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Influence of Electrons on Atomic Nuclear Transitions

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Abstract

Nuclear excitation energies are typically in the keV–MeV range, whereas electronic energy levels are usually on the order of 10 eV. As a result, the influence of electrons on nuclear transitions has often been regarded as negligible. However, the development of the ^{229}Th nuclear clock, whose first excited nuclear state lies at only 8.3 eV, has shown that electronic effects can become important and may strongly modify nuclear transition rates in a charge-state-dependent manner. For example, the measured half-lives of ^{229}Th differ significantly in 1+, 2+, 3+, and 4+ ions embedded in crystals [1–4]. Meanwhile, advances in highly charged ions make it possible to match keV-scale electronic and nuclear energy levels, providing a new route to manipulate nuclear transitions through electronic degrees of freedom.

The hyperfine interaction resolves nuclear radiative decay into hyperfine-structured branches. Through nuclear hyperfine mixing, the lifetime of the ^{229}Th isomer can be strongly shortened in highly charged ions [5]. In this work, we further show that destructive interference between nuclear and electronic transition contributions, enabled by nuclear hyperfine mixing, can suppress selected decay channels [6]. In some cases, a single hyperfine transition channel can be inhibited by several tens of times. This suggests that the combination of ion traps and highly charged ions may provide a pathway toward narrower nuclear-clock transitions under suitable conditions.

The mechanism is general and is not limited to ^{229}Th. We also apply the theory to ^{193}Pt and ^{201}Hg ions and find similar channel-selective transition inhibition. These results establish a new route for engineering nuclear transition properties and open promising opportunities for nuclear quantum optics and related technologies where precise control of nuclear coherence and lifetimes is essential.

References

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