Quantitative estimate of the $\lambda/2$ contamination in the incident neutron beam at 4G

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By measuring incident neutron flux using proper absorbers, we have estimated ratio of main (λ) and half-lambda ($\lambda/2$) components in the incident neutron beam at 4G. This result can be used for the so-called Cowley correction, which is mandatory for the detailed analysis of the spectral weight function in wide energy range obtained under the $k_{\rm f}$-fixed configuration.

INTRODUCTION

To estimate spectral weight function precisely, we need to carry out several corrections to raw data obtained using triple-axis spectrometers. These corrections include absorption correction, beam defocus correction, detector efficiency correction, and so on. The significant $\lambda/2$-neutron contamination to the incident neutron beam is unavoidable for the thermal neutron energy range with the $k_{\rm f}$-fixed mode, and this contamination gives rise to the inaccurate measure of the incident flux by the beam monitor. Thus, correction for the higher harmonic contamination, so-called the Cowley correction, is also indispensable for the precise determination of the spectral weight function. To perform the Cowley correction, we need to know the ratio of the main (λ) and second harmonic ($\lambda/2$) neutron intensities in the incident neutron beam. In this note, we will report the determination of the $\lambda/2$ intensity by utilizing $1/v$-dependence of the absorption factor of the natural B element.

PRINCIPLE AND PRACTICE

Absorption coefficient have $1/v(\propto 1/k)$ dependence for the neutrons with energy well below the absorption edge:

$$\mu(k) = \mu_0 \frac{k_0}{k}, \tag{1}$$

where, $\mu(k)$ and μ_0 are the absorption coefficients for the measuring wave-number k, and for the 2200 m/s ($k_0 = 3.494$ Å^{-1}). Using the above absorption coefficient, the absorption factor for a single wave-number k is given as:

$$af(k) = \exp[-\mu(k)t], \tag{2}$$

where t is the thickness of the absorber (usually in cm). Assuming that there are λ (k) and $\lambda/2$ ($2k$) components with the intensities I_1 and I_2 in the incident beam, neutron intensity after the absorber with thickness t is written as:

$$I(k,t) = I_1 \exp[-\mu(k)t] + I_2 \exp[-\mu(2k)t]. \tag{3}$$

Since the above function is non-linear in t, by measuring intensity with changing the absorber thickness t, we can estimate the intensities I_1 and I_2. In reality, we used the monitor detector to count the intensity, which has also $1/v$ efficiency for the thermal neutron range. Denoting an unknown efficiency factor c, the above equation should thus be modified as:

$$I_{\rm obs}(k,t) = c\left\{\frac{I_1}{k}\exp[-\mu(k)t] + \frac{I_2}{2k}\exp[-\mu(2k)t]\right\}. \tag{4}$$

We use this equation to obtain the flux ratio for the λ (k) and $\lambda/2$ ($2k$) components.

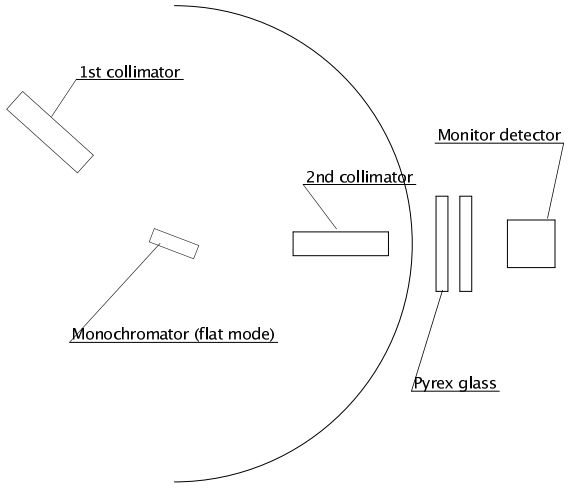

FIG. 1: Experimental setup for the Pyrex absorption measurement. The first collimator was 40', whereas the second one was 80'. The monochromator was in the flat mode, in order to avoid unnecessary focusing effect.

As an neutron absorbing material, we selected the Pyrex glass plates from Asahi Techno Glass (ATG) corporation (possibly TE-32.) The Pyrex has about 12.7 wt.% of B_2O_3, from which we expected to have an absorption coefficient of $\mu_{\rm calc} \simeq 3.65$ cm^{-1} for 2200 m/s neutrons. We note that the other constituents of the Pyrex are SiO_2 (80.9 wt.%), Al_2O_3 (2.3 wt.%), Fe_2O_3 (0.03 wt.%), Na_2O (4.0 wt.%), and K_2O (0.04 wt.%). These constituents are neither neutron absorber nor incoherent scatterer, and thus we decided that the Pyrex is

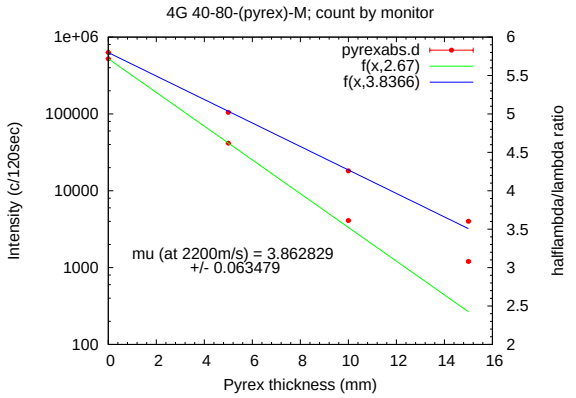

FIG. 2: Neutron intensity at the monitor detector for the four different absorber thicknesses $t = 0, 5, 10$ and 15 mm. The result is fitted to the exponentially decaying function, and the absorption coefficient of the presently used Pyrex plates was determined as $\mu_0 = 3.86(6)$ cm^{-1} for the 2200m/s neutrons.

proper absorber for the present purpose. In view of the considerable absorption coefficient of the Pyrex, we prepared a few plates of 5 mm and 10 mm thickness; several pieces were combined to have variation of total thickness ranging from 0 mm to 15 mm.

Experimental setup is shown in Fig. 1. The first and second collimations were selected to be 40' and 80', respectively, whereas the monochromator was set to the flat mode, to avoid unnecessary focusing effect. The Pyrex plates were placed just after the beam outlet at the monochromator drum surface, and immediately after the plates, the monitor detector was placed with which we measured the absorbed neutron beam intensity.

EXPERIMENTAL RESULTS

First of all, we have determined the absorption coefficient of the Pyrex plates by using well monochromated beam using the inpile PG filter. The two incident wave numbers $k_{\rm i} = 2.67$ Å^{-1} and $k_{\rm i} = 3.8366$ Å^{-1} was used for this purpose. The neutron intensity at the monitor detector versus Pyrex thickness is shown in Fig. 2 for the two incident energies. By simultaneously fitting the results to the equations:

$$I^{2.67} = I_0^{2.67} \exp\left[-\frac{2.67\mu_0 t}{k_0}\right],$$
$$I^{3.8366} = I_0^{3.8366} \exp\left[-\frac{3.8366\mu_0 t}{k_0}\right], \qquad (5)$$

with $I_0^{2.67}$, $I_0^{3.8366}$ and μ_0 as fitting parameters, we have obtained $\mu_0 = 3.86(6)$ cm^{-1} as a result. We note that the experimentally determined absorption coefficient is reasonably close to the calculated value ($\mu_{\rm calc} \simeq 3.65$ cm^{-1}),

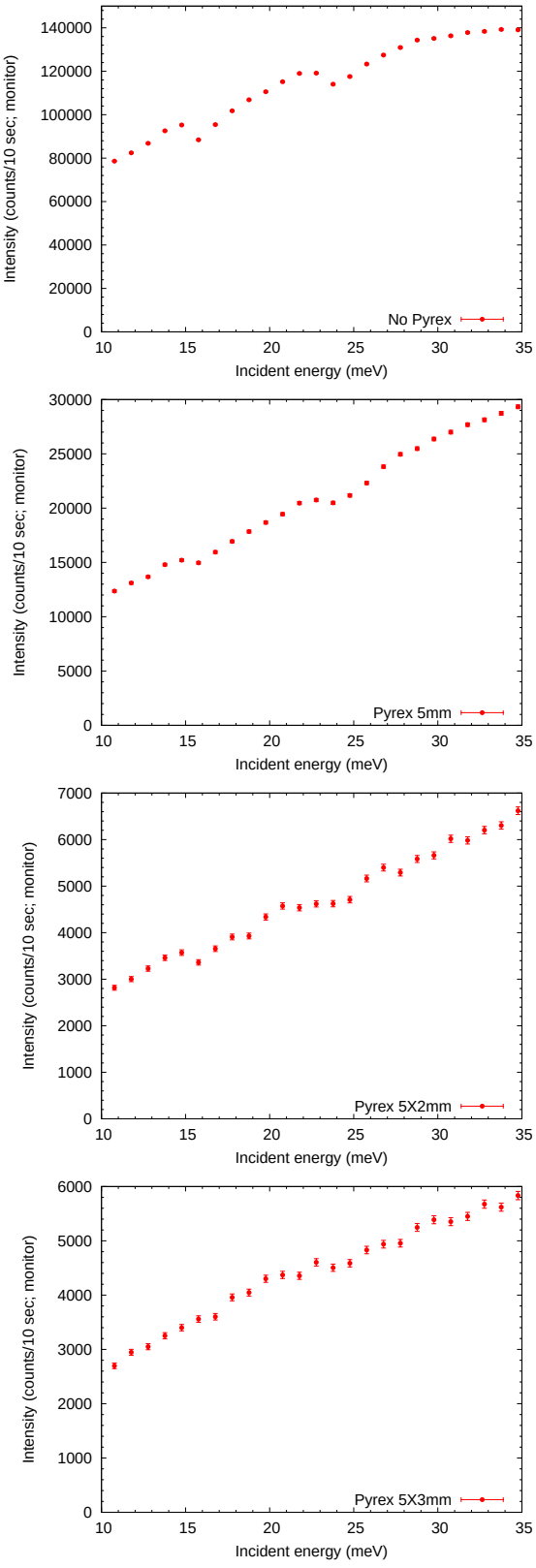

FIG. 3: Neutron intensity at the monitor detector as a function of the incident energy. Four different absorber thicknesses $t = 0, 5, 10$ and 15 mm (from top to bottom) are tried.

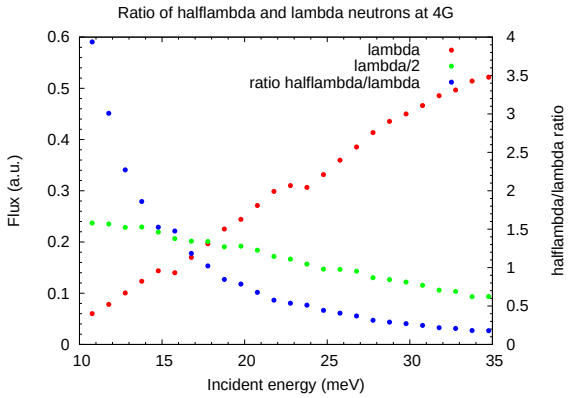

FIG. 4: Neutron intensity at the monitor detector for the four different absorber thicknesses $t = 0, 5, 10$ and 15 mm. The result is fitted to the exponentially decaying function, and the absorption coefficient of the presently used Pyrex plates was determined as $\mu_0 = 3.86(6)$ cm^{-1} for the 2200m/s neutrons.

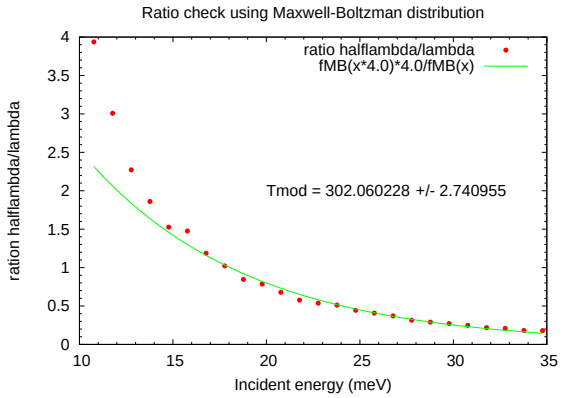

FIG. 5: Comparison between the experimentally determined ratio $I(\lambda/2)/I(\lambda)$, and theoretical one calculated from the Maxwell-Boltzmann distribution.

in view of the uncertainty for the composition of the commercial Pyrex glass.

Using thus characterized Pyrex plates, we have measured the neutron intensity with changing the Pylex thickness as $t = 0$, 5, 10, and 15 mm. The resulting neutron flux at the monitor detector is shown in Fig. 3 as a function of incident neutron energy. At each incident energy, the thickness dependence of the neutron intensity is fitted to Eq. (4) using octave. The octave script for the simultaneous automatic fitting is given in the 4G web site. The resulting I_1, I_2, and the ratio I_2/I_1 are shown in Fig. 4.

DISCUSSION

The energy of the PG monochromatized incident beam is determined by the following equation:

$$E_{\rm i} = \frac{\hbar^2 k_{\rm i}^2}{2m} = \frac{\hbar^2}{2m}\left(\frac{\tau_{\rm M}}{2\sin(\theta_{\rm M})}\right)^2, \qquad (6)$$

where the common nortation was used for the variable names. Assuming that the lattice parameter distribution of the PG crystal is sufficiently small, the energy distribution width for the monochromatized beam may be given as:

$$\Delta E_{\rm i} = -2E_{\rm i}\cot(\theta)\Delta\theta. \qquad (7)$$

Since the angular divergence $\Delta\theta$ is the same for the λ and $\lambda/2$ components in the incident beam, the energy widths for the two components may only be determined by the difference of the incident energy. Thus, we obtain:

$$\Delta E_{\rm i}|_{{\rm for}\lambda/2} = 4.0\Delta E_{\rm i}|_{{\rm for}\lambda}, \qquad (8)$$

since $E_{\rm i}|_{{\rm for}\lambda/2} = 4.0E_{\rm i}|_{{\rm for}\lambda}$.

The Maxwell-boltzmann distribution, to which the reactor neutron distribution should follow, is written in terms of the energy as:

$$f_{\rm MB}(E_{\rm i}) = A\sqrt{E_{\rm i}}\exp(-E_{\rm i}/k_{\rm B}T_{\rm mod}), \qquad (9)$$

where $T_{\rm mod}$ is the moderator temperature. The flux ratio, measured with the PG monochromator, should thus be given as:

$$fr(E_{\rm i}) = \frac{\Delta E_{\rm i}|_{{\rm for}\lambda/2} f_{\rm MB}(4E_{\rm i})}{\Delta E_{\rm i}|_{{\rm for}\lambda} f_{\rm MB}(E_{\rm i})} = \frac{4f_{\rm MB}(4E_{\rm i})}{f_{\rm MB}(E_{\rm i})}. \qquad (10)$$

Shown in Fig. 5 is the comparison of the above theoretical value to the experimental result. As seen in the figure, except for the low energy part, the correspondence is satisfactory with the reasonable moderator temperature $T_{\rm mod} = 302$ K. The low energy inconsistence may be due to the inclusion of the third harmonic neutrons. This correspondence supports that we may use the presently estimated flux ratio for the correction purpose in an energy range of $E_{\rm i} > 15$ meV. To reliably deduce the ratio of higher harmonic neutrons in the low energy range, we need to measure the absorption factors much precisely with more thickness points.

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