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Nucleonics: Toward the Precise Control of Nuclear States

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In 2023, we published "The Emergence of Quantum Energy Science,"which laid out how quantum principles well-known in the realm of Quantum Information Science have been put to use in various energy fields, including solar cell engineering, batteries, and nuclear engineering [1]. Since then, our focus has remained on nuclear applications, collecting theoretical and experimental evidence that suggests the possibility of precisely manipulating nuclear states. Just as the semiconductor revolution of the 1940s enabled precise control over electronic states—giving rise to modern *electronics*—we anticipate that *nucleonics*, the precise manipulation of nuclear states, will be similarly transformative.

Historically, nuclear state manipulation has been coarse, relying on high-energy sources such as particle accelerators or nuclear chain reactions. As a result, nuclear engineering has focused on engineering *around* nuclear reactions, rather than engineering the reactions *themselves*. Nuclear decay and reaction parameters have been regarded as fixed and immutable, limiting possibilities for highly controlled nuclear processes.

In this presentation, we outline key theoretical and experimental findings supporting nucleonics. At the core of this approach is the coupling of nuclear states with their environment, particularly through quasi-particles in solid-state lattices such as phonons and magnons (as explored by Matt Lilley in his presentation). Such couplings may enable nonradiative transfer of energy between nuclear donor and receiver systems under conditions of resonance and aided by well-known quantum phenomena such as Dicke enhancement [2]. In parallel to model development, we pursue experimental work to test corresponding hypotheses under a research program funded by the US Department of Energy (see my colleague Matt DeCapua's presentation) [3]. We also motivated and designed extensions to well-established experiments, such as Chumakov et al.'s demonstration of nuclear superradiance (see Jonah Messinger's presentation on nuclear supertransfer) [4].

Nucleonics promises fundamentally new approaches to the exploitation of nuclear energy, the remediation of nuclear waste and the transmutation of materials. Key challenges involve bridging the gap between traditionally disconnected fields such as solid-state physics and nuclear physics as well as quantum engineering and nuclear engineering [5]; and the continued integration of model development with experiments reporting nuclear anomalies. This presentation concludes with a roadmap for the field of nucleonics, outlining key experimental and theoretical milestones. Our goal is to establish a rigorous scientific foundation for this emerging field and to pave the way for its technological realization. We invite researchers across the quantum energy community to contribute to this effort, as advancing nucleonics will require broad interdisciplinary collaborations.

[1] Metzler et al. (2023). The emergence of quantum energy science. J. Phys. Energy, 5(4), 041001.
[2] Metzler et al. (2024). Known mechanisms that increase nuclear fusion rates in the solid state. New J. Phys., 26(10), 101202.
[3] US DOE (2023). US Department of Energy announces funding to projects studying low-energy nuclear reactions. https://arpa-e.energy.gov
[4] Chumakov et al. (2018). Superradiance of an ensemble of nuclei excited by a free electron laser. Nat. Phys., 14(3), 261–264.
[5] Aleta et al. (2019). Explore with caution: Mapping the evolution of scientific interest in physics. EPJ Data Sci., 8(1), Art. 1.

Theme

Theme 2. Quantum effects in energy processes and materials

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