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Measuring α-variation using highly-charged ions: clocks, calculations and astrophysics

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Several recent proposals to measure α-variation use highly-charged ions, in which the effects of a possible variation are enhanced [1]. These systems include potential new clocks that are predicted to have extraordinarily high accuracy [1-4]. In systems where the transitions are available due to level crossings, the clocks can have extremely high sensitivity to variation of the fine-structure constant α, potentially improving current limits on time-variation of α by up to two orders-of-magnitude.

The experimental spectroscopy of one such candidate, the Ir17+ ion which has two holes in the otherwise closed 4f14 5s2 valence shells, has shown that current theoretical methods have severe limitations in accurately describing the spectrum [5]. That study included (along with the experimental spectrum) the results of several calculations including different variants of configuration interaction (CI), multiconfigurational Dirac-Fock, and Fock-space coupled cluster. None of the theories tested were able to unambiguously identify the entire observed spectrum. Furthermore many existing methods of calculation –such as the combined configuration interaction and many-body perturbation theory (CI+MBPT), correlation potential methods, and coupled-cluster methods –are designed to work well in one or two-valence-electron atoms and particularly in near-neutral systems.

We have developed an ab initio method of calculating atomic spectra and properties in complicated systems, such as HCIs and particularly where electron-holes play an important role. Based on the CI+MBPT method [6], we have implemented Wick contractions numerically in AMBiT allowing the inclusion of configurations with arbitrary numbers of valence holes and electrons. As a first test case, we have performed calculations of spectra and sensitivity to α-variation for the Hg+ ion, where the clock transition 6s to 5d−1 6s2 has been compared with an Al+ clock to get the best current limit on time-variation of α [7]. We present results of the full CI+MBPT method with holes, and updated limits on time-variation of α based on the existing experiment [8].

The enhanced sensitivity to α-variation of highly-charged ions is also exploited in astrophysical measurements of metal lines in the spectra of white-dwarf stars [9]. These are used to probe the dependence of α on a strong gravitational field. While the FeV and NiV ions used in this study are less highly-charged, many of the limitations in the accuracy of calculations are common to the clock HCIs.

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Summary

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