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The ^{3}He filter on a polarized thermal neutron three-axis spectrometer

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Abstract

The use of Heusler alloy crystals in the thermal-energy range implies severe neutron flux losses as compared to pyrolithic graphite. On TAS instruments using successively two such devices (polarizer and analyzer) this results in overall penalty factors of up to two orders of magnitude in detector count rate as compared to the unpolarized neutron work. First tests of the ^{3}He filter carried on the IN20 spectrometer confirmed the filter performance followed the theoretical predictions, permitting optimization of the filter transmission versus the neutron beam polarization. In general, higher monochromatic flux for neutron energies above 30 meV can be expected, accompanied by an increase of the solid angles due to the use of PG or silicon focusing crystals of a considerably larger size than possible with magnetic crystals. © 1998 Elsevier Science B.V. All rights reserved.

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The ^{3}He spin filter technique [1, 2] appears to be the most promising way to improve the performance of polarized neutron three-axis spectrometers in the upper thermal-energy range. The availability of the gas polarization and compression facilities at ILL (cf. Ref. [3]) made possible first experimental tests on the IN20 spectrometer in early 1997.

The filter cell of 90 mm internal diameter, filled to a pressure of 2.25 bars with gas polarized to 48% was mounted at the exit of the monochromator protection in magnetic shielding boxes built of 2 mm mild steel and of 2 mm μ-metal The boxes contained a solenoid to create a vertical guiding field of about 10 Oe for the ^{3}He nuclear spins. The IN20 setup consisted of a PG 002 monochromator with 60′ Soller collimators, of a perfect Si(3 1 1) sample and of a Heusler analyzer. Fig. 1 displays the observed spectral variation of the filter performance and illustrates the connection between the filter opacity and its polarizing ability. These results are in excellent accord with the values calculated from cell parameters and from complementary measurements (15% polarization loss due to the magnetic shielding box). Of equal importance is the observed cell polarization relaxation time of 45 h which implies a good homogeneity of the internal guiding field. In order to achieve

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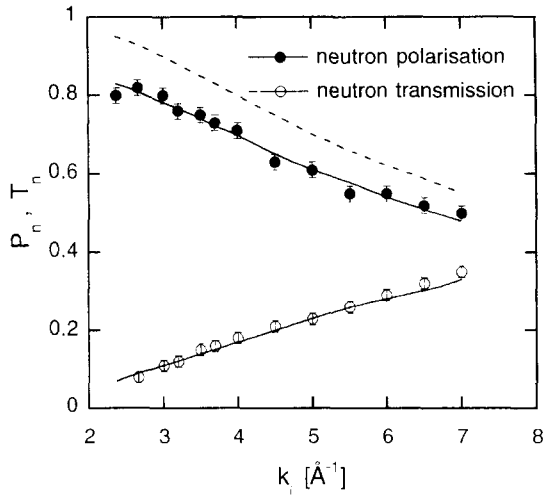

Fig. 1. Spectral variation of the neutron beam polarization and of the filter transmission observed with the ^{3}He filter cell described in the text. The solid lines correspond to calculations based on independently measured filter and spectrometer parameters, the dotted curve represents neutron beam polarization corrected for losses in the magnetic shielding.

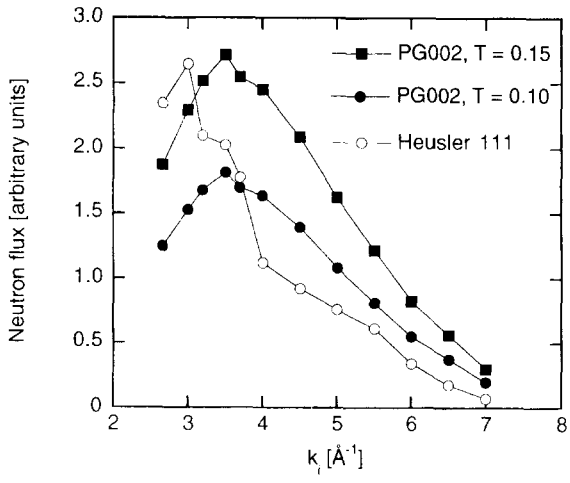

Fig. 2. The polarized neutron flux (arbitrary units) from the IN20 Heusler monochromator compared with that of a PG002 in combination with a polarizing filter of 10% and 15% transmission.

a neutron beam polarization above 90% the transmission of the actually available filter does not exceed 10% to 15% (cf. Fig. 1). Fig. 2 shows that in the IN20 conditions the filter technique provides an advantage in output flux over a Heusler crystal at $k_i > 3.5$ Å^{-1}.

For a more involved performance comparison we have to realize that the freedom of choice of the filling pressure of a filter, and hence of its opacity, allows an optimum compromise between the polarizing ability and the transmission for given experimental conditions [4]. We recall that a typical polarized neutron inelastic scattering experiment consists in determining the spin-flip (SF) and non-spin-flip (NSF) cross-section parts, σ_{SF} and σ_{NSF}, respectively, from the count rates Z_{SF} and Z_{NSF} observed in the two scattered neutron polarization channels. We can write

$$\sigma_{SF} = \frac{[(P^2+1)Z_{SF} + (P^2-1)Z_{NSF}]}{2P^2T^2} \quad (1)$$

with P and T representing the neutron polarization and transmission of each of the two devices, assumed to be identical. Then we can define a figure of merit Φ of the TAS setup as the reciprocal of the relative error in the value of the spin-flip cross-section σ_{SF} and maximize Φ to find optimum experimental conditions. Without going into further details we also notice that Φ depends implicitly on the ratio σ_{SF}/σ_{NSF} and hence on the proportion of time spent counting in each of the polarization channels.

Assuming that in the course of an experiment one can always reach the optimum conditions corresponding to the instantaneous ^{3}He gas polarization, we can attempt a comparison of the filter performance with that of Heusler alloy crystals in situations typical for inelastic neutron scattering with $\sigma_{SF}/\sigma_{NSF} \approx 10^{-1}$–$10^1$. In Fig. 3 the figures of merit of the actually available spin filters fall into the range of gas polarizations between 60% (initial) and 40% (after 1 day of decay) while the values corresponding to helium polarization of 80% represent an upper limit possible to reach by foreseeable progress of the present technologies. The solid lines in Fig. 3 display the corresponding values for Heusler crystals, providing wavelength-independent neutron polarizations of $P \approx 95\%$ and overall reflectivities reaching about 10–20% of those of pyrolithic graphite (including the inherent $\frac{1}{2}$ factor due to the beam polarization). It is mainly the configurations in which the crystal performance drops below this level – e.g. the higher-thermal

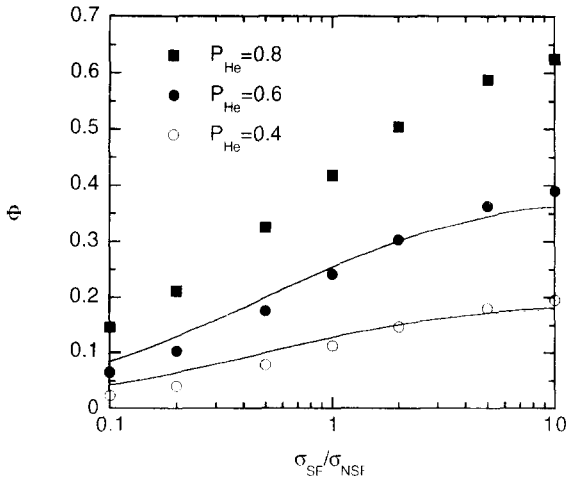

Fig. 3. The figure of merit Φ of a setup using optimized spin filters with ^{3}He gas polarizations of 40%, 60% and 80% compared with that of a pair of Heusler crystals providing reflectivities of 10% and 20% of pyrolithic graphite (the lower and upper solid curves, respectively).

energy range (Fig. 2), large focusing crystal arrays – where the filter technique in its present incarnation is already attractive for applications.

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