THE NCNR NEUTRON SPIN ECHO SPECTROMETER

The first experiments have been performed on the NCNR's Neutron Spin Echo (NSE) Spectrometer, which is the only spectrometer of its kind in the United States. This cold neutron spectrometer allows studies of dynamic processes in macromolecular systems that are relevant to, among others, polymer [1] and biomedical [2] sciences. It covers a time-scale of 0.01 ns to 100 ns and a length-scale of 2 Å to 200 Å with the equivalent of extremely high energy resolution and moderate Q-resolution. Unlike the other high-resolution inelastic instruments at the NCNR, which measure in the energy domain, the NSE spectrometer measures, in the time domain, the real part of the intermediate scattering function, I(Q,t). This is done by using the neutron's spin precession in a magnetic field as a clock to determine the energy transfer in the scattering process.

The NSE spectrometer, developed in partnership with Exxon Research and Engineering and the Forschungszentrum Jülich in Germany [3], is located at the end position of the NG-5 guide. The guide is tapered horizontally and then deviated so that the spectrometer is out of the direct line of sight of the reactor core, thereby reducing the background and the radiation load on the sample region [4]. The taper is followed by a Neutron Velocity Selector (NVS), which transmits a $\Delta\lambda/\lambda$ = 10 % FWHM band of neutrons to the spectrometer. The last element of the guide is a transmission polarizer [5], which produces a polarized beam of neutrons with spin anti-parallel to the beam direction for wavelengths greater than 5 Å. The neutrons precess, from the first $\pi/2$ flipper (1) to the sample, through a phase angle that is determined by the time that the neutron spends in the solenoidal magnetic field (4) and the field integral along the neutron path. Near the sample, a π flipper (2) rotates the spin by 180° around the vertical axis. If the solenoid on the second arm of the spectrometer provides the same field integral for the scattered neutron and if the scattering is elastic, the neutron will precess through the same phase angle as along the first arm and will end up with the original spin orientation at the final $\pi/2$ flipper (3). This $\pi/2$ flipper rotates the spin back into the horizontal plane. If the neutron is scattered quasielastically, it will precess a slightly different number of times in the second arm of the spectrometer and end up at the second $\pi/2$ flipper rotated by some angle that is proportional to the wavelength shift. The analyzer (7) projects the component of the neutron spin that is parallel to the field direction onto the detector.

Figure 2 shows the detector count rate as a function of current in the phase coil (5), which changes the field integral on one arm of the spectrometer. The field integrals for the first and second arms of the spectrometer are equal at the echo point where the amplitude is at a maximum, since for an elastic scatterer the neutrons all arrive at the analyzer in phase. As the phase current is changed, the neutron spins rotate away from the polarization axis of the analyzer (7) and the count rate is changed. The period of this oscillation is proportional to the mean wavelength. The envelope of the

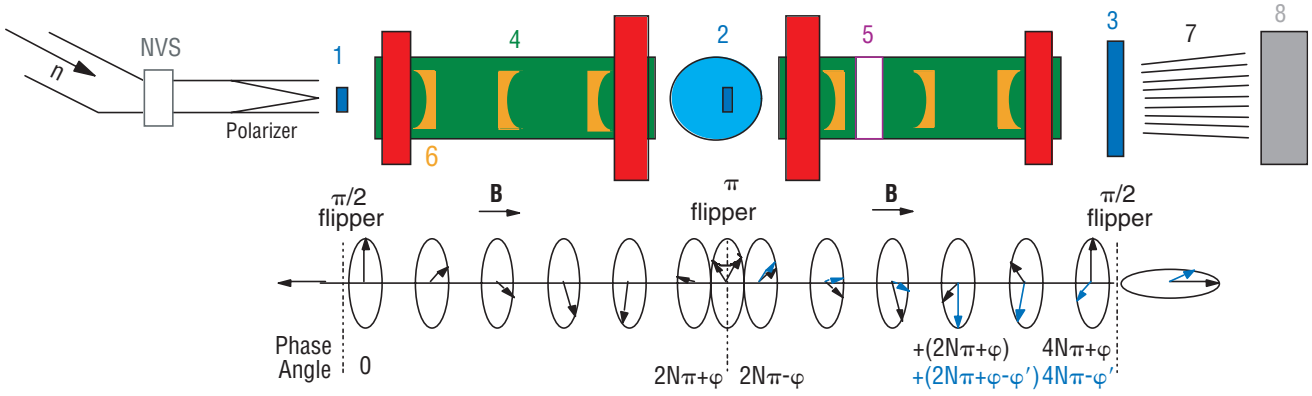

FIGURE 1. (Top) Schematic plan view of the NSE spectrometer. The numbers refer to spectrometer elements as described in the text. (Bottom) Changes of neutron spin orientation passing through the spectrometer elements for elastically (black) and inelastically (blue) scattered neutrons.

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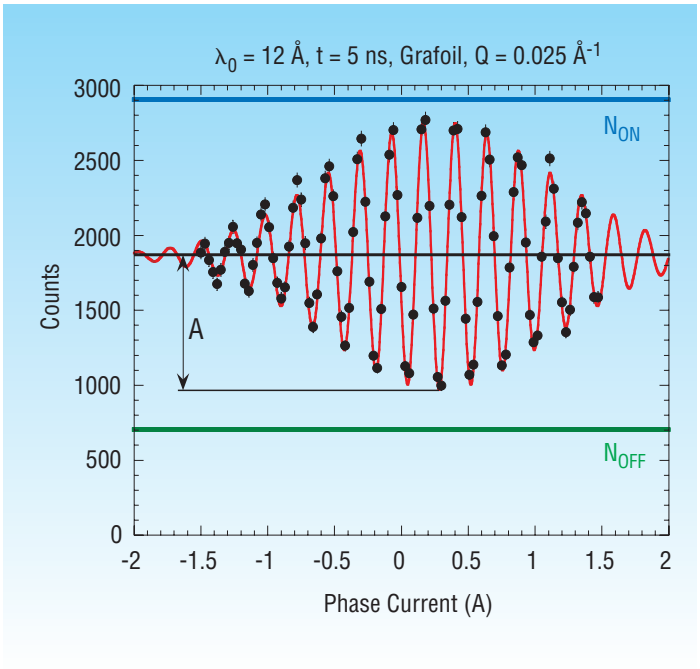

FIGURE 2. Phase scan of an echo for an elastic scatterer (Grafoil). A is the amplitude at the echo point; N_{ON} and N_{OFF} are counting rates with the π flipper on and off, respectively, and the $\pi/2$ flippers off.

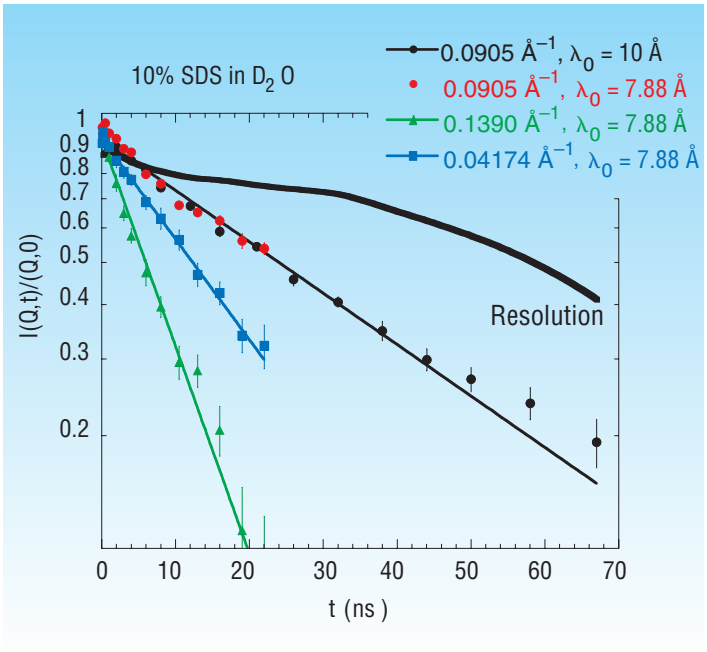

FIGURE 3. Normalized and resolution-corrected measurements of the intermediate scattering function at the indicated Q-values for 10 % SDS in D_2O at room temperature. The resolution curve is a normalized measurement of an elastic scatterer (Grafoil) at 10 Å.

oscillations gives the wavelength distribution. The amplitude A is proportional to I(Q,t), which can be normalized by measuring the difference in intensity with the π flipper on and off, $N_{ON} - N_{OFF}$. For the normalizing measurement, which is proportional to I(Q,t = 0), the $\pi/2$ flippers are off since there is no precession of the neutrons in this configuration. Instrumental resolution effects are removed by dividing the normalized sample signal by the normalized values from an elastic scatterer.

We have also verified the operation of the correction elements (6) which allow non-axial and divergent neutrons to satisfy the echo condition. These are essential for operation at high fields. The value of the resolution amplitude at 25 ns in Fig. 3 would be at least a factor of ten smaller without the contribution of the correction elements.

As an example of the science that is available through NSE, we have reproduced the measurements of Hayter and Penfold [6] on a micellar solution of 10 % sodium dodecylsulfate (SDS) in D_2O. Fig. 3 shows the normalized intermediate scattering function versus time at several Q values at, well below, and well above the interaction peak in the structure factor. The effective diffusion constant $D_{eff}(Q)$, obtained from I(Q,t) ; $\exp(-D_{eff}(Q)Q^2t)$, varies inversely with the structure factor, reaching a minimum at the structure factor peak, an effect analogous to DeGennes narrowing. As a result, in a dilute solution of interacting micelles, one may unambiguously separate the structure factor from the form factor, which may not be done with only a SANS measurement.

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