Time–dependent recoil in vacuum: Improved sensitivity to hyperfine fields and nuclear moments

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The so-called recoil in vacuum (RIV) method has proved powerful as a technique to measure the magnetic moments of short-lived excited states of exotic nuclei produced as radioactive beams [1, 2]. When a recoiling ion from a nuclear reaction leaves the target and enters vacuum, the free-ion hyperfine fields couple the nuclear angular momentum, $\boldsymbol{I}$, to the atomic angular momentum, $\boldsymbol{J}$, and together they undergo a precession about the total, $\boldsymbol{F}$, at a frequency proportional to the nuclear moment times the strength of the hyperfine magnetic field at the nucleus. The method can therefore be used either to study free-ion hyperfine interactions (if the nuclear moment is known) or measure nuclear moments (if the hyperfine fields are known). In principle, the hyperfine fields can be calculated by atomic physics calculations such as Multiconfiguration Hartree Fock (MCHF), especially if the ions have simple electronic configurations (i.e. few electrons remain bound to the ion).

To date, the TDRIV measurements in which the hyperfine fields are determined precisely by atomic physics calculations have been applied only to ions with H-like (or near H-like) configurations. Because the hyperfine frequency of the $1s$ electron increases as Z^3, the highest-Z nucleus with a single electron for which the TDRIV method has been observed is ^{24}Mg. At higher Z the precession due to H-like configurations becomes too fast to observe. Thus to apply the method to higher-Z nuclei requires that one consider the weaker fields of shielded electrons, such as Li-like ions ($2s$ electron) or Na-like ions ($3s$ electron). The disadvantage is that a Na-like ion, for example, has many more excited states than an H-like ion, with the potential to wash out the unique frequency of the atomic ground-state configuration.

Nevertheless, recent measurements at the Australian National University on Ge and Se ions [3], have found that there is a marked difference between the hyperfine fields of Ge and Se ions recoiling into vacuum under nearly identical conditions. This observation implies that the net hyperfine fields for Ge and Se ions, with about 12 remaining electrons, are being determined by relatively few low-excitation atomic configurations. If this inference can be confirmed, there is a possibility that precise g-factor measurements can be performed, based on the hyperfine fields of alkali-like electron configurations. We are planning time-differential measurements to test this hypothesis. Details of the experiment design and progress in the experiments will be reported.

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