Preliminary evaluation on the performance of CD_4 and ortho-D_2 as VCN moderator materials

M. Utsuro[1], T. Shima[1], H. Shimizu[2], K. Mishima[2], and T. Momose[3]
[1] *Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan*
[2] *Institute for Chemical and Physical Research (RIKEN), Wako, Saitama 351-0106, Japan*
[3] *Graduate Course of Science, Kyoto University, Kitashirakawa Oiwakecho, Sakyo-ku, Kyoto, 606-8502 Japan*

Very cold neutrons (VCN) with the kinetic energy lower than the cold neutrons (CN) but higher than the ultracold neutrons (UCN) have the characteristic properties much attractive for utilizing to various kinds of fundamental physics experiments as to study on precision measurements of neutron-nuclear interactions or to explore new type of neutron optical experiments on gravity interactions. However, theoretical as well as experimental studies on the VCN source are very few.

Solid ortho-deutrium (SO-D_2) has much superior performance and there are several projects of SO-D_2 UCN source under developments in the world. On the other hand, from the viewpoint of the molecular energy structures, deuterated methane (CD_4) has much lower rotational energy levels in the molecules than those in the deuterium molecules and also than the Debye temperature of SO-D_2.

From these viewpoints, we have carried out some theoretical analysis to evaluate the possible performance on SO-D_2, CD_4 and SO-D_2+CD_4 mixtures.

1. Effective neutron temperature in infinite solid ortho-D_2 moderator.

The effective mechanism for VCN and UCN productions in SO-D_2 is the lattice vibrations, and the effective neutron temperature is given by the next formula [1]

$$\left(\frac{T_n}{T_{n0}}\right)^{7/2} - \left(\frac{T_m}{T_{n0}}\right)^{7/2} = 1, \tag{1}$$

where T_m is the moderator temperature, T_n the effective neutron temperature in an inifinite size of the moderator, and T_{n0} being the limiting neutron temperature at $T_m = 0$ given by

$$k_B T_{n0} = \left[\frac{M}{13\gamma m} \cdot \frac{\sqrt{E_0}\sigma_a(E_0)}{\sigma_s}\right]^{2/7} \cdot (k_B \Theta_D)^{6/7}, \tag{2}$$

where M is the D_2 molecular mass, m the neutron mass, $\gamma = 4.23$, $\sigma_a(E_0)$ the D_2 absorption cross section of a neutron at the energy E_0, σ_s the neutron scattering cross section of a D_2 molecule, and Θ_D the Debye temperature of solid D_2. Application of these equations give the result of $T_{n0} = 10.5K$.

2. Effective neutron temperature in infinite solid free-rotator of CD_4

We assume here the effetive mechanism for the VCN moderation in solid CD_4 is the free rotation of a CD_4 molecule [2], then by making use of the effective rotational mass $M_r/m = 8$, we obtain;

$$\frac{T_n}{T_m} \cong 1.02, \qquad \text{for} \;\; T_m \cong 10 \sim 20K. \tag{3}$$

This result means that at the lowest temperature limit, the energy spectrum of moderated neutrons shows a sharp peak at the energy of the lowest rotational excitation energy, *i.e.* at $E = 0.55$ meV, or $T_{n0} \cong 6K$.

3. Finite moderator size

For the VCN moderator with a finite size, covering around the moderator with an effective VCN reflector is necessary. One of the most attractive material for such VCN reflector will be graphite [3] or further improved carbon material, as shown in Fig. 1. We can expect the effective VCN reflectivity higher than 95% for such a kind of material.

4. Solid-CD_4+ortho-D_2 mixture

We performed a preliminary neutron scattering experiment at JRR-3, JAERI Tokai, to study on the rotational freedom of CD_4 molecules in solid CD_4 at the low temperature below 20K, and we found such rotational motions are strongly hindered by the effect of intermolecular interactions. Therefore, we are proceeding to the thought of developing a new material of CD_4 and O-D_2 mixture, for example CD_4 trapped in SO-D_2, in which CD_4 molecules could rotate nearly freely [4].

5. Numerical calculation

We have carried out a preliminary numerical study on the VCN energy spectrum to be obtained in these moderator combinations. Typical results of these numerical studies are shown in Fig. 2. The Figure indicates the possible advantage of free rotator CD_4 trapped in SO-D_2. Therefore, we are going to carry out an experimental test on such kind of combination as trapped CD_4 in solid D_2.

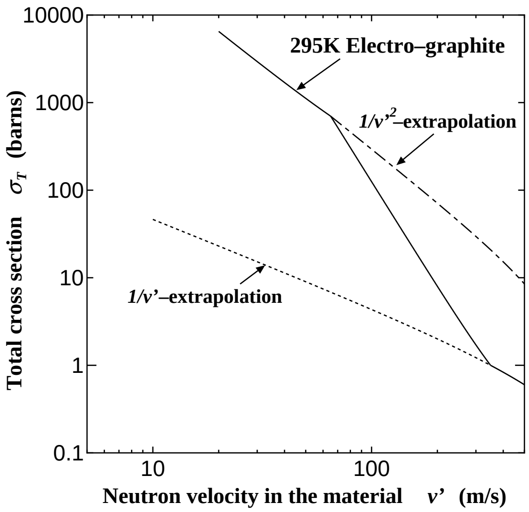

Figure 1: Measured total cross section σ_T in VCN region for electro-graphite [3] (solid line) *versus* neutron velocity v' within the material.

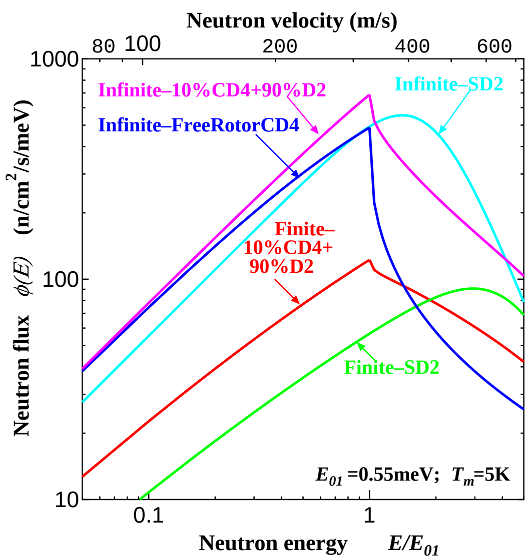

Figure 2: Calculated results of VCN spectra for typical cases of CD_4 and ortho-D_2 moderators. (Neutron flux is normalized to the source intensity corresponding to the specific loss rate of 1 n/cm^3/s.)

References

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