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Doppler and sympathetic cooling for the investigation of short-lived radionuclides

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Ever since its introduction in the mid 1970s, laser cooling has become a fundamental technique to prepare and control ions and atoms for a wide range of precision experiments. In the realm of rare isotope science, for instance, specific atom species of short-lived radionuclides have been laser-cooled for fundamental-symmetries studies [1] or for measurements of hyperfine-structure constants [2] and nuclear charge radii [3].

Nevertheless, because of its simplicity and element-universality, buffer-gas cooling in a linear, room-temperature Paul trap is more commonly used at contemporary radioactive ion beam (RIB) facilities. Recent advances in experimental RIB techniques, especially in laser spectroscopy and mass spectrometry, would however strongly benefit from ion beams at much lower beam temperature as in principle attainable by laser cooling. In addition, sympathetic cooling of ions which are co-trapped with a laser-cooled ion species could open a path for a wide range of sub-Kelvin RIBs.

Within the MIRACLS low-energy apparatus, we demonstrate that laser cooling is compatible with the timescale imposed by short-lived radionuclides as well as with existing instrumentation at RIB facilities [4]. To this end, a beam of hot 24Mg+ ions is injected into a linear Paul trap in which the ions are cooled by a combination of a low-pressure buffer gas and a 10-mW, cw laser beam of ~280 nm. Despite an initial kinetic energy of the incoming ions of several electronvolts at the trap's entrance, temporal widths of the extracted ion bunch corresponding to an ion-beam temperature of around 6 K are obtained within a cooling time of 200 ms. Moreover, sympathetic cooling of co-trapped K+ and O2+ ions was demonstrated. As a first application, a laser-cooled ion bunch is transferred into a multi-reflection time-of-flight mass spectrometer. This improved the mass resolving power by a factor of 4.5 compared to conventional buffer-gas cooling.

This contribution will include the experimental results of our laser-cooling studies as well as a comparison to our 3D simulations of the cooling process which paved the way for further improvements of the technique. An outlook to future experiments with laser- and sympathetically cooled ions at radioactive ion beam facilities will be given.

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