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Quasi-elastic measurements using neutron spin flippers

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Abstract

A method for low-resolution quasi-elastic measurements using commonly available components on a polarized neutron beam reflectometer is demonstrated. By amplitude modulation of the current in a neutron spin flipper placed between the neutron beam polarizer and polarization analyzer, the intensity of the neutron beam illuminating a sample is similarly modulated (or chopped). We show that the intensity contrast between subsequent chopped pulses is dramatically reduced by a sample that changes neutron velocity.
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Keywords: Polarized neutron reflectometry; Quasi-elastic; Neutron spin flipper; Intensity modulation

1. Introduction

In this paper we demonstrate the possibility to use an amplitude modulated neutron spin flipper to produce a chopped neutron beam to perform quasi-elastic experiments.

The setup used is shown in Fig. 1: polarizer, spin flipper and analyzer are located between the neutron source and the sample. If the current in the flipper is modulated, then the intensity of the neutron beam is similarly modulated (see Fig. 2). However, if energy is exchanged between the sample and the neutron beam, the neutron velocities are affected which influences the modulation of the scattered neutron beam intensity (e.g., by smearing the transition from beam-on to beam-off).

2. The experiment

That quasi-elastic sample dynamics can be probed through the use of a fast-modulated intensity of the neutron beam has been well demonstrated [1,2]. The time scale of the dynamics that can be probed by an instrument depends upon the frequency of the modulation:

$$\tau = \omega_D \frac{\hbar L_s}{m v^3} \qquad (2.1)$$

with ω_D the modulation frequency at the detector, L_s the sample-to-detector distance, the velocity of neutrons v, $\hbar$ is the Planck-constant and τ the time resolution of the setup.

Formula (2.1) is taken from Refs. [2,3] for the description of a Modulation of Intensity by Zero Effort (MIEZE)—a variant of the neutron spin-echo technique, which modulates the intensity of the neutron beam incident on the sample in the frequency range of a few MHz. Since MIEZE and the application we discuss here differ only in the method the modulation is produced (and this difference is not relevant to the derivation of Eq. (2.1)), the relation is equally valid for both techniques. Both techniques have the same time resolution if the geometry of the instrument after the sample and the frequency of the intensity modulation are the same (though in practice the approach used here is suitable only for modulation frequency in the range of tens of kHz, since the modulation period cannot be shorter than the time the neutrons need to travel through the flipper). Likewise, the method used to analyze data taken with MIEZE is equally applicable to the analysis of data taken using modulation of conventional spin flippers.

In order to relate a measurement of the distortion of the modulation of the beam intensity at a certain time resolution to the energy of quasi-elastic scattering from the sample, we compare the intensities of the neutron beam from a transition for flipper-on (an intensity minimum in the lower beam of Fig. 2) to flipper-off (an intensity

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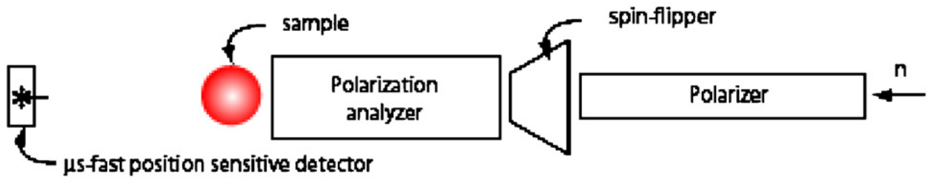

Fig. 1. Setup of the experiment: polarizer, spin flipper and analyzer are upstream the sample.

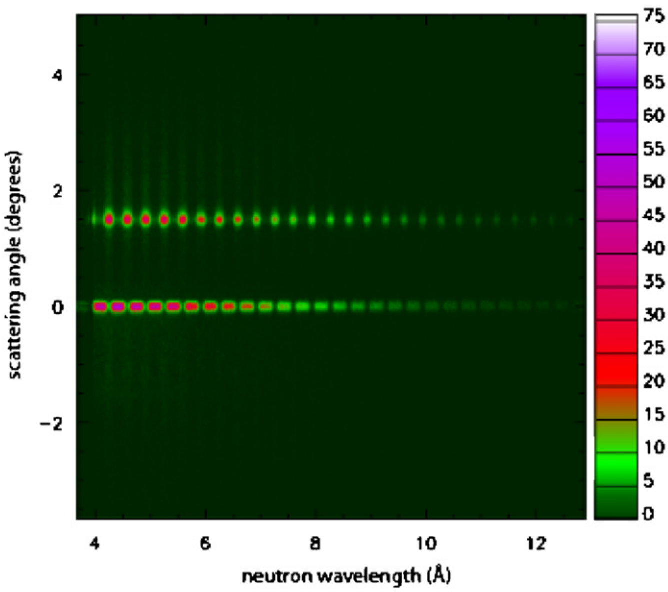

Fig. 2. (Color online): Beam modulation at 1 kHz without a sample, the upper beam is produced by reflection of the spin-up neutron beam from the analyzer which otherwise transmits the spin-down beam. The neutron intensity alternates between the transmitted and reflected channels following the amplitude modulation of the flipper. (In this figure the position sensitive detector measures angle in the horizontal plane, i.e., the plane defined by the neutron beam incident on and reflected from the polarization analyzer. The apex of the scattering angle is at the center of the polarization analyzer.)

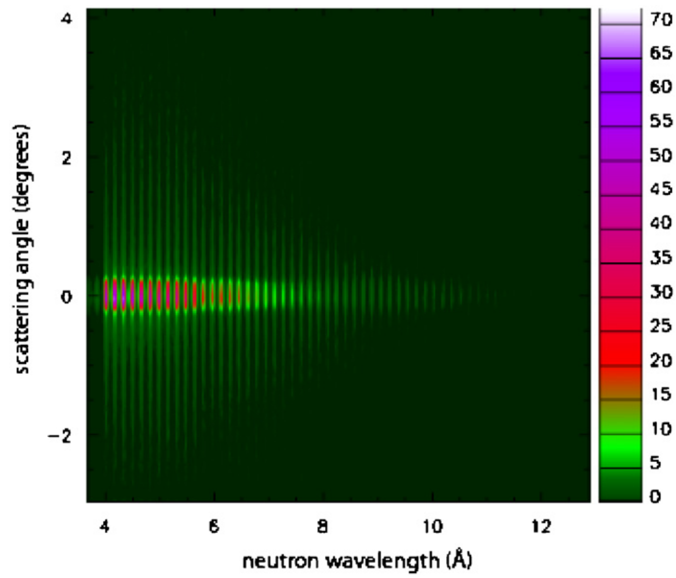

Fig. 3. (Color online): Beam modulation at 2.2 kHz with a diamond powder as the elastic scattering sample. (Scattering angle is measured from the sample in the vertical plane. The beam reflected by the analyzer was masked).

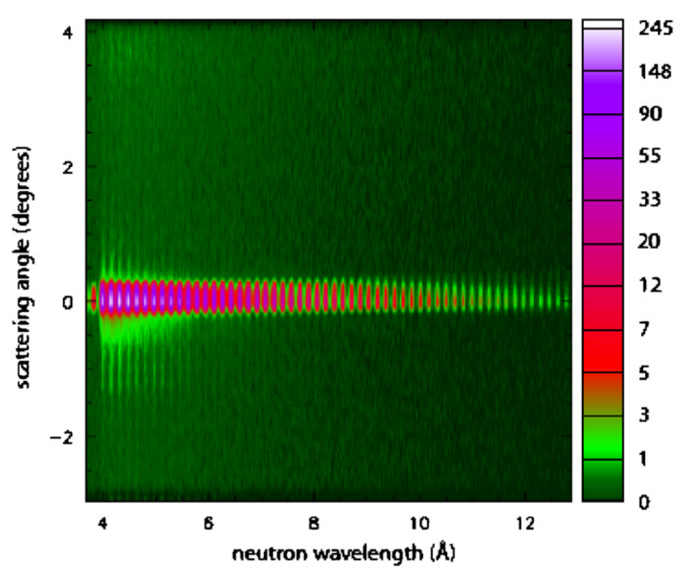

Fig. 4. (Color online): Beam modulation at 2.2 kHz with deuterated SDS in H_2O as the quasi-elastic scattering sample.

maximum) then to flipper-on (these transitions are seen in Figs. 2–4) (inset)). The ratio of these intensities is the contrast that is measured as a function of neutron velocity—in our case Tof. By comparing the velocity dependence of the contrast without a sample (C_0) to one with a sample ($C_s = C_0 - \Delta C$), we can determine how the sample changed the velocity of the neutron and thus measure the energy exchanged between the neutron beam and the sample. A change in contrast (ΔC) will be visible if the transferred energy changes the arrival time at the detector so that the change in the Tof is a significant fraction of the period time of the modulation. If a quasi-elastic scattering sample introduces an average energy transfer of $\pm\Delta e$, the signal at the detector will be smeared, since the neutrons arrive at different phases $\Delta\varphi = \pm(\tau\,\Delta e/\hbar)$ compared to the case without energy transfer. ΔC can be written as

$$\frac{C_0 - \Delta C}{C_0} = \cos\left(\frac{\tau \Delta e}{\hbar}\right) \quad (2.2)$$

In order to realize the setup shown in Fig. 1, the Asterix beamline at the Lujan Center in Los Alamos was modified. The analyzer was moved to the sample region, a neutron