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# HYSPEC: A crystal time-of-flight hybrid spectrometer for the spallation neutron source with polarization capabilities

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## Abstract

The hybrid spectrometer (HYSPEC) is a unique direct geometry inelastic scattering instrument under construction at the spallation neutron source (SNS). It combines the intensity enhancement features of focusing Bragg crystals with time-of-flight energy analysis. It will be located at beam-line 14B, which views a coupled liquid hydrogen moderator. A neutron beam from the moderator will travel along a curved guide, through a Fermi chopper and will then be focused onto a sample in an external building, 39 m from the source. In this configuration the intensity at the sample position is more than an order of magnitude larger than for other planned inelastic instrument. A movable detector bank 4.5 m from the sample will cover an angular range of 60° in the horizontal plane and 15° in the vertical direction. An important feature of HYSPEC is the ability to do neutron polarization analysis experiments. A Heusler crystal, which polarizes the neutron beam, can be used as the focusing crystal and a series of bender analyzers will analyze the polarization of the scattered beam.


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*Keywords:* Inelastic neutron scattering; Polarized neutrons

Much of our understanding of the physical properties of materials comes from inelastic neutron scattering studies of single crystal samples. These include studies of magnetic fluctuations as well as phonon behavior relevant for a wide variety of topics such as superconductivity, magnetism, ferroelectricity, charge order, phase transitions. Previously, most of this work was done on triple-axis spectrometers situated at continuous sources where parametric studies are typically performed over limited regions of momentum and energy space. Recently, experiments at ISIS on the MARI and MAPS instruments have shown that pulsed neutron sources can also be very effective for the study of excitations in single crystals. Construction of the 1.4 MW SNS at Oak Ridge National Laboratory creates an opportunity to pursue the development of novel approaches to the inelastic neutron spectroscopy at the pulsed sources. Moreover, polarized neutrons are currently only used in a limited fashion at pulsed sources and their use is restricted to longer wavelength instruments.

With this in mind we have developed an instrument that will take advantage of the focusing crystals used on 3-axis spectrometers and the time-of-flight (TOF) techniques ideally suited for pulsed neutron sources. The instrument, called HYSPEC combines the TOF technique for energy analysis with Bragg focusing optics to enhance the flux on a relatively small sample. Moreover, by using focusing Heusler crystals and polarizing benders, the instrument can do inelastic scattering with the polarization analysis.

Fig. 1 shows an engineering drawing of the layout and the important components of HYSPEC [1,2]. It is located on beam line 14B viewing the coupled hydrogen moderator. HYSPEC is designed to use both the cold and thermal neutrons in the energy range from 3.6 to 90 meV. After the beam leaves the target monolith it passes through Box A, which contains a T0 chopper to stop the fast neutrons and prompt gamma-rays and a T1A frame overlap chopper, which removes the lower energy neutrons (E < 3.6 meV).

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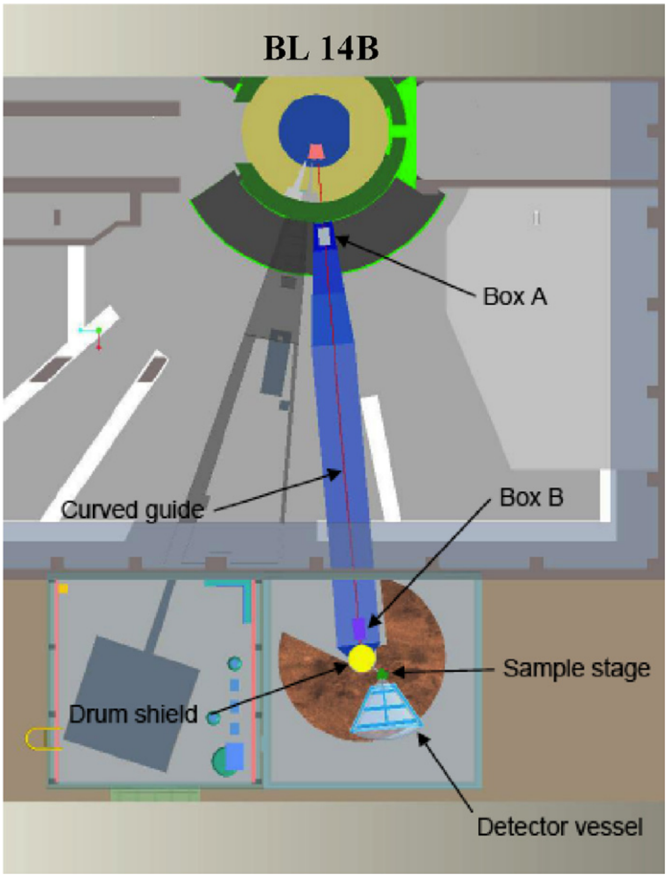


Fig. 1. HYSPEC layout on the SNS experimental floor at beam line 14B viewing a coupled liquid hydrogen cold moderator.

This conditioned neutron beam is transported to an external building at ~35 m from the moderator by a curved supermirror-coated guide. The guide curvature is designed to remove the unwanted epithermal and fast neutrons in the 200–200 MeV range. A narrow energy band of neutrons is then selected from the broad band emerging from the guide by a T2 straight slotted Fermi chopper in Box B which operates at multiples of the 60 Hz source frequency. By varying the rotation rate of the T2 chopper one can adjust the intensity and resolution of the incident beam. An additional chopper (T1B) in Box B operating at the source frequency is needed to suppress various higher-order neutrons that are transmitted by the T2 chopper. The monochromatic neutron beam is then guided into a drum shield housing a focusing pyrolytic graphite (PG) crystal array which focuses the large ($40 \times 150\,\mathrm{mm}^2$, $W \times H$) beam onto a $20 \times 20\,\mathrm{mm}^2$ spot size at the sample position.

The use of a focusing crystal and the design for a small beam at the sample position is motivated by the fact that many new and novel materials can only be grown as single crystals in small sizes. Another advantage of using a focusing crystal is that a Heusler crystal can replace the PG crystal for polarized beam operation.

The focused monchromatic beam, polarized or non-polarized, is directed towards the sample area which is not a part of the secondary flight-path enclosure vessel housing detectors. This allows using the standard ancillary equipment such as low-temperature cryostats, furnaces, high field magnets, or pressure cells. An assembly of 160 linear position sensitive $He^3$ detectors, each 1.2 m long, will detect the scattered neutron beam and its energy will be analyzed by the time of flight. The sample to detector distance is 4.5 m. The detector array will cover an angular range of 60° in the horizontal plane and 15° in the vertical plane. The detector vessel will be filled with argon gas. The detector vessel is attached by an arm to the sample stage and will rotate about the sample to vary the scattering angle and thus the momentum transfer. Just behind the front window of the detector vessel is a coarse 3° collimator whose main purpose is to shield the detectors from the powder Bragg scattering from aluminium in the window. In front of the detector vessel is place for a variety of optical components.

In the unpolarized mode of operation a radial collimator will be used to reduce the scattering from the sample environments and to adjust the momentum resolution as desired. In the polarized mode of operation the radial collimator will be replaced by a polarization analyzer assembly consisting of an array of 20 supermirror bender transmission polarizers made of a stack of bent supermirror-coated Si plates preceded by a collimator. The setup for a single bender is shown in Fig. 2. The critical angle for internal reflection by the supermirror depends on the direction of the neutron spin with respect to the polarization of the bender. Hence, neutrons in one spin state are reflected at a critical angle while those in the other spin state are transmitted through the polarizer. The proposed arrangement allows for detecting both spin states of the

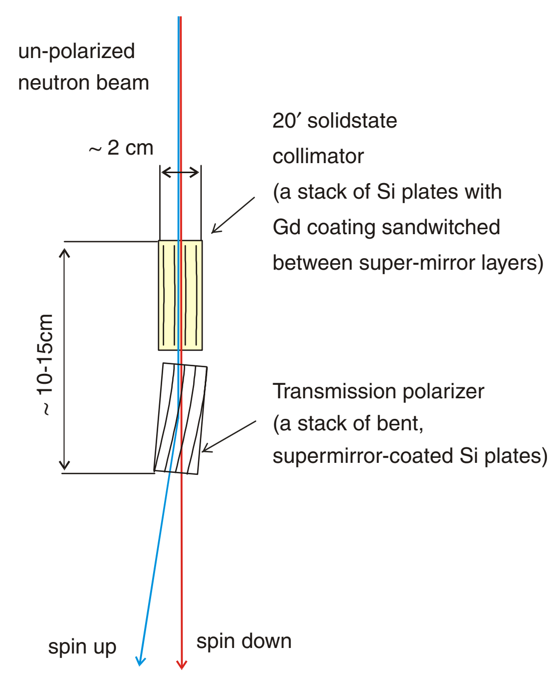


Fig. 2. Schematic arrangement of a single collimator and a supermirror bender transmission polarizer. The angular splitting of the spin-up and spin-down beams is determined by the difference of the critical angles for the corresponding spin polarizations.

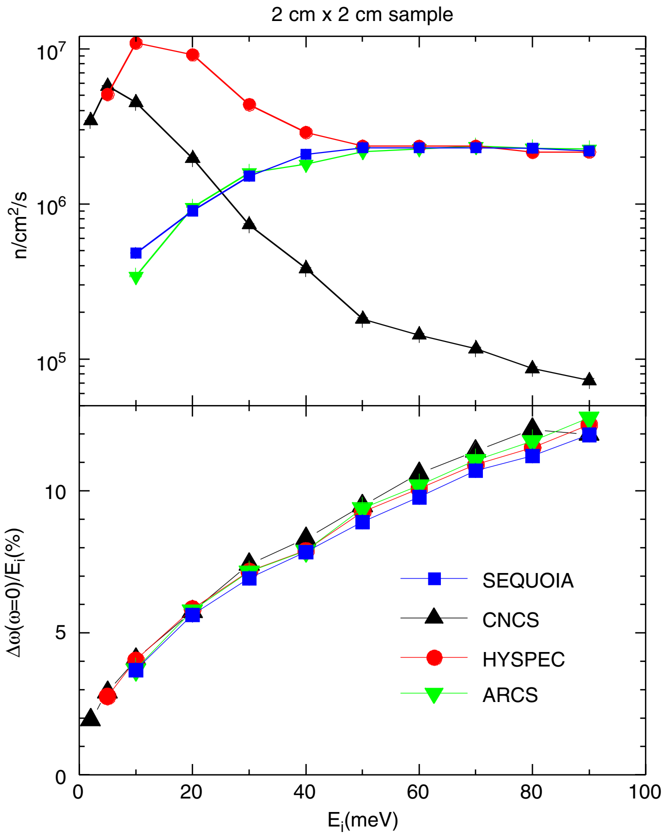


Fig. 3. The flux-on-sample and energy transfer resolution for the four SNS direct geometry instruments under the conditions optimized for the HYSPEC spectrometer [5].

scattered beam simultaneously. This method has been tested and is in use at several laboratories [3,4]. An alternative method of analyzing the polarization of scattered neutrons is the use of polarized-$He^3$ transmission cells. Although this is not planned for use in HYSPEC, it will be designed to allow $He^3$ analysis at a later date.

There are four direct geometry instruments for neutron spectroscopy that are being built at the SNS. These are HYSPEC, Cold Neutron Chopper Spectrometer (CNCS) on BL5, ARCS (BL18) and SEQUOIA (BL17). The latter two view a water moderator and are optimized for higher energies. Granroth and Abernathy [5] performed Monte Carlo simulations using the McStas package to quantify and compare the flux-on-sample of each instrument. Although the characteristics and the operating range of each instrument are different, a meaningful comparison can be performed by adjusting the parameters of all instruments to achieve roughly the same energy resolution. Fig. 3 shows the flux-on-sample comparison of the four instruments under conditions optimized for the HYSPEC spectrometer. In the energy range from 5 to 50 meV HYSPEC clearly provides superiour neutron flux. In comparison with ARCS and SEQUOIA this is not unexpected since these instruments view a water moderator and are optimized for a higher incident energy. When compared with the other cold source instrument (CNCS), HYSPEC has considerably more flux for incident energies $E_i > 5.0$ meV.

To summarize, HYSPEC fills an important niche in the suite of instruments planned for the SNS. It will provide a superior flux-on-sample in the thermal neutron energy range and a high signal-to-noise ratio thanks to the use of collimators, the curved guide, and removal of the sample from the direct beam. With the moveable detector bank, it will cover a wide region of momentum space and will be able to focus on a particular region in $q$ and $E$ space. It satisfies one of the initial recommendations to the SNS by the Inelastic Neutron Scattering Workshop [6] in providing an inelastic instrument with "triple axis capabilities with high signal to noise" as one of the first generation of SNS instruments. Perhaps, the most important advantage of HYSPEC is that it is designed to provide the full polarization analysis capability of the incident and scattered neutron beams using the existing, proven and easy-maintenance technology.

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