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Neutron Transmission through Sapphire Crystals: Experiments and Simulations

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Introduction

Sapphire crystals are excellent filters of fast neutrons, while at the same time exhibit moderate to very little absorption at smaller energies. We have performed an extensive series of measurements in order to quantify the above effect. Alongside our experiments, we have performed a series of simulations, in order to reproduce the transmission of cold neutrons through sapphire crystals. Those simulations were part of the effort of validating and improving the newly developed interface between the Monte-Carlo neutron transport code MCNP and the Monte Carlo ray-tracing code McStas.

Experiments

We used the codes MCNP and McStas to simulate the transmission of cold neutrons through sapphire crystals. For the MCNP simulations, we have used newly acquired sapphire cross section libraries⁵⁶, while allowing for energies below ~0.1 eV and cold neutrons lower than ~0.1 eV. Although not shown here, we have used a newly developed MCNP + McStas interface to reproduce our cold neutron/sapphire transmission as a function of wavelength. Different lines correspond to different crystal thickness between 10-120 mm, the minimum transmission for a 120 mm sapphire crystal is around -30%. This goes up to -50% when considering wavelengths between 1.5-6Å.

Simulations

We used the codes MCNP and McStas to simulate the transmission of cold neutrons through sapphire crystals. For the MCNP simulations, we have used newly acquired sapphire cross section libraries⁵⁶. McStas on the other hand, uses a semi-analytical formula⁵⁷ to calculate neutron absorption by sapphire crystals (the relevant component file is Sapphire_Filter.comp within the regular McStas distribution).

We performed a series of simulations, reproducing our experimental setup, in order to: a) test the performance of a newly developed interface between the two codes⁵⁸, b) compare experimental results to the sapphire cross sections for MCNP and the semi-analytical formula used by McStas.

Simulations

Although not shown here, we have used a newly developed MCNP + McStas interface to reproduce our cold neutron/sapphire transmission experiments presented above, in our effort to test the performance of the “coupling” interface. The relatively simple geometry of the experimental set-up, made it a good benchmark for the coupled code. We were able to reproduce successfully our experimental results and provide thus a validity test of the coupling interface.

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References

[1] Caranaf J et al. (2013); to be published

Figure 1: Experimental set up: crystals in place with shielding and He detector

Figure 2: Energy distribution of fast neutron fluence at BOA

Figure 3: Cross sections of ¹¹Cd (BOA’s experimental shutter) and ³He (neutron detector). For the fast neutron measurements, our experimental set-up was securely shielding against neutrons lower than ~0.1 eV, while allowing for energies 0.1eV-10⁻⁶eV

Figure 4: Horizontal measurements (scan) of fast neutron transmission through sapphire crystals of varying thickness: after 120mm-thick crystal, the integral intensity is reduced by a factor of ~6 (i.e. ~17% of fast neutrons go through; Fig 5), while the peak intensity is reduced by factor ~13 (or ~7% transmission, Fig 6).

Figure 5: Integral intensity (and its reduction factor) of fast neutrons transmitted through sapphire, as a function of the crystals’ thickness. The integral intensity of the transmitted fast neutrons dropped to ~17% after a 120mm-thick crystal (reduction factor of ~6).

Figure 6: Peak intensity (and its reduction factor) of fast neutrons transmitted through sapphire, as a function of the crystals’ thickness. The peak intensity of the transmitted fast neutrons dropped to ~7.5% after a 120mm-thick crystal (reduction factor of ~13).

Figure 7: Cold neutron transmission as a function of wavelength. Different lines correspond to different crystal thickness between 10mm and 120mm. The agreement is very good for crystal thickness >30mm. For smaller crystal thickness, between 10mm and 30mm, the minimum transmission is ~50% when going through a 120mm-thick sapphire crystal.

Figure 8: Comparison of McStas (dashed lines) and MCNP simulations (solid lines) of cold neutron transmission through sapphire. Different colors correspond to different crystal thickness, between 10mm and 120mm. Experimental values and calculated values for MCNP calculations best agree for crystal thickness ≥30mm. For smaller wavelengths 2-7Å and crystal thickness, the difference increases to ~4%.

Figure 9: Comparison of McStas (dashed lines) and MCNP simulations (solid lines) of cold neutron transmission through sapphire. Different colors correspond to different crystal thickness, between 10mm and 120mm. The agreement is very good for crystal thickness ≥30mm. For smaller wavelengths 2-7Å and crystal thickness, the difference increases to ~4%.

Figure 10: Integral intensity (and its reduction factor) of fast neutrons transmitted through sapphire, as a function of the crystals’ thickness. The integral intensity of the transmitted fast neutrons dropped to ~17% after a 120mm-thick crystal (reduction factor of ~6).

Figure 11: Peak intensity (and its reduction factor) of fast neutrons transmitted through sapphire, as a function of the crystals’ thickness. The peak intensity of the transmitted fast neutrons dropped to ~7.5% after a 120mm-thick crystal (reduction factor of ~13).

Figure 12: Cold neutron transmission as a function of wavelength. Different lines correspond to different crystal thickness between 10mm and 120mm. The agreement is very good for crystal thickness >30mm. For smaller crystal thickness, between 10mm and 30mm, the minimum transmission is ~50% when going through a 120mm-thick sapphire crystal.

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