Reversal of the isotopic dependence of energy confinement from current to future tokamaks

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Isotopes are widely observed to enhance the energy confinement across various tokamaks, as evidenced by a scaling law $\tau_E \propto M_i^{\sigma}$, where τ_E denotes the energy confinement time and M_i represents the isotope mass-to-hydrogen mass ratio. The exponent σ typically falls within the range of approximately 0.2 to 0.5. Recent advancements, exemplified by a sophisticated global gyrokinetic simulation [Lei Qi et al., Phys. Rev. Res., **6**, L012004, (2024)], have effectively quantified these isotope effects. This breakthrough prompts an exploration of the implications for future tokamaks, such as ITER, DEMO, and forthcoming fusion plants, which are characterized by larger dimensions or stronger magnetic fields. Notably, while current tokamaks typically exhibit $\rho^{*-1} \equiv \frac{a}{\rho_i} \sim 10^2$, future iterations are anticipated to feature $\rho^{*-1} \sim 10^3$. Dedicated gyrokinetic simulations reveal a reversal of the isotopic dependence of energy confinement from current to future tokamaks. Isotopes are found to degrade the energy confinement time as ρ^{*-1} approaches 10^3. This reversal prompts a comprehensive analysis of the underlying physical mechanisms, which will be elaborated upon in this study.