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Coulomb crystallization of sympathetically cooled highly charged ions

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Wave functions of inner-shell electrons significantly overlap with the nucleus, whereby enormously magnified relativistic, quantum electrodynamic (QED) and nuclear size effects emerge. In highly charged ions (HCI), the relative reduction of electronic correlations contributions improves the visibility of these effects. This well known facts have driven research efforts with HCI, yet the typically high temperatures at which these can be prepared in the laboratory constitutes a serious hindrance for application of laser spectroscopic methods. The solution for this, cooling HCI down to crystallization has remained an elusive target for more than two decades. By applying laser cooling to an ensemble of Be^{+} ions, we build Coulomb crystals that we use for stopping the motion of HCI and for cooling them. HCI, in this case Ar^{13+} ions are extracted from an electron beam ion trap with an energy spread of a few 100's of eV, due to the ion temperature within the trap. Carefully timed electric pulses in a potential-gradient decelerate and bunch the HCI. We achieve Coulomb crystallization of these HCI by re-trapping them in a cryogenic linear radiofrequency trap where they are sympathetically cooled through Coulomb interaction with the directly laser-cooled ensemble. Furthermore, we also demonstrate cooling of a single Ar^{13+} ion by a single Be^{+} ion, prerequisite for quantum logic spectroscopy with potentially 10^{-19} relative accuracy. The strongly suppressed thermal motion of the embedded HCI offers novel possibilities for investigation of questions related to the time variation of fundamental constants, parity non-conservation effects, Lorentz invariance and quantum electrodynamics. Achieving a seven orders-of-magnitude decrease in HCI temperature, from the starting point at MK values in the ion source down to the mK range within the Coulomb crystal eliminates the major obstacle for HCI investigation with high precision laser spectroscopy and quantum computation schemes.