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Characterisation of high-intensity light sources by ponderomotive forces on highly-charged ions

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The ultra-intense X-ray pulses produced by novel free-electron lasers promise many applications, e.g. for protein structure-determination or time-resolved molecular spectroscopy. This requires the pulses to be well-characterised in terms of focal shape, duration and intensity. Providing tools for calibrating these properties is however a difficult task, leading to various approaches utilising different physical effects.

Spatial inhomogeneity in oscillatory electromagnetic fields causes the well-known ponderomotive force to be exerted on charged particles along the negative field gradient. As experiments with focused laser pulses on helium atoms have shown, due to Coulomb attraction, the net drift momentum of bound electrons is transferred to the ionic core, giving rise to a significant center-of-mass acceleration. From measurements on the deflection of atomic beams or trapped highly charged ions one may acquire information on the laser's intensity and gradient, possibly providing an additional tool for calibration.

A numerical implementation and first results showing this beyond-dipole effect for a single-electron system will be presented. As the large spatial extent of the predominantly ionised electronic wave function poses an enormous challenge in terms of computational resources, the solution of the Schrödinger equation is restricted to a one-dimensional model to ensure a high degree of convergence. The motion of the ionic core is obtained by a semi-classical description employing Ehrenfest dynamics via adiabatic coupling. It is found that, depending on the ionisation potential, at certain intensity thresholds the character of the deflection changes, with effects due to the gradient-dependence of the ponderomotive forces being increasingly outweighed by the field's direction at the instance of ionisation.

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