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POSSIBLE CHOPPER-MONOCHROMATOR FOR COLD NEUTRONS

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As is known[1], slow neutrons, on traversing a ferromagnetic, experience small angle scattering on magnetic inhomogeneities. They are either diffracted or refracted in dependence on how large the phase difference is of the neutron waves traveling same distances in an inhomogeneity and in a homogeneous medium.

The refraction index n for the neutron wave traveling in the magnetic medium is:

$$1-n^2 = \left(\frac{\lambda^2 N\bar{b}}{\pi} \pm \frac{\mu B}{E}\right), \tag{1}$$

where N is the atomic density of the medium; $\bar{b}$, the mean neutron coherent scattering length; μ, the magnetic moment of the neutron; B, the magnetic induction value in the medium; E and λ, the energy and wavelength of neutron, respectively. Signs "+" and "–" stand for the parallel and antiparallel orientation of the neutron spin with respect to the $\vec{B}$ direction.

The difference in phases of the neutron waves scattered on the inhomogeneities having opposite directions of magnetization is

$$\phi = \frac{2\pi}{\lambda}\,\frac{\mu B}{E}\,\delta \tag{2}$$

where δ is the inhomogeneity size along the direction of the neutron propagation. At $\phi \ll 1$, the diffraction dominates, and at $\phi \gg 1$, the refraction does (really already at $\phi \geqslant 3$, the neutron scattering is virtually the result of refraction). The characteristic angle of diffractive scattering $\alpha \sim 2\lambda/\delta$, the characteristic angle of neutron deflection on refraction by a single interdomain interface $\Delta\theta = \frac{\mu B}{E}\,\mathrm{ctg}\,\theta$, here θ is the grazing angle of the neutron wave incident on the interface (it is assumed here that $\theta > \theta_{crit} = (2\mu B/E)^{1/2}$, the critical angle of total reflection).

In typical ferromagnetics traversed by slow neutrons it is refraction that plays the main role in the small angle scattering. If a ferromagnet is nonmagnetized, it can be assumed that neutron deflections are uncorrelated and the angular broadening of the beam is proportional to $(\tau/\delta)^{1/2}$, where τ is the thickness of the sample, δ the mean domain size. The experimental data[3,4] favour this assumption. A simple model of sharp interdomain boundaries[4] led to the expression for the total width at half maximum of the angular distribution of transmitted neutrons, which looks as follows:

$$\Gamma_\theta = \frac{4{,}7\mu B}{E}\left(\frac{\tau}{2\delta}\right)^{1/2}. \tag{3}$$

This formula yields $\Gamma = 2\times10^{-2}$, for cold neutrons with $\lambda = 20$Å, at $\tau = 5\times10^{-2}$ cm and $\delta = 5\times10^{-4}$ cm, $\mu B = 1.2\times10^{-7}$ eV.

Investigations by Scharpf et al.[5] have shown that the real situation is not so simple, as the refraction depends on the character and thickness of interdomain boundaries.

In the case of polycrystalline ferromagnetics a question still remains unsolved about the conditions under which the small angle scattering is determined by the size of grains or domains and the thickness of interdomain boundaries. Thus the expression (3) gives just an approximate estimate on the broadening.

In various experiments there has been observed a considerable decrease in the angular broadening of the transmitted neutron beam distribution under the action of an external saturating magnetic field applied to the ferromagnetic sample. By exploring this fact and the method of pulsed magnetization and demagnetization of thin plates from magnetically soft materials (such as armco-iron, etc.) it is possible to realize the pulsed intensity modulation and monochromatization of a cold neutron beam. This procedure enjoys special convenience, if performed on a pulsed source of cold neutrons. A chopper monochromator based on this principle can be arranged as follows: a few ferromagnetic foils in pulsed magnets environment are placed successively on the cold neutron beam at the distance ℓ_i from the neutron source which satisfies the condition:

$$\ell_i = v t_i , \qquad (4)$$

where v is the cold neutrons velocity to be monochromatized; t_i, the time, with respect to the neutron pulse, at which the i-th ferromagnetic foil gets magnetized for a short period in the field of the corresponding pulsed magnet. In between of the foils are to be positioned the Soller neutron collimators with the smallest possible angles of collimation. With the angle of collimation 10^{-3} and the beam broadening on transmission through a demagnetized sample 2×10^{-2}, the outgoing intensity from the collimator will be 20 times smaller that in the case of a magnetized ferromagnetic sample. When a set of choppers is used, the degrees of intensity modulation are multiplied. The monochromatization extent depends on the magnetization-demagnetization rate, the foil thickness, $\Delta\ell$, and the distance between neighbour foils,

$$\frac{\Delta\lambda}{\lambda} = \left[\left(\frac{\Delta\ell}{\ell}\right)^2 + \left(\frac{\Delta t}{t}\right)^2 \right]^{1/2}, \qquad (5)$$

where $t = \ell/v$, Δt is the time interval in which the ferromagnetic gets magnetized. At $v = 2\times10^4\ \mathrm{cm\cdot s^{-1}}$ ($\lambda = 20$ Å), $\ell = 5\times10^2$ cm, $\Delta\ell = 2\times10^{-2}$ cm, $\Delta t = 10^{-6}$ s, $\Delta\lambda/\lambda = 6\times10^{-5}$, $\Delta E = 2\times10^{-8}$ eV.

Currently, in the experiments with slow neutrons besides the conventional mechanical method two electromagnetic methods are being explored for the pulsed modulation and monochromatization of neutrons.

One exploits the pulsed remagnetization of a single crystal of ^{7}Li-ferrite resulting in the change of the Bragg diffraction intensity with the change of tne magnerization direction[6]. At that there is formed a pulsed beam of monochromatic thermal neutrons with energies satisfying the Bragg diffraction condition. The other method uses a polarizer and an analyzer for slow neutrons in combination with a placed between them spin-flipper, either a radiofrequency[7] or pulsed[8] one. This chopper, in principle, does not impose a limit on the use of long wavelengths. Its resolution depends on the length of the neutron spin reverse region (according to ref.[8] it is 0.65 cm).

The method is suggested as the complement to the two above methods in the range of very cold neutrons. At the same time this method is potentially capable of providing experimenters with rather high neutron monochromatization.

An extra advantage is the simplicity within the method of the variation of the energy of the neutrons to be monochromatized. To do this it is only necessary to choose other moments t_i for pulsed magnetization of the foils in accordance with eq.(4). On some respects the proposed chopper is analogous to the earlier constructed one for the pulsed modulation of ultracold neutron beams[9]. However, that chopper[9] had employed the *reflection* of neutrons, while here we propose the neutron *refraction* to be exploited.

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