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Exotic Atoms in Flight

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The precision spectroscopy and decay properties of exotic atoms, such as antihydrogen and true muonium provide important tests of quantum electrodynamics as well as fundamental symmetries of the Standard Model. The production mechanisms for such exotic atoms are also of great interest, since they have important implications for analogous phenomena in hadron physics. For example, the production of relativistic antihydrogen has led to a new method for computing hadronization at the amplitude level in color-confining quantum chromodynamics using the off-shell T-matrix for quarks and gluons and the boost-invariant light-front wavefunctions of hadrons. Conversely, the application of Dirac's front form; i.e., light-front quantization, provides a Lorentz-frame-independent description of atoms in flight and unexpected insights into the Lorentz-boost properties of atomic wavefunctions. The front-form also provides frame-independent relativistic Hamiltonian methods for solving perturbative and non-perturbative problems in QED. I will also discuss other QED/QCD analogs such as nuclear-bound quarkonium – heavy quark-antiquark states bound to hadrons and nuclei through the QCD van der Waals interaction – and "atomic alchemy" – the conversion of muonic atoms to electronic atoms – the atomic analog of exclusive flavor-changing B-meson weak decay. The unambiguous renormalization scale-setting procedure of QED provides the key for setting the renormalization scales for processes in QCD, independent of the choice of renormalization scheme: the "principal of maximal conformality". The analysis of QED scattering amplitudes which are sensitive to the Coulomb phase has led to the discovery of analogous quark rescattering effects in QCD, including nonzero factorization-breaking phenomena such as the pseudo-T-odd Sivers effect in polarized-proton semi-inclusive deep inelastic lepton scattering reactions. Finally, I will discuss how the use of light-front quantization resolves the apparent 10^{120} discrepancy between properties of the QED vacuum and the measured cosmological constant.

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