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Experimental studies on cold neutron beam focusing by magnetic field

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Abstract

A wavelength spectrum which clearly indicated the neutron beam focusing around 14 Å by a magnetic field was observed. The intensity of neutrons at the focusing wavelength increases by about 40 times compared with the case without the field. The spatial dependence of the intensity of the focusing neutrons and the wavelength distributions were also measured. The distribution changed drastically width position around the wavelength of focusing region.

I. Introduction

An efficient target-moderator-reflector assembly and spectrometers with good performance are indispensable to improve the total performance of the neutron scattering facility. Furthermore, devices to improve the transmittance of neutrons between the moderator and the spectrometers are very important necessarily for the existing facilities and also for the new spallation sources planed in the world, in which the performances of the spectrometers should be optimized totally by taking into account all performances, namely, performances of; the moderator system, the beam transport lines and the spectrometers.

Keywords: focusing, magnetic field, gain, wavelength dependence, spatial distribution

So far, neutron guide tube has been mainly used.

New device to transport or focus the neutron beams, multi-capillary fibers, has been proposed and used. Neutron beam control by using a magnetic field is a new candidate. Principle of focusing of the neutrons by using magnetic fields is well known[1]. Neutron beam profiles focused by a magnetic field were reported as an accompanying results of ^{3}He focusing, in which intensity gain by focusing and the energy dependence are not presented[2].

We were trying the observe the neutron focusing in order to know the fundamental features of the focusing effects and during almost the same period the neutron focusing by using sextuple magnets was observed independently[3] by using the Hokkaido linac as a neutron generator. We could get an intensity gain of about 30 times around 14Å neutrons when using 2mm diameter entrance and exit collimators.

After then, we have performed the focusing experiments to obtain information such as spatial distributions and spatial dependent wavelength spectra. Here, we report the results of the focusing by using a sextuple magnet neutron lens.

II. Principal of neutron focusing by a magnetic field

A trajectory of neutron can be controlled by using an inhomogeneous magnetic field due to an interaction between the neutron magnetic moment and the magnetic field[1]. A motion in a magnetic field is described by

$$\left(\frac{d^2\mathbf{r}}{dt^2}\right) = \mp\left|\frac{\mu}{m}\right|\nabla|\mathbf{B}|,$$

μ: magnetic moment of neutron
m: mass of neutron
-:corresponding to neutron spin parallel to field
+: corresponding to neutron spin anti-parallel to field

In the case of sextuple magnet the field is defined as $|B|=c(x^2+y^2)/2$. Here, c is constant.

We chose the z axis along the neutron beam line, and the x (horizontal) and y(vertical) axes are perpendicular to the beam line.

The solution for parallel case is for focusing one, and the other for the dispensing one. The solution for the focusing neutrons is as follows[3];

$$(x,y) = (x,y)\big|_{z=0}\cos(zm\lambda\omega/h) + (V_x,V_y)\big|_{z=0}\sin(zm\lambda\omega/h),$$

where $\omega^2=|c\,\mu/m|$, λ is the neutron wavelength, and z is the distance from the entrance of the neutron lens. When $z=(h\,\pi/m\,\lambda\,\omega)$, the neutrons with a wavelength λ are focused.

III. Experimental

Magnets used in this measurement are a permanent magnet, NEOMAX-48[4], which is a sintered anisotropic magnet ($Nd_2Fe_{14}B$). Flux density reported is 1.39T. The size of the magnet is 5mm×5mm×50mm. We composed a sextuple magnet unit by using this magnet as shown in Fig.1. The magnet unit is made of aluminum block with a size of 24mm×24mm×50mm and a neutron beam hole of 10mm diameter is opened along the center of the unit. In this case c is estimated to 3.9×10^4 T/m^2. A 2m tube consisting of 40 magnet units, we call this system as "neutron lens" in this paper, is shown in Fig.2. Cd pipes are placed inside the neutron beam hole to suppress neutron reflections from the surfaces of the magnet units. We put Cd slits at entrance and exit of the lens to collimate the neutron beam. We chose 2mm in diameter from the neutron intensity point of view. However, the intensity gain by focusing and the region of the focusing wavelength are dependent on the size of the holes. The wavelength of neutrons focused by this lens is expected to be around 13 Å.

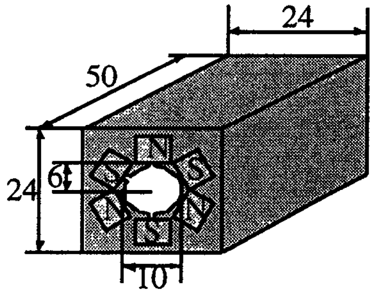

Fig.1 Sextuple magnet unit composed of NEOMAX-48.

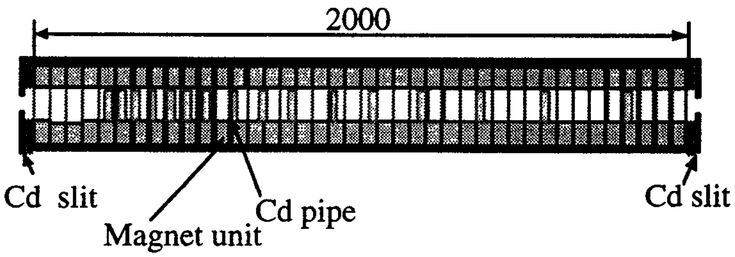

Fig.2 Schematic view of the neutron lens tube consists of 40 magnet units.

Experiments were performed by using a cold neutron source equipped in Hokkaido linac since linac parameters such as pulse width and repetition rate can be adjust according to experimental demands, and a flight path with no disturbance is available; to use dedicate beam line is not so easy in the existing large facilities used for the scattering experiments. These can allow us to measure spectra without distortion and also to estimate easily a gain of neutron intensity. From these reason the Hokkaido linac facility is very convenient for the experiments to study the fundamental processes of neutron devices.

A schematic view of the experimental set-up for the neutron beam focusing is indicated in Fig.3. The flight path length from the center of the moderator to the detector is about 5.1m. A 2m flight tube, which was evacuated, was used to make short the flight path as short as possible within allowance of wavelength resolution, since it allows us to operate the linac at higher repetition rate, namely, higher neutron intensity. The neutron lens tube is placed just after the flight tube. Neutron collimaters with a hole of 2mm diameter are set at entrance and exit of the lens. The orientation of the neutron lens to the neutron beam line was adjusted by using two goniometers.

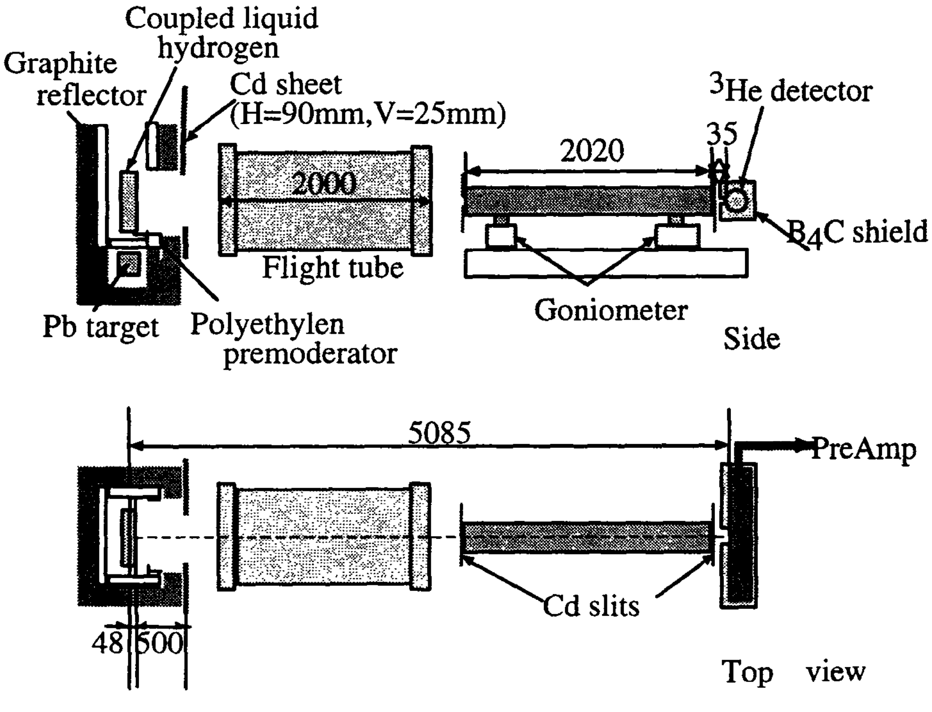

Fig.3 Schematic view of the experimental set-up for the measurements of neutron beam focusing.

The operational conditions of the linac was as follows; electron pulse width = 3 μ s, reparation rate = 40Hz, average current=20 μ A, and electron energy 35MeV.

IV. Results and Discussion

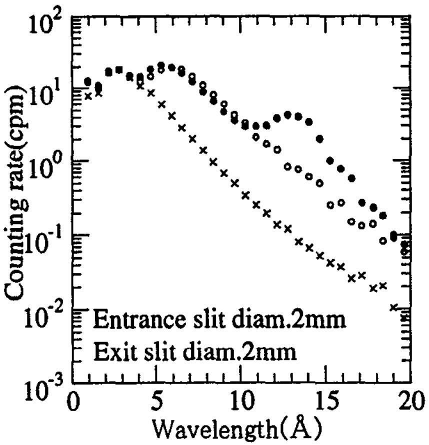

Fig.4.Wavelength spectra through the neutron lens tube without Cd pipes as well as a direct one without magnet units.

× : Without magnet units,
● : Magnet field ON,
○ : Magnet field OFF

First we measured wavelength spectra through the neutron lens without Cd pipes, which are shown in Fig.4. The direct spectrum from the moderator (without magnet units) is also shown. The measurement of "magnetic field off" means the one using the same material as the magnet but not magnetized. We observed a large hump around 14 Å when compared the spectrum in the case of field-on with that in field-off and we considered that it was due to the neutron focusing. However, a hump around 6 Å also appeared in the spectra through the neutron lens compared with the direct spectrum. We thought that this was attributed to the neutron reflections from the surfaces of the magnet units. This effect causes a large error in the estimation of the neutron intensity gain obtained by the focusing. Then, we decided to put Cd pipes with a thickness of 0.5mm in the neutron beam hole to suppress the reflection, which were already indicated in Fig.2.

Figure5 shows the wavelength spectra from both cases, field on and off, where the hump around 6 Å disappeared. The enhancement around 14 Å is huge. We have defined the intensity gain by dividing intensity (field on) by intensity (field off). The gain

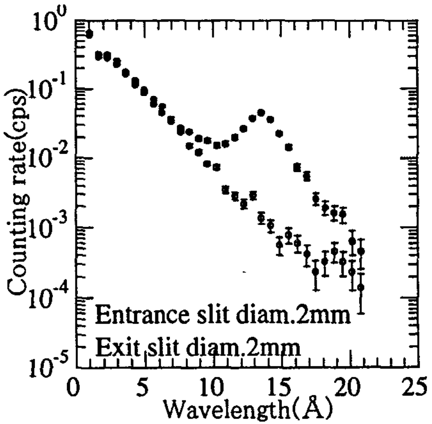

Fig.5 Wavelength spectra through the neutronlens tube with Cd pipes.

● : Magnet field ON,
○ : Magnet field OFF

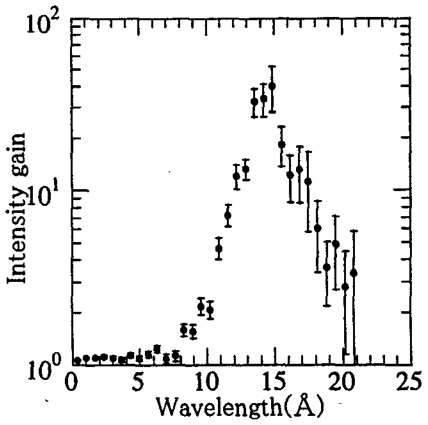

Fig.6 Intensity gain factor as a function of wavelength.

factor is shown in Fig.6 as a function of wavelength. The gain starts to increase around 8 Å, make a peak around 13~15 Å and decrease at longer wavelength. We can get a gain factor of about 40, which is very large.

We also examined the spatial dependence of the intensity of the focused neutrons and the wavelength spectra. We measured the spectra by moving the Cd slit attached to the detector along X and Y axes. Figure7 shows the spatial distributions along (a) X axis (horizontal direction) and (b) Y axis (vertical direction) at the exit of the neutron lens. The origins do not correspond to the exact geometrical centers of both axes, which were only for convenience for experiments. Both distributions have very similar shapes with a full width at half maximum of about 2mm.

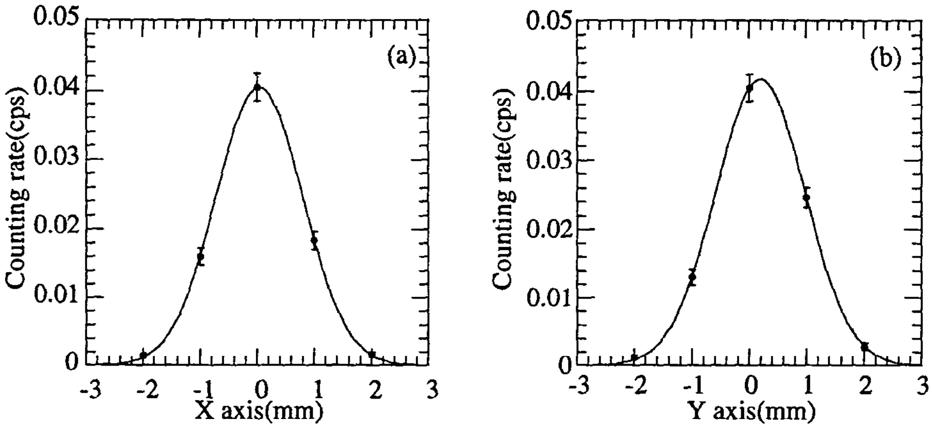

Fig.7 Spantial distributions of neutrons around 14 Å.
(a)X axis: horizontal, (b) Y axis: vertial

The change of the wavelength distributions along X axis is indicated in Fig.8, which are only for comparison of the spectral shape, not for intensity comparison. Almost the same distributions were obtained for Y axis. We can recognize the drastic intensity change around 14 Å. The distributions are depressed around 14 Å at ±2mm. These data clearly demonstrate the feature of the focusing.

V. Conclusion

Neutron beam focusing by magnetic field has beam clearly observed. The gain factor is about 40 . However, the gain factor suggested by our preliminary simulation is about twice as large as that of the experiments. The discrepancy may be due to the reflections from Cd pipes. This effect should be estimated by calculation.

Here, we examined the focusing phenomena, where the focused neutrons are polarized ones but after focusing the neutrons disperse. However, if we put a spin-flipper between a convex and a concave lens, first we can focus the neutron beam and after then align the orientations of the neutrons. This system necessarily produces polarized neutrons.

We are now planning to make a such a system and to use in the neutron scattering experiments.

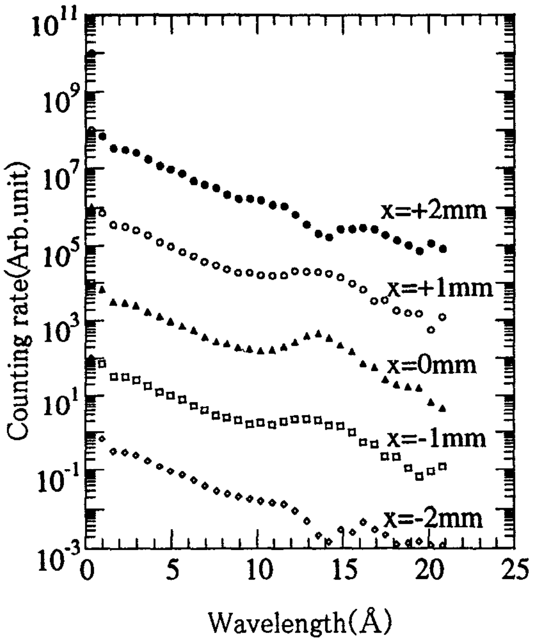

Fig.8 Spantial dependence of wavelength spectra along X (horizontal) axis.

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