ANISOTROPY OF DEPOLARIZATION OF A NEUTRON BEAM

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When a beam of polarized neutrons passes through a ferromagnetic sample consisting of a large number of domains, the neutrons become depolarized. This phenomenon is extensively used in the investigation of magnetic materials [1 - 3]. For a quantitative description of the depolarization, it is customary to start with an analysis of the rotations of the neutron spin around the field B_i of the i-th domain through an angle $\phi_i = g(B_i\delta_i/v)$, where g is the gyromagnetic ratio for the neutron, δ_i is the dimension of the domain, and v is the neutron velocity.

Assuming that the induction B_i is constant over the entire domain the induction vectors in different domains are randomly directed, and on passing through the domain the neutron spin experiences a small rotation $\phi_i << 1$, Halpern and Holstein [4] derived a formula for the depolarization:

$$\frac{P}{P_o} = \exp\left(-\frac{g^2}{3v^2}\sum_i B_i^2\delta_i^2\right), \qquad (1)$$

where P_0 and P are the polarizations of the incident and transmitted beams.

Recently, however, Maleev and Ruban [5] have shown theoretically that under the assumption made by Halpern and Holstein, namely that B_i is constant in the domain, sight was lost of the connection between the direction of the polarization $\vec{P}_0$ and the neutron velocity vector $\vec{v}$, which leads to anisotropy of the depolarization.

The point is that in the derivation of formula (1) no account was taken of the demagnetizing fields that are produced as a result of the presence of magnetic poles on the boundaries between the domains. This fact is simplest to take into account when neutron scattering is considered, as was indeed done by Maleev and Ruban. They connected the depolarization with the cross section for small-angle magnetic scattering (within the limit of the angular width of the beam). Since the polarization of the scattered neutrons is connected with the polarization of the incident beam via the scattered vector $\vec{e}$ [7]:

$$\mathbf{P} = -\mathbf{e}(\mathbf{e}\,\mathbf{P}_o), \qquad (2)$$

it follows that the depolarization depends on the orientation of $\vec{P}_0$ relative to $\vec{e}$, and consequently also relative to the velocity vector $\vec{v}$, so that $\vec{e} \perp \vec{v}$ in the case of elastic scattering. As a result of their analysis of scattering, Maleev and Ruban [5] have shown that the polarization component $P_\perp$ perpendicular to the velocity vector should become depolarized more strongly than the component $P_\parallel$ which is parallel to v, with

$$\alpha = \frac{\ln P_\perp/P_{o\perp}}{\ln P_\parallel/P_{o\parallel}} = \frac{3}{2}, \qquad (3)$$

whereas according to formula (1) we have $\alpha = 1$.

The present communication is devoted to an experimental observation of the anisotropy of the depolarization of a neutron beam on ferromagnetic domains of nickel at room temperature.

The work was performed with a setup described earlier [1]. The neutron wavelength was $\lambda \approx 4$ Å. A special system of magnets has made it possible to guide to the sample neutrons polarized along any direction in space. The samples were located in a near-zero magnetic field (H < 0.04 Oe). The samples were made of nickel powder pressed into tablets with effective nickel thicknesses 0.07, 0.14, and 0.42 mm. The domain dimension estimated from formula (1) was of the order of 10^{-4} cm.

The table lists the results obtained for

$$\alpha_x = \frac{\ln P_x/P_{ox}}{\ln P_z/P_{oz}} \text{ and } \alpha_y = \frac{\ln P_y/P_{oy}}{\ln P_z/P_{oz}},$$

where the z axis coincided with the direction of the beam v, and the x and y axes were perpendicular to z and were located in the vertical and horizontal planes, respectively.

Experiment No.	Nickel thickness mm	$\frac{P_z}{P_{oz}}$	α_x	α_y
1	0.07	0,86 ± 0,01	1,62 ± 0.20	1,68 ± 0,20
2	0,14	0,65 ± 0,01	1,54 ± 0,07	1,57 ± 0,07
3	0,42	0.46 ± 0,01	1,50 ± 0,05	1,45 ± 0,05
4	0,42	0,49 ± 0,01	1,55 ± 0.08	1,67 ± 0,09

In experiments 1, 2, and 3 (see the table) the vector $\vec{P}_0$ was directed successively along the axes x, y, and z, and the polarizations P_{0x} and P_x, P_{0y} and P_y, and P_{0z} and P_z were measured respectively. The measurements were made for different depolarization levels, as determined by the sample thickness. The third column of the table lists these levels, with the depolarization along the z axis as an example.

It can be concluded from the experiment that for all the investigated samples one observes a distinct anisotropy of the depolarization, and that the obtained values of α agree with the theoretical value $\alpha = 1.5$.

In experiments with longitudinal direction of $\vec{P}_0$, such a polarization anisotropy leads simultaneously to rotation of the polarization vector towards the z axis. Thus, in experiment No. 4, the polarization vector $\vec{P}_0$ was so inclined to the chosen coordinate system that its projections on the axes were comparable in magnitude ($P_{0x} \simeq P_{0y} \simeq P_{0z}$). The ratio of the projections was altered by passage of neutrons through the sample ($P_x \simeq P_y < P_z$). This rotation of the polarization is not taken into account in any way by formula (1) and can result in considerable distortions of the experimental results. Thus, in experiment No. 4 we have $P_z/P_{0z} = 0.49 \pm 0.01$ and $P_x/P_{0x} = 0.33 \pm 0.01$, i.e., the difference between $P_{\parallel}$ and $P_{\perp}$ reaches 30%. On the other hand, the true depolarization, which is determined from the absolute magnitude of the vector $\vec{P}$, amounts to $|\vec{P}|/|\vec{P}_0| = 0.43 \pm 0.02$. This must be taken into account in experiments on neutron depolarization.

In conclusion, we are grateful to S.V. Maleev and V.A. Ruban for a discussion of questions connected with depolarization of the neutrons, and to E.I. Zabidarov for supplying the necessary nickel samples.

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QUANTUM FREQUENCY REFERENCE AT 3.39 μ WAVELENGTH

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A number of advantages of optical standards (references) over frequency standards in the radio band were pointed out in [1]. Until recently, however, the characteristics of optical standards were much inferior to quantum generators operating in the radio band, particularly, the reproducibility of the frequency of laser radiation was at best $\sim 1 \times 10^{-11}$ [2 - 4]. We report here the development and investigation of a laser which is not inferior in its frequency characteristics to the best frequency standards of the radio band.

The optical frequency standard is based on an He-Ne laser with an internal nonlinearly-absorbing methane cell [1 - 2]. A considerable increase of stability and reproducibility of the frequency was attained as a result of investigations of the optimization of the laser parameters. First, narrow and contrasty power peaks were obtained at the frequency of the vibrational-rotational transition $\nu_3[P(7)]$ of the CH_4 molecules by lowering the methane pressure in the cell to several millimeters, by choosing the intensity of the saturating field, and by greatly decreasing the resonator losses (the Q of the peak is $\sim 1 \times 10^9$ and the relative magnitude reaches 15 - 20% as against 2 - 3% in [2 - 4] . Second, the use of an amplifying laser tube with a special discharge-gap configuration [5] has greatly lowered the noise of the gas-discharge plasma. The "low-noise" amplifier tube consisted of a series of channels 9 cm long alternating with spheres of 3 cm diameter, and ensured suppression of the low-frequency noise in the laser radiation by an approximate factor of 250 compared with tubes of the usual construction. The high contrast of the peaks, the considerable reduction of the noise, and also the effective shielding of the generators against external acoustic, mechanical, and temperature disturbances have all made it possible to effect a highly accurate tuning of the laser generation frequency to the crest of the power peak.

The stability and reproducibility of the laser frequency was investigated with a setup consisting of two generators with absorbing cells, systems for tuning the laser frequency to the crest of the molecular resonance, and a laser heterodyne "coupled" with a 3-MHz shift to the frequency of one of the investigated generators. The radiation of each of the stabilized lasers was mixed independently with the heterodyne radiation. The time-synchronized measurement of the frequencies produced by optical heterodyning of two "beat" signals has made it possible to determine the magnitude and direction of the frequency shifts of the radiating lasers, eliminating by the same token the instability of the heterodyne frequency and the mutual influence of the generators on each other.

A typical plot of the fluctuations of the difference frequency for two independently stabilized generators is shown in Fig. 1. At an averaging time of 100 sec, in time intervals of several hours, the mean-squared frequency deviation of each generator from its mean value was 2.4 Hz, corresponding to an instability of 3×10^{-14}.

A study of the influence of the generator parameters and of its operating conditions on the frequency of the output radiation has shown that the most important factor limiting the reproducibility of the laser frequency is the