NATIONAL RESEARCH CENTRE "KURCHATOV INSTITUTE"
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7-order enhancement of the Stern-Gerlach effect of neutrons diffracting in a crystal

ABSTRACT

We carried out a measurement to investigate the diffractive amplification of small interactions of the neutron.

We spatially split a non-polarized neutron beam passing through a 21.6 cm thick silicon crystal into two polarized beams with opposite spin orientations using a small magnetic field gradient of 3.1 G/cm (analogy to the Stern-Gerlach effect).

To do this we used a two-crystal Laue diffraction scheme and Bragg angles close to the orthogonality. At the maximum achieved diffracting angle θ_B = 82°, we got the splitting of 4.1 ± 0.1 cm.

The amplification factor compared to that in the absence of the crystal was 1.1×10^7 in good agreement with the theory [1].

References

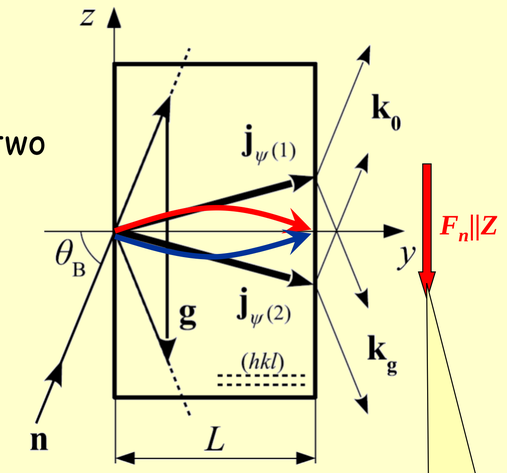
1. V. V. Voronin, S.Y u. Semenikhin, D. D. Shapiro et al, Physics Letters B **809** (2020) 135739

NEUTRON DIFFRACTION IN CRYSTAL

There are two types of Bloch waves $\psi^{(1)}$ and $\psi^{(2)}$, which are two orthogonal super positions of the direct wave and wave reflected from crystallographic planes:

$\mathbf{j}_{\psi(1)}$ and $\mathbf{j}_{\psi(2)}$ - the neutron fluxes for two Bloch waves

Symmetric Laue diffraction in a crystal



Neutron trajectory for Laue diffraction

$$\frac{\partial^2 z}{\partial y^2} = \pm \frac{\tan^2(\theta_B)}{m_0} \frac{\pi}{d} \frac{F_n}{2E_n}$$

Gain factor

Trajectory of free neutron

$$\frac{\partial^2 z}{\partial y^2} = \frac{F_n}{2E_n}$$

Diffraction in crystal
N.Kato , J. Phys. Soc. Japan (1963) **19**, 971

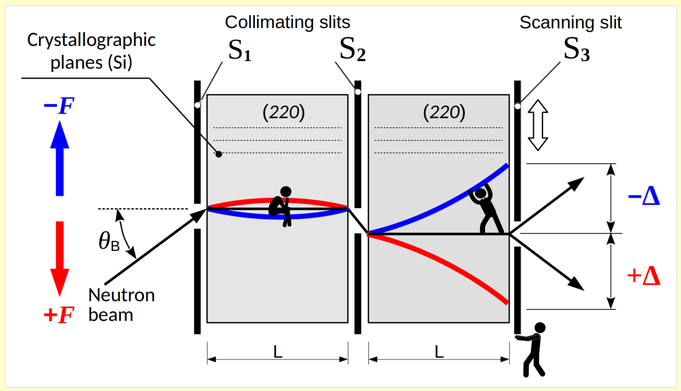
A SCHEME OF THE EXPERIMENT

Gain factor for the diffracting neutron

$$K_d = \frac{\tan^2\theta_B}{m_0} \cdot \frac{\pi}{d}$$

where "Kato mass" is

$$m_0 = \frac{2F_g d}{V}$$

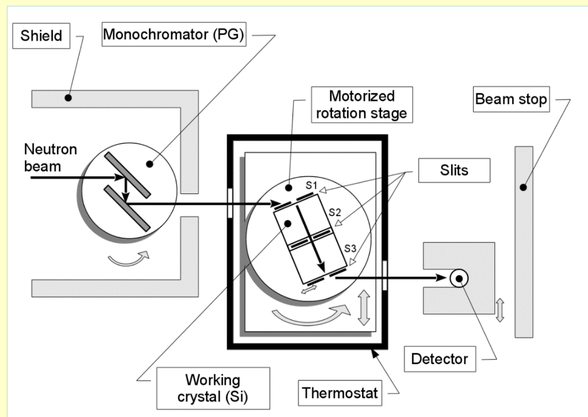


Diffraction in deformed crystal
*N.Kato , J. Phys. Soc. Japan **19** (1963) 971*

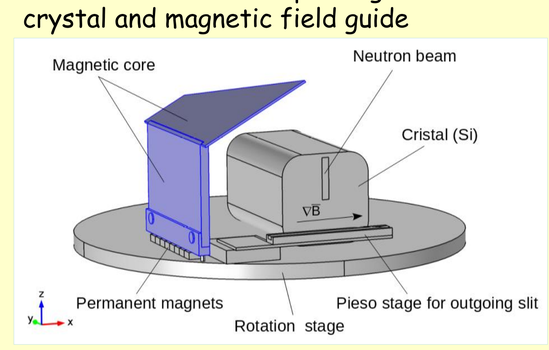
$$K_d^{Si(220)} = 2.1 \cdot 10^5 \cdot \tan^2\theta_B$$

An external force deflects a neutron from a straight trajectory, i.e. causes it to move along a curve. This change in trajectory results in a spatial shift of the neutron beam at the exit of the second crystal. To measure this effect, we propose to use two-crystal geometry. The crucial feature of the proposed setup is its sensitivity to external forces acting on neutrons.

SETUP

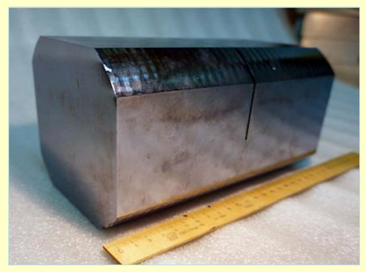


Schematic 3D view on probing silicon crystal and magnetic field guide



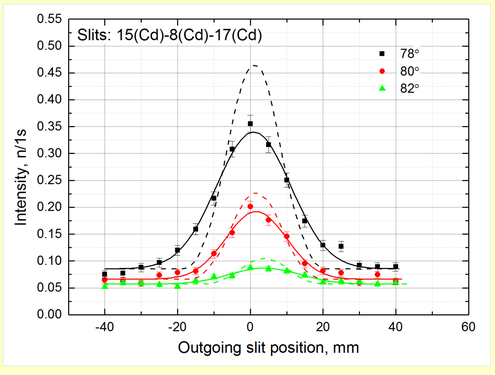
$$\nabla\left|\vec{B}\right| = 3.0 \pm 0.3\ \text{G/cm}$$

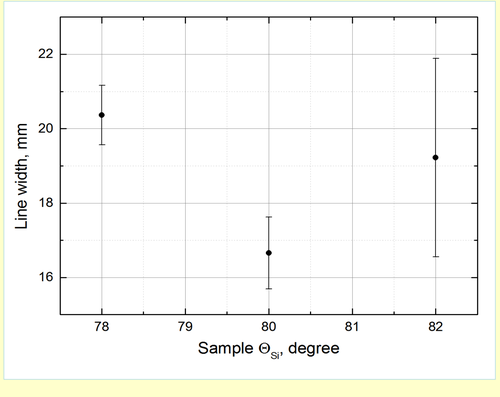
- Two-crystal monochromator. A pyrolytic graphite (PG) crystal with (002) crystal plane, d=3.35Å spacing and ~ 1^0 mosaic.
- The Si crystal (220) **130×130×218 mm³** is installed on a table of a rotating stage placed inside a thermo-controlled chamber. This rotating table is used to vary the Bragg angle with accuracy 0.03^0. The crystal is partly cut (the width of the cutout is 1.6 mm) to perform the two-crystal Laue diffraction scheme.
- The crystal is kept at the fixed temperature by thermostat Julabo F34-HE (stability ~ **±0.01K**).
- Detector ^{3}He.



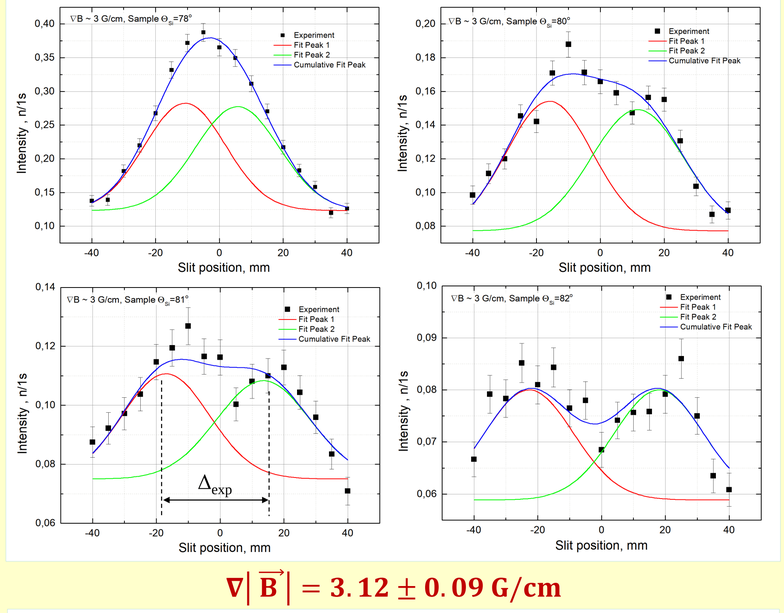
RESULT OF EXPERIMENT

No field affecting the neutron

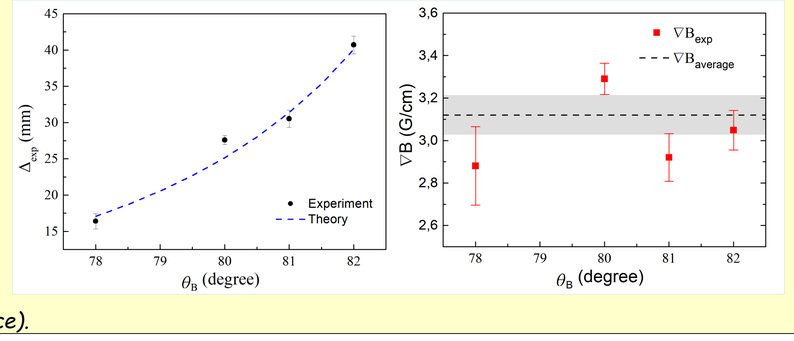




Unpolarised beam splitting at different Bragg angle



$$\nabla\left|\vec{B}\right| = 3.12 \pm 0.09\ \text{G/cm}$$



Experiment has been done in October 2018 at the PF1b (ILL, France).

CONCLUSION & MOTIVATION

The diffraction gain factor for neutron inclination in the external field was measured first for Bragg angle close to π/2. It coincide with the theory

Theory	Experiment
$K_d^{(220)} = 2.1 \cdot 10^5 \cdot \tan^2\theta_B$	$K_{exp} \sim 2.0 \cdot 10^5 \tan^2\theta_B$

for $\theta_B = 82^\circ$ and (220) Silicon plane

$K_d^{(220)} = 1.1 \cdot 10^7$	$K_{exp} = 1.0 \cdot 10^7$

Such an ultra-precise spectroscopy technique can be used for a broad range of experiments:

- ✓ The sensitivity to the **neutron electric charge** can be improved by **an order of magnitude** compared with the current experimental limit;
- ✓ **The equivalence of the inertial and gravitational mass of the neutron** can be verified with an **accuracy of 10^{-5}** (compare with the current experimental value **1.7×10^{-4}**);
- ✓ **Neutron scattering amplitudes** can be measured with higher accuracy for both solids and gases;
- ✓ Neutron diffraction in perfect crystals and **crystal properties** on the inter-planar **distance homogeneity of $\Delta d/d \sim (10^{-6} - 10^{-8})$** can be studied.