Dark matter scattering off electrons

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Synopsis Dark matter particles have small velocity in comparison with velocities of atomic electrons. In the adiabatic approximation all the transitions could be exponentially suppressed. However, due to the cusp of Coulomb functions at $r = 0$ the suppression of atomic ionization is only by a power of the momentum transfer, q^{-n}. The electron relativistic effects are large near $r = 0$, change the power from $n = 8$ in the non-relativistic case to $n = 6 - Z^2\alpha^2$ and enhance the differential cross section by up to 1000 times. The results of our relativistic many-body calculations are used to interpret possible detection of Dark matter by DAMA collaboration as well as the results of other experimental groups.

Atoms and molecules can become ionized during the scattering of a slow, heavy particle off a bound electron. Such an interaction involving leptophilic weakly interacting massive particles (WIMPs) is a possible explanation for the anomalous 9σ annual modulation in the DAMA dark matter direct detection experiment [1]. We demonstrate the applicability of the Born approximation for such an interaction by showing its equivalence to the semiclassical adiabatic treatment of atomic ionization by slow-moving WIMPs.

In Refs. [2, 3] we consider the WIMP-type dark matter scattering on electrons that results in atomic ionization and can manifest itself in a variety of existing direct-detection experiments . The scattering on electrons requires new light force carriers. We account for such new forces explicitly, by introducing a mediator particle with scalar or vector couplings to dark matter and to electrons. We then perform numerical relativistic Hartree-Fock-Dirac calculations (with finite nuclear size) of atomic ionization relevant to the existing experiments. Our goals are to consistently take into account the atomic physics aspect of the problem (e.g., the relativistic effects, which can be quite significant) and to scan the parameter space - the dark matter mass, the mediator mass, and the effective coupling strength - to see if there is any part of the parameter space that could potentially explain the DAMA modulation signal. While we find that the modulation fraction of all events with energy deposition above 2keV in NaI can be quite significant, reaching 50 %, the relevant parts of the parameter space are excluded by the XENON10 and XENON100 experiments.

Using the relativistic Hartree-Fock approximation, we [4, 5] also calculated the rates of atomic ionization by absorption of pseudoscalar particles (called axions for short, although they may differ from QCD axions by their mass) in the mass range from 0 to ~ 50 keV. We present numerical results for atoms relevant for the direct dark matter searches (*e.g.* Na, Ar, Ge, I and Xe), as well as the analytical formula which fits numerical calculations with few per cent accuracy and may be used for multi-electron atoms, molecules and condensed matter systems.The fitting is done for $18 < Z < 60$ and for dark matter particle energies from 10 to 50 keV.

References

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