Experimental Report

11/04/2014

Proposal: **3-15-73** **Council:** 10/2012

Title: Larger violation of Bell's inequality with spin-path bipartite entanglement in neutrons

This proposal is continuation of: 3-14-71

Researh Area: Physics

Main proposer: **HASEGAWA Yuji**

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Samples: neutron

Instrument	Req. Days	All. Days	From	To
S18	28	28	26/03/2013	09/04/2013
			29/04/2013	13/05/2013

Abstract:

Investigations on entanglement between degrees of freedom (DOF) of neutrons successfully confirmed quantum contextuality: the violation of a Bell-like inequality, Kochen-Specker-like phenomena, and characteristics of tripartite Greenberge-Horne-Zeilinger (GHZ) state have been observed. In addition, recent experiments concerning the tripartite entanglement successfully approve a linear form of the entanglement witness: so-called Greenberger-Horne-Zeilinger (GHZ) as well as W states are generated and used for the experiments. In parallel, we achieved a new spin-manipulation method using a Mu-metal pipe and a radio-frequency (RF) spin-flipper to entangle efficiently the spin DOF, which exhibit quite high efficiency of the manipulation. By using these new progresses, we are going to perform an experiment, which is expected to provide clearer and higher violation of Bell's inequality with spin-path bipartite entanglement in neutrons.

Experimental reports

Experimental No.: 3-15-73

Title: Larger violation of Bell's inequality with spin-path bipartite entanglement in neutrons

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Short summary:

In this period, we concentrate on the development of the new setup for polarized neutron interferometer experiments: in particular, the function of newly designed and fabricated spin-rotators is tested. This setup is planned to be used for two experiments:

(i) Violation of a Bell-inequality measurement: new measurement is expected to exhibit much larger violation than former experiments. For this goal, development of a new interferometer setup is required.

(ii) Weak measurement of neutron's ½-spin: new theory suggests a possibility of performing a spin weak-measurement by using a neutron interferometer. A full determination of spin weak-values is expected.

When we can establish the use of efficient spin manipulation in the perfect-crystal interferometer, this will open up wide filed of neutron optical studies of quantum mechanics, namely the foundation of quantum mechanical phenomena. For instance, we expect such experiment as a quantum Cheshire-Cat experiment, 3-Box paradox experiment, wave-particle duality with a new flavor of weak values and so an will be feasible in a short period.

Report on research work:

1. Weak measurement and weak values in quantum mechanics

In conventional von-Neumann type measurements of quantum mechanics, a (strong) interaction between the quantum system and the measurement apparatus couples both of them, which inevitably disturb the quantum system. Another scheme was proposed some time ago to extract some, definite but subtle, information of the system even by weakening the interaction: in this case, the quantum system is less disturbed and still, more or less, in the similar state before the measurement. The measurement apparatus then records not the usual eigenvalues of the observable but what has been known as weak values.

2. New setup for precise interferometer experiments with polarized neutrons

In the former polarized-neutron interferometry, we almost always had difficulties in manipulating spin in the interferometer. This is because the perfect-crystal interferometer is so sensitive to the ambient circumstances that mechanical vibrations and the thermal disturbances can easily degrade and wash out the interferograms: the environmental stability is easily disturbed by the use of spin rotations inserted in the interferometer. Thus, a new scheme is to be developed for further experiments, where higher efficiency and stabilities are required. We decided to make a $\pi/2$spin-rotation before the interferometer and the spin-rotators with water-cooling system in each beam of the interferometer. (see Fig.1)

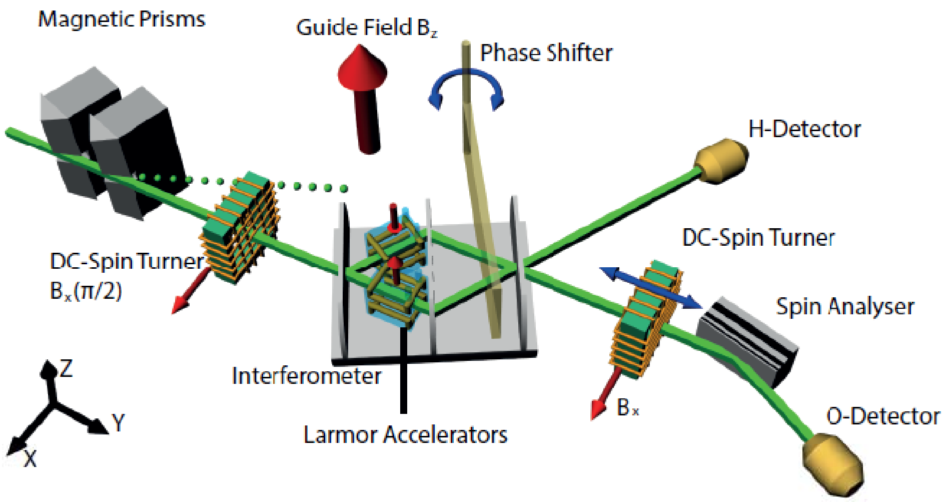
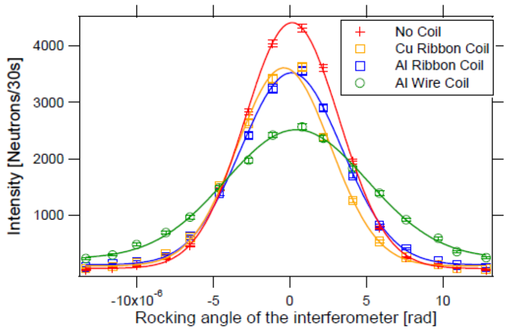


Fig.1 new polarized-neutron interferometer setup.

3. Test of π/2 spin rotator in font of the interferometer

We have tested π/2 spin rotators with several different materials; for instance, (i) Cu ribbon, (ii) Al ribbon, (iii) Al wire coils are tested. Rocking curves measured at S18 are shown in Fig.2 and the final rocking curve with π/2 spin rotators of Cu ribbon is shown in Fig.3. Clear separation of spin-up and –down peaks are seen.



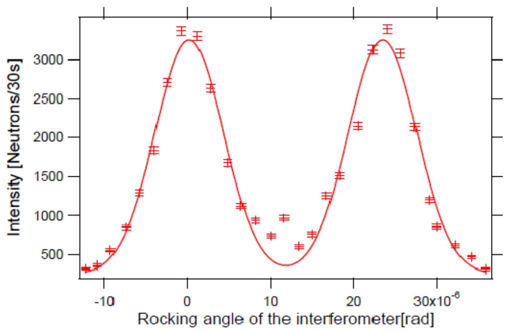
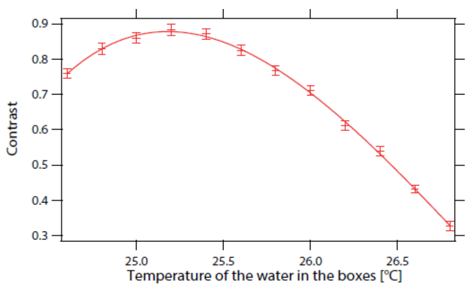


Fig.2 Rocking curve with some materials. Fig.3 Final Rocking curve of the interferometer

4. Adjustment of the interferometer

For experiments requiring higher precision, the realization of high original contrast of the interferogram, which is obtained with empty interferometer, is important. We adjusted the water-temperature of the cooling box for the spin rotators: the temperature scan shows a need of optimization of the cooling-water temperature. (see Fig.4) Finally, we made a position scan of the incident beam, which is shown in Fig.5. This reveals that the interferometer has only a “sweet spot”, where the contrast reaches above 80%, only in a small region. The function of the interferometer, confirmed here, is so good that, we hope, this set up will be used for further interferometer experiments with polarized neutron beams.



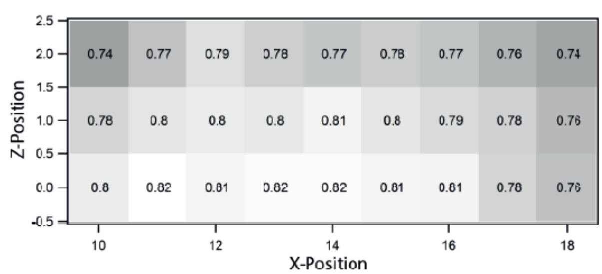


Fig.4 Contrast-dependence on water-temperature. Fig.5 Distribution of interferogram contrast.