SCATTERING OF THERMAL NEUTRONS BY POLARIZED NUCLEI OF A FERROMAGNET

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The interference phenomena which occur in the scattering of thermal neutrons by polarized nuclei constituting a ferromagnetic lattice are considered. It is pointed out that because of interference between magnetic and "incoherent" nuclear scattering, one can determine the sign of the "incoherent" amplitude a_{inc}; to do this it is sufficient to use an unpolarized beam of thermal neutrons.

It is known that the interaction of slow polarized neutrons with polarized nuclei enables one to get valuable information about the spin dependence of the nuclear forces.[1]

On the one hand, by measuring the cross section for resonance capture of polarized neutrons by samples containing polarized nuclei one can determine the angular momentum of the compound states formed. Experiments of this kind have been done for the isotopes Mn^{55},[2] In^{115},[3] Sm^{149},[4] and Tb^{159}.[5]

On the other hand, the study of Bragg scattering of polarized thermal neutrons by the nuclei of atoms in a crystal lattice when the degree of polarization of the nuclear spins is greater than zero enables one to determine the magnitude of the ratio of the "incoherent" scattering amplitude

$$a_{inc} = \sqrt{I(I+1)}\,(a_+ - a_-)/(2I+1) \qquad (1)$$

to the "coherent" amplitude

$$a_{coh} = [(I+1)\,a_+ + Ia_-]/(2I+1), \qquad (2)$$

where $a_\pm$ are the scattering amplitudes in the states with total angular momentum $J_\pm = I \pm 1/2$ (where I is the nuclear spin). The possibility mentioned occurs because in the scattering of a polarized neutron beam there is interference between the "coherent" and "incoherent" scattering, which is proportional to the degree of polarization f_N of the nuclei of the target.

Since the magnitude of a_{inc} can be measured independently (for most nuclei such measurements have already been done), having determined the ratio a_{inc}/a_{coh} from experiment one can find the amplitudes a_+ and a_-. Recently such interference effects have been observed for polarized V^{51}[6] and Co^{59}[7] nuclei, where the intensity of the Bragg reflections was measured in the case of vanadium, while the transmission effect was studied for the case of cobalt.

In the present paper we wish to point out the possibility of determining the "incoherent" amplitude a_{inc} in experiments on Bragg scattering of unpolarized thermal neutrons by polarized nuclei making up a ferromagnetic lattice. Such a possibility is related to the fact that in the scattering of neutrons by a crystal with ferromagnetically ordered atomic spins and a nonzero degree of polarization of the nuclei, there is interference between the nuclear and magnetic scattering even in the case where the incident neutron beam is unpolarized. Here the "incoherent" part of the scattering participates in the interference.

Using the results of Halpern and Johnson,[8] one can show by simple computations that the angular distribution of the elastic Bragg scattering of unpolarized neutrons by a monoisotopic ferromagnetic lattice, magnetized to saturation, is given by the formula

$$\frac{d\sigma}{d\Omega} = \left\{\left[a_{coh}^2 + a_{inc}^2\frac{If_N^2}{I+1}\right] + \left[a_m^2(q) + 2a_{inc}a_m(q)\frac{If_N}{\sqrt{I(I+1)}}\right] \times [1-(\mathbf{em})^2]\right\}\sum_{ll'} e^{i\mathbf{q}(\mathbf{R}_l - \mathbf{R}_{l'})} \qquad (3)$$

Here $\mathbf{m}$ is a unit vector along the direction of magnetization, $\mathbf{e} = \mathbf{q}/q$, and $\mathbf{q}$ is the scattering vector. The magnetic scattering amplitude is $a_m(q) = (r_0\kappa_n)SF(q)$, where r_0 is the classical radius of the electron, κ is the neutron magnetic moment (in nuclear magnetons), and S is the spin of the atom, F the magnetic form factor. The lattice sum in (3) determines the directions of Bragg reflections ($\mathbf{R}_l$ is the radius vector to the l-th atom in the crystal).

Using (3), and denoting by $N_\perp$ ($N_\parallel$) the number of neutrons recorded at the maximum of the diffraction peak for the case of $\mathbf{m} \perp \mathbf{e}$ ($\mathbf{m} \parallel \mathbf{e}$), we find

$$\frac{N_\perp - N_\parallel}{N_\parallel} \approx \left(\frac{a_m}{a_{coh}}\right)^2 \left[1 + 2\frac{a_{inc}}{a_m}\frac{If_N}{\sqrt{I(I+1)}}\right], \quad f_N \ll 1. \tag{4}$$

Having measured the quantity (4) experimentally, one can determine the sign of the "incoherent" amplitude, which, in principle, is sufficient for finding the amplitudes a_+ and a_-, since $|a_{inc}|$ can be found from measurements of the "incoherent" scattering cross section σ_{inc}, while the "coherent" amplitude is known from independent data.

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