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Proposing Nuclear Supertransfer in an 57Fe Ensemble

In 1964, Terhune and Baldwin proposed that nuclei, when arranged in a solid-state lattice, cannot be treated as independent systems but rather as integrated two-level quantum systems indirectly coupled via interaction with the "common electromagnetic and phonon fields."[1] In 2018, Chumakov et al. demonstrated the superradiant decay of 57Fe nuclei at room temperature, wherein the nuclear decay lifetime exhibited up to a fifteen-fold acceleration for a ten-fold increase in the size of the ensemble excited by a free electron laser. [2] In addition to superradiance, indirect coupling of an ensemble of 57Fe nuclear excitons to ground state nuclei via uniform, shared oscillator modes can stimulate cooperative resonance excitation transfer (i.e., supertransfer), otherwise prohibited by weak nearest-neighbor coupling. By nature of it being a second-order coupling and the destructive interference inherent to symmetric excitation transfer, supertransfer is difficult to engineer in general and has never been demonstrated at the nuclear scale. [3] Herein, we propose a novel solution to realize nuclear excitation supertransfer.

In particular, we propose modifications to the Chumakov et al. experiment in which an 57Fe crystal is housed in a solenoid with an oscillating, strong magnetic field that is uniform over the spatial extent of the sample to facilitate indirect coupling. In addition, we introduce Pb to the boson field to break the destructive interference. More specifically, the 14.4 keV 57Fe M1 magnetic dipole transition can be treated as a two-level system. In the pseudo-spin formalism, resonance excitation transfer is mediated by two symmetric virtual state pathways, which destructively interfere, stunting excitation transfer rates. The Pb, with its 2p electron spin-flip atomic transition, introduces a loss channel to break destructive interference by core-shell electron ionization, potentially enabling observable nuclear supertransfer rates. The demonstration of nuclear excitation supertransfer would unveil new possibilities for engineering nuclear state transitions and possibly nuclear reaction parameters.

[1] Terhune and Baldwin. Phys. Rev. Lett., 14:589–591,1965.
[2] Chumakov et al. (2018). Nat. Phys., 14(3), 261–264.
[3] Loyd and Mosheini (2010). New Journal of Physics 12, 075020.

Theme

Theme 2. Quantum effects in energy processes and materials

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