Neutron moderators

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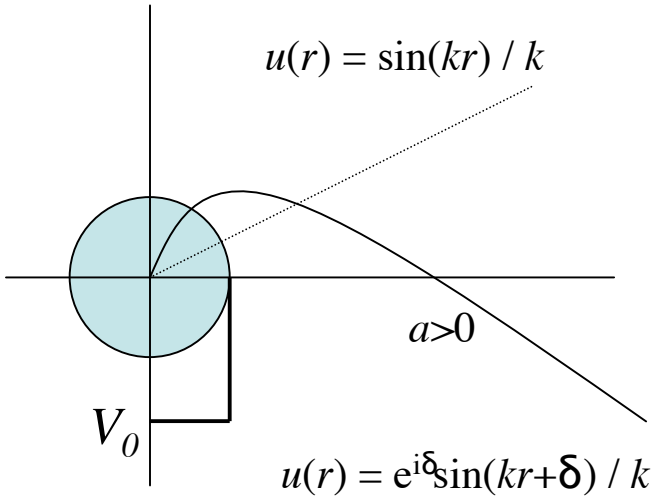
Caging Neutron



wavefunction of a particle scattered by potential

$$\psi \xrightarrow[kr<<1]{} 1 + f/r$$

$$f = -\frac{1}{4\pi}\frac{2m}{\hbar^2}\int e^{i(k-k')x}V(\mathbf{x})d^3x$$

radial wavefunction of reflected n

$$R(r) \xrightarrow[kr<<1]{} e^{i\delta}\cos\delta\cdot(1+tan\delta/kr)$$

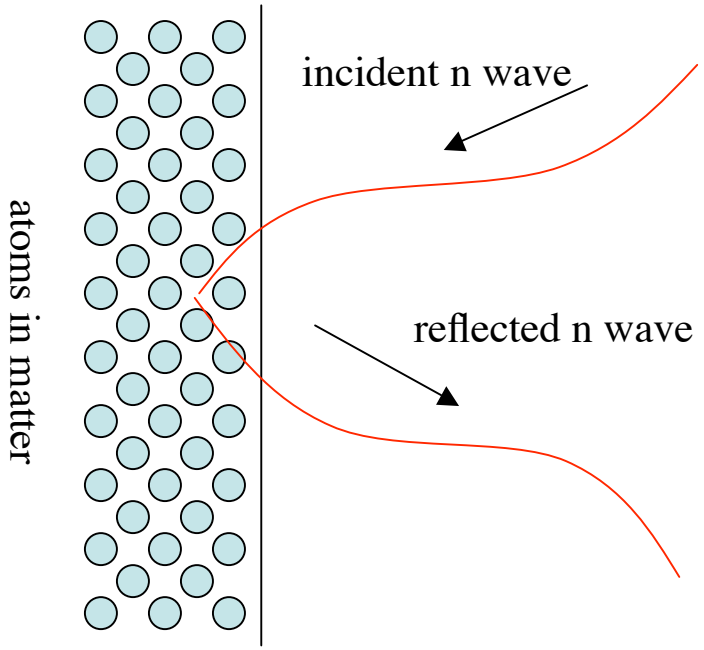
$$tan\delta \approx -ka \quad (a: \text{scattering length})$$

$$\Rightarrow \quad f = -a$$

Fermi Potential : A potential that satisfies $f = -a$

$$V(\mathbf{r}) = (2\pi\hbar^2/m)a\delta(\mathbf{r}-\mathbf{r_i})$$

$\mathbf{r_i}$: position of nucleus



Fermi potential of matter :

$$V_F = (2\pi\hbar^2/m)aN$$

a : scattering length

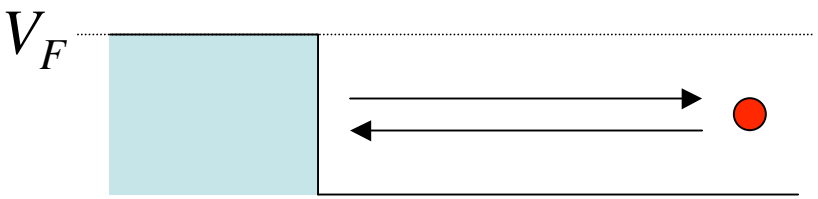
N : density of nucleus

Example : Ni (a=14.4 fm, N=8.93*10^{-17} fm^{-3})

V_F(Ni) = 335 neV

Al (a=3.45 fm, N=6.02*10^{-17} fm^{-3})

V_F(Al) = 54 neV

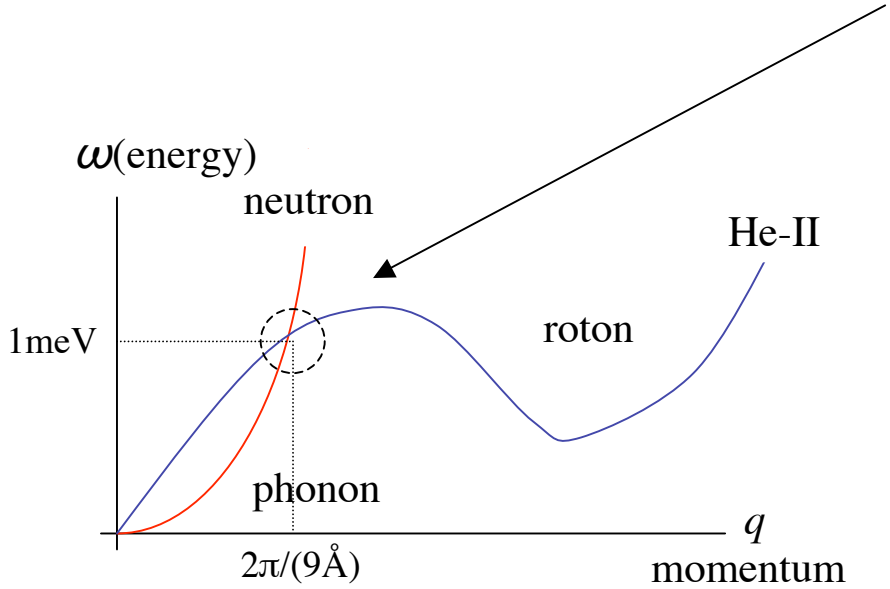


Positive V_F produces repulsive force.

If energy of neutron is small, the neutron is all reflected at the surface of matter.

A neutron to be all reflected is called “UCN” ; Ultra Cold Neutron.

Super thermal method



Energy-momentum dispersion relation

@this point

phonon's dynamical behaviour is same as neutron.

Energy of neutron is efficiently shifted to phonons at this point.

UCN density
= (cross section) * (neutron flux) * (life)

Cross section :

$$\sigma = 4\pi a^2 (k_f / k_n)\{v_n / (v_n - v_g)\}S(q)$$

k_f : final state neutron wave number

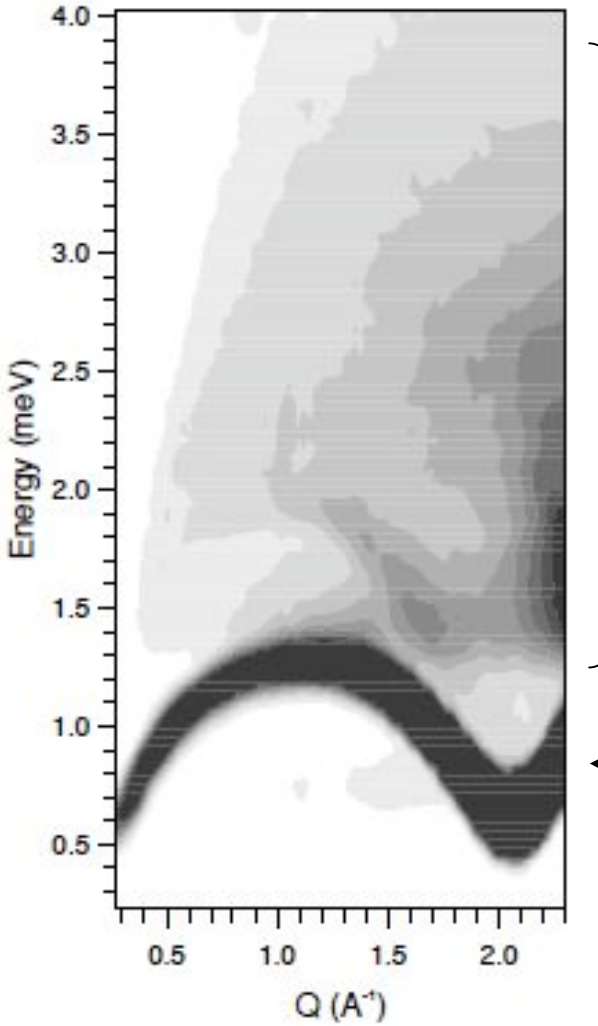
k_n : neutron wave number at the intersection

v_n : neutron velocity at the intersection

v_g : phonon group velocity at the intersection

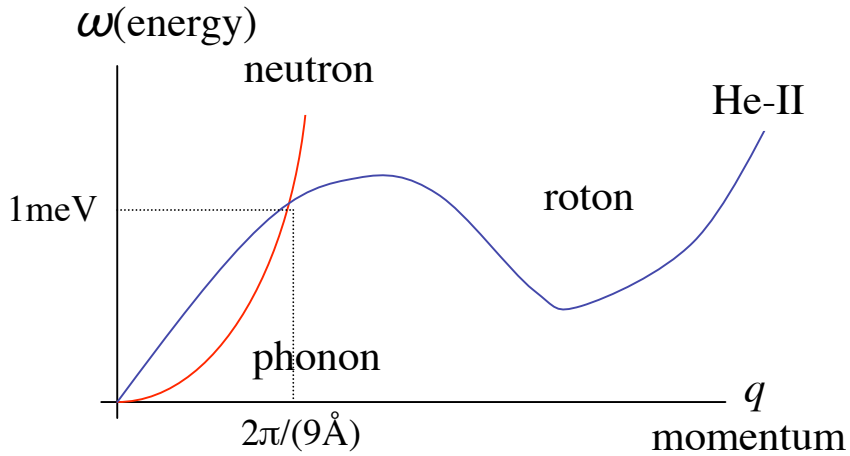
S : structure factor

contour graph of $S(q, \omega)$



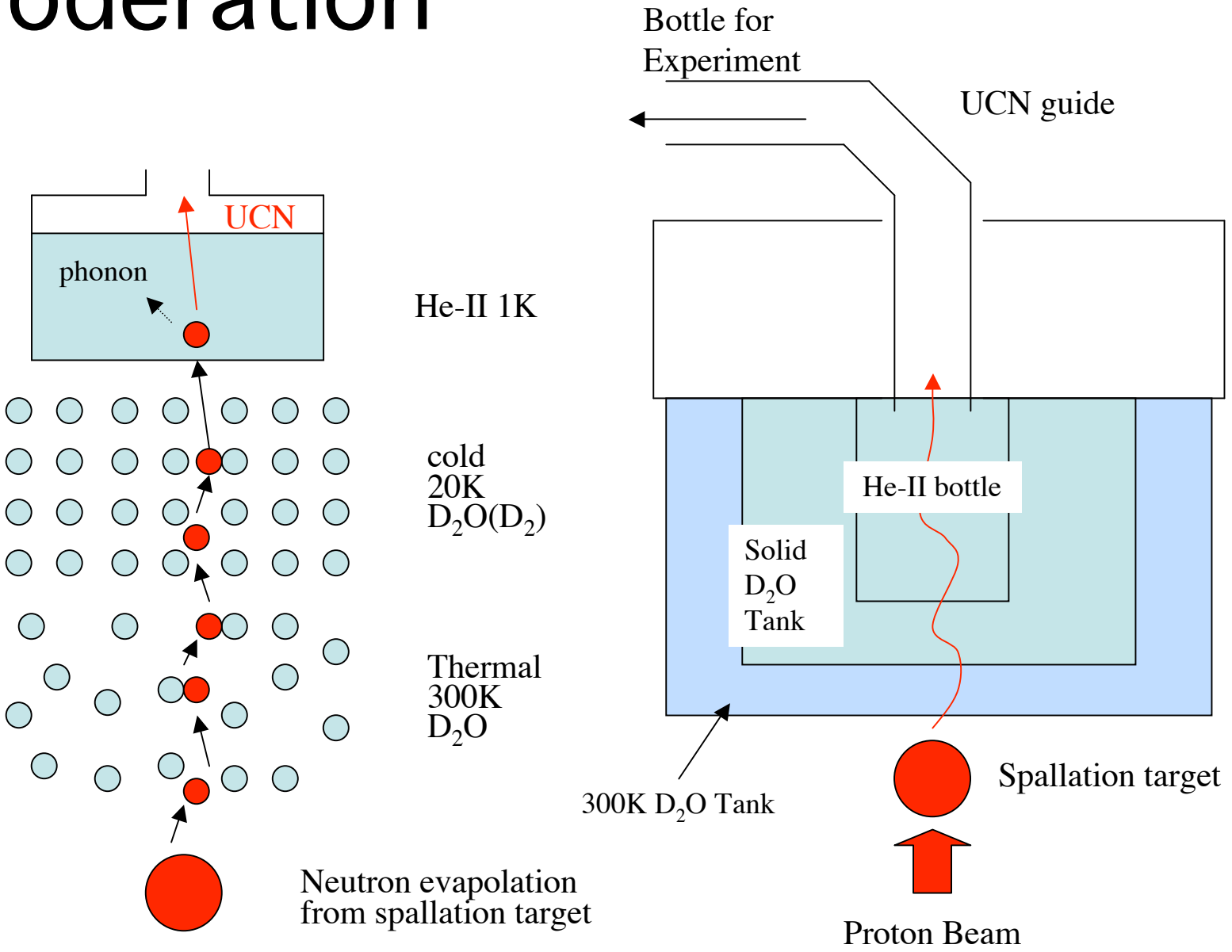
multi phonon excitation

single phonon excitation



It's confirmed that a neutron with 1meV energy is efficiently moderated in He-II.

Moderation


Bottle for
Experiment
UCN guide
UCN
phonon
He-II 1K
cold
20K
$D_2O(D_2)$
Thermal
300K
D_2O
He-II bottle
Solid
D_2O
Tank
300K D_2O Tank
Spallation target
Neutron evapolation
from spallation target
Proton Beam

Features of Moderator candidates

(1)Solid deuterium (D)

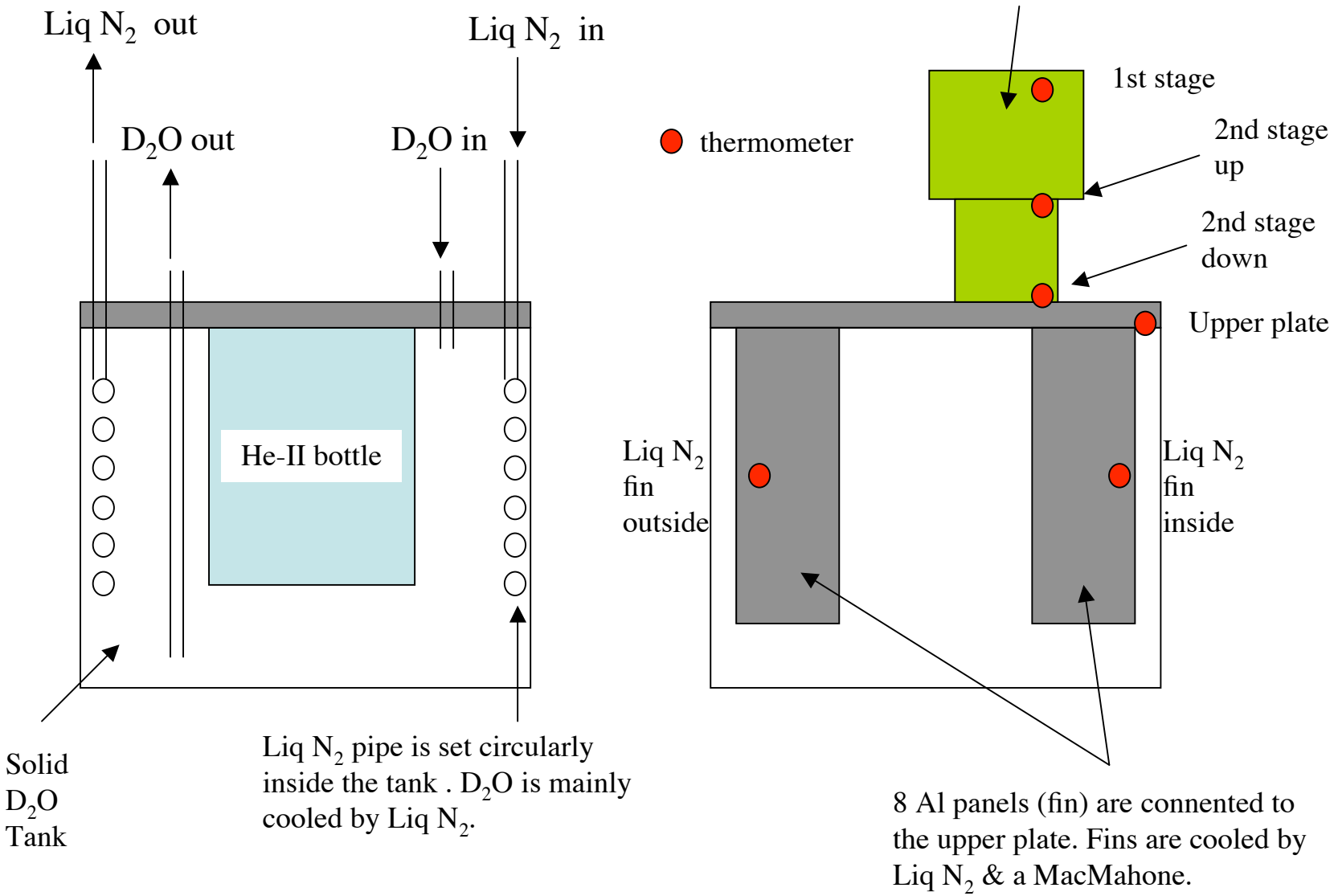
(1)UCN formation cross-section is large.
(2) Operative temperature is relatively high (5K).

(2) He-II

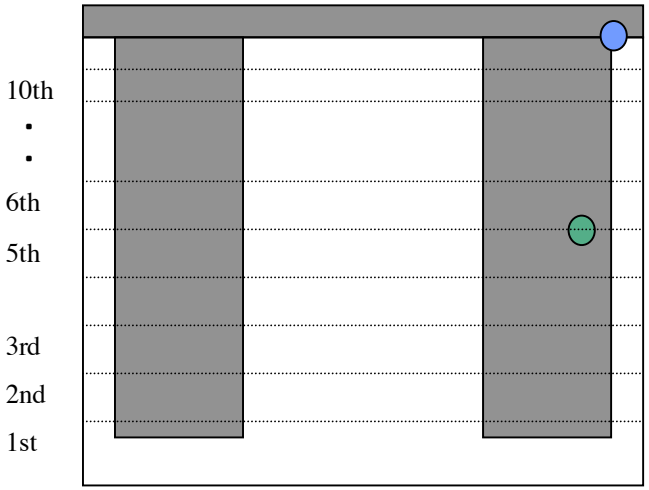
(1) UCN storage life time is long.
(2) Mean free path of UCN is long.
(3) Fermi Potential of He-II is small that it's negligible.

We adopted He-II as a moderator.

D_2O Solidification



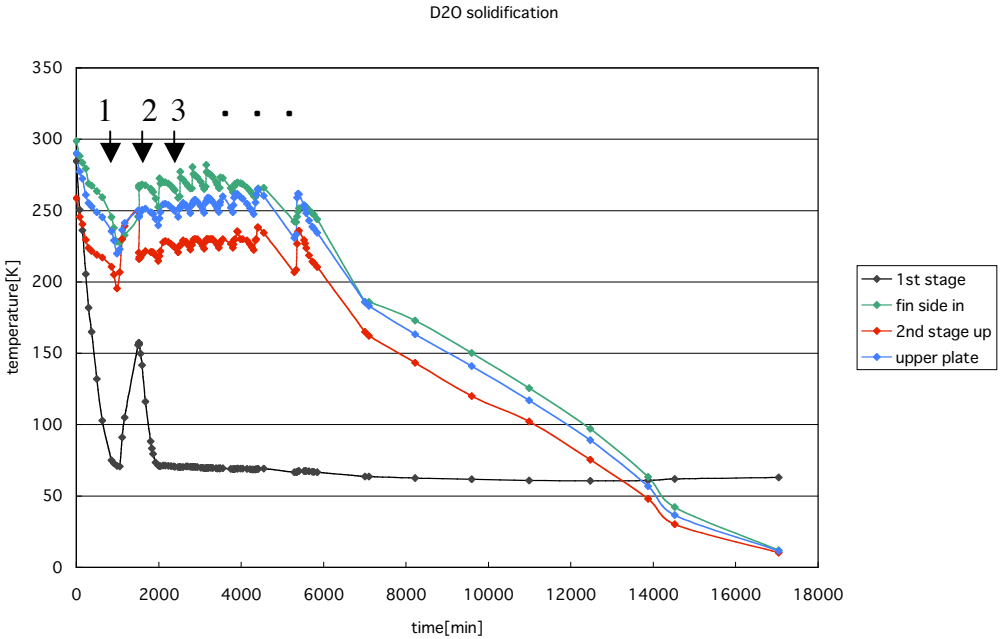
D_2O Tank



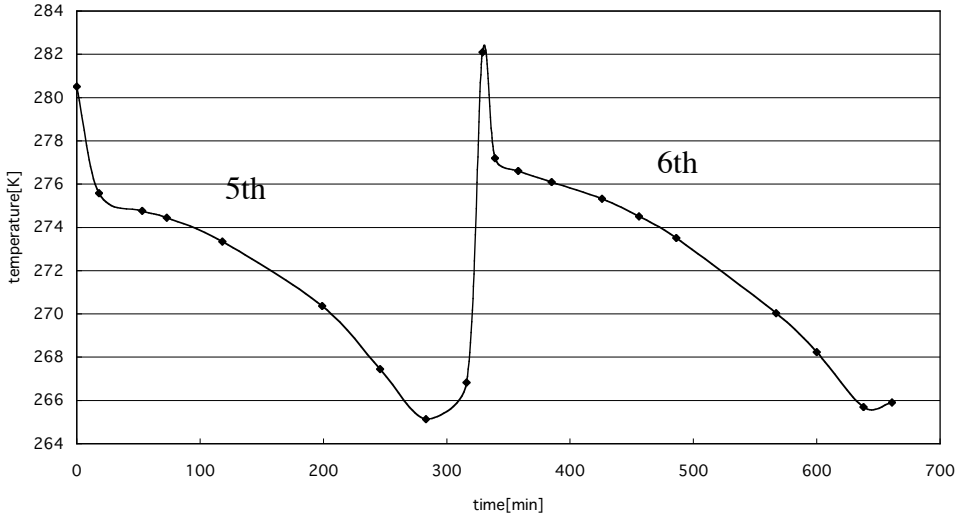
D_2O solidification is carried out in 10 steps. We injected 10 liters of D_2O per injection and repeated injection and solidification 10 times.

The total amount of D_2O is about 110 l.

The time needed for D_2O to be solidificated is about 80 hours, and to be cooled to 10K, it's about 180 hours.



Temperature change of each thermometer
D2O solidification(temperature : fin side in)



Temperature change of 5th & 6th solidification

Summary

- Utilizing Fermi potential of matter, neutron with low energy can be caged.
- Neutron is efficiently moderated by single phonon excitation of He-II. This efficient moderation arises on the intersection of dispersion curves.
- He-II has many merits as a moderator. He-II seems to be more suitable for moderating neutron than heavy Hydrogen.
- D_2O solidification needs about 80 hours, and cooling to 10K needs about 180 hours.