

Ultra Cold Neutrons at a Spallation Source

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Ultra Cold Neutrons (UCN) can be produced at spallation sources using a variety of techniques. To date the technique used has been to Bragg scatter and Doppler shift cold neutrons into UCN from a moving crystal. This is particularly applicable to short-pulse spallation sources and is the method planned for a UCN source that is under construction at LANSCE. However, large gains should be possible using cryogenic UCN sources. Spallation sources are particularly well suited for such sources given the lower heat loads and simpler engineering requirements than are possible at a reactor. The most attractive cryogenic source appears to be a frozen deuterium source and research is under way at Gatchina to demonstrate technical feasibility. If successful, a source of this type could be implemented at future spallation sources with a UCN density that may be two orders of magnitude higher than that presently available at reactors.

KEYWORDS: UCN, spallation source, cryogenic UCN source

1. Introduction

Ultra cold neutrons are neutrons whose wavelengths are sufficiently long (typically greater than 500 Angstroms) that they can undergo total internal reflection at all angles from the surfaces of a variety of materials. This leads to the possibility that UCN can be totally confined within a bottle for periods in excess of 100 seconds, making a compact source of stored neutrons for use in measurements of fundamental physics.

UCN may also be of interest in materials science, as UCN are highly sensitive probes of surface properties of materials. As the wavelengths are quite long (a few hundred Angstroms), they are well suited to studies of macromolecules, which are of great interest in areas such as biology. Current research in these areas employs reflectometry in which cold neutrons are scattered at glancing angles from materials. Studies of the Bragg scattering curves provide detailed information about the structure of the material in the region between pure surface physics and true bulk matter. UCN may potentially provide a complementary approach to reflectometry. To date the low intensities of UCN available have precluded UCN as a normal method employed in materials research. Very intense sources of UCN are required before it will be possible to test the use of UCN as a materials science probe.

2. UCN Rotor Sources

The highest UCN density to date has been achieved at the ILL reactor by converting cold neutrons into UCN by multiple reflection from the rapidly moving blades of a turbine. This technique involves Doppler shifting 40–50-m/s neutrons down into the UCN regime (< 8 m/s) and can make effective use of the high cold neutron flux from cold moderators at reactors to provide continuous beams of UCN. This device has produced measured UCN densities of 87 UCN/cm^3 , a world record.¹⁾ The ILL source first gravitationally decelerates the cold neutrons in an 18-m vertical guide tube between the liquid

deuterium moderator and the turbine converter. This novel approach substantially reduces the losses in the transport of the cold neutrons as thick windows in the guide tube can be avoided and transport losses are less due to the smaller number of average reflections necessary for a neutron to reach the turbine. Thus, the ILL source provides the benchmark that other sources must be compared to.

The considerations for UCN production at a spallation source are quite different from a reactor. In a spallation source, a proton beam strikes a high-Z target in which approximately 1 neutron per 30 MeV of beam power (compared to about 180 MeV for a reactor) is produced.²⁾ These fast neutrons are then thermalized and cooled in a variety of moderators. For UCN production, the spallation neutrons must be first moderated in a liquid hydrogen moderator. I will discuss UCN production at two different types of spallation sources: short pulse (SPSS) and long pulse (LPSS) spallation sources. The SPSS is characterized by facilities like LANSCE, ISIS, and IPNS where the proton pulse is typically a few microseconds or less. In this case, the pulse width of cold neutrons is determined by the moderator. At a LPSS, the pulse width may range from a millisecond to continuous wave (cw). In this case, the pulse width of the cold neutrons is dominated by the pulse width of the proton beam. A LPSS is characterized by either SINQ (cw) or the proposal at LAMPF to construct a 1-MW spallation source using the beam directly from the LAMPF accelerator.

At a SPSS, the high-energy spallation neutrons are not fully moderated and at present, the time-averaged flux is at least an order of magnitude less than that at the ILL reactor. However, one can take advantage of the pulsed nature of the source to produce and store UCN at the peak intensities available, which are comparable to or can exceed that at a reactor. A technique for doing this was demonstrated many years ago at the ZING-P' source at Argonne National Laboratory³⁾ and at a test setup at

LAMPF. This technique involves Doppler-shifted Bragg scattering of neutrons to convert 400-m/s neutrons down into the UCN regime. A rotor carrying a scattering crystal (for example, Mica) moves away from the neutron pulse from the liquid hydrogen moderator at one half of the velocity of the neutrons that will be converted into the UCN regime. The rotor velocity required is determined by the Bragg scattering condition associated with the lattice spacing of the crystal. For mica one reflects 199 m/s neutrons in the center of mass frame; the incident neutrons are reflected back from the crystal with the same velocity at which they impinge on the crystal. In the laboratory frame, the 398 m/s neutrons are stopped. Thus, a puff of UCN is produced which then begins to expand. Some fraction of the UCN cloud will drift into a guide tube placed close to the position at which the rotor intersects the neutron beam. A shutter at the entrance to the guide tube opens while the puff is expanding and closes after a few ms. Thus, it is possible to bottle the UCN at the peak flux rather than the average flux. The penalty paid is that the filling time will be longer at a SPSS than at a reactor. However, for a rather wide range of experiments, this is not a serious concern.

At Los Alamos, we are installing such a rotor converter on the existing LANSCE cold moderator. The moderator is a gadolinium-decoupled liquid para-hydrogen LHe moderator 12 cm \times 12 cm \times 5 cm deep, which is irradiated by fast neutrons from both the upper and lower tungsten LANSCE targets in a flux-trap geometry. The moderator is viewed by a ^{58}Ni -lined guide tube with a cross-section of 6 cm \times 6 cm. At a position about 8 m from the moderator at the end of the guide, a 6 cm \times 6 cm Mica crystal moving away from the neutron pulse at a velocity of 199 m/s will be installed on the end of a rotor that rotates in synchronism with the beam pulse rate (20 Hz).

A schematic view of the apparatus planned at LANSCE is shown in Fig. 1. We expect to produce UCN at a density of at least 10 UCN/cm³ using the existing liquid hydrogen moderator at LANSCE. It is expected that in the near future LANSCE will begin operations on a nine-month production schedule every year. This will allow a fundamental physics program to begin. A new fully coupled moderator (i.e., without any poisoners) will be installed in 1997. This will increase the width of the neutron pulses and will result in an increase in the density of UCN by a factor of about three. As the power of SPSS is expected to increase from the current 100-kW level to initially 1 MW and later to 5–10 MW, one can expect substantial advances in the UCN densities to be achieved.

3. Cryogenic UCN Sources

A rotor converter is a fairly simple instrument to implement and is well suited to a SPSS and would be compatible with a LPSS as long as the neutron pulse lengths did not exceed several hundred microseconds. Even with longer neutron pulse lengths, a rotor would still operate, but with lower efficiency. Ultimately it seems that in order to obtain substantial gains in densities one will need to go to some form of cryogenic UCN moderators. Investigations have been carried out to study

production of UCN in superthermal sources in which neutrons are down scattered by phonon emission in liquid ^4He .⁴ The upscattering rate should be very low as the phonon density in such a moderator is very low. Proof-of-principle tests of this idea have been carried out at reactors and it appears that high densities of UCN can be obtained in the liquid He moderator.⁵ However, it has proven difficult to implement this as a realistic source because there have been technical problems in trying to efficiently extract the UCN from the source. Efficient extraction from the liquid source requires a windowless extraction system that is compatible with the reactor requirements.

While the LHe superthermal source certainly merits further efforts, a potentially more attractive scheme for producing UCN is a technique now under development by the research group of A. Serebrov at the Gatchina reactor.⁶ This employs a frozen D₂ moderator at 4–6 K, which is placed close to the active zone of the reactor. The density of UCN in this source is increased dramatically by the Boltzmann factor at this lower temperature. Estimates indicate that gains of up to a factor of 10–100 can be achieved at a reactor with this technique compared to the turbine source currently in use at ILL. Very preliminary results from the Gatchina group have shown a gain in UCN densities achieved of a factor of 10 compared to a liquid deuterium source. Additional gains may be possible at a LPSS. The advantage of a spallation source is that the heat loads on the moderator are much less than at a reactor, thus providing one more freedom to optimize the moderator design and minimize its distance from the spallation target, thus increasing the fluxes.

A 1-MW Linac-only spallation source based on the LAMPF accelerator has been proposed as a means to provide complementary capabilities to those available at the short-pulse LANSCE spallation source. The new spallation target would be constructed in Experimental Area A at LAMPF, which will no longer be used for nuclear physics research after 1996. The LAMPF linac is envisaged to operate at 60 Hz providing 1.25 mA (with some potential to go to 2.5 mA) current of 800-MeV protons with a duration of 1.0 ms per pulse. The accelerator would operate at 60 Hz to the LPSS with a 1-ms beam pulse width, thus yielding a 6% duty factor. The beam would impinge on a tungsten flux trap split target viewed by up to six moderators that could be either water or liquid hydrogen. These moderators would produce beams of thermal and cold neutrons for use in materials science and defense programs. It is planned that a UCN source would be installed at the LAMPF LPSS.

The time-averaged beam power of this source is as much as sixty times less than the thermal power of research reactors. However, the energy required to produce a neutron at a spallation source is roughly 30 MeV as compared to 180 MeV at a reactor. In addition, it is possible to make a brighter neutron source using a spallation target than at a reactor. These factors yield a gain of ten for thermal neutrons and a gain of fifteen for cold neutrons relative to a reactor. In addition, it is possible (for some classes of experiments) to make use of

the time structure of the beam to advantage. In the case of Small-Angle Neutron Scattering (SANS), taking advantage of timing information can provide data rates comparable to those that can be achieved using an optimized SANS instrument at the Institut Laue Langevin (ILL), which is the best neutron-beam research-reactor source in the world.

For UCN, estimates indicate that densities of 10^3 - 10^4 UCN/cm³ could be achieved. Such a source would provide the densities required to carry out a fundamental physics research program that could probe for physics beyond the standard model with substantially improved sensitivity. The existence of such an intense UCN source may also prove of interest to materials science as a complementary probe to reflectometry. Assuming funding is provided in the near term, a cryogenic UCN source could be implemented at a LAMPF LPSS within the next five years.

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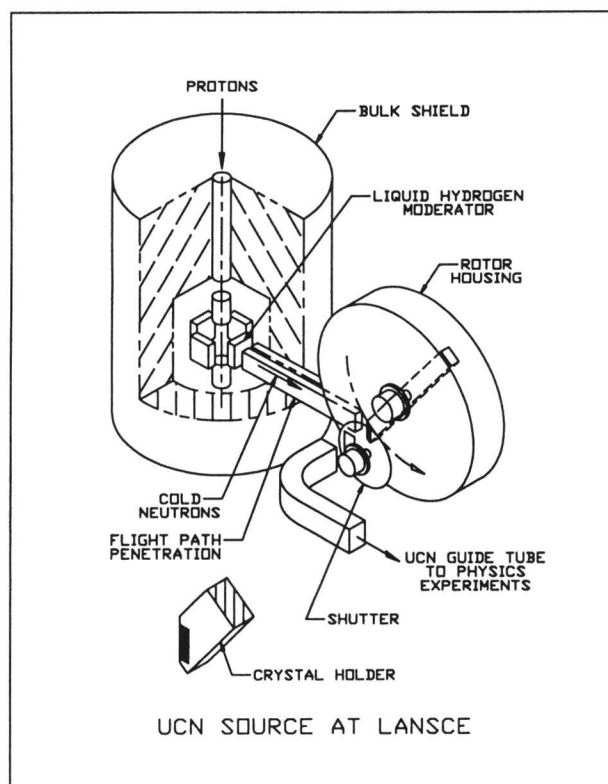


Figure 1: Schematic of planned UCN apparatus at LANSCE

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