

Sample Environment of the HRC Spectrometer at J-PARC

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The High Resolution Chopper Spectrometer (HRC) is installed at the Materials and Life Science Experimental Facility (MLF) of the Japan Proton Accelerator Research Complex (J-PARC) to study the dynamics of materials in a wide energy-momentum space with high resolution. We are developing sample environments and control systems to perform inelastic neutron scattering in multiple extreme environments. This report provides a summary of the sample environment.

KEYWORDS: inelastic neutron scattering, pulsed neutron

1. Introduction

The High Resolution Chopper Spectrometer (HRC) is installed at the Materials and Life Science Experimental Facility (MLF) of the Japan Proton Accelerator Research Complex (J-PARC) and is utilized for a wide range of dynamical studies of materials over a wide energy-momentum space with high resolution [1]. In addition to conventional inelastic scattering in the wide-angle range, HRC can perform neutron Brillouin scattering (NBS), i.e., inelastic neutron scattering close to the forward direction with low-angle detectors. Therefore, HRC is a highly valuable instrument that can propose three types of inelastic scattering experiments, such as high-resolution experiments in a conventional energy-momentum space, NBS, and sub-eV neutron spectroscopy [2, 3]. We have been able to observe spin-wave excitations of approximately 1 meV [4] and crystalline electric field excitations [5] benefiting from high resolution in the conventional energy range, gaps in ferromagnetic spin-wave excitations [6] in the NBS, and Stoner excitations [7] at sub-eV neutron incident energy using these features. We are now developing a sample environment for various experiments in these measurement areas.

2. Instrument properties

Figure 1(a) shows the layout of the HRC [8], and the characteristic parameters of the HRC are summarized in Table I. The sizes of the HRC are $L_1 = 15$ m (the distance between the neutron source and the sample), $L_2 = 4$ m (the distance between the sample and the detector), and $L_3 = 1$ m (the distance between the Fermi chopper and the sample). The neutron flux passing through an area of

Table I. Characteristic parameters of HRC.

Moderator	Decoupled H_2 100×100 mm ²
Flight path	$L_1 = 15$ m, $L_2 = 4$ m (wide-angle bank), $L_2' = 5.2$ m (NBS bank), $L_3 = 1$ m
Incident energy	$3 \leq E_i \leq 1000$ meV
Energy resolution	$\Delta E/E_i \geq 2\%$ ($E = 0$ meV)
Scattering angle	Horizontal: $-31^\circ \sim -13^\circ$, $3^\circ \sim 62^\circ$ (L_2), $-5.1^\circ \sim -0.6^\circ$ (L_2') Vertical: $\pm 20^\circ$ (L_2), $\pm 4^\circ$ (L_2')
Maximum sample size	50 × 50 mm ²
Curved Fermi choppers	High intensity: slit width = 2.4 mm, radius = 1300 mm High resolution: slit width = 1.2 mm, radius = 1000 mm
Incident collimators	0.3° , 1.5°
Detectors	³ He PSDs

100 × 100 mm² decoupled moderator travels through the guide tube and reaches the sample with a maximum width of 50 × 50 mm². Neutrons scattered by the sample are detected by the downstream ³He position sensitive detectors (PSDs), which cover a scattering angle up to $\phi = 62^\circ$. In addition, HRC has a small angle bank for NBS with a range of -0.6° to -5.1° at $L_2' = 5.2$ m. HRC has two types of curved Fermi choppers for monochromatizing neutrons. Both choppers have high resolution, but one is for high intensity and the other for higher resolution. This spectroscopy employs an incident collimator and an oscillating collimator to reduce background noise. An incident collimator made of Cd sheets with collimation angles of 1.5° and 0.3° is installed upstream of the sample. Furthermore, an oscillating collimator is installed downstream of the sample to suppress scattering from sources other than the sample.

The PSDs in the HRC are located at the thick solid line in Fig. 1(a). Figure 1(b) shows the measurement range when the incident neutron energy E_i is 3-1000 meV. Here, the area between the two red solid lines and that between the two blue solid lines indicate the measurement ranges by NBS bank and wide-angle bank, respectively. Figure 1(c) shows an enlarged view of the small scattering vector Q range, which is the focus of magnetism research. The minimum angles of the detectors in the NBS bank and wide-angle bank are 0.6° and 3° , respectively, and these detectors can measure the position of the red and blue curves on the low- Q side. These curves in red and blue follow $E = (\hbar^2 Q^2/2m)/\sin \phi$, which are obtained as the envelopes of the scan loci $\hbar^2 Q^2/2m = 2E_i - E - 2[E_i(E_i - E)]^{1/2} \cos \phi$ for the minimum angles, below $E = 20$ and 100 meV, respectively, and in the E range larger than these values follow the scan loci with $E_i = 1000$ meV. Here, E , \hbar , and m are the energy transfer, Dirac's constant, and neutron mass, respectively, and ϕ is the scattering angle. The red and blue curves on the high- Q side are the scan loci for $\phi = 5.1^\circ$ and 62° with $E_i = 1000$ meV, respectively.

3. Experiment control environment

3.1 Software environment

The measurements are performed using an originally developed program called YUI [9]. YUI provides an easy-to-understand graphic user interface for all users to configure measurement sequences. It can perform simple measurements with DAQ-MW [10] and temperature and angle scans. The time of these measurements can also be controlled by time and proton number. In addition, various collimators, Fermi choppers, and refrigerators can be controlled, and the status of the T0 chopper and vacuum scattering chamber can be monitored. The obtained time-of-flight measurement data can be visualized using HANA [9], which has been developed by us, and DAVE MSlice [11] by creating an SPE file using HANA.

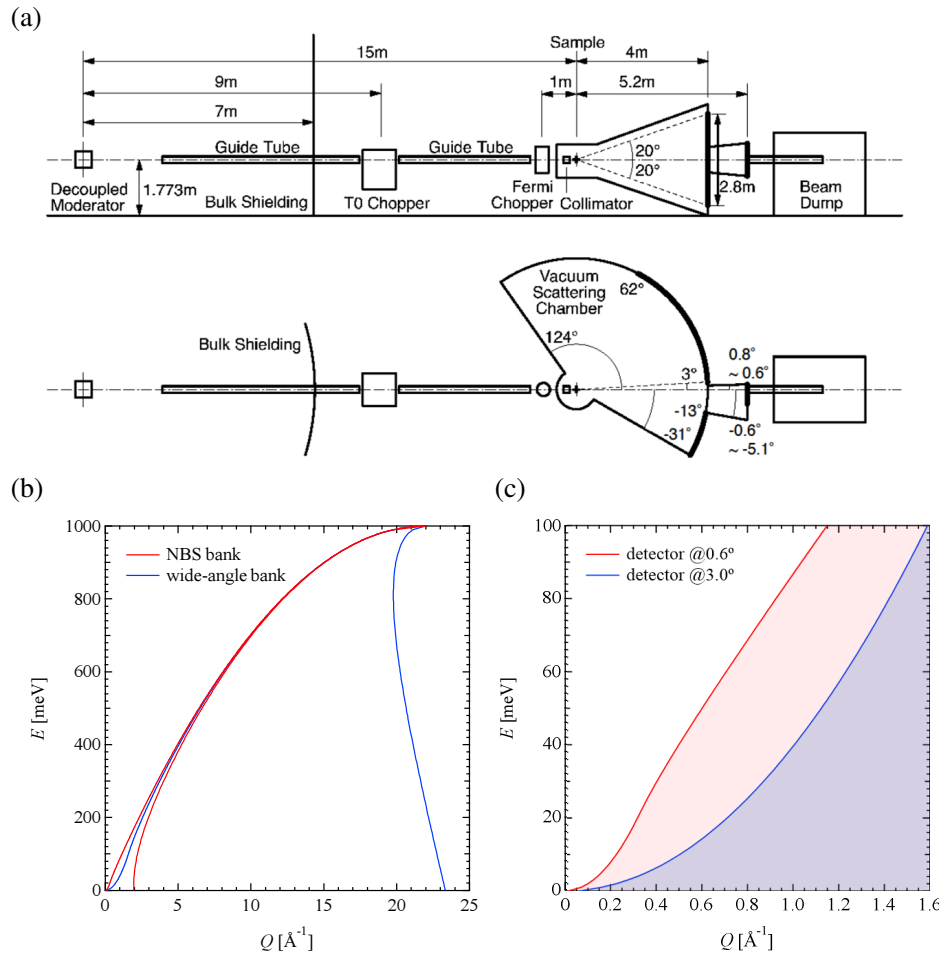


Fig. 1. (a) Layout of HRC spectroscopy. Thick lines indicate the detector arrays of PSDs (Reproduction from Ref. [8]). (b) The measurable range when the incident neutron energy is $E_i = 3\text{-}1000$ meV. The red and blue solid lines indicate the measurement ranges by NBS bank and wide-angle bank, respectively. (c) Enlarged view focusing on low- Q .

3.2 Sample environment

Table II shows the refrigerator groups owned by HRC and their performance. Most of these refrigerators have a thermometer for temperature control and a thermometer attached to the sample cell to obtain accurate sample temperatures. HRC's vacuum scattering chamber is connected to a cryopump across a gate valve, allowing the scattering chamber to be evacuated in approximately 20 min. The most commonly used refrigerator is the Gifford-McMahon (GM), which can be temperature-controlled in the range 4-300 K and requires approximately 3 h to reach the minimum temperature from 300 K (room temperature). As this refrigerator is on a goniometer, it has approximately 190° degrees of freedom. We use standard cells for the wide-angle bank experiments and flat cells for the NBS bank experiments to account for transmittance, as shown in detail on the web page [12].

1K refrigerator is a ^3He circulation type refrigerator. Similar to the GM refrigerator, this refrigerator can rotate the sample using a goniometer. Because it is a bottom-loading type, samples are mounted at room temperature, and it requires approximately 12 h to reach the lowest temperature of 0.6 K. A ^3He one-shot type Heliox refrigerator is available for experiments at lower temperatures. This refrigerator requires approximately 24 h to liquefy the ^3He and reach a minimum temperature of 0.3 K after the sample is installed. In addition, recondensation of ^3He requires approximately 4 h.

The measurements can be obtained from our control program YUI, while the temperature control is performed on a control program developed by Oxford Instruments. Although Heliox is a great refrigerator, we purchased a new one-shot type ^3He sorption refrigerator for use in conjunction with the polarized inelastic scattering spectrometer POLANO [13], J-PARC MLF. This refrigerator will also aim to control temperature from the YUI and is scheduled for commissioning by the end of 2023. In addition, a cryofurnace was installed in 2022 to achieve high-temperature measurements. This top-loading cryofurnace has two sticks, one for high temperature and the other for low temperature. In the low-temperature control, it takes about 7 h to reach the minimum temperature; however, it takes about 1 h to reach the minimum temperature if the sample is changed at about 100 K. In contrast, at the high-temperature control, it can heat a standard sample cell to 735 K by temperature-controlling at 800 K.

Table II. The refrigerator groups owned by HRC and their performance. The first line shows the common name of the refrigerator, and the second line shows the range of possible temperature control. The third line shows the sample mounting method, the fourth line shows the reaching time, and the fifth line shows the availability of temperature control by YUI.

refrigerator	temperature [K]	sample setting	time [h]	YUI
GM	4-300	bottom	3	○
1K	0.6-300	bottom	12	○
Heliox	0.3-300	bottom	24	×
sorption	0.3-300	bottom	20	○
cryofurnace	4-735	top	~7 (cooling), 2 (warming)	○
magnet	0.3-300	top	~2	○

As an external field environment, a magnet refrigerator is available for experiments up to 5T. This refrigerator can apply a longitudinal magnetic field, and the beam acceptance size is $20 \times 20 \text{ mm}^2$. We have also conducted high-pressure experiments up to 1.5 GPa. The sample space in the pressure cell used in this case is 10 mm long and 5 mm in diameter. This type of pressure cell can be installed in a standard sample cell without considering sample dispersal, and it can also be installed in the HRC's refrigeration group without considering attachments [4].

4. Summary

Since receiving its first beam in 2010, the HRC has become one of the world's most valuable inelastic neutron scattering instruments in collaboration with KEK and ISSP of the University of Tokyo. In recent years, when the instrument has been generally upgraded, the sample environment has been improved, and the measurable temperature range has been extended to 0.3-735 K. In addition, experiments under magnetic fields and pressures could be conducted now. We expect to obtain scientifically valuable measurement data in the future due to these developments, taking advantage of the multiple extreme environments and high-resolution features.

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