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Atomic Methods for Axion and WIMP Detection

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We present our recent proposals to exploit the parity and time-reversal violating effects in atoms, nuclei, and molecules to search for evidence of various background cosmic fields, and to constrain the interaction strengths of these fields with fermions.

Candidates for such background fields include dark matter (e.g. axions) and dark energy, and also are motivated by various Standard Model extensions.
Certain interactions of static and dynamic background cosmic fields would lead to the mixing of opposite parity states in atoms and molecules. This would, in turn, give rise to observable parity and time-invariance violating effects. The measurement of such effects would shed light on the interactions that gave rise to them.

Of particular interest is the interaction of a dynamic pseudoscalar field with atomic/molecular electrons and nuclei. Such a field could describe axions, a hypothetical pseudoscalar particle invoked to solve the strong CP problem from QCD, now also a leading cold dark matter candidate.
We perform calculations of the parity and time-invariance violating effects that such a field would induce in atoms [1,2], and demonstrate a potential very large enhancement of the effects in diatomic molecules.

Crucially, the effects we consider here are linear in the small parameter that quantifies the interaction strength between the dark matter particles and ordinary matter particles; most current dark matter and axion searches rely on effects that are proportional to quadratic and higher powers of this parameter.

Oscillating electric dipole moments have the potential to be measured with very high accuracy, and experimental techniques in this field are evolving fast, making this a particularly exciting area for potential discovery in the near future.
Pairs of closely spaced opposite parity levels that are found in diatomic molecules may also lead to a significant enhancement in these effects [2,3].

We are also investigating a possible explanation for the DAMA annual modulation result - a 9 sigma result claimed to be a detection of WIMP dark matter.
This result is controversial, however, because of null results of several other experiments.
The DAMA experiment is sensitive to scattering off both electrons and nuclei. Most other DM detection experiments, however, reject pure electron events, meaning that DM particles that interact favorably with electrons could potentially explain the DAMA modulation without being ruled out by the other null results.
We perform accurate relativistic Hartree-Fock atomic calculations to determine model-independent cross-sections and event rates for the atomic ionization induced by the interaction with dark matter for xenon, iodine, and sodium.
Our results have implications for the interpretation of the DAMA annual modulation signal in terms of WIMP–electron scattering.

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2. B. M. Roberts, Y. V. Stadnik, V. A. Dzuba, V. V. Flambaum, N. Leefer, and D. Budker. Parity-violating interactions of cosmic fields with atoms, molecules, and nuclei: Concepts and calculations for laboratory searches and extracting limits [Editors' Suggestion]. Phys. Rev. D 90, 096005 (2014).
3. Y. V. Stadnik, and V. V. Flambaum. Axion-induced effects in atoms, molecules, and nuclei: Parity nonconservation, anapole moments, electric dipole moments, and spin-gravity and spin-axion momentum couplings. Phys. Rev. D, 89, 043522 (2014).

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