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Ultracold neutron production and extraction from solid deuterium at the PSI UCN source

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Ultracold neutrons (UCN) with kinetic energies below 300 neV can be confined for hundreds of seconds in storage volumes made from materials of high Fermi potential. The UCN source at the Paul Scherrer Institut (PSI) delivered UCNs for the measurement of the currently best limit on the permanent electric dipole moment of the neutron and will continue to do so for the follow-up experiment n2EDM.

The source moderates free neutrons from a spallation target, first in room temperature heavy water and then in 5 Kelvin cold solid deuterium (sD_2). Superthermal moderation in solid deuterium by phonon excitation, the last step to obtain UCNs, is a well-known process to convert cold neutrons to ultracold neutrons at high intensity. The deuterium temperature as well as the isotopic and spin-isomeric purity have a strong influence on the UCN output from the moderator. We measured these parameters and deduced the UCN lifetime in the solid deuterium. Furthermore, we estimated the fraction of UCNs that escape the moderator and can be transported to experiments by comparison of detailed Monte Carlo simulations with measurements of the UCN count rates at different deuterium filling levels. Our analysis indicates that the mean free path that the UCN travel in the moderator to reach the surface is shorter than what is expected based solely on the UCN lifetime in deuterium. We attribute the lower than expected UCN extraction to neutron scattering on defects in the solid deuterium, caused by thermal stress during freezing and cooling. Precise control of the temperature and the rate of crystallization of 22'000 cm^3 of solid deuterium poses challenges. With continuous improvements on the cryogenic system as well as operational experience we were able to improve the freezing and cooling procedures. We observe that slow freezing, as well as slow cooling and annealing of the solid deuterium in the moderator increase the UCN output considerably.

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