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POLARISING FILTER TESTS AT ISIS

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1. INTRODUCTION

For the efficient use of polarised neutrons on a pulsed source such as ISIS, a neutron polariser capable of polarising over a broad band of neutron energies is required, so that time of flight techniques can be used. For this reason monocromating polarisers such as Heusler crystals, which are used at reactor sources, are not suitable. Furthermore, although supermirrors do provide white beam polarisation, they are inefficient at energies greater than $\simeq$ 30 meV. In principle neutron polarising filters, based on preferential absorption of one of the two neutron spin states by aligned Sm^{149} nuclei, give a good performance at all neutron energies below 200 meV [1,2]. However, in order for adequate nuclear alignment to be obtained, the filter must be maintained at $\simeq$0.02K in a dilution refrigerator. Previous measurements[2] have shown that heating of the filter is too great for efficient operation of the filter in a white beam on ISIS, given the limited cooling power of the currently available dilution refrigerator.

The primary purpose of the measurements presented here was to determine whether the filter is suitable for polarising an incident beam which is monochromated by a Fermi chopper. It was anticipated that the large reduction of neutron intensity by the chopper would largely eliminate any beam heating problems. In section 2 we outline the principle of neutron polarisation by Sm filters, in section 3 we describe the measurements and in section 4 we discuss the interpretation of these measurements and their implications for future progress.

2. PRINCIPLE OF FILTER OPERATION

The nuclear absorption cross-section for the two neutron spin states is[1]

$$\sigma\pm = \sigma(1\pm\rho)PN \tag{1}$$

where $\sigma+$ and $\sigma-$ are the absorption cross-sections for the + and - spin states, ρ is a statistical spin weighting factor (ρ = 7/9 for Sm^{149}) and PN is the nuclear polarisation. Thus the filter transmission for the two spin states is

$$T\pm = \exp[-Nt\sigma(1\pm\rho)PN] \tag{2}$$

where Nt is the number of Sm^{149} atoms/unit area of filter.

The polarising efficiency of the filter is defined as the beam polarisation of an initial unpolarised beam after it has passed through the filter.

$$P = (T+ - T-)/(T+ + T-) = -\tanh(\rho PN\sigma) \tag{3}$$

The fraction of incident neutrons transmitted by the filter is

$$T = (T+ + T-)/2 = \exp(-\sigma Nt)\cosh(\rho PN\sigma Nt) \tag{4}$$

These equations are complicated by the presence of any depolarisation effects due to domain misalignment within the filter. However previous measurements [1,2] have shown that these effects are small and they can be neglected.

The filter operates efficiently within the region of energy where the Sm^{149} absorption cross-section is the dominant source of neutron attenuation. For Sm^{149} the 96 meV resonance absorption peak provides a sufficiently large cross-section for incident neutron energies between 0 and 200 meV.

3. MEASUREMENTS

The preparation and characterisation of the filter has been described in a previous report[2]. A schematic diagram of the experimental apparatus is shown in figure 1. The choppper was phased to give an incident energy of 88±1 meV. In figure 2 we show a superposition of spectra from the four detectors indicated in figure 1 in the absence of the filter. In figure 3 is shown the transmission of the filter as a function of time, after the circulation was started on the dilution refrigerator. As the filter cooled, the transmission of the filter increased according to equation 4. The ratio of the transmission with the filter cold to that 'warm' (ie $> 1K$ where $PN=0$) is

$$R = \cosh(\rho PN\sigma Nt) \tag{5}$$

It can be seen from figure 3 that $R \simeq 0.0062/0.0024 = 2.6$, so that from equation (5), $\rho PN\sigma Nt = 1.6$. The value of σNt can be obtained from the 'warm' transmission; $\sigma Nt = -\ln(0.0024) = 6.03$. Thus using $\rho = 7/9$, we obtain $PN = 0.34$. The observed nuclear polarisation is given by the product of the nuclear polarisation within a single domain and the average alignment of the domains within the sample. Previous measurements have shown that the latter quantity is $\simeq 0.9$, so that the nuclear polarisation within a single domain is $\simeq 0.34/0.9 = 0.38$. From this value for the nuclear polarisation the temperature of the filter can be determined from the Brillouin function, given the known hyperfine interaction between the Sm nuclei and the Sm f electrons [3].

A nuclear polarisation of 0.38 corresponds to a filter temperature of $\simeq 0.07K$.

We note that the neglect of depolarisation effects within the filter leads to a worst case estimate for the filter temperature. If depolarisation is taken into account the calculated operating temperature is reduced. However the estimate of 0.07K should be accurate to within 10%.

A measurement of R at 88 meV with the chopper removed from the beam gave a value of $R \simeq 1.2$, which corresponds to a temperature of 0.2K. Thus since the cooling power of an ideal dilution refrigerator [4] is proportional to T^2, it follows that the presence of the chopper reduced the beam heating by a factor $(0.2/0/07)^2 \simeq 8$.

Previous white beam measurements[2] on the filter in a beam current of 1μA (compared with 100μA during the measurements reported here) gave a transmission ratio of 10, which corresponds to a temperature of 0.03K. Assuming, as previously mentioned, that the cooling power of the refrigerator is proportional to T^2, the heating was less by a factor of $(0.2/0.03)^2 \simeq 50$ at 1μA than at 100μA. The discrepancy of a factor 2 between this estimate of the beam heating and the reduction expected from the reduced beam current gives an indication of the accuracy of the estimation of beam heating.

4. DISCUSSION

The reduction of beam heating by a factor of only $\simeq 8$ in the presence of the chopper suggests that significant beam heating is produced by high energy neutrons and also possibly by the $t=0$ gamma ray flash from the incident beam. The measurements suggest that in order to reduce the filter operating temperature to below 0.02K, we require a further reduction in beam heating by a factor $\simeq$10. In figure 4 we show the neutron transmission of the Fermi chopper as a function of time of flight. Many more neutrons are transmitted at short times, where the incident neutron intensity is high, than in the chopper pulse.

The high energy neutrons and the γ flash can be eliminated by the installation of a Nimonic chopper, such as those used on HET and MARI to reduce fast neutron background. This should result in a further reduction in beam heating and allow for efficient operation of the polarising filter.

REFERENCES

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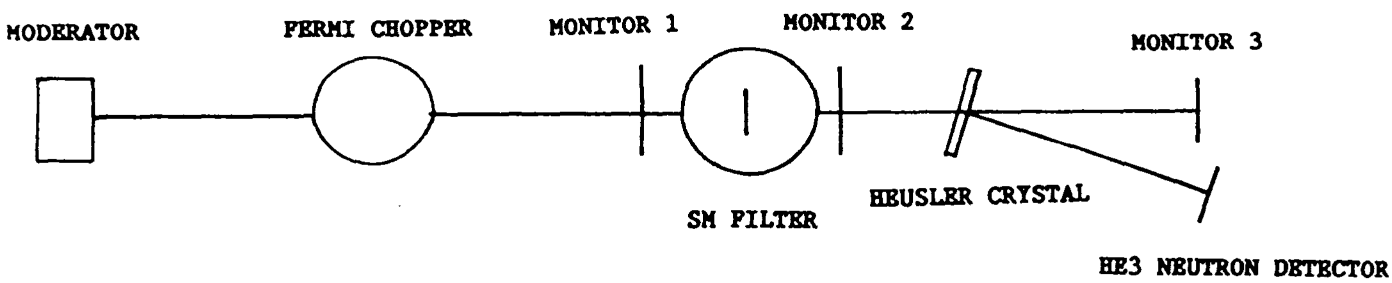

FIGURE 1. SCHEMATIC DIAGRAM OF APPARATUS

Q(J.B.Hayter): What is the cost of a polarizing filter with current technology?
A(W.G.Williams): The best high power dilution refrigerators cost about £120K.

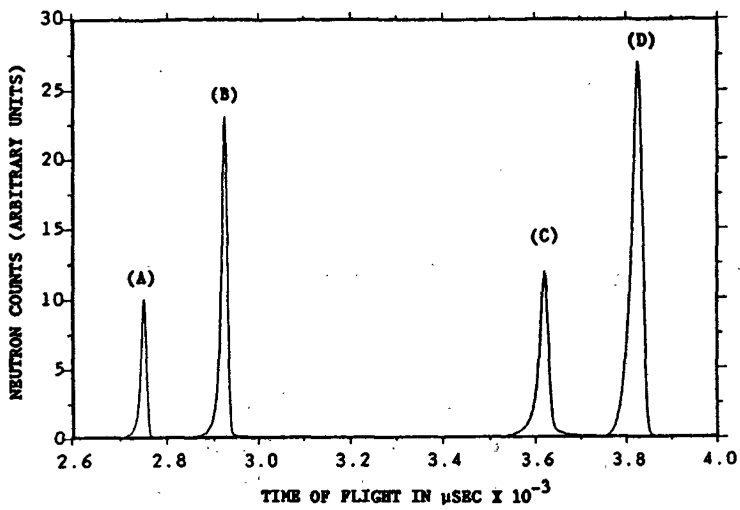

FIGURE 2. DETECTED INTENSITY WITH CHOPPER PHASED TO GIVE INCIDENT ENERGY OF 88.7 MEV. POLARISING FILTER OUT OF BEAM. (A) MONITOR 1, (B) MONITOR 2, (C) MONITOR 3, (D) INTENSITY IN HE3 COUNTER AFTER REFLECTION FROM HEUSLER.

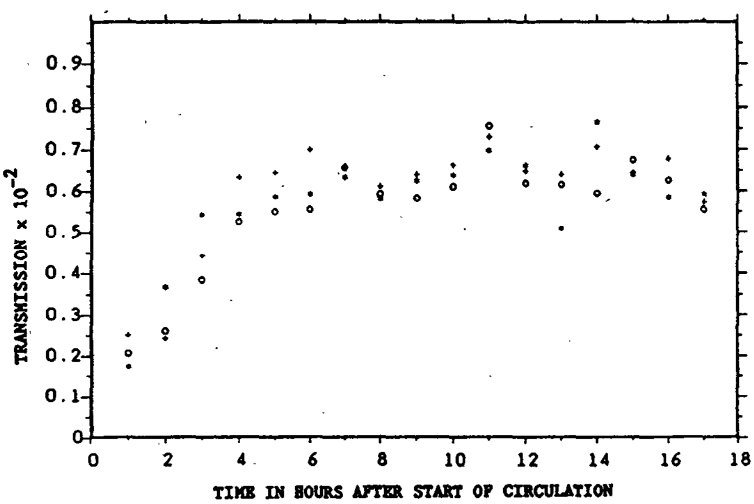

FIGURE 3. TRANSMISSION OF POLARISING FILTER AS A FUNCTION OF TIME. THE CIRCULATION ON THE DILUTION REFRIGERATOR WAS STARTED AT TIME ZERO. THE TRANSMISSION WAS MEASURED INDEPENDENTLY USING MONITOR 2 (+), MONITOR 3 (*), AND THE HE3 COUNTER (o).

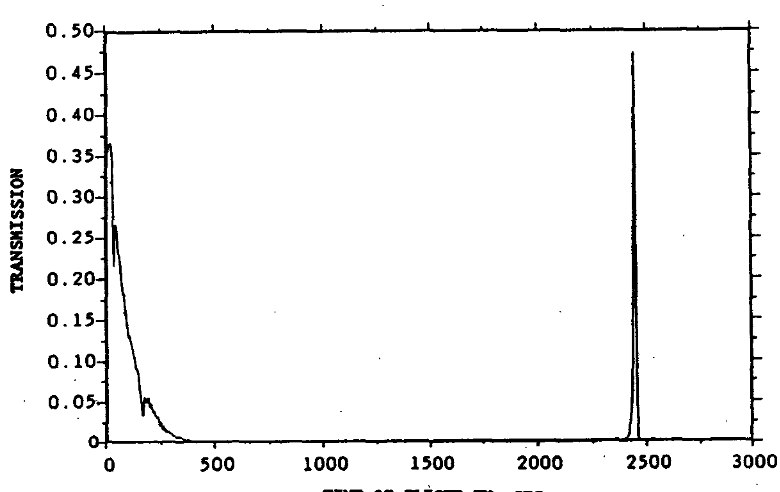

FIGURE 4. TRANSMISSION OF CHOPPER