A NEUTRON SPECTROMETER FOR USE IN THE LONG WAVELENGTH LIMIT

by

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In this paper I want to describe a possible neutron spectrometer for long wavelengths ($\lambda \sim 50$ to 1000 Å, $v \sim 80$ to 4 m/s, $E \sim 40$ to 0.1 μ eV) which uses Bragg scattering off a moving crystal to produce a narrow velocity band of Doppler shifted neutrons. There are several long wavelength spectrometers currently in use with applications in biological measurements and macroscopic effects in materials science.[1,2,3] The proposed spectrometer would have the advantage of time-of-flight (TOF) determination of the neutron energy.

For adequate TOF measurements in the energy range of interest, a flight path of only a few meters can be tolerated because of absorption losses. The pulse width at the source must be narrow, 10 times narrower than is possible from current pulsed sources in the 1000 Å region. It may also be difficult to extract long wavelength neutrons out of the pulsed source due to absorption losses in moderators and beam tubes. The design which I am considering utilizes a crystal mounted on the end of a rotor[4] such as the arrangement appearing in another paper in these proceedings (the Doppler shifting converter for the production of ultra cold neutrons). It has been demonstrated that moving crystals are good velocity selectors and can shift

the neutron wavelengths on reflection,[5,6] but I want to emphasize that the Bragg scattering occurs only in a short time interval ($\sim$ 400 μs for our present rotor). This permits an intense source of long wavelength neutrons with narrow pulse width generated close to a TOF spectrometer.

Our present rotor design with a thermica crystal generates neutrons with a perpendicular velocity component ($v_\perp$) from 3 to 20 m/s as shown on Fig. 1. Other velocity intervals can probably be produced by either changing rotor speed, crystal angle or working at higher order reflections.[6] Though we generate reasonable counting rates (0.6 n/(m/s) - pulse), the disadvantage of the rotor is the wide beam divergence ($\sim 80^\circ$). Use of collimation would severely reduce the counting rates; however, there is a class of experiments where angle information is not required (large energy transfer experiments and transmission experiments where only $v_\perp$ is important).

We have tested the principle of such a spectrometer using the Argonne rotor with the experimental setup shown on Fig. 2. We used two magnetic foils arranged in series where we could alter the transmission of neutrons by polarization.[7] The foils were 0.1 mil Ti coated with a 500 to 1500 Å-thick layer of natural iron. Electromagnets were used to saturate the magnetization in the foils. When very low velocity neutrons of the appropriate spin orientation strike the foils, the magnetic and nuclear amplitudes in Fe add together and the neutrons are reflected. In the other spin state the amplitudes subtract allowing some of the neutrons to pass through the foils. For an unpolarized beam and two foils magnetized in the same direction, the transmission T is greater in the magnetized case. (In the unmagnetized case the transmission varies as T^2.) An example of data taken with a 1500 Å Fe layer is shown on Fig. 3 showing a clear separation in the two cases. (The

separation would be even more pronounced with Fe^{54} because the magnetic and nuclear scattering amplitudes are close to the same magnitude.)

Another phenomenon occurs for particular incident velocities on thin layered foils; the neutrons resonate or get trapped.[1] This is easily demonstrated by a calculation where the material layers are represented by square potentials in a simple one-dimensional Schroedinger problem. The resonances give rise to preferential absorption in the various layers which can be detected by changes in transmission as a function of incident velocity. On Fig. 4, data showing this effect are presented. The calculated curves agree with the data for an Fe thickness $\sim$ 450 Å. We see one resonance near 10 m/s and evidence for a second near 12.5 m/s. (The unmagnetized data is again related to the square of the transmission in the magnetized case.)

The physical flight path was 56.89 cm from the crystal center to the He^3 counter. The uncertainty was 4.0% due to lack of knowledge in where these neutrons originated in the crystal ($\pm$ 1.35 cm), where they stopped in the detector ($\pm$ 0.5 cm), and the horizontal motion of the crystal ($\pm$ 0.4 cm) as it swung in front of the spectrometer. Folding in the pulse width ($\sim$ 400 μs) yields a TOF precision given by

$$\Delta v/v = \sqrt{(0.04)^2 + (0.0008v)^2} \qquad (1)$$

where v is in m/s. $\Delta v/v$ is 4% at 3 m/s, 4.1% at 10 m/s and 4.3% at 20 m/s. The energy sensitivity is $\Delta E/E = 2\,\Delta v/v$.

Using the data on Fig. 4 the observed spectrometer sensitivity can be estimated. The full width of the first transmission dip at 10 m/s is 0.2 μ eV, centered at an energy of 0.5 μ eV. The dip spans 5 data points (plotted

in 0.5 m/s bins) which follow the predicted curve. This is true in both the magnetized and unmagnetized data. Therefore, the sensitivity is estimated to be

$$\frac{\Delta E}{E} \approx \frac{0.2}{5} \times \frac{1}{0.5} = 8\% \qquad (2)$$

which yields $\Delta E \approx 0.04$ μ eV. This result agrees with the calculation using (1) for our spectrometer.

The data on Fig. 4 took about 25 minutes to collect at 5 Hz pulse rate on the Argonne ZING-P' source ($\sim$ 7500 pulses). This yields about 0.01 counts/0.5 (m/s) - pulse with a background of 10^{-3} counts/0.5 (m/s) - pulse. The count rates are lower than expected from the data on Fig. 1 ($\sim$ 0.3 counts/0.5 (m/s) - pulse), and this is due in part to a different Thermica crystal package mounted on the rotor for our spectrometer test which had a lower reflectivity, but also it is due to the accentuated losses in the longer flight path in our spectrometer. (Losses for long wavelength neutrons in long tubes have been measured to be $\sim 1/(1 + 1.2L)$ where L is the flight path in meters.[8])

Finally, I want to describe the expected performance for a spectrometer that could be used at IPNS with a 1% energy sensitivity. A 2.95-m long flight path is required as well as a reduction in the source pulse rate to 3 Hz to achieve a velocity descrimination at 9 m/s. The guide losses yield 20% of the counting rate observed above, but this is offset by an expected increase in flux of 10 at IPNS over ZING-P'. In the 10 m/s range (0.5 μ eV) we expect a count rate of 0.18 n/0.05 (m/s) - s (bins of 5 nano eV) at a 3 Hz pulse rate. In the 4 m/s range (0.1 μ eV) we require a pulse rate of 1 Hz with an expected counting rate of 0.024 n/0.02 (m/s) - s (bins of 1 nano eV).

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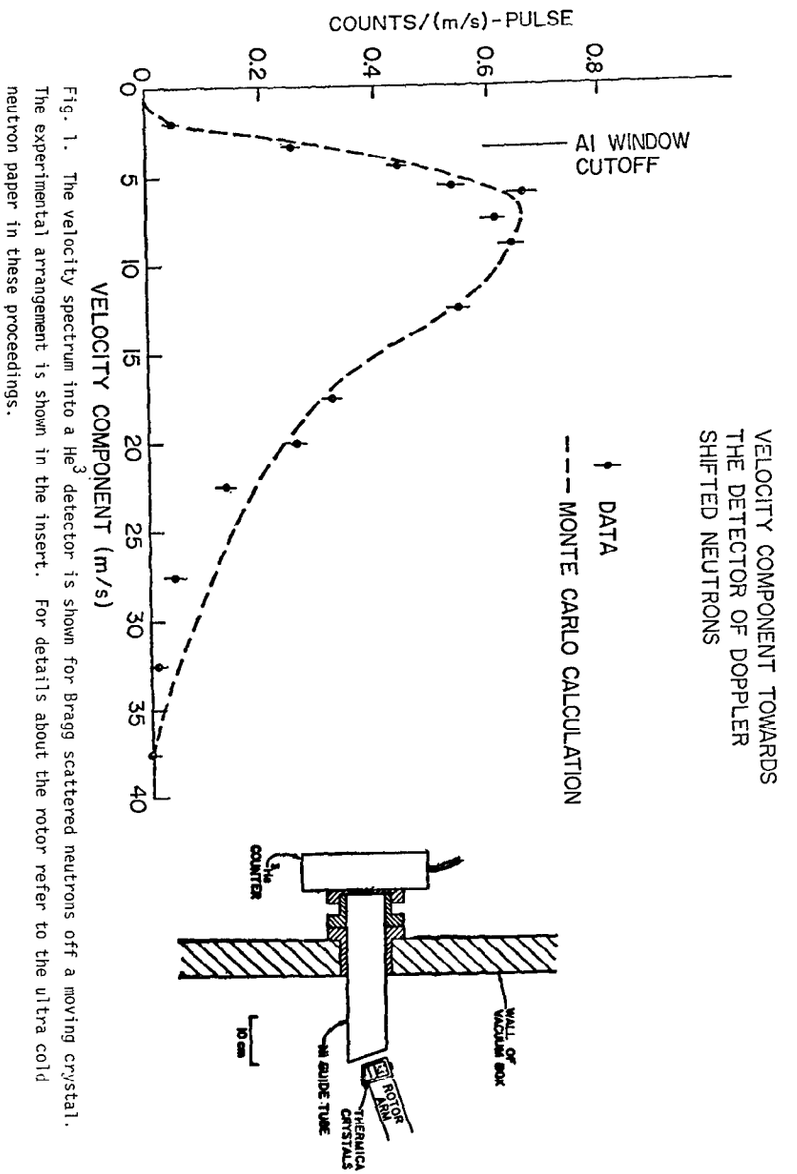

Fig. 1. The velocity spectrum into a He^3 detector is shown for Bragg scattered neutrons off a moving crystal. The experimental arrangement is shown in the insert. For details about the rotor refer to the ultra cold neutron paper in these proceedings.

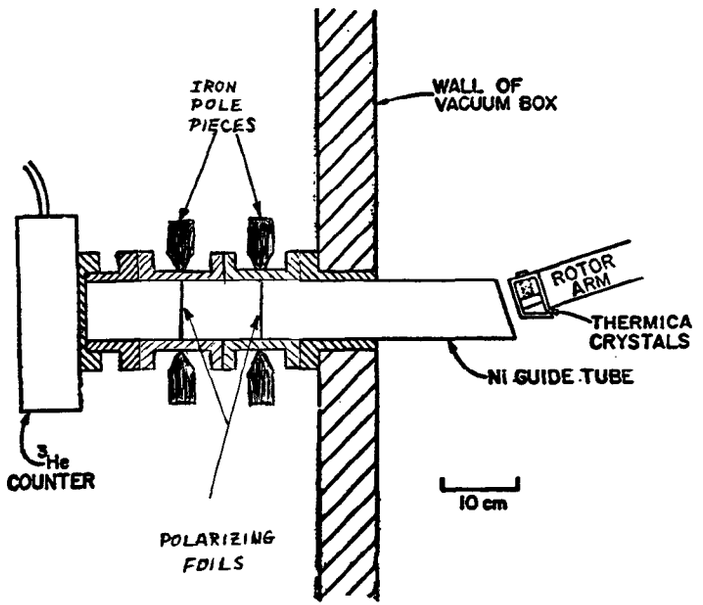

Fig. 2. The time-of-flight spectrometer with two thin foil polarizers is shown schematically. The foils are magnetized perpendicular to the neutron direction by external electromagnets.

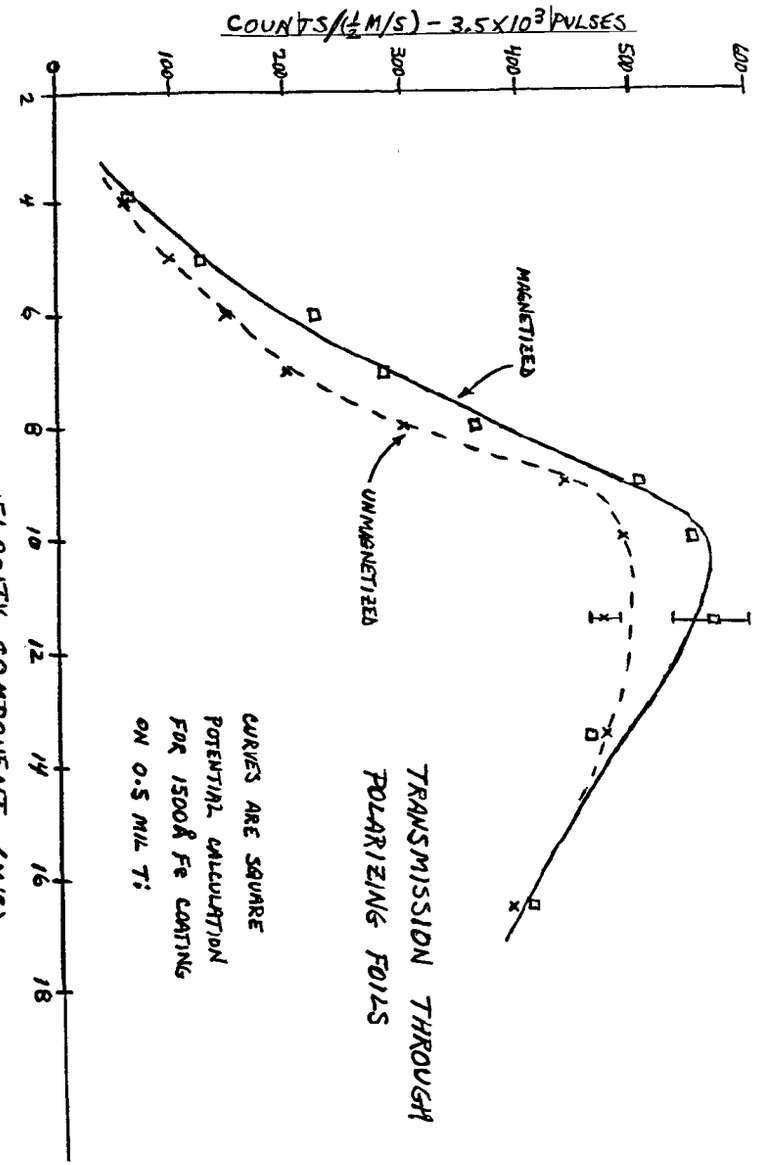

Fig. 3. Transmission data are shown for two foils with parallel magnetization. Refer to the text for a discussion of the curves.

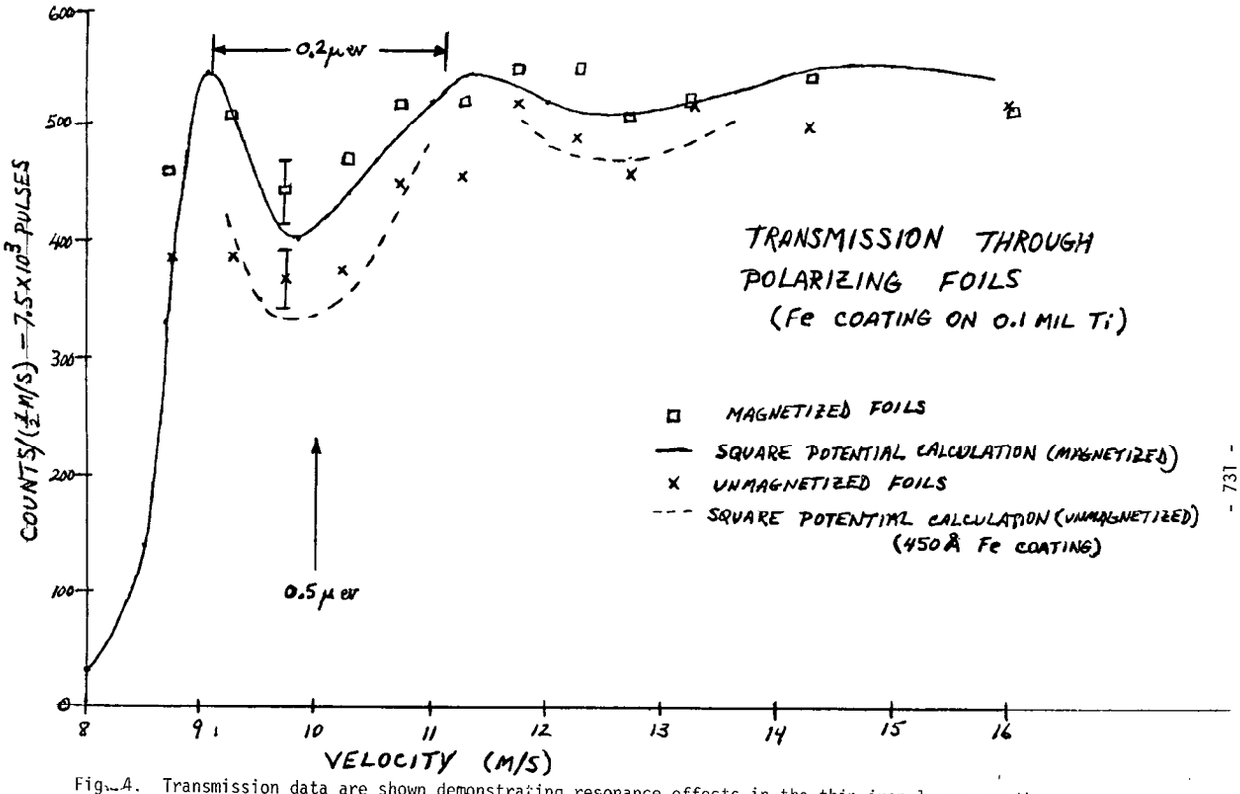

Fig. 4. Transmission data are shown demonstrating resonance effects in the thin iron layers on the polarizing foils. The energy sensitivity at 0.5 μ eV is 0.04 μ eV determined from the width of the dip in the transmission curves.