Institute for Quantum Matter (IQM)
EFRC Director: Collin Broholm
Lead Institution: Johns Hopkins University
Class: 2022 – 2024

Mission Statement*: To realize revolutionary quantum materials and structures in which entanglement and coherence drive collective quantum effects.*

Understanding and controlling quantum matter presents one of the grand challenges at the intellectual frontier of the 21st century physical sciences. By enabling new technologies, this fundamental research on crystalline solids has the potential to transform almost every aspect of modern life. As we confront the demands of unprecedented growth in global energy needs and seek to extend the information technology revolution, new materials developed though a deep understanding of the underlying fundamental quantum physics will play an essential role.

The mission of the Institute for Quantum Matter (IQM) is to discover and understand emergent properties in material systems that have the potential for transformative impacts on energy and information technologies. IQM tightly integrates materials discovery and synthesis (single crystals and thin films), advanced experimentation (neutron scattering, optical spectroscopies, transport, ultrasound, tunneling, and high magnetic field techniques) and theory (analytical and numerical).

In the past funding period, IQM discovered new quantum materials and new quantum collective phenomena including magnets with strong quantum fluctuations, superconductivity in a Dirac material with massless charge carriers, and topological materials where quantum transport properties can be controlled by magnetic fields and stress. IQM's unique inter-disciplinary research environment leads to unique training opportunities for students and postdocs so that IQM alumni have gone on to start their own groups and become quantum science leaders in their own right.

In the present funding period IQM will focus on selected high impact collaborative projects involving multiple PIs and combining a full range of synthesis, spectroscopic, and theoretical methods to achieve conclusive answers to key questions in quantum materials science. The research will be organized in three interlocking thrusts:

Quantum Entangled Magnetism. While conventional magnetic materials contain ordered static structures of atomic scale magnetic moments, these continue to fluctuate in quantum entangled magnets and give rise to unique collective materials properties. Prospective applications may be anticipated in quantum computing and quantum sensing. Building upon discoveries at IQM and elsewhere, IQM will seek evidence for quantum entangled magnetism in single crystalline materials at low temperature and when subjected to extreme conditions of pressure, strain, and magnetic fields. We shall explore quasi-two-dimensional magnets with competing interactions based that promote quantum fluctuations. We shall synthesize ultra-pure single crystalline samples of quantum spin liquid candidates and explore their physical properties, contrasting them with the properties of more disordered samples. Prompted by our recent theoretical and experimental discoveries, we shall examine how strain in 2D quantum magnets affects collective magnetic properties. We shall explore the quantum magnetism of honeycomb spin-1/2 materials based on the magnetically anisotropic $3d^7$ Co^{2+} ions in pursuit of quantum entangled magnetism through high field measurements and chemical doping.

Engineering Correlated Superconductivity. Superconductors have obvious applications in energy distribution and as the basis for qubits in quantum computers, while simultaneously giving new insight about macroscopic quantum physics. Based on our activities in the previous grant period, and recent broader discoveries, we shall explore superconductivity built from correlated, topological, and quantum entangled matter. We shall complete ongoing collaborative IQM projects exploring superconductivity in metals with light electrons resulting from topologically protected band crossings. IQM has developed evidence for anomalous bulk superconductivity in an intermetallic material that may be linked to the Dirac nature of the electronic band structure. IQM will explore the possibility of superconductivity in related materials with magnetic rare earth ions. Using the Josephson effect, we shall explore the properties of proximitized superconductivity in Mn_3X thin films samples sputtered at IQM (see below).

Magnetic Topological Materials and Phenomena. IQM will develop new materials functionality based on electronic topology in conducting and insulating single crystals and thin films that incorporate magnetism. A signature focus is on the Mn_3X family of compounds where we are examining the rich interplay between antiferromagnetic domains and electrical transport including electrical domain switching monitored through the anomalous Hall effect. Proximity induced superconductivity will be explored by sputtering patterned superconducting films onto Mn_3X. We shall use small angle neutron scattering to study the domain wall structure and hysteretic field response of topological magnetic semimetals. These experiments may pave the way to the use of neutrons to probe electrically driven domain switching. Inelastic neutron scattering will be used to determine interactions between rare earth magnetic ions mediated by Weyl fermions. We shall explore magnetic topological insulators with the potential to display strong quantized magneto-electric responses.

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