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4.3 Summary of Spallation UCN Source Session

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Spallation UCN source is discussed in a target and instrument session. Here is the content of the spallation UCN source session.

Spallation UCN source for KEK-JAERI joint project	Yasuhiro Masuda (KEK)
UCN at PSI	Guenter Bauer (PSI)
UCN at Munich	Erwin Gutsmiedl (Munich)
Solid state UCN detector	Toshio Kitagaki (Tohoku)
Neutronics calculation of cold neutron in a He-II chamber	Yoshiaki Kiyanagi (Hokkaido)
Optimization for a vertical He-II UCN source	Kenji Mishima (Osaka)

The first three talks concern with new UCN sources for fundamental physics experiments, for example, neutron electric-dipole-moment (EDM) measurements, neutron β-decay experiments, quantum mechanical tests and surface-physics experiments. All the three UCN sources use the superthermal-UCN-production which was proposed by Golub. The superthermal method uses phonon excitation for neutron cooling. The neutron cooling is schematically shown in Fig. 1. The point of neutron cooling is in an energy-momentum relation between neutron and interacting particle. If the interacting particle has the same energy-momentum dispersion curve as the neutron, the neutron energy and momentum is effectively transferred to the interacting particle. The transfer efficiency is well explained by a parameter called lethargy ξ, which is

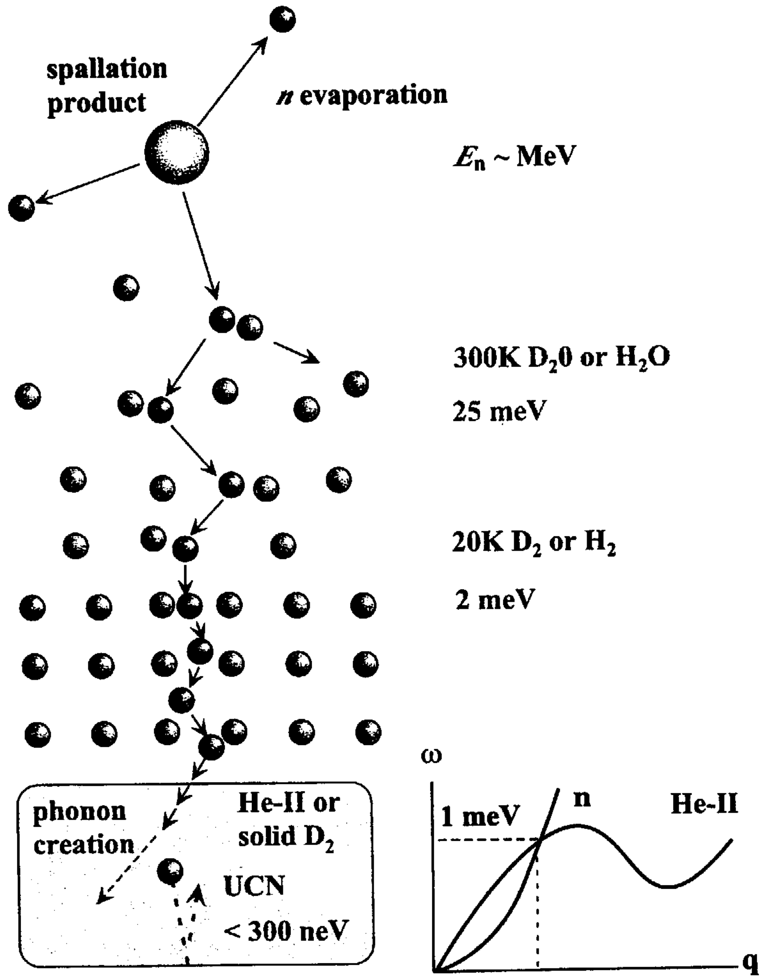

Fig. 1 Neutron cooling by phonon

approximated by

$$\xi = 2/(M/m + 2/3). \tag{1}$$

M and m are the interacting particle and neutron mass, respectively. The lethargy is a logarithm of an average neutron-energy loss-rate for one collision. Free protons or deuterons in 300-K and 20-K moderators are used for neutron moderation from MeV to meV region. Below 20 K, almost all materials freeze and therefore, neutrons in the meV region can not excite free particle motion. It means the mass M becomes too large to slow down neutrons. Below the cold neutron region, phonon excitation is used for the neutron cooling. The phonon dispersion curves of He-II and solid deuterium intersect at the cold neutron region with the neutron dispersion curve. As a result, cold neutrons can be further slowed down to a UCN region through the intersection points. Large phonon phase-space is used at the neutron cooling. As a result UCN density is greatly improved. Previous UCN sources used neutron deceleration by the gravity or Doppler effect. In these methods, the UCN density was limited by the Liouville's theorem. The UCN density does not increase upon the deceleration, since the phase-space volume is invariant for the conserved system.

The UCN source presented by Masuda uses the phonon in He-II, while the UCN sources presented by Bauer and Gutsmiedl use the phonon in solid deterium. The produced UCN density is represented by the same equation as

$$\rho_{\mathrm{UCN}} = \tau \int dE\ \sigma(E \rightarrow E_{\mathrm{UCN}})\ N\ \Phi(E).$$

for the both methods. τ is a neutron storage time, N nuclear number density and $\Phi(E)$ neutron flux at E. σ is the UCN-production cross section which is obtained by the form factor, $S(q, \omega)$ of a quantum system as

$$d^2\ \sigma / d\Omega\ d\omega = b_c^2\ k_f/k_i\ S(q, \omega)$$
$$q = k_i - k_f$$
$$E = E_i - E_f$$

b_c is the bound coherent scattering length. The neutron storage time is obtained by the reciprocal of the sum of nuclear absorption, up-scattering and β-decay rates. The up-scattering is a reverse process, where a UCN goes back to a usual neutron. The temperature of UCN source material is kept low to reduce the up-scattering rate by phonon to the same order as the UCN loss rates. In Table 1, a comparison between He-II and solid deuterium as UCN source material is shown.

Table 1 Parameters of UCN source material

	solid D2	He-II
$\tau_{\mathrm{abs}} = 1/N\sigma_{\mathrm{abs}}v$	200 ms	∞
operation T	5 K	0.8~1.2 K
b_c	6.67 fm	3.07 fm
$S(q, \omega)$	unknown	known

The PSI-UCN source will use a 24-kW proton-beam for the production of neutrons by the spallation reaction. The neutrons are moderated in ambient-temperature heavy water and then converted to UCNs in 5-K solid deuterium. The expected UCN density is several 1000 UCNs/cm^3. The Munich UCN source will be placed in a 20 MW reactor. The UCN source material is also 5-K solid deuterium. The expected UCN density is similar as the PSI-UCN source. The joint-project UCN source will use a 12-kW proton-beam for the production of spallation neutrons. The neutrons are moderated in ambient-temperature heavy water and 20-K heavy water and then converted to UCNs in 1-K He-II. Mishima discussed cold neutron flux in a vertical He-II bottle. In his Mote Carlo simulation, 20-K heavy water was treated as the 20-K ideal gas which comprises deuteron and oxygen with nuclear number density ratio of 2 : 1. The expected UCN density is 10^5 UCNs/cm^3 for the 12-kW proton-beam. If the neutron temperature is 80 K, we should take a reduction factor of 1/8 into account. Kiyanagi discussed cold neutron flux in a horizontal He-II bottle. He used 20 K deuterium as a cold moderator material in his Monte Carlo simulation. The expected UCN density in the He-II bottle is 4×10^5 UCNs/cm^3 the 12-kW proton-beam.

The large difference in the UCN density between He-II and solid deuterium UCN source is due to a difference in the neutron absorption rate, $1/\tau_{abs}$. The phonon up-scattering rate at the operation temperature become comparable to other dominant UCN loss rates. The dominant UCN loss process is nuclear absorption and a spin incoherent scattering for the solid deuterium UCN source, while the neutron β decay rate for the He-II UCN source. The last loss rate is much smaller than the former two loss rates.
In Fig. 2, the history of UCN production is shown. The new UCN sources will make a breakthrough for UCN production.

The operation of the superthermal source should be carried out very low temperature to reduce the up-scattering rate, that contradicts the requirement to realize a high intensity UCN source. We need high cold neutron flux near the neutron source center where γ heating is large. In this point of view, the spallation neutron source has great advantage, since it has a lower γ to neutron ratio than the reactor.

The spallation neutron source has another advantage for the UCN production. A pulsed operation is rather easy, which will greatly improve background problems. Almost all kinds of radiation promptly emitted from the source upon the proton beam irradiation quickly disappear after switching off the proton beam.

Kitagaki discussed a UCN detector for the superthermal UCN sources. A thin film of LiF or LiOH is used for the conversion of neutrons to charged particles. The charged particles are detected by a Si-PIN diode. He showed UCNs whose energy were

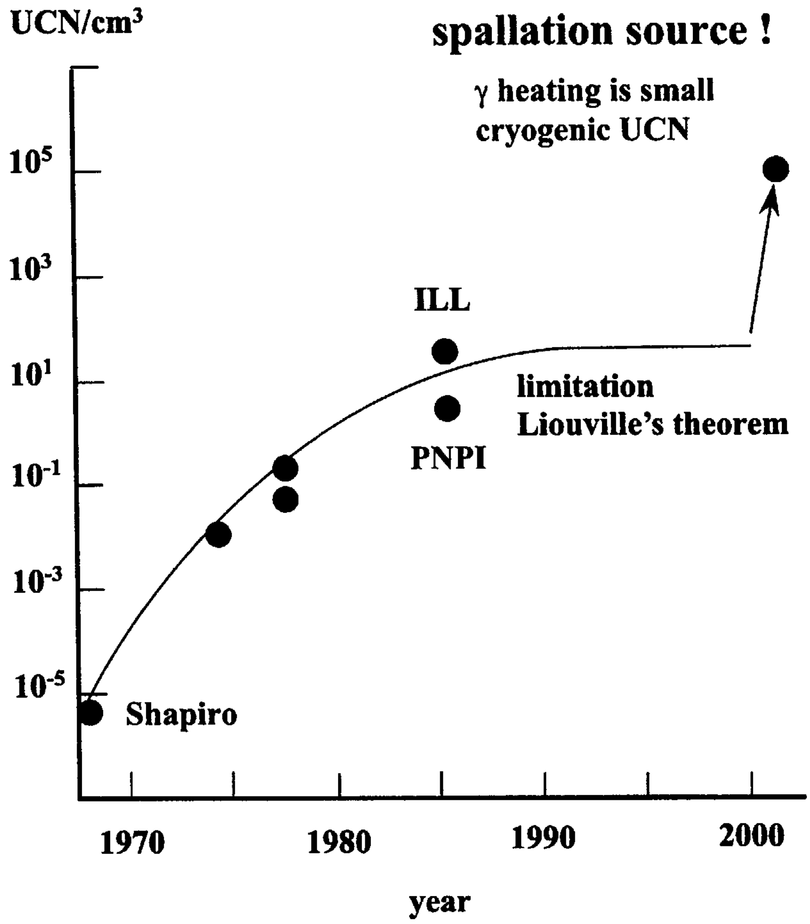

Fig. 2 History of UCN production

below the critical energy of the film material were detected by the UCN counter. It may due to the surface structure of the lithium compounds. The UCN detector works at very low temperature.