PENNING-TRAP EXPERIMENTS FOR EXTREME-FIELD PHYSICS

M. Vogel[*,†,1], **Z. Andelkovic**[*], **G. Birkl**[‡], **M. Ebrahimi**[*], **Z. Guo**[*], **T. Murböck**[‡], **W. Nörtershäuser**[‡], **W. Quint**[*,§], **S. Ringleb**[¶,†], **S. Schmidt**[‡], **N. Stallkamp**[*], **Th. Stöhlker**[*,†], **M. Wiesel**[*,‡,§]

[*] GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany
[†] Helmholtz-Institut Jena, 07743 Jena, Germany
[‡] Technische Universität Darmstadt, 64289 Darmstadt, Germany
[§] Physikalisches Institut, Ruprecht Karls-Universität Heidelberg, 69120 Heidelberg, Germany
[¶] Institut für Optik und Quantenelektronik, Universität Jena, 07743 Jena, Germany

Synopsis We present the concept, status and results of three Penning-trap experiments that address extreme-field physics with highly charged ions confined in Penning traps. The ARTEMIS experiment uses highly charged ions as nanoscale high-field laboratories to the end of measuring the electron's magnetic moment when subjected to electromagntic fields up close to the Schwinger limit. The SpecTrap experiment adresses precision laser spectroscopy of confined highly charged ions, for which cooling by ion Coulomb crystals has been implemented. The HILITE experiment allows advanced studies of short-pulse particle-light interaction with highly charged ions subjected to high-intensity laser fields.

The physics of extreme electromagnetic fields comprises two interesting yet distinct regimes: on the microscopic scale there are extreme electric and magnetic fields in the vicinity of an atomic nucleus which significantly alter the properties of bound electrons. With field strengths almost up to the Schwinger limit, contributions from quantum electrodynamics play an important role in electronic structure, state lifetimes, and magnetic moments. Corresponding calculations can be tested with utmost accuracy. In turn, this allows access to fundamental constants and symmetries.

This can superbly be studied in highly charged ions when confined in a Penning trap and cooled close to rest. We present the ARTEMIS experiment [1] within the HITRAP collaboration for precision optical and microwave spectroscopy of confined and cooled highly charged ions, aimed at measurements of electron magnetic moments (g-factors) on the ppb level of accuracy, nuclear magnetic moments on the ppm level of accuracy, and of higher-order Zeeman effects [2]. We present the concept, status, and first results.

Particularly for optical precision spectroscopy of highly charged ion as addressed by the SpecTrap experiment [3], cooling of the confined ions under investigation is an essential prerequisite. We have implemented cooling of externally produced ions down to the Doppler limit by embedding into a crystal of singly charged Mg ions. Such crystals have been produced by a combination of buffer gas cooling and laser cooling in the Penning trap, reducing the ion kinetic energy by more than eight orders of magnitude from hundreds of eV to micro-eV within seconds [4]. Sympathetic cooling of highly charged ions by such crystals opens the way to Doppler-free optical spectroscopy of fine structure and hyperfine transitions in these ions.

Macroscopic counterparts of the microscopic extreme fields in nuclear vicinities are generated in foci of highly intense lasers. The electromagnetic fields in and close to the laser focus evoke strongly non-linear optical effects in atoms and ions such as multi-photon ionization to high charge states. We present the HILITE experiment which features a Penning trap for the preparation and positioning of well-defined ion targets, as well as for non-destructive detection and confinement of reaction products in studies with various high-intensity and / or high-energy lasers [5].

References

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[1]E-mail: m.vogel@gsi.de