# EXTREME ENVIRONMENTS

## Neutrons can explore the physics of matter under extreme conditions

Oak Ridge National Laboratory (ORNL) is the US epicenter of neutron scattering, a powerful technique for studying the nature of materials in helping develop products such as jet engine turbine blades, landing gear, welded airframes and other mission critical components.

Both scientists and non-scientists can access ORNL's research facilities via the US Dept. of Energy's User Program. ORNL's two world-leading, complementary neutron research user facilities — the High Flux Isotope Reactor (HFIR) and the Spallation Neutron Source (SNS) — are open to researchers to facilitate their studies in science and technology. Together, HFIR and SNS offer users over 30 advanced instruments and their supporting laboratories to use for a wide range of materials research experiments.

*"High-pressure neutron scattering at ORNL provides a uniquely powerful window into the quantum world, enabling direct visualization of magnetic correlations in quantum materials under extreme conditions. By simultaneously perturbing lattice geometry and electronic bandwidth while preserving sensitivity to spin degrees of freedom, this approach reveals the intrinsic entanglement among spin, orbital, lattice, and charge that governs emergent quantum states."*

Weiwei Xie
**Michigan State University**
Photo credit: Richard Staples

## No neutron science experience is necessary

Oak Ridge National Laboratory's Neutron Science User Program invites you to collaborate with us, onsite or remotely, to achieve greater success. No neutron science experience is necessary, as our experts work closely with users to ensure the success and safety of their experiments. We can help you find the neutron techniques, instruments and sample environments best suited for your research.

## Neutron users can access neutron facilities — at little or no cost

Beam time is granted through a proposal system managed by the User Program and is free of charge (with the exception of travel costs, if necessary) as long as researchers intend to publish their results to the scientific community. A fee is charged only for proprietary research that will not be made public.

## Contact the Neutron Users Office


Web: neutrons.ornl.gov/users
Email: NeutronUsers@ornl.gov
Phone: 865-574-4600 or 865-341-4451

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## Neutrons offer improved results from studying materials under extreme conditions

ORNL neutrons help scientists better understand the physics of matter under extreme conditions. From penetrating dense materials and probing light elements, to their neutral charge and magnetic moment, neutrons facilitate studies that are difficult or impossible for other research techniques. Recent improvements in spatial resolution and higher flux have enabled neutron scattering to investigate the structure-property relationships up to 10X faster and with better data from much smaller samples, in materials in extreme conditions and far from equilibrium.

## Example of studies in extreme environments

#### High Pressure

- In situ high pressure neutron powder diffraction was used to discover a new transition pathway between amorphous Si/Ge and a metastable crystalline rhombohedral structure at 7 GPa.
- Neutron powder diffraction enabled simultaneous studies of the pressure-temperature dependance of magnetism in $Cr_2O_3$ from 0-20 GPa and 10-320 K, providing an understanding of magnetic anisotropy and exchange interactions under increasing pressure.
- Single crystal neutron diffraction probed the behavior of hydrogen atoms during the hydrogen bond symmetrization process under high pressure conditions in $NaCu_2(SO_4)_2 \cdot H_3O_2$.
- Neutron total scattering experiments revealed the local structure of deuterated ammonia showing a pronounced H-bond correlation and how the packing motif drives the structure.

#### High Temperature

- Neutron powder diffraction was performed on yttria-stabilized zirconia and lanthanum zirconate using an aerodynamic levitator to understand their thermal expansion behaviors up to 2500°C.
- The dynamics of metallic liquids such as $Zr_{50}Cu_{50}$ and $Zr_{80}Pt_{20}$ were studied with inelastic neutron scattering up to 1600°C, using an electrostatic levitator to prevent reaction with the container which can cause oxidation or contamination.
- In situ neutron powder diffraction of rare-earth sesquioxide crystals was performed by cooling a melt from 2500°C to understand the crystallization process and how to tailor the structural stability.

#### High Magnetic Field

- The temperature dependence of the low-energy spin structure and excitations of the Kagome metal FeGe were determined at 0 T and 11 T using inelastic neutron spectroscopy.
- Inelastic neutron scattering measurements using a 14 T vertical field magnet to understand the exchange interactions, demonstrated that $BaCo_2(AsO_4)_2$ could be a rare case of an almost perfect 2D honeycomb magnet.
- Neutron diffraction and inelastic scattering measurements in high magnetic fields were used to study the evolution of magnon excitations in the honeycomb antiferromagnet $CoTiO_3$.

#### Non-equilibrium systems

- In situ single crystal neutron diffraction of $Ca_2RuO_4$ revealed that increasing the electrical current density above 0.15 $A/cm^2$ induces a non-equilibrium orbital state at 80 K.
- Time-resolved small-angle neutron scattering found liquid-like clusters in supercritical fluids provided evidence of non-equilibrium phase separation.
- A Li-mediated $N_2$ reduction reaction was studied using time-resolved neutron reflectometry to understand metastable phases of formation of the solid electrolyte interface layer.
- Neutron total scattering measurements showed that metastable tetragonal $ZrO_2$ consists of an underlying complex structure of ferroelastic, orthorhombic nanoscale domains that are stabilized by a network of domain walls.

## Unique sample environment capabilities

- Magnetic fields up to 14 T
- Low temperatures down to <30 mK
- High temperature furnaces up to 2500°C
- Levitators to prevent contact with containers
- Pressure cells routinely up to 40 GPa (over 100 GPa in special cases)
- Gas flow cells including hazardous gases, and many others