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Ab Initio Nuclear Theory for Neutrinoless Double-Beta Decay

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The search for neutrinoless double-beta decay ($0\nu\beta\beta$) stands among the most promising avenues for uncovering new physics. An observation would confirm Majorana neutrinos, establish lepton-number violation, and potentially reveal the absolute neutrino mass scale. As next-generation experiments propose to push half-life sensitivities up to two orders of magnitude beyond previous efforts, reliable nuclear matrix elements (NMEs) are essential, since extracting neutrino masses or distinguishing decay mechanisms is impossible without them. Because $0\nu\beta\beta$ is an inherently beyond-Standard-Model (BSM) process, multiple mechanisms may contribute to the decay. While the standard light-neutrino channel has been extensively studied, short-range contributions such as heavy-neutrino exchange remain far less explored within nuclear theory. Heavy sterile Majorana neutrinos are strongly motivated in many BSM frameworks, e.g. seesaw models, where they may play a significant or even dominant role in $0\nu\beta\beta$ decay.

We present the first ab initio calculations of heavy-neutrino-exchange NMEs for four major experimental isotopes. Starting from internucleon forces derived from chiral effective field theory, we use the in-medium similarity renormalization group to obtain effective valence-space Hamiltonians and consistently transformed decay operators. Because heavy-neutrino exchange is short-range, the associated operators show strong sensitivity to the renormalization procedure. Using different chiral interactions and operator-renormalization choices, we obtain NME ranges that are consistent with—but generally smaller than—those from phenomenological methods. Combining our ab initio NMEs with current experimental limits yields a minimum lower bound of 2.51×10^8 GeV for the effective heavy-neutrino mass, assuming heavy-neutrino exchange dominates the decay.

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