ZEEMANS – High Magnetic Field Beam Line

Scientific impact, user demand, and two recent National Academy of Science reports[1,2] identify neutron scattering in high magnetic fields as a priority area. The enhanced brightness of the proposed second target station and progress in high field technology now offer the opportunity for a quantum leap. With continuous fields in excess of 35 T and versatile neutron instrumentation capable of all forms of scattering, the ZEEMANS facility would define the frontier in high field neutron scattering and offer unprecedented new scientific opportunities.

Science Case

The wide-ranging scientific program of the National High Magnetic Field Laboratory (NHMFL) indicates the scientific value of controlling the electronic and nuclear state of materials with magnetic fields in the range from 1 to 100 T. Neutron scattering offers the capability of probing electronic and nuclear structure and dynamics at the atomic scale opens an exciting array of scientific opportunities. The goal is to create nothing less than the world center for high magnetic field neutron scattering at Oak Ridge National Laboratory in conjunction with construction of the STS. A facility reaching fields beyond 35 T and offering the full range of neutron spectroscopy, diffraction, reflectometry, and SANS with the intensity, resolution, and coverage offered by STS, would have major impact across the whole range of materials based sciences enabling ground breaking experiments that would:

- Expose the structure and dynamics of previously inaccessible quantum matter in correlated metals and insulators;
- Characterize vortex matter in new regimes of high temperature superconducting materials;
- Determine the multiplicity of collective electronic resonances in technologically relevant materials;
- Locate hydrogen in materials relevant to medicine, biology, physical chemistry, and materials science through nuclear spin labeling; and
- Elucidate of the texture and structure of materials during high field processing.

The proposed ZEEMANS facility would thus enable a broad research program and open new directions of inquiry based on the unique magnetic and nuclear interactions of neutrons with materials. Zeemans would create an exciting technological and scientific link between the programs at NHMFL and ORNL's Neutron Sciences Directorate.

Science Requirements

ZEEMANS integrates neutron spectroscopy, diffraction, reflectometry, and SANS with a high field magnet. While such an instrument would be competitive on the first target station, its performance would offer a world leading new capability on STS. By leveraging the highest brightness moderator and the low repetition rate ZEEMANS will deliver performance estimated to be ~20 × TOPAZ and 40 × HYSPEC for single crystal diffraction and spectroscopy respectively. ZEEMANS requires a sample environment integrated into the high field magnet design capable of controlling the sample temperature from 50 mK to 1,000°C.

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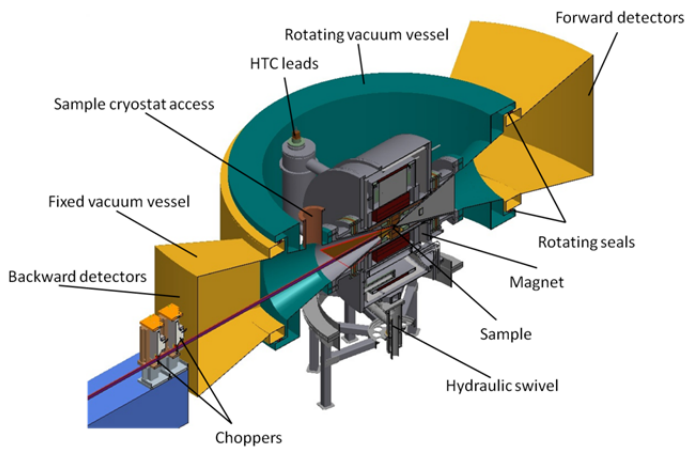
[1] National Research Council (US). Committee on Opportunities in High Magnetic Field Science, National Academy of Sciences (US) and National Science Foundation (US), Opportunities in high magnetic field science. 2005, Washington, D.C.: National Academies Press.

[2] National Research Council (US). Committee to Assess the Current Status and Future Direction of High Magnetic Field Science in the United States., National Academy of Sciences (US), High Magnetic Field Science and its Application in the United States. 2013, Washington, D.C.: National Academies Press.

Technical Description

ZEEMANS is best located on the high intensity coupled moderator and because of the significant infrastructure required for the magnet facility will be optimally placed on beam line 1. The beam line will be curved and may include a bender to avoid a direct line-of-sight view of the moderator. It will incorporate a number of neutron choppers and adjustable optical components (the last 5 m of the guide system) so as to tailor the neutron beam for individual scattering techniques. The instrument will include the capability to provide a polarized neutron beam and to perform analysis of the scattered beam polarization. A previous National Science Foundation–funded project resulted in a conceptual and engineering design for the superconducting magnet system that provides a head start for ZEEMANS.[3] The figure below shows the concept for the detector vessel and magnet that was developed in that project.



While the current world leading 25 Tesla facility at the Helmholtz Zentrum Berlin is based on a resistive magnet that requires Mega-Watt power and cooling systems, advances in high Tc technology now indicate a fully superconducting 35 Tesla-40 Tesla magnet system is possible. For this field range, the magnet will inevitably define the geometry of the instrument and it will be the main technological challenge. It will furthermore require significant specialized infrastructure in the form of a dedicated helium liquefaction plant and specialized sample environment systems to cool and rotate the sample within the high field. Ongoing magnet development and prototyping work is needed to enable the construction of ZEEMANS as a day one instrument on the STS. ZEEMANS will deliver record-breaking scientific capabilities and through an ongoing partnership with the NHMFL, define state of the art in ultra high field neutron scattering for the foreseeable future.

Key parameters of ZEEMANS

Parameter	Description
Moderator	High-intensity coupled moderator
Sample size	Maximum: 2×2 cm^2
Moderator–sample distance	60 m
Sample–detector distance	5 m
Inelastic: Energy range SANS and diffraction: -range	10 meV $\leq E_i \leq$ 200 meV 1Å $\leq \lambda \leq$ 10 Å
Inelastic resolution	$\Delta E/E_i$ range between 1 and 15% depending on E_i and chopper settings
Detector	8 mm linear position-sensitive detector, ^{3}He

[3] A. T. Savici and G. E. Granroth, in SNS Technical Report, SNS-NSSD-TOF-TR-0002-R00 (2009); G. E. Granroth, et al., in ICANS XIX, 19th meeting on Collaboration of Advanced Neutron Sources; A. T. Savici, et al. J. Phys.: Conf. Ser. 251 0120573 (2010).