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A state-of-the-art many-body atomic response of xenon and germanium atom used for direct dark matter detection

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In recent years, significant strides have been made in direct dark matter detection experiments, driven by advancements in detector technologies and the scaling up of detector sizes, predominantly motivated by the Weakly Interacting Massive Particle (WIMP) paradigm. In the realm of dark matter (DM) scattering processes, understanding the contributions from electronic and nuclear degrees of freedom is crucial. While the prevailing approach in constraining DM interactions typically focuses on one type at a time, it's essential to acknowledge that detector-measured events stem from a confluence of potential sources.
Moreover, it is essential from an experimental standpoint to ascertain the optimal process and kinematic range for constraining specific types of dark matter interactions with electrons or nucleons. Achieving this necessitates reliance on theoretical analysis. In this study, we endeavor to tackle these inquiries utilizing atomic detectors, notably Germanium and Xenon, where calculations are predominantly feasible using nonrelativistic effective field theory. We calculate and examine their scattering with nonrelativistic light dark matter (LDM) particles spanning a mass range from MeV to GeV. The sub-GeV dark matter regime remains relatively underexplored yet holds significant promise for next-generation experiments. Our investigation delves into computing the atomic response function (ARF) of target atoms like Germanium and Xenon, pivotal for the operation of DM search experiments and the exploration of DM-electron interactions. Employing an approach grounded in ab initio calculations within the framework of the multi-configuration relativistic random-phase approximation (MCRRPA) and Frozen Core Approximation (FCA), we unveil that the ionization rate of atoms via DM-electron scattering can generally be delineated by four independent atomic responses. Specifically, we present ARF for DM-atom scattering through interactions at the leading order (LO), leveraging robust, state-of-the-art atomic many-body calculations. Our novel atomic responses demonstrate numerical significance across various scenarios, such as the investigation of light-dark matter (LDM) particle scattering with atomic electrons within the effective field theory framework. Subsequently, we utilize these atomic responses to establish 90 percent confidence level (C.L.) exclusion limits on the strength of a wide array of DM-electron interactions, inferred from the null results of DM search experiments utilizing Germanium and Xenon targets. Our computations yield differential cross-sections within a 5% error margin in RRPA and 20% in FCA, underpinning the reliability and precision of our findings.
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