Exploiting Photogenerated Radical Pairs as Spin Qubits for Quantum Information Science

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Chemistry is fundamental to the development of complex matter that can address critical societal problems ranging from energy production to healthcare and information sciences. This same strategy is now being applied to the rapidly expanding field of Quantum Information Science (QIS), which seeks to harness the fundamental quantum nature of matter and photons to advance computation, communication, and sensing. Chemical synthesis affords the opportunity to build novel QIS systems from the bottom up, which allows control over the nature of the quantum bit (qubit) itself, thus enabling the careful tuning of individual quantum states. We will discuss how photogenerated radical pairs can function as spin qubit pairs capable of carrying out quantum operations such as electron spin state teleportation and controlled-NOT (CNOT) logic.

Quantum teleportation is a procedure that transfers a quantum state over an arbitrary distance from one location to another through the agency of quantum entanglement. Measuring a quantum state in an attempt to copy it destroys the information it contains, leaving teleportation as the only option for transmitting the state with high fidelity. Demonstrations of this phenomenon in molecular systems amenable to tailoring by chemical synthesis, with its inherent advantages in constructing complex functional structures, have been notably absent. We have now demonstrated electron spin state teleportation with 90% fidelity in a covalent electron donor-acceptor-stable radical system (A). This result affords the possibility that chemical synthesis can create complex nanostructures for QIS applications.

Implementation of the two-qubit CNOT gate is necessary to develop a complete set of universal gates for quantum computing. Here we demonstrate that a photogenerated entangled spin qubit pair within a covalent donor-chromophore-acceptor molecule (B) can be used to successfully execute a CNOT gate with 97% fidelity. Our results show that photogenerated molecular spin qubit pairs can be used to execute this essential quantum gate at moderate temperatures, which makes it possible to develop structures to execute more complex quantum logic operations using electron spins initially prepared in pure spin states.