CHESS – Chopper Spectrometer for Small Samples

CHESS is a chopper spectrometer optimized for very small samples (~ 1 mm – 1 cm) and medium energy resolution, complementary to the higher resolution STS spectrometer, HERTZ. CHESS will take full advantage of the increased peak brilliance of the high brightness STS coupled moderators and of recent advances in instrument design and technology to achieve unprecedented performance in the cold energy range. For small samples, the performance will exceed that of CNCS by a factor of ~200.

Science Drivers

The dynamic structure factor, $S(Q, \omega)$, as measured in an inelastic neutron scattering experiment contains information necessary to understand the microscopic interactions in a wide range of quantum and functional materials. However, the traditional large sample size requirement has limited the applicability of this technique and prevented exploration of a great number of materials. CHESS will enable inelastic neutron scattering on smaller samples than had previously been possible, opening the technique to a broader range of materials such as:

- Small single crystals produced by high pressure synthesis as, for example, the $S = 1/2$ kagome staircase material $\beta$-Cu$_3$V$_2$O$_8$.

- Organic superconductors (deuterated) whose synthesis is based on electrocrystallization from which only small single crystals can be obtained.

- Epitaxially grown single crystals that are often used to develop new materials with tailored electronic, optical, or magnetic properties. If such crystals can be grown to micrometer thickness, studies of their excitations using CHESS are feasible.

- Materials under the most extreme conditions which necessitate small sample volumes such as very high-pressure (>40 GPa) which provides an ideal, clean tuning parameter for exploration of quantum phase transitions.

- Highly absorbing samples where isotopic substitution is not possible such as iridium containing compounds where both stable isotopes absorb neutrons.

Science Requirements

Traditionally, intensity limitations have meant that inelastic neutron scattering measurements could be performed only with relatively large samples (~1 gram of material if it does not contain hydrogen). However both source and neutron optics advancements now make it possible to break that paradigm so inelastic neutron scattering can be conducted on the most interesting high quality materials that typically are not available as large (cm sized) single crystals. CHESS offers the following capabilities:

1. A cold neutron direct geometry time-of-flight spectrometer optimized for small samples (~ 1 mm–1 cm) and medium energy resolution. This will enable mapping excitations over a broad wave vector and energy range for samples with a cross-sectional area as small as 1 mm$^2$.

2. The instrument will include full three-dimensional polarization analysis to enable separate measurements of multiple components of the $S_{\alpha\beta}(Q,\omega)$ tensor.

3. The low repetition rate of STS will enable simultaneous measurements with multiple incident energies, greatly increasing measurement efficiency particularly in materials with excitations covering a broad range of energies.

---

Technical Description

Optimized for small samples, CHESS only requires a viewed moderator surface of a few cm horizontally and vertically and is ideally located on beam line 19 viewing the 3x3 cm² HPCM face ‘c’. The guide entrance will be illuminated with approximately ±3–4 degrees of neutron beam angular divergence. The beam line will be straight and will incorporate a number of choppers to shape the neutron pulse, block the high-energy prompt pulse to minimize background, control the sub-frame durations to support repetition rate multiplication, and monochromate the incident neutron energy. The energy resolution will be tunable in the 2.5–4.5% range, which is typical for direct geometry inelastic instruments. The 10 Hz STS repetition rate coupled with a 25–30 m incident flight path means that all incident energies down to 1 meV can be accessed in the first frame using repetition rate multiplication methods. The neutron beam delivery system must be adaptable to increase beam divergence for small samples to as large as ±4° in either the horizontal or the vertical direction as required. Relaxed energy resolution allows relatively close placement of the detectors to the sample.

It is essential to fully integrate dedicated sample environment equipment into the design of the secondary spectrometer. Extreme conditions in temperature, magnetic field, pressure, strain, and any combination thereof drive the science and must be developed and accommodated within the initial project. Automated sample loading systems for low T measurements will also be required on this new generation of high count rate inelastic machines. Also, polarization analysis will be essential for many magnetic experiments because the general science direction is toward systems with smaller moments (spin-1/2) with magneto-elastic effects or excitation continua, whereas traditional methods of isolating magnetic scattering (through temperature variation) are inadequate. These requirements have the following implications:

- All ferromagnetic materials must be avoided within a radius of at least 2 m from the sample position.
- Strict limits must be imposed on the magnetic permeability of the steel of the tank and such components.
- Large coils for magnetic guide fields (several meters in diameter) must be incorporated in the design of the secondary spectrometer.
- There must be at least 50 cm of room between the guide exit and the sample position, and the beam must be shaped such that no diaphragm is needed between the guide exit and sample.
- A collimator between the sample and detector will be required.

### Key parameters of CHESS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderator</td>
<td>High-peak-brightness coupled moderator, side c</td>
</tr>
<tr>
<td>Sample size</td>
<td>1x1 mm² to 1x1 cm²</td>
</tr>
<tr>
<td>Moderator–sample distance</td>
<td>25–30 m</td>
</tr>
<tr>
<td>Sample–detector distance</td>
<td>2.5–3.5 m</td>
</tr>
<tr>
<td>Energy range</td>
<td>0.5 meV ≤ Ei ≤ 100 meV</td>
</tr>
<tr>
<td>Resolution</td>
<td>2.5–4.5% variable ΔE/Ei, range; ΔQ &lt; 0.05 Å⁻¹</td>
</tr>
<tr>
<td>Detector</td>
<td>1.5 cm diameter linear position-sensitive detector, ³He</td>
</tr>
</tbody>
</table>