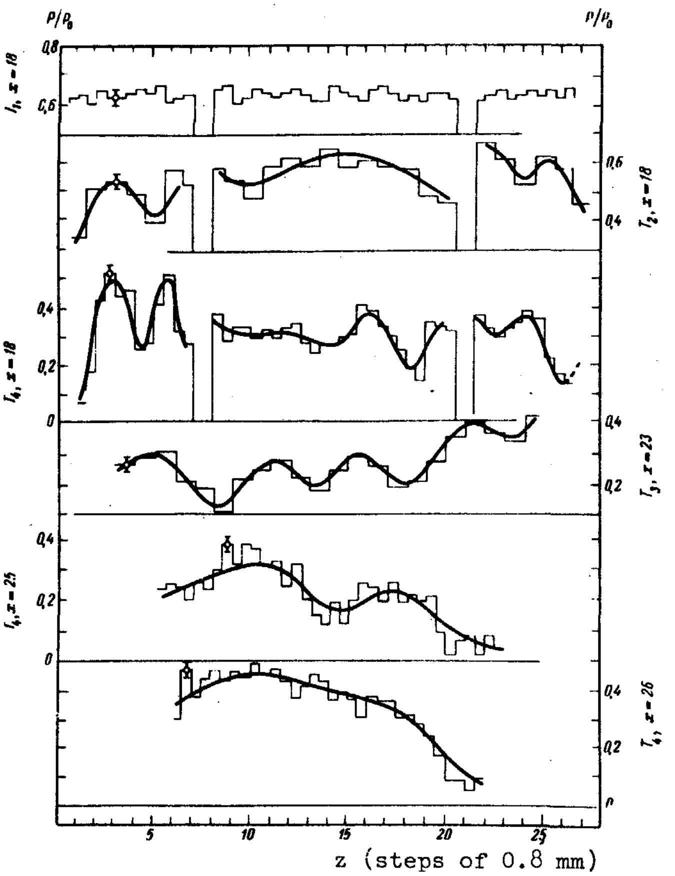
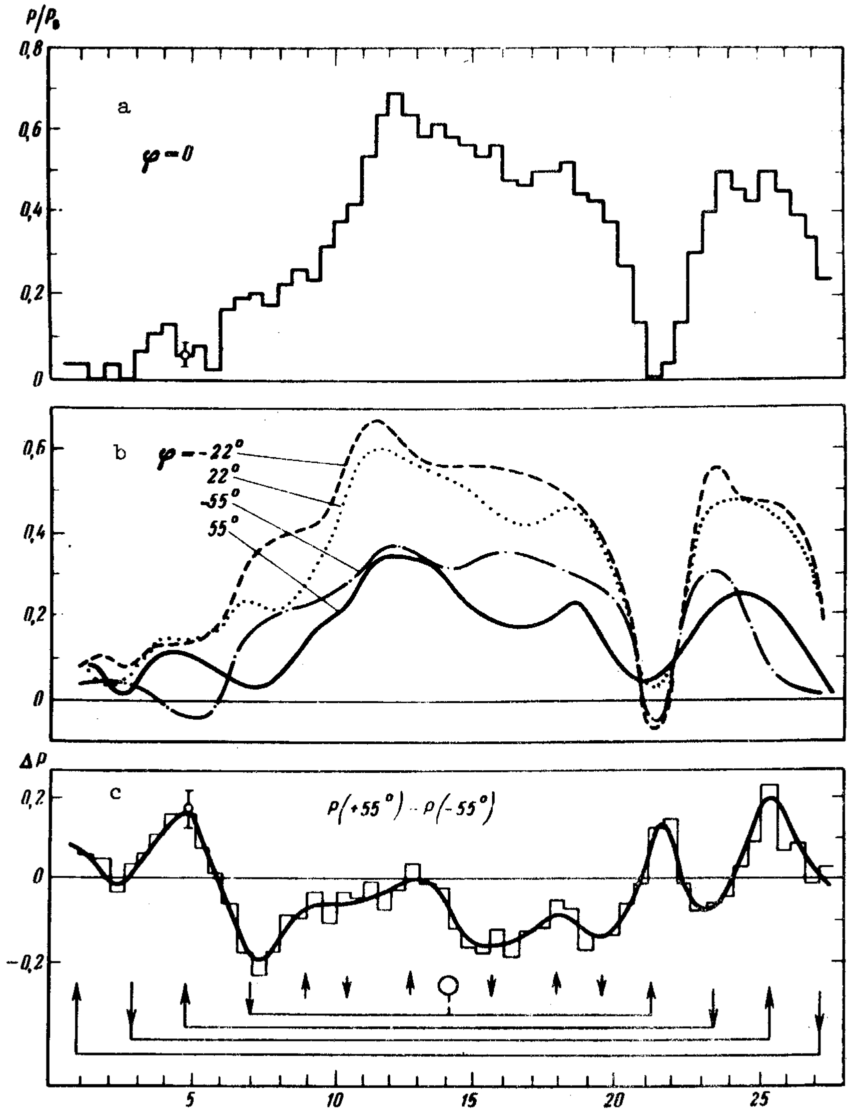


Fig. 2

single-crystal nickel. The ring had an inside and outside diameter 12.5 and 22 mm, respectively. The [111] axis was perpendicular to the plane of the disc (and ring). The disc and ring were placed coaxially in parallel planes 5 mm apart. Figure 1 shows the depolarization of a neutron beam with a cross section 10 × 1.5 mm by a sample (disc), as a function of the temperature. The temperature is expressed in terms of the thermal emf (TEMF) of a copper-constantan thermocouple. The region of T investigated subtended ∿0.5°C. Figure 2 shows histograms of P(z) in different vertical sections x (the z axis is vertical, $x \perp z \perp y$, where y is the axis of the horizontal beam, x and z are given in units of 0.8 mm). The values of T indicated on the diagrams correspond to the markers on the F(T) curve of Fig. 1. It follows from Fig. 2 that the inhomogeneity of the magnetization appears at $T \lesssim T_2$. Comparison of the curves with x = 18, 23, 25, 26 (chords passing at different distances from the geometric center of the ring) leads to the conclusion that an inhomogeneity in the form of coaxial annular layers with opposite magnetization directions sets in at $T \simeq T_3$ and T_4; the radial period of the rings is 2.5 - 3 mm. In the case of a disc of 22 mm diameter and 4.3 mm thickness, such an annular symmetry is not revealed directly by the distribution of the polarization (Fig. 3, $\phi = 0$, where ϕ is the angle of rotation of $\vec{P}$ in the vertical plane; this rotation is effected by the phase-shifting magnet). A periodic structure with periods 3 - 4 mm appears when $\vec{P}$ is rotated through a certain angle ϕ in either direction (Fig. 3b). The difference histogram $\Delta P = P(+55°) - P(-55°)$ shown in Fig. 3c demonstrates convincingly the presence of an inhomogeneity that is symmetrical with respect to the center of the curve and is manifest in an inclination of P in the yz plane. The maximal inclinations of $\vec{P}$ reach 25°, corresponding to oscillation of the x-components of the induction in the sample with amplitude $4\pi M_x \simeq 4$ G. The directions of M_x are indicated by the arrows in Fig. 3c. The values of $4\pi M_x$ for the other investigated samples range from 0 to 30 G for a temperature interval of 0.3°C.

Thus, from an analysis of the results on six investigated samples it can be concluded that inhomogeneous magnetization exists in the ferromagnetic phase near T_c ($\tau = |T = T_c|/T_c \gtrsim 10^{-4}$). The form of the inhomogeneity is connected with the shape of the sample: the symmetry is circular for round objects, and a periodicity in at least two dimensions in the plane of the sample is observed for rectangular samples. The characteristic dimensions of the inhomogeneity are comparable with the sample thickness (2 - 4 mm). The inhomogeneity is not connected with the ferromagnetic domains in their usual representation, indicating that the crystallographic anisotropy near T_c is small.

Fig. 3



An investigation of the behavior of the magnetization in an external field can indicate the extent to which an inhomogeneity of this type is connected with the frequently discussed [2, 3] question of the shift of the phase-transition point in a magnetic field. The polarized-neutron procedure uncovers qualitatively new possibilities of investigating the ferromagnetic phase transition.

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