POLARIZED NEUTRON DIFFRACTION BY VORTEX LINE LATTICE IN UNIAXIAL SUPERCONDUCTORS

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The unpolarized neutron diffraction by VL has been used widely to study spatial magnetic field distribution of VL, its symmetry and imperfections, the correlation to the crystal lattice in Nb, Nb-Ta [1]. However in the case of high-T_c superconductors there is only one successful paper [2].

The theory of the unpolarized neutron diffraction from VL had been suggested in [3]. In this paper we consider the polarized neutron diffraction by VL in uniaxial superconductors.

The differential scattering cross-section into a small solid angle $d\Omega$ by VL is given by [3,5]:

$$d\sigma/d\Omega = (\mu \mu_n m_n/2\pi\hbar^2)^2 \mid \int_V d V < \Psi \mid \vec{\sigma}\vec{H} \mid \Psi_0 > \exp [i (\vec{k}_0 - \vec{k}) \vec{r}] \mid^2 \qquad (1)$$

Here $\mu = -1.91$ is the neutron magnetic moment in nuclear magnetons μ_n, m_n is the neutron mass, $\vec{k}_0$ and $\vec{k}$ are the neutron wave vectors before and after the scattering, Ψ_0 and Ψ are the spin parts of the neutron wave functions before and after the scattering, $\vec{H}$ is the magnetic field of vortex, $\vec{\sigma}$ are the Pauli matrices. The integral in (1) is calculated over the superconductor's volume V.

At first we consider the spin-flip cross-section. Let the z-axis be paralell to the vortex axis, i.e. to the inductance $\vec{B}$. The spin functions Ψ_0 and Ψ are chosen in the form $\Psi_0 = \begin{pmatrix}0\\1\end{pmatrix}$, $\Psi = \begin{pmatrix}1\\0\end{pmatrix}$. By substituting Ψ_0 and Ψ into (1) and carring out [3] the following calculations we obtain for spin-flip cross-section:

$$(d\sigma/d\Omega) = \rho\,[H_x^2(\vec{Q}) + H_y^2(\vec{Q})]\sum_{\vec{\tau}_{hk}} \delta(\vec{Q} - \vec{\tau}_{hk}). \tag{2}$$

$$\vec{Q} = \vec{k}_0 - \vec{k} = \vec{\tau}_{hk} \tag{3}$$

Here $\rho = (\pi \mu B V/\Phi_0^2)^2/S$, Φ_0 is the flux quantum, S is an area of the superconductor in x,y plane, B is the induction, $H_x(\vec{Q})$ and $H_y(\vec{Q})$ are the Fourier transforms of H_x, H_y, $\vec{\tau}_{hk}$ is the vector of the reciprocal lattice for the (hk) reflection. The relation (3) is the Bragg equation for the (hk) reflection from the two-dimensional VL.

The same calculation of the non spin-flip cross-section results in the following expression:

$$(d\sigma/d\Omega)_{hsf} = \rho H_z^2(\vec{Q}) \sum_{\vec{\tau}_{hk}} \delta(\vec{Q} - \vec{\tau}_{hk}) \tag{4}$$

The total cross-section of unpolarized neutrons is a sum of (2) and (4).

Using $(d\sigma/d\Omega)_{sf}$ and $(d\sigma/d\Omega)_{hsf}$ one can get the number of the scattering neutrons with spin up and down. Then the neutron beam polarization after the (hk) reflection is given by [5]:

$$\frac{P}{P_0} = \frac{(d\sigma/d\Omega)_{nsf} - (d\sigma/d\Omega)_{sf}}{(d\sigma/d\Omega)_{nsf} + (d\sigma/\Omega)_{sf}} = \frac{H_z^2(\vec{\tau}_{hk}) - H_x^2(\vec{\tau}_{hk}) - H_y^2(\vec{\tau}_{hk})}{H_x^2(\vec{\tau}_{hk}) + H_y^2(\vec{\tau}_{hk}) + H_z^2(\vec{\tau}_{hk})} \tag{5}$$

Here P_0 is the polarization before the scattering.

Note that in isotropic superconductors the vortex has only the H_z component. Therefore in this case the spin-flip scattering and the change in polarization are absent.

References

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