Center for Molecular Quantum Transduction (CMQT)
EFRC Director: Michael R. Wasielewski
Lead Institution: Northwestern University
Class: 2020 – 2028

Mission Statement: *To develop the fundamental scientific understanding needed to conduct quantum-to-quantum transduction through a bottom-up synthetic approach that imparts atomistic precision to quantum systems.*

Molecular architectures provide unmatched flexibility for tailoring spin properties, electronic properties, and geometry, which are essential for interfacing disparate quantum degrees of freedom. Molecular synthesis allows bottom-up construction of novel materials with structural reproducibility and modularity, atomic scale spatial control, and access to uniquely molecular degrees of freedom that can be used to conduct spin-photon and spin-spin transduction. Thus, **CMQT** research on quantum-to-quantum transduction responds directly to PRO 3 of the DOE Report of the Basic Energy Sciences Roundtable on *Opportunities for Basic Research for Next-Generation Quantum Systems*. **Key hypothesis:** Quantum information can be transferred coherently between the quantum degrees of freedom available in molecules to access new functionality for quantum information science (QIS).

CMQT is uniquely positioned to exploit recent breakthroughs from our team including landmark coherence times and stabilities of molecular qubits, new quantum materials, as well as the ability to create hybrid qubits and resonant photonic architectures. Moving forward, our approach includes both ensemble-level studies to rapidly understand interactions, and development of single-molecule methods to interface molecular QIS with other QIS platforms. We will also leverage innovative physical measurement techniques with high spatial, temporal, and spectral resolution to understand how to transition quantum-to-quantum transduction from the ensemble to the single-molecule level. These tools include ultrafast optical and microcavity techniques, pulsed microwave and optically detected magnetic resonance (ODMR), ultrafast low temperature measurements using superconducting resonators, and x-ray structural techniques. Theory approaches include electronic structure, spin dynamics, and exciton dynamics calculations.

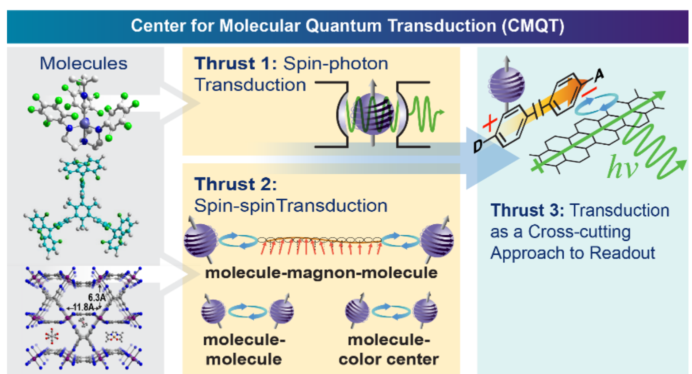

Fig. 1. Overview of **CMQT** research.

Achieving molecular quantum-to-quantum transduction is necessarily an interdisciplinary effort, requiring the scope of an EFRC to assemble the needed expertise for design and synthesis of molecular and solid-state materials, measurement of coherent quantum states at the single quantum level, and seamless incorporation of theory and modeling of materials and measurements. **CMQT**'s team of chemists, physicists, and materials scientists has been assembled with exactly this challenge in mind. Each team member brings a suite of tools to bear that have been extensively validated by our current **CMQT** research, and a history of successful collaborations with one another as evidenced by joint publications.

Thrust 1. Molecular Spin-Photon Quantum Transduction (co-Leaders: Goldsmith and Fuchs). *The goal of Thrust 1 is to develop quantum-to-quantum transduction between molecular spins and photons, spanning* *organic and hybrid materials, with photons spanning visible, telecom, and microwave frequencies.* Strong interactions are necessary for quantum transduction. During 2020-2024, **CMQT** established spin-photon interactions in (1) molecular spin materials coupled to microcavities, and (2) molecular color centers, which are molecular analogues to diamond nitrogen vacancy (NV) centers where spin determines photon emission. During 2024-2028, **CMQT** will build on these platforms and use spin-photon coupling to link spin-spin transduction platforms from Thrust 2 with photons for wider transmission (**Fig. 1**).

Thrust 2. Molecular Spin-Spin Quantum Transduction (co-Leaders: Johnston-Halperin and Long). *The goal of Thrust 2 is to explore the transfer of angular momentum in spin-spin interactions to develop a modular and generalized approach to transducing quantum information between dissimilar quantum systems.* We will explore both local, e.g., qubits within the same molecule or between coupled molecular-solid state qubits, and distributed, e.g., spin-magnon and spin-magnon-spin, coupling to understand and control flow of quantum information. Work will focus on three regimes of spin-spin coupling: (1) transduction between paramagnetic molecular spins and excitations of ferrimagnetically ordered materials like vanadium tetracyanoethylene, $V(TCNE)_x$, (magnons or spin-waves), (2) transduction between paramagnetic electron spins within extended molecular systems, and (3) transduction between paramagnetic spins on different materials, e.g., molecules and solid-state color centers (**Fig. 1**).

Thrust 3. Molecular Transduction as a Cross-cutting Approach for Readout (co-Leaders: Stern and Flatté). *The goal of Thrust 3 is to pioneer new strategies for employing transduction to enhance readout of quantum information contained in molecular spin qubits.* By deploying approaches from Thrusts 1 and 2, **CMQT** will apply two distinct but complementary methods using transduction between molecular spin and charge states to facilitate readout: (1) transducing a spin qubit to a different spin-sensitive host whose state can be more easily read out, and (2) converting a spin qubit to a charge state accessible for electrical readout, which can potentially be compatible with on-chip quantum information platforms. In both approaches, transduction in or between molecules is a key step that enables new measurement schemes (**Fig. 1**) to address the important and pervasive problem of readout of quantum systems.

Center for Molecular Quantum Transduction (CMQT)	
Northwestern University	Michael Wasielewski (Director), Mark Hersam, Matthew Krzyaniak, George Schatz, Nathaniel Stern, Roel Tempelaar, Ryan Young (Director of Operations)
Princeton University	Nathalie de Leon
University of Iowa	Michael Flatté
Massachusetts Institute of Technology	Danna Freedman
Cornell University	Gregory Fuchs
University of Wisconsin-Madison	Randall Goldsmith
Ohio State University	Ezekiel Johnston-Halperin
University of California, Berkeley	Jeffrey Long
Rice University	Xuedan Ma
University of Chicago	Peter Maurer
University of California-San Diego	Joel Yuen-Zhou

Contact: Michael R. Wasielewski, Director, m-wasielewski@northwestern.edu
847-467-1423, http://cmqt.org