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Experiment on Transportation of Very Cold Neutron Flux by a Multipole Magentic Field

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Experiment on transportation of very cold neutron(VCN) and ultracold neutron(UCN) flux by a magnetic multipole field is described. The magnetic field is produced by two pairs of permanent magnets. The UCN and VCN flux intensity after passing through the multipole field has been compared with that passing through a relatively weak multipole field. The counting rate of the former case is 10.27±4.72% higher than that of the latter. The magnetic multipole field suppresses UCN and VCN flux divergence.

KEYWORDS: ultracold neutron, very cold neutron, magnetic transportation

§.1 Introduction

The interaction of the neutron magnetic moment with an externally applied magnetic field has been used for neutron confinement experiments.[1-3]. Neutrons are confined in a magnetic bottle by the force $\nabla\mu\cdot B$, where μ is the magnetic dipole moment of neutron with the absolute value of 6.01×10^{-8} eVT^{-1} and B is the magnetic field. We have been studying a scheme of magnetic bottle for ultracold neutrons which is produced by the combination of the quadrupole field and the mirror field.[4]. Both of these fields generate the inward gradient force directing into the magnetic bottle for neutrons with the magnetic moment antiparallel to the external field.

As a preliminary experiment of neutron confinement with such a magnetic system, we have passed a flux consisted of very cold neutron(VCN) and ultracold neutron(UCN) through the multipole magnetic field for suppressing the flux divergence. To avoid the divergence, a VCN and UCN flux is usually transmitted through a metal tube the inner walls of which reflect neutrons. On the metal walls, however, there exist impurities that absorb neutrons and cause loss of the flux. The magnetic transmission can avoid such a flux loss mechanism since the neutrons do not touch the material wall.

§.2 Experimental Set-up

A flux consisted of VCN and UCN has been produced by retarding a thermal neutron flux from the Kyoto University Research Reactor with a supermirror turbine reflector.[5] The presice energy spectrum of VCN at the outlet of the supermirror turbine is measured. However, the neutron energy spectrum at outlet of used port of the supermirror turbine is not known. In this study, we use a device remodeling TOF system as shown Fig.1. Fig.2 shows the cross section of the magnetic neutron guide tube.

The vacuum tube with a rectangular cross section is made of titanium which absorbs neutrons. The upper and lower parts of inner walls are covered by neutron mirror plates which are glass plates with a thin copper layer. The mirror plates are used to increase the counting rate of neutrons incident on the detector. Around the vacuum

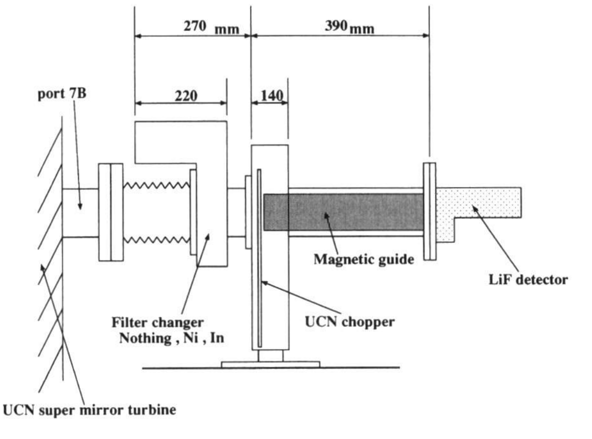

Fig. 1. Neutron magnetic transportation system.

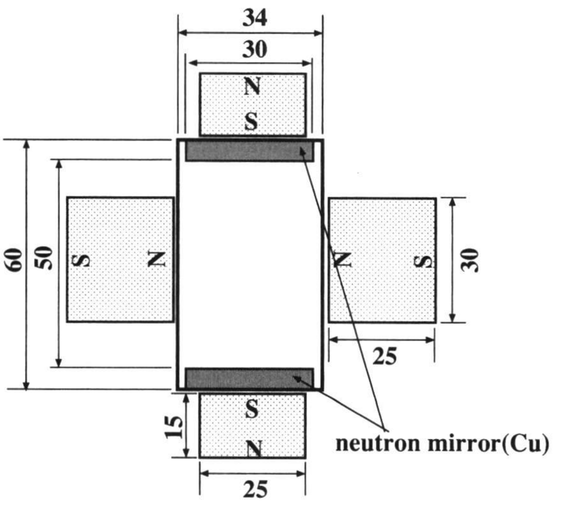

Fig. 2. The cross section of the magnetic neutron guide tube. Length of the tube is 30cm.

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tube, two pairs of magnet blocks are arranged as shown in Fig.2. Each magnet block consists of several pairs of permanent magnet pieces.

2.1 Configurations of the magnetic field

The experiment has been carried out in two configurations of the arrangement of magnet pieces: one is the high field configuration which is produced by arranging magnet pieces in such a way that they intensify the magnetic field of each other, the other one is the low field configuration that is produced opposite way. In both configurations, since the magnet blocks are arranged similarly, effect of the magnetic blocks on the experimental scheme is the same except the strength of magnetic field. Fig.3 shows the magnetic isobars in the cross section of the guide tube for (a) the high field and (b) the low field configurations.[6] The maximum field of the high field case is 0.15T and that of the low field case is 0.05T: there is significant difference in the magnetic field strength between the configurations.

2.2 Detecting system

The neutrons transmitted through the guide tube are detected by a combination of semiconductor detector and thin film of ^{6}LiF.[7] Fig.4 shows the fine geometry of the detector. Incident neutrons produce a couple of charged particles through the nuclear reaction:

$$^{6}\mathrm{Li} + \mathrm{n} = \mathrm{t}\ (2.7\mathrm{MeV}) + \alpha\ (2.0\mathrm{MeV}). \quad (2.1)$$

One of charged particles will be detected by the diode. Range of alpha particle and triton in Si are 7 μm and 40 μm, respectively. In order to estimate the back ground counting rate, an indium film with the thickness of 0.2 mm is inserted in front of the guide tube.

§.3 Experimental Results

3.1 Transportation by the neutron mirror guide

The energy spectrum of neutron, especially UCN, at outlet of the port of the supermirror turbine is not known. In order to measure UCN flux included in the neutron flux at the used output port of the supermirror turbine, we have changed the experimental set-up as follows: removed the magnet block guide from the magnetic guide, and covered all of the inner wall of the magnetic guide with the neutron mirror plates. From the difference of transportation by the guide (neutron mirror guide) between the case with the thin Ni film installed on the used port and the case without film, we estimate the quantity of UCN flux. Fig.5 shows the pulse-height spectra of neutron detector. The total counts and the counting rate which are the sum of Fig.5, are summarized in Table I. Unexpectedly, there is no difference between the two configurations. This result suggests that the detector can't detect UCN, or the neutron flux doesn't include amount of significant UCNs. Later, it became clear by experiments[7] that the neutron flux doesn't include amount of significant UCNs. So, a more accurate measurement for a longer measuring time and under an

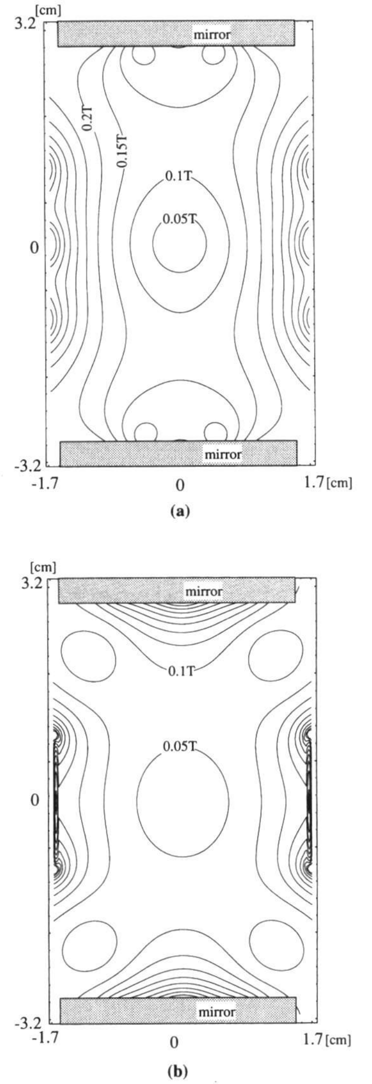

Fig. 3. The magnetic isobar in the cross section of the guide tube.

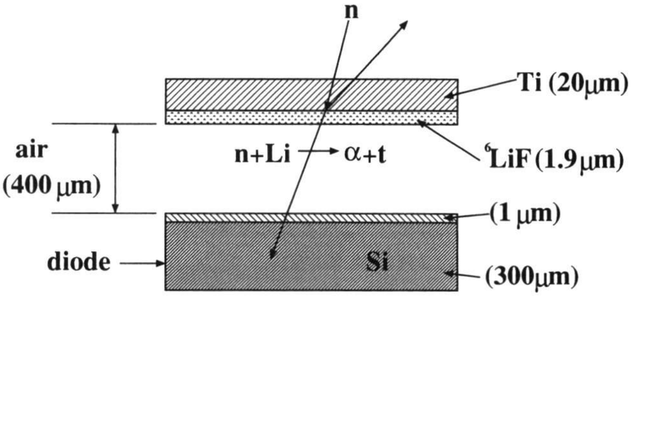

Fig. 4. Fine geometry of the detector.

Table. I. Experimental results of transportation by the mirror guide. (neutron filter effect)

Configuration	Measurement Time [s]	Total Counts	Count Rate [counts/s]
no Ni filter	7000	1155	0.165±0.049
Ni filter	7000	1155	0.165± 0.049

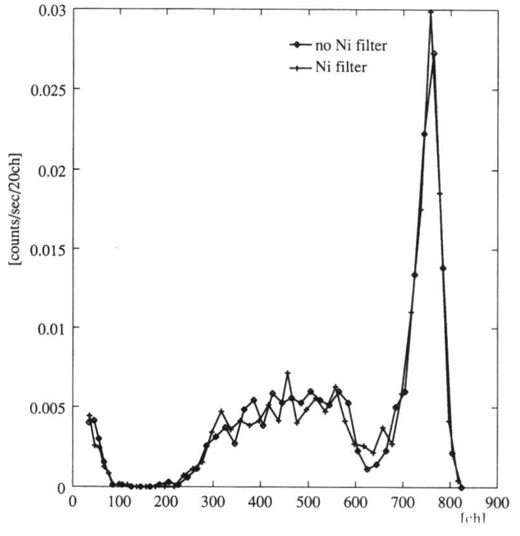

Fig. 5. The pulse-height spectra of neutron detector.

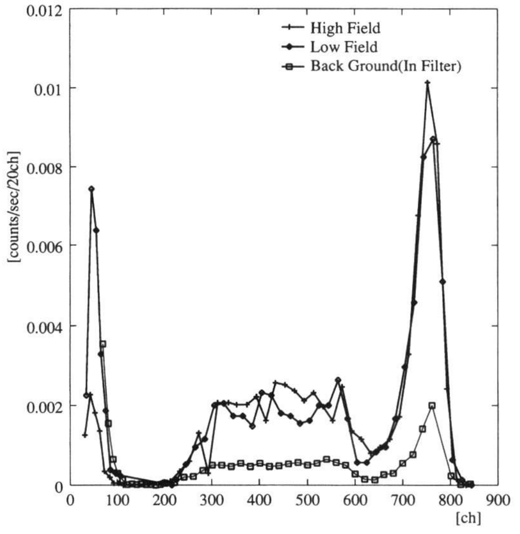

Fig. 6. The energy spectrum of detected neutrons for the high field configuration, the low field configuration, and the back ground counting.

improved condition in electrical backgrounds to the detector system was necessary for distinguishing the UCN contribution.

3.2 Transportation by the magnetic guide

Fig.6 shows the pulse-height spectra of neutron detector for three cases, which are, the high field configuration, the low field configuration, and background counting. The measurement of background counting is performed under the low field configuration. The middle peak and the right-hand side peak are due to α-particles and tritons, respectively.

Experimental results for three cases are summarized in Table II. Based on Table II, we can observe contrast of the case of high field configuration with that of low field one. We compare each value of their total counts subtracted by the background counting. The former is 16.65±9.10% larger than the latter.

§.4 Discussion and Conclusion

Table III shows the ratio between total counts of α-particles and of tritons. The total counts of α-particle and triton are the sum of counts in 150-630 ch and counts in 630-850 ch, respectively, in Figs.5 and 6. Although the ratio of the α-particle counting rate to the triton counting rate should be about unity, the ratio is too large in the case of the insertion of the indium filter. This might happen because the pulse-height spectrum from neutron counter is smeared by the γ-rays emitted from the indium filter due to the thermal neutron bombardment. Considering the unreliability of background counts, we have compared the total counts of high field case directly with those of low field case. The difference in counting rate between the high and low magnetic field configurations is $(0.0661 \pm 0.0018) - (0.0600 \pm 0.0020) = 0.0061(1 \pm 0.436)$[c/s]. While there is a some statistical scattering, it appears that the magnetic multipole field configurations have an effect for the transport of very cold neutrons.

Table III. Ratio of counting rate between alpha particle and triton.

Configuration	α/t
no Ni filter	0.86± 0.49
Ni filter	0.87± 0.50
High Field	1.024± 0.055
Low Field	0.962± 0.060
Background	1.695± 0.086

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Table. II Experimental results of transportation by the mirror guide. (magnetic field effect)

Configuration	Measurement Time [s]	Total Counts	Count Rate [counts/s]
High Field	19,800	1,310	0.066± 0.0018
Low Field	15,500	930	0.060± 0.0020
Indium filter (background)	107,000	2,461	0.0230± 0.00046