5–3 Realization of a Highly Polarized Neutron Beam across a Wide Energy Range

— Development and Application of a Neutron Polarization Device Using Highly Polarized ^{3}He —

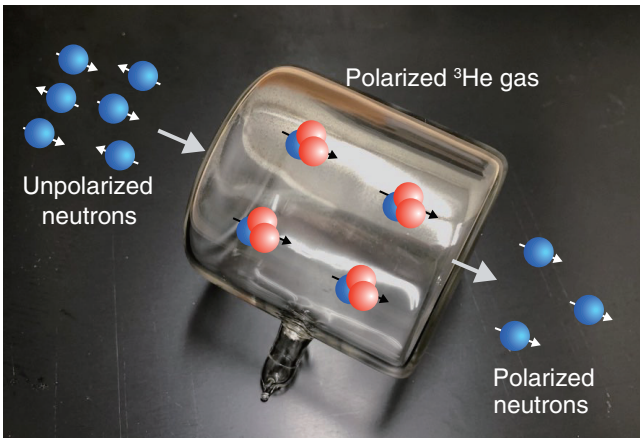

Fig.5-5 Fabricated ^{3}He spin filter
The developed ^{3}He spin filter is a neutron polarization device composed of polarized gaseous ^{3}He gas and alkali metal encapsulated into a special glass cell that does not include boron. ^{3}He has a large absorption cross-section (10666 b) of neutrons with an anti-parallel spin state; nevertheless, the absorption cross-section of neutrons with a parallel spin state is approximately zero. The neutron beam is polarized as it passes through a glass cell containing polarized ^{3}He. The ^{3}He spin filter can polarize neutrons over a wide energy range, including high-energy neutrons over 100 meV.

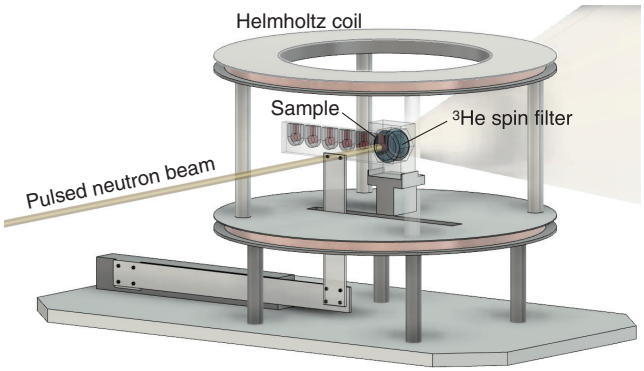

Fig.5-6 Instrument used for neutron polarization analysis that uses the ^{3}He spin filter in a small-angle neutron scattering experiment
The spin of neutrons scattered by a sample was analyzed using the ^{3}He spin filter. A magnetic field was applied to the ^{3}He spin filter with a Helmholtz coil to maintain ^{3}He polarization during the experiment. By installing this instrument to beamline BL15 (i.e., TAIKAN), we verified the usefulness of the ^{3}He spin filter to determine the structure of a material containing hydrogen atoms.

Neutrons have important characteristics such as having no electric charge, high transmittance, and a large cross-section for light elements, as well as having a spin. However, magnetic supermirrors, widely used to polarize neutrons, can only polarize neutrons below several tens of meV. The pulsed neutron source at the Materials and Life Science Experimental Facility in J-PARC can provide neutrons across a wide energy range (from 1 meV to 1 keV), unlike reactor neutron sources.

To further broaden this range, we developed a ^{3}He spin filter, which is a neutron polarization device comprising nuclear spin-polarized gaseous ^{3}He encapsulated in a glass cell (Fig.5-5). The ^{3}He spin filter can polarize neutrons with energies ranging from 1 meV to 10 eV by adjusting the amount of ^{3}He gas and is suitable to analyze the spin of neutrons scattered by a sample due to its large solid angle coverage. The key to developing this device was determining how to polarize the ^{3}He gas with a high polarization ratio while maintaining the polarization on the neutron beamline. Since impurities in the glass cell reduce the ^{3}He polarization, we constructed a vacuum system to supply ^{3}He gas to the glass cell while minimizing contamination. A laser irradiation system of approximately 100 W was also constructed to polarize the ^{3}He gas. Finally, the developed ^{3}He spin filter demonstrated a ^{3}He polarization of 85%, representing the highest documented neutron polarization. Generally, ^{3}He polarization gradually decreases when laser irradiation is stopped due to impurities inside the glass cell and the surrounding non-uniform magnetic field. Therefore, we established a gas filling procedure to remove impurities inside the glass cell and developed a uniform magnetic field environment on the beamline to maintain a long-lasting ^{3}He polarization.

The developed ^{3}He spin filter was installed in beamlines BL04, BL06, BL10, BL15, and BL21, and experiments using neutron beams were performed. A neutron beam of approximately 1 eV was successfully polarized in BL04: Accurate Neutron-Nucleus Reaction measurement Instrument (ANNRI); this allowed us to discover the angular distribution of the γ-rays emitted in the polarized neutron absorption reaction of ^{139}La. Additionally, we verified that neutron polarization analysis using the ^{3}He spin filter can be used to determine the position of hydrogen atoms in materials in pulsed neutron small-angle scattering experiments (Fig.5-6) during experiments performed using the small and wide-angle neutron scattering instrument "TAIKAN" (BL15). Many experiments using ^{3}He spin filters have since been performed, and various scientific results are expected to be obtained in the future.

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Reference

Okudaira, T. et al., Development and Application of a ^{3}He Neutron Spin Filter at J-PARC, Nuclear Instruments and Methods in Physics Research Section A, vol.977, 2020, 164301, 8p.