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Coherent manipulation of single electronic and nuclear spins in diamond

LILIAN CHILDRESS, Bates College & Harvard University

The complex environment of solid-state systems poses a central challenge for solid-state realizations of quantum bits. Nevertheless, we show that the solid-state environment of a single spin can be understood, controlled, and even utilized as a resource. Using coherent manipulation of a single electronic spin associated with a nitrogen-vacancy (NV) center in diamond, we probe the ^{13}C nuclear spin bath formed by impurities in the surrounding diamond lattice. We show that this environment is effectively separated into a set of individual, proximal ^{13}C nuclear spins which are coupled coherently to the electron spin, and the remainder of the ^{13}C nuclear spins, which cause the loss of coherence. By manipulating the NV center via microwave and optical excitation, we demonstrate robust, room-temperature initialization of the two-qubit register formed by the electronic spin and the nearest-neighbor ^{13}C nuclear spin. Within this register, arbitrary quantum states can be transferred between the electronic and nuclear spin, while the nuclear spin qubit can be well isolated from the electron spin, even during optical polarization and measurement of the electronic state. Finally, we observe coherent interactions between individual nuclear spins, and demonstrate that they have excellent coherence properties, approaching those of isolated atoms and ions. Combined with teleportation-based quantum gates, such registers offer a basis for scalable, optically coupled quantum information systems.