Symposium Precision spectroscopy of highly ionized matter (SYPS)

jointly organized by
the Atomic Physics Division (A),
the Mass Spectrometry Division (MS), and
the Plasma Physics Division (P)

Danyal Winters
GSI Helmholtzzentrum für
Schwerionenforschung GmbH
Planckstraße 1
D-64291 Darmstadt
D.Winters@gsi.de

Frank Herfurth
GSI Helmholtzzentrum für
Schwerionenforschung GmbH
Planckstraße 1
D-64291 Darmstadt
F.Herfurth@gsi.de

Paul Gibbon
Jülich Supercomputing Centre
Forschungszentrum Jülich GmbH
D-52425 Jülich
P.Gibbon@fz-juelich.de

The symposium for "Precision spectroscopy of highly ionized matter" brings together three separate fields: plasma physics, atomic physics, and mass spectrometry. Six well-known representatives from these communities have been invited to give overviews of their respective research areas, highlighting progress in high-precision spectroscopic methods. These sophisticated techniques are the key to probing highly ionized matter in various forms, including: slow and cold highly charged ions in traps; fast and relativistic highly charged ions in EBITs and storage rings; and hot, dense plasmas generated by high-intensity lasers.

Overview of Invited Talks and Sessions

(lecture room A 001)

Invited Talks

SYPS 1.1	Fr	11:00–11:30	A 001	**Status of QED tests in heavy highly charged ions** — •Paul Indelicato
SYPS 1.2	Fr	11:30–12:00	A 001	**Penning trap mass spectrometry with highly charged ions** — •Szilard Nagy
SYPS 1.3	Fr	12:00–12:30	A 001	**Diagnostic of Hot Dense Plasmas by Advanced XUV and X-ray Spectroscopy** — •Ingo Uschmann
SYPS 1.4	Fr	12:30–13:00	A 001	**Measurements of masses and beta-lifetimes of stored exotic highly charged ions** — •Fritz Bosch
SYPS 2.1	Fr	14:00–14:30	A 001	**Exciting and ionizing trapped highly charged ions with electrons and photons in an EBIT** — •José R. Crespo Lopéz-Urrutia
SYPS 2.2	Fr	14:30–15:00	A 001	**Precision x-ray spectroscopy of intense laser-plasma interaction experiments** — •Nigel Woolsey

Sessions

SYPS 1.1–1.4	Fr	11:00–13:00	A 001	**Precision spectroscopy of highly ionized matter I**
SYPS 2.1–2.2	Fr	14:00–15:00	A 001	**Precision spectroscopy of highly ionized matter II**

SYPS 1: Precision spectroscopy of highly ionized matter I

Time: Friday 11:00–13:00 Location: A 001

Invited Talk SYPS 1.1 Fr 11:00 A 001

Status of QED tests in heavy highly charged ions — •Paul Indelicato — Laboratoire Kastler Brossel, École Normale Supérieure, Université Pierre et Marie Curie, 75005 Paris, France

In the last few years the use of heavy-ion storage rings and low-energy ion sources has lead to a steady increase of the availability of high-precision measurements of transition energies in few-electron highly charged ions. At the same time, accurate calculations of QED and relativistic effects in one, two, and three-electron systems have become available, which include all one- and two-loop radiative corrections, evaluated to all orders in the fine structure constant, as well as exact second-order electron-electron interaction corrections. In this talk I will present recent results obtained at the ESR storage ring in Darmstadt, and with low-energy ion sources in Heidelberg and Paris. Elements ranging from medium-Z to uranium have been studied. Comparison with theory and experiment will be discussed. Perspectives connected with future facilities and progress in hydrogen and helium will be outlined.

Invited Talk SYPS 1.2 Fr 11:30 A 001

Penning trap mass spectrometry with highly charged ions — •Szilard Nagy — Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

The application of ions with multiple charges in high-precision Penning trap mass spectrometry has a major benefit. The measurable quantity, *i.e.* the cyclotron frequency ν_c of a charged particle in a magnetic field B, increases linearly with the charge q according to $\nu_c = qB/(2\pi m)$, leading to a potentially large gain in the relative precision $\delta\nu_c/\nu_c$ of the measurement. Results from the SMILETRAP Penning trap mass spectrometer for highly charged ions will be reviewed with emphasis on fundamental physics questions. Among the highlights are: a newly evaluated ^{76}Ge double beta-decay Q-value relevant for the search of neutrinoless double beta-decay; the most precise tritium beta-decay Q-value, which is of importance in the search for a finite rest mass of the electron anti-neutrino; the masses of the lithium-like and hydrogen-like ^{40}Ca ions, which are indispensable input values for the evaluation of g-factor measurements of the bound electron in these ions, and bound state QED tests. New Penning trap facilities dedicated to highly charged ions will be discussed, such as HITRAP at GSI Darmstadt or the PENTA-TRAP high-precision Penning trap mass spectrometer at the Max Planck Institute for Nuclear Physics in Heidelberg.

Invited Talk SYPS 1.3 Fr 12:00 A 001

Diagnostic of Hot Dense Plasmas by Advanced XUV and X-ray Spectroscopy — •Ingo Uschmann — Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität, 07743 Jena, Germany

Hot and dense plasmas are currently investigated for their importance both as ultrashort, bright XUV and x-ray sources and in the context of Inertial Confinement Fusion. The development of high intensity- and high power laser systems as well as short wavelength Free-Electron Lasers has provided the means to create laboratory plasmas with high temperatures and nearly solid density. These kinds of plasma emit intense x-ray emission resulting from recombination or interaction of the hot electrons and ions within the material. Analysis of these x-rays provides important information about the laser-matter interaction, yielding fundamental plasma parameters such as density, temperature, their spatial gradients, and the strength of local electromagnetic fields. High performance XUV mirrors and gratings as well as a combination of Bragg-reflection from crystals with bent surfaces allow spatially resolved imaging of keV x-ray emission in selected spectral ranges. Spherically or toroidally bent crystals provide either two dimensional images or focused x-ray spectra combined with a spatial resolution. Applications of high-resolution XUV- and x-ray spectroscopy will be presented to study energy coupling of fast electrons or intense XUV pulses to solid density plasma, providing detailed information on environmental conditions in hot dense plasmas.

Invited Talk SYPS 1.4 Fr 12:30 A 001

Measurements of masses and beta-lifetimes of stored exotic highly charged ions — •Fritz Bosch — GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

The ion storage-cooler ring ESR at GSI-Darmstadt, coupled to a high-energy synchrotron and a fragment separator, allows addressing the ground state properties of stored and cooled, highly charged exotic ions, in particular their masses and beta-lifetimes. For direct mass measurements two techniques were developed and continuously improved, namely Schottky-Mass-Spectrometry (SMS) for long-lived (half-life $>$ 1 s), and Isochronous-Mass-Spectrometry (IMS) for short-lived (half-life $>$ 10 μs) nuclides. Both of these complementary methods provided an overwhelming harvest during the last few years. Masses of several hundreds of nuclides could be determined with relative accuracies of better than 5×10^{-7} (SMS) and 5×10^{-6} (IMS), respectively, and at the ultimate sensitivity of one single stored ion. Thus, even nuclei very far from stability can be reached providing bright perspectives, in particular for experiments at the FAIR storage rings to come. Furthermore, for the first time, two-body beta decay of highly charged ions could be investigated at the ESR, which has an obvious impact for nucleosynthesis in hot stellar plasmas. In this context the orbital electron capture decay of hydrogen-like and helium-like ions was addressed. The still puzzling results obtained by single-ion decay spectroscopy, a technique recently developed at the ESR, will be presented and tentatively interpreted.

SYPS 2: Precision spectroscopy of highly ionized matter II

Time: Friday 14:00–15:00 Location: A 001

Invited Talk SYPS 2.1 Fr 14:00 A 001

Exciting and ionizing trapped highly charged ions with electrons and photons in an EBIT — •José R. Crespo López-Urrutia — Max-Planck-Institut für Kernphysik, D-69117 Heidelberg, Germany

Hot cosmic matter, which can *e.g.* be found in black hole accretion disks, active galactic nuclei, supernova remnants, and in the warm-hot intergalactic medium, can be prepared and studied in the laboratory with electron beam ion traps (EBITs). A fundamental interest arises from the fact that, for bound electrons, quantum electrodynamic (QED) as well as relativistic contributions grow steeply with the fourth power of the nuclear charge, and thus from small perturbations to major effects. Denuding atoms from most of their electrons in a controlled way exposes these magnified effects even better, and allows for electronic correlation studies along isoelectronic sequences. In EBITs, highly charged ions (HCI) are produced, and their interactions with nearly monoenergetic electrons, with tunable lasers (both in the visible and soft X-ray region), and with keV photon beams from synchrotrons are used to excite and precisely measure electronic resonances. In particular, novel X-ray free-electron lasers (FLASH, LCLS), and synchrotron radiation (BESSY II) allow to go beyond the current accuracy limits. A report on recent results on few-electron QED, photoionization of HCI, dielectronic and trielectronic recombination processes, and laser spectroscopy of forbidden transitions investigated at the Heidelberg EBIT laboratory will be given.

Invited Talk SYPS 2.2 Fr 14:30 A 001

Precision x-ray spectroscopy of intense laser-plasma interaction experiments — •Nigel Woolsey — Department of Physics, University of York, York, YO10 5DD, United Kingdom

Detailed knowledge of electric and magnetic fields and properties of fast electron beams following the interaction of high-intensity, ultra-short laser pulses is a key area for fast ignition and secondary source generation. X-ray spectroscopy is a powerful method for in situ measurement

of the physics that occurs in laser-produced plasmas. Combining high spectral and spatial resolution enables measurement of plasma waves, magnetic fields and the properties of electron beams as they propagate through a target. This discussion will include experiments demonstrating the viability of precision spectroscopy at laser intensities of 10^{21} Wcm^{-2}, a significant milestone as this suggests that spectroscopy is as an effective probe of fast electron physics in regimes relevant to a new generation of lasers such as ELI and HiPER.