**Center for Molecular Quantum Transduction (CMQT)**
**EFRC Director: Michael R. Wasielewski**
**Lead Institution: Northwestern University**
**Class: 2020 – 2024**

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

Quantum-to-quantum transduction is the coherent exchange of information between quantum systems, which is an essential element of quantum information science. To achieve this goal, **CMQT** explores the underlying interactions among quantum spins, excitons, and vibrational excitations of molecules and molecular materials that are relevant to molecular quantum-to-quantum transduction. **CMQT** comprises an interdisciplinary team of chemists, physicists, and materials scientists with the individual expertise and collective breadth to create knowledge in this emerging area.

*Why use molecules and why now?* To date, research in spin-based QIS has demonstrated success by harnessing and exploiting defects in solids. Using molecule-based systems offers the advantages of structural reproducibility, atomic scale spatial control, structural modularity, and access to uniquely molecular degrees of freedom (DOFs), i.e. the various pairwise interactions between photons, excitons, magnons, phonons, spins, and charges (**Fig. 1**). The number of quantum DOFs available in molecular systems make them attractive targets for quantum transduction, as quantum information can be transferred coherently between DOFs.

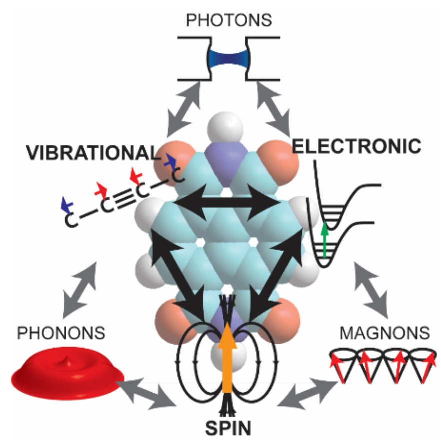


**Fig. 1.** Synergistic **CMQT** research directions. Thrust 1 focuses mainly on spin and electronic DOFs. Thrust 2 adds phononic and magnonic DOFs. Thrust 3 adds photonic and vibrational DOFs.

Molecular architectures provide unmatched flexibility for tailoring the properties that are critical to quantum transduction, and molecular synthesis affords the opportunity to build novel molecular materials from the bottom-up, both of which are at the heart of our proposed research. Thus, molecular systems offer an exceptional opportunity to explore the interface between quantum systems essential for sensing, communication, and computation.

**CMQT** exploits recent breakthroughs from our team including landmark coherence times and stabilities of molecular qubits and quantum materials, the ability to create hybrid qubits, and resonant photonic architectures. As we move 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 are also leveraging cutting-edge 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.

Our goals are embodied by three cross-cutting Thrusts with closely integrated approaches and team synergies that progressively exploit the flexibility and tunability of molecular architectures to address quantum-to-quantum transduction at increasing length scales. Individually, the Thrusts each pose and answer fundamental questions relevant to quantum transduction in different regimes, ranging from local to long-distance. Taken together, the Thrusts develop a transformative integrated framework for how molecules can facilitate quantum transduction at all the scales relevant for quantum information science.

**Thrust 1. Localized Molecular Quantum-to-Quantum Transduction (co-Leaders: Fuchs and Freedman).** *The goal of this Thrust is to develop new mechanisms and strategies to coherently couple localized molecular DOFs and thus lay the foundation for molecular quantum-to-quantum transduction.* Designer molecular qubits with long coherence times and tunable interactions enable quantum state transduction between molecular quantum states demonstrated at the ensemble level to be transitioned rapidly to quantum measurement at the single molecule level. We are exploring synthesis and measurements that leverage atomic precision to enable quantum transduction through local interactions.

**Thrust 2. Distributed Molecular Quantum-to-Quantum Transduction (co-Leaders: Johnston-Halperin and Long).** *The goal of this Thrust is to demonstrate quantum transduction within distributed molecular quantum systems.* Thrust 2 explores quantum transduction in ensembles of tailored molecular qubits including those developed in Thrust 1 that interact *via* spin-magnon coupling to delocalized, highly coherent, magnon modes in molecule-based magnetic thin films. This approach bridges the length scales of single molecules with those of state-of-the-art solid-state quantum systems.

**Thrust 3. Multiscale Molecular Quantum-to-Quantum Transduction (co-Leaders: Goldsmith and Weiss).** *The goal of this Thrust is to use the combination of flying qubits (photons) and molecular DOFs to achieve quantum transduction over multiple length scales within hierarchical quantum systems.* Thrust 3 incorporates the molecular systems established in Thrusts 1 and 2 into photonic structures to demonstrate coherence transfer between multiple molecular DOFs and between these DOFs and photons, including producing heralded photons necessary to probe quantum aspects of energy-important light-harvesting processes, such as natural and artificial photosynthesis.

Achieving molecular quantum-to-quantum transduction is necessarily an interdisciplinary effort, requiring the scope of an EFRC to assemble the necessary expertise in the design and synthesis of molecular and solid-state materials, the capacity to measure coherent quantum states at the single quantum level, and the ability to seamlessly incorporate theory and modeling of materials and measurement schemes with the experimental constraints of real systems. **CMQT** is working toward meeting this challenge.

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