Compared to the upcoming D_2 UCN source at PSI, a factor 10 increase in UCN density might be possible, however, but in a much smaller volume (50 litres compared to 2000 litres at PSI). This means that in experiments where an experimental volume of more than a few hundred litres needs to be filled with UCN, the PSI source should offer a better UCN density than the source proposed here. However, many experiments, notably all EDM experiments under way, employ volumes less than 50 litres, for which the proposed UCN should be able to outperform the PSI source.

There are several UCN source projects going beyond the PSI UCN source, which aim at UCN densities in the range 1 – $2\times10^4/cm^3$, such as the Mini-D_2 source at Munich, an in-pile He-4 source at Gatchina, the D_2 Pulstar source at North Carolina and an accelerator-driven He-4 UCN source at TRIUMF. Compared to these developments the UCN source proposed here requires only modest cooling power and is therefore much cheaper. Moreover, the fact that ILL has the world's most intense cold neutron beams, means that its UCN sources do not have to have an in-pile configuration to generate the most intense source, which enables easy access to the converter volume, facilitating trouble-shooting and providing much greater versatility of use and maintenance. These advantages have helped establish ILL as the place where the most significant results with UCN have been produced, in turn leading to a particularly strong user base. A development of a helium UCN source started at the TU Munich with a working prototype is currently being continued at the ILL within the ESFRI framework which includes a feasibility study of key issues of the proposed large UCN source.

A key technical problem yet to be solved concerns the several metres long He-4 converter which has to fulfil two basic requirements simultaneously: (1) efficient guiding of cold neutrons with low losses over a long distance, (2) a large UCN storage time constant. This requires the development of a new type of special coatings for neutron guides with weak UCN absorption (e.g. Be, BeO, diamond-like carbon as last layer on a supermirror guide).

A very preliminary cost estimate for the proposed UCN source is 1.6 M€. About half of the amount needs to be spent for the necessary modifications of the casemate and the construction to carry the source cryostat, and the other half for the large converter vessel, the UCN extraction system and the superconducting UCN polariser. This number assumes that the equipment being currently developed within the ESFRI project can be carried over into this project (such as a He-3 cryostat with 100 mW cooling power at 0.5 K).

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17. UCN up-scattering as a source of highly intense monochromatic pulsed beams

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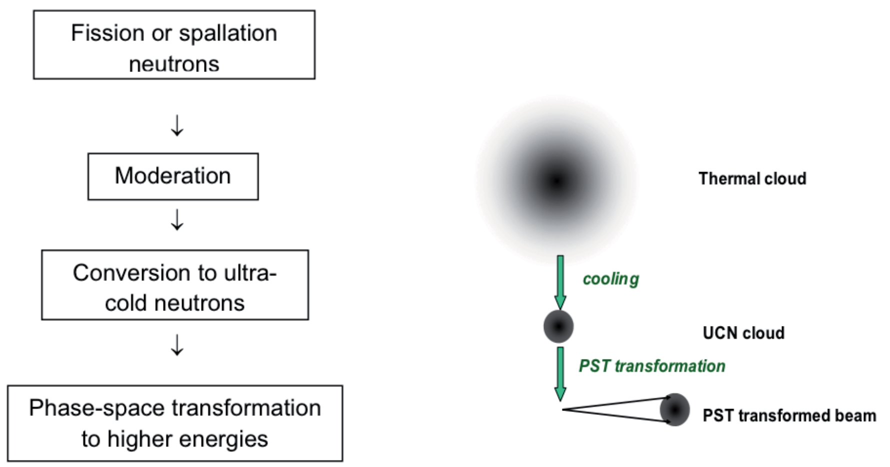
Abstract

The present proposal opens new possibilities to increase the usable neutron flux by advanced neutron cooling and phase space transformation methods. Thus a new instrument should be installed where the available neutron flux is used more efficiently. The essential point is an increase of phase space density and brilliance due to a more effective production of ultra-cold neutrons and a following transformation of these neutrons to higher energies. Recently reported progresses in the production of UCN´s and in the up-scattering of such neutrons make the time mature to step towards a new method to produce high intense pulsed neutron beams.

Motivation

The strengths of neutron sources is limited by the heat transfer from the reactor or the spallation target respectively. Therefore an alternative method is proposed which is based on ultra-cold neutrons and their up-scattering by fast moving Bragg crystals. The basic principle is shown in the figure below. A thermal cloud becomes compressed by cooling and shifted toward higher energies by a fast rotating Bragg crystal.



Since impressive progress has been reported in UCN production and their up-scattering to cold and thermal energies these methods should be combined to step towards new horizons in monochromatic pulsed beam production. Intensity gains in the order of 100 to 1000 can be anticipated. By this method pulsed beams with higher intensity and variable repetition rate can be produced at stationary neutron sources than at pulsed ones because the accumulation factor in the UCN production becomes important. This will attract new users and will make neutron science more competitive to other techniques.

Description of the instrument

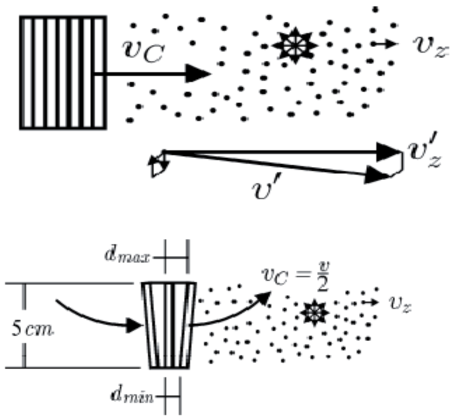
The main components are:

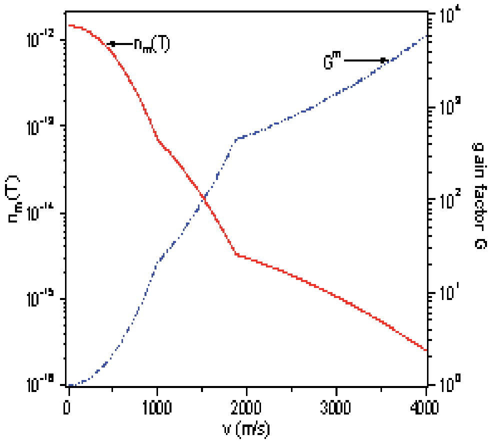
- An advanced UCN sources based on superfluid He-4 or ortho-deuterium which are under development at different places, including the ILL. Phase space density gains in the order of 100 are anticipated in comparison with existing sources. Both methods can be implemented at ILL at a neutron guide or a new in-pile source.
- A phase space transformer based on fast moving Bragg crystals where their velocity v_c and lattice distant d_{hkl} are related as

$$v_c = h/md_{h,k,l} \qquad \text{i.e.} \qquad v_c[m/s] = 1978/d_{h,k,l}[Å],$$

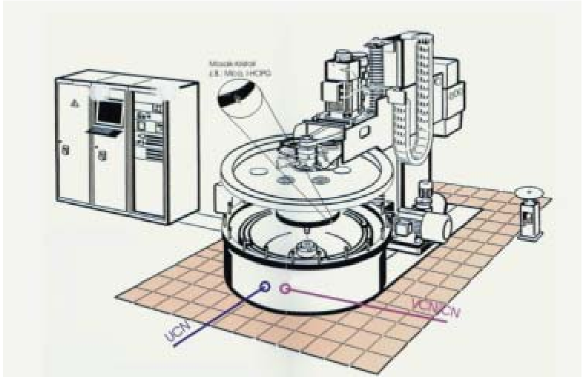
which can for an extended crystal be fulfilled for a linearly moving crystal only. The related neutron velocity becomes twice v_c.

The up-scattering process can be accomplished by inverse Bragg diffraction from a fast moving single crystal in backscattering position as shown in the next figure, where the maximum achievable gain factor is shown as well.





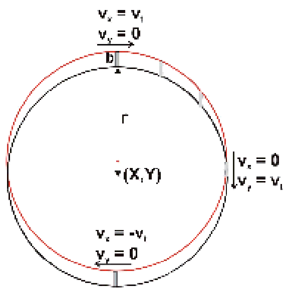
Related test measurements have been made with a rotating system and in order to keep the mechanical stress from the rotational motion within reasonable limits one had to use intercalated graphite compounds with potassium and with a rather large lattice constant of $d_{h,k,l}$ = 8.74Å and a mosaic spread of about 5.5 degrees (i-HOPG). Thus pulsed beams with a mean wavelength 8.74 Å have been produced. The repetition rate can be varied by the number of crystals mounted at the device. he whole machinery is shown in the next figure. The measurements delivered very promising results [1] which justify the development of this technique further.

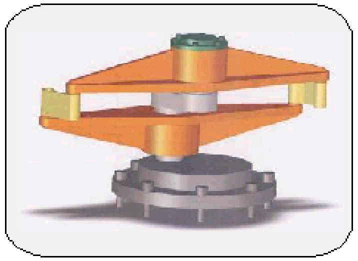


The following values and parameters have been achieved [2]:

$$v_0 = 552 \text{ m/s} \ (\lambda = 8.74 \text{ Å})$$
$$\Delta v/v_0 = 0.34\%$$
$$\Delta t = 0.28 \text{ ms}$$
$$\Delta\alpha_H = 14°; \quad \Delta\alpha_V = 1.2°$$
Rep. Rate: 440 Hz (or 220 Hz)
Peak Intensity: 1200 $cm^{-2}s^{-1}$
Average Flux: 350 $cm^{-2} s^{-1}$

To develop this technique further a linear motion of the crystals has to be realized which can be achieved with a double arm rotator unit tested for other purposes by industry. The nest figure shows the principle of such an advanced system foreseen for the ILL upgrade.





Analytic and Monte-Carlo calculations show that mean intensities up to 3.5×10^6 $cm^{-2}s^{-1}$ of a highly monochromatic pulsed beam with a brilliance of $4.5.10^{11}$ $cm^{-2}s^{-1}str^{-1}Å^{-1}$ can be generated by phase space transformation of a dense UCN gas with new UCN sources and linear moving PST-crystals. Consequently, up-scattering of UCN may become an attractive method to produce highly monochromatic pulsed neutron beams. Installation of such systems can upgrade existing neutron sources and can open new horizons for advanced neutron research.

References

[1] S. Mayer et al., Nucl.Instr.Meth. A608 (2009) 434
[2] Nucl.Instr.Meth. A608 (2009) 434 and Neutron News 21 (2010) No.2, 26