Neutron resonance interferometry

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Neutron Resonance Spin Echo (NRSE) is a new, quickly progressing method for manipulation of the spin in neutron beam scattering experiments [1-3]. The magnetic field precession area of the conventional Spin Echo (SE) technique is replaced in this method by a pair of resonance coils, placed in field B_0 and operated at frequency ω_0, satisfying the resonance condition $\omega_0 = \gamma_n B_0$ and separated by a distance L of zero magnetic field. In terms of precession this pair of RF coils simulates a DC field integral $2\gamma_n B_0 L$. Thus the resonance coil may be realized as a basic element for a new type of the interferometer [4,5] and opens a new field, which may be referred to as Neutron Resonance Interferometry.

We investigated the possibilities of neutron resonance phenomena for interferometry both experimentally and theoretically. In our first experiments [6] spin precession produced in a classical manner and by Neutron Resonance are combined as two arms of a spin echo machine. A magnetic field scan in the classical SE coil revealed a spin echo signal of the precession produced by the NRSE arm. The neutron spin flip probability ρ in the resonance coils turns out to be a key parameter of the NRSE arm. The limiting cases $\rho = 0$ and $\rho = 1$ lead respectively to Larmor precession with phase φ_1 in the static magnetic fields of the NR flippers *or* to NRSE precession with φ_2. The case $0 < \rho < 1$ produces quantum interference resulting in additional echo's with phases $\varphi_3 = (\varphi_1 + \varphi_2)/2$ and $\varphi_4 = \pm(\varphi_1 - \varphi_2)/2$. The amplitude of each pattern depends on the spin flip probability ρ, and the initial polarization. These experiments demonstrate explicitly the quantum mechanical principle of linear spin state superposition of neutron particle waves, and the interference as a result of that.

Furthermore we studied in [7] the neutron multiwave interference phenomena based on Ramsey's resonance method of "separated oscillating fields"[8]. A neutron passes through N *identical* successive resonant coils ($\omega_0 = \gamma_n B_0$), which flip the neutron spin with a probability ρ smaller than 1. These coils are separated by path lengths L, over which a homogeneous field B_1 is present. Because the spin flip probability ρ is smaller than 1, the number of waves for a neutron is doubled after each flipper, so as to produce 2^N neutron waves at the end of the setup. The phase difference between any pair of waves is a multiple of a "phase quantum" determined by the line integral of the field difference B_1-B_0 over the length L. Highly regular stationary patterns of the quantum mechanical probability R in (B_1, ρ) - space appear due to pair interference between individual waves.

The neutron multilevel interference phenomena are generated when a neutron passes through a series of N *non-identical* resonant coils operated at the successive conditions $(\omega_0 + n\Delta\omega) = \gamma_n (B_0 + n\Delta B)$ with n =0,1… N-1. Each coil produces again the spin flip with probability ρ between 0 and 1; thus the number of waves for the neutron is doubled again after each coil, finally giving 2^N interfering neutron waves. The phase difference between any pair is a multiple of a time dependent "phase quantum" $\Delta\ \Psi(t)$. The analysis predicts for each number N a highly regular pattern for the quantum mechanical probability to find the neutron spin in one specific state as a function of ρ and $\Delta\ \Psi$. These patterns evolve in time and show revivals after a time T determined by the step $\Delta\omega$ according to $T = 2\pi/\Delta\omega$. For some adjustments of the system an analytical solution is obtained. Application of multilevel interference in high-resolution neutron MIEZE type spectrometers is discussed.

To show the possibilities opened with neutron resonance interferometry we demonstrate explicitly the phenomenon of 4π-periodicity of the spinor [9]. It is also shown in [10] that the Neutron Resonance Spin Echo can be produced by resonance coils with adiabatic passage of the neutron spin, i.e. with Gatchina-type of the resonance flipper. Using this type of the flipper we demonstrated possibility to realize Spin echo of four different neutron waves/ wavepackets, which are produced in a typical Neutron Resonance Spin echo setup [11]. The experiment opened the possibility to measure a composite correlation function, combined from several pair correlation functions.

The work was partly supported by INTAS foundation (Grant No. INTAS-03-51-6426) and RFFR (project 05-02-16558).

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