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Laser Spectroscopy of the Heaviest Elements

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The study of the hyperfine structure and the isotope shifts of spectral lines enables properties of atomic nuclei to be obtained in a comprehensive and nuclear model-independent way. These properties include the spin, magnetic dipole and electric quadrupole moments, and changes in the mean-square charge radii. Hence, the establishment of such optical studies in the region of deformed nuclei around nobelium-254 would inevitably attract a high level of interest of both, nuclear physics and atomic physics communities. For atomic physics, for instance, already the observation of atomic transitions in these very heavy elements would provide a stringent test of atomic theories and models addressing relativistic and quantum electrodynamic effects.
These studies, however, stagnated for many years at the element fermium for which weighable samples can still be obtained. Elements beyond fermium are challenging in this respect as they are solely produced in nuclear fusion reactions, best at rates of a few atoms per second when utilizing powerful particle accelerators. Only recently successful laser spectroscopy of nobelium in single atom-at-a-time quantities was reported [M. Laatiaoui et al., Nature, 538 (2016) 495]. Several atomic transitions in nobelium-254 were observed and characterized for the first time, providing valuable data and a powerful benchmark for atomic modelling.
To this end, the so-called RAdiation Detected Resonance Ionization Spectroscopy (RADRIS) technique was employed. The fusion products of interest were separated from the primary beam and thermalized in a buffer-gas stopping cell. Those remaining in a positive charged state were accumulated on a catcher filament. Then, the accumulated atoms were evaporated from the filament, ionized in a two-step photoionization process by pulsed lasers and finally guided by suitable electric fields to a silicon detector where they were unambiguously identified via their unique radioactive decay fingerprint.
The investigations were extended to the isotopes nobelium-253 and nobelium-252, which were produced at even lower rates than nobelium-254. Moreover, first steps towards laser spectroscopy of lawrencium-255 were initiated. In my talk, I will highlight the recent findings and give prospects for high-precision measurements using the in-jet laser ionization spectroscopy [R. Ferrer et al., accepted to Nat. Commun.] capable of resolving nuclear isomerism in atomic spectra of these heaviest radionuclides.

Primary author: Dr LAATIAOUI, Mustapha (KU Leuven)

Presenter: Dr LAATIAOUI, Mustapha (KU Leuven)