Moderator Research at LENS: Design and Performance of the LENS Cryogenic Moderator.

Low Energy Neutron Source

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Abstract

A unique aspect of the LENS neutron source is the limited activity developed near the source, which provides opportunities for conducting research on neutron moderators that is difficult to perform elsewhere. In this poster we report on two separate experiments that exhibit this valuable feature of the LENS facility. One makes use of the ease with which moderators at LENS may be exchanged or altered to validate models used to predict the performance of moderator designs for other existing facilities, and the other makes use of the low moderator temperatures (below 10K) available at LENS to improve both the LENS source itself and to develop materials/designs for future sources.

Overview

In one experiment, we demonstrate the ability of LENS to act as a test bed for new neutronic designs by investigating the difference between Gd and Cd poison plates in a deccoupled polyethylene moderator. This result provided valuable information to guide the design of the second inner reflector plug at the SNS. Changing from the current Gd-plate design to one based on Cd could increase significantly the lifetime of this $2M component, but it is essential that the numerical calculations predicting the neutronic performance of the new design be validated before such a significant change to the design is deployed.

A major goal for the LENS facility is the development of neutron moderators that can deliver neutron beams with spectral temperatures below that available at other sources. Therefore in our second experiment we demonstrate the present performance of the LENS cryogenic moderator and discuss some ideas to lower the spectral temperature of our source. Recently interest has been growing within the neutron scattering community in the idea of a very cold neutron (VCN) source. Such a source would have a spectral peak at wavelengths on the order of 2.0nm and useful neutron flux out to on the order of 10nm, and it would be attractive in fields ranging from fundamental physics to small-angle and quasielastic scattering. Both ISIS and the SNS are allowing for possible future installation of VCN moderators in the designs of their respective second target stations. LENS is in a unique position to take a leading role in the development of such moderators since the moderators experience very little thermal loading (less than a few watts even at 10kW of proton beam power) when compared to existing spallation sources, where thermal loads are more typically on the order of kW.

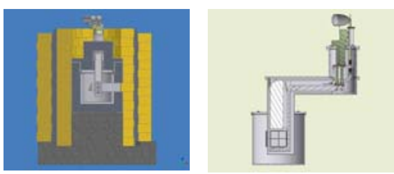

Figure 1 (above) The essential features in the LENS Target Moderator Reflector (TMR) assembly are a Be target, a 50cmx50cm cylindrical water reflector, and a solid methane moderator. The 1-cm thick moderator is cooled by a closed-cycle He refrigerator to which it is linked by a 99.999% pure aluminum bar. When operating at 10kW beam power, we anticipate a thermal load of less than 300 mW on the second stage of the refrigerator for this moderator. We can operate the moderator at temperatures well below 10K with this load. Initial MCNP simulations indicated a negligible difference in moderator performance for thicknesses greater than 1 cm (since it is fed by a thermal spectrum from the reflector), however more recent work with an improved MCNP kernel for methane suggests that 2cm might enhance the performance of this cold source.

Figure 2 (below) The vacuum vessel surrounding the moderator is intentionally oversized to facilitate experiments on larger moderators. This reduces the coupling (and therefore the neutron flux available to instruments) from what we could achieve with better coupling. To redress this aspect of the design, and to increase the effective thickness of the moderator without increasing the thermal load on the fridge, we have added polyethylene within the vacuum vessel on five sides of the moderator and to the (40K) thermal shield between the moderator and the target.

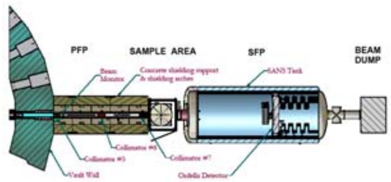

Figure 3 The SANS beam can be used to characterize the spectra and emission time distributions from candidate moderators, and to perform total cross section measurements of candidate materials for VCN production (such as alloys of methane and argon or ethane, deuterated materials etc.).

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Figure 4 (below) Compares the ratio of spectra from room-temperature decoupled polyethylene moderators with different poison plates to MCNP simulations of this ratio using the geometry displayed in figure 2. The various theoretical curves are shown to display the insensitivity of the results to the thickness of the Cd decoupling layer applied to the exterior of the moderator containment vessel. The data have been scaled down by a one parameter scaling factor to fit the predictions in the high-energy limit (5-10 eV). The scaling factor used is consistent with the combined uncertainties from alignment of the moderators within the reflector and in our measurement of the proton current delivered to the target during the measurements (5%). We note an apparent problem with the model's ability to predict accurately the high-energy side of the Cd absorption resonance that can only be detected with experiments such as this.

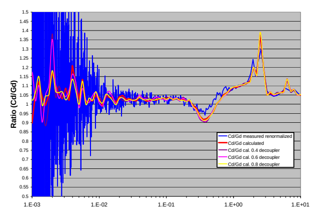
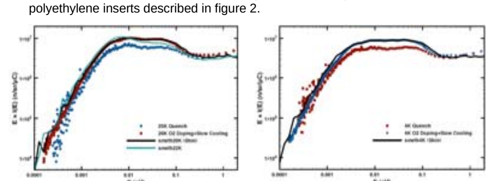


Figure 5 (below) Measurements of the LENS spectrum at two different temperatures and for two different preparation conditions are shown along with the predictions for that spectrum from MCNP with two scattering kernels. The left figure compares predictions with smeth22K (presently the best available from standard libraries) with a kernel developed at LENS (smeth20K/Shin, see also poster PH1.3). The two measured spectra differ in the manner of preparation of the methane: in one case the methane was cooled quickly from its freezing point (90K), and in the other it was cooled slowly and doped with 1.0% O_2 to catalyze spin conversion in the methane. Note that the slower cooling with O_2 doping increases the cold flux by a factor of almost 2, and that the kernel developed at LENS does a better job of describing the data for the doped moderator. The right figure compares experiments performed at 4K with the predictions of the Shin kernel at this same temperature. We note that this ability to extend the temperature range of the simulations is a distinct advantage of the kernel we have developed. These experiments were performed without the polyethylene inserts described in figure 2.



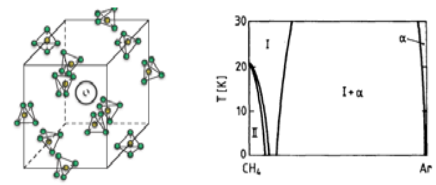


Figure 6 Solid methane exists in three forms at low temperature. Above 20K, all methane molecules in the crystal may freely rotate (phase I), but below this temperature ¾ of the molecules are in low-symmetry sites and become hindered rotors (phase II). With the addition of pressure, the fourth molecule in each unit cell can also become hindered (phase III). We note, however, that with doping (e.g. by Ar) the I-II phase transition may be suppressed, thereby opening the possibility of having all molecules act as free rotors well below 20 K.

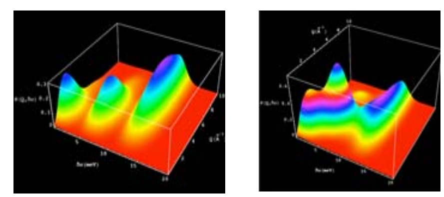


Figure 7 A further advantage of the development of our kernel is that we can explore more intelligently the effect of the moderator dynamics on the neutron cooling. In phase II (see figure 6) we can separately investigate the contributions from the librations and tunneling (between adjacent orientational minima) of the hindered rotor and free rotor molecules within the crystal. The figure on the left shows the contributions of the hindered rotors to the dynamical structure factor (S(q,ω)) whereas the figure on the right shows the contribution from the free rotors. Both figures also show the contribution from phonons (the large broad band above 10 meV). Clearly the free rotors contribute more spectral weight to S(q,ω) at the lowest energy and are therefore presumably more effective in moderating neutrons to lower temperatures. Therefore, doping of the methane with Ar may provide a mechanism for reducing the spectral temperature of the moderator.

Conclusions

The LENS facility is uniquely positioned to make significant contributions in the field of moderator development. This includes both performing experiments to validate new designs and the development of very cold neutron (VCN) spectra. We have initiated an effort in VCN production by demonstrating our abilities to run moderators at temperatures well below 10K, to modify the neutronic details of the TMR to tune the spectrum, and to develop MCNP scattering kernels suitable for modeling the neutronic performance of real moderator materials. Future work will include the effects of annealing on moderator performance and investigation of a wider variety of candidate materials as well as characterization of moderator system performance at higher power levels.

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