ELISA – the world's first (?!) electrostatic storage ring

Søren Pape Møller, Department of Physics and Astronomy, Aarhus University, Denmark

I will give a description of my personal involvement in the conception, development and first years of operation of the ELISA electrostatic storage ring. The realization of such an electrostatic storage ring might in retrospect seem trivial, but at the time many concerns arose.

I believe the success was due to the availability of the right resources and experience at the right time including:
1. The construction and operation of the MAGNETIC dual purpose ion AND electron storage ring ASTRID
2. Knowledge, experience and design tools for storage rings
3. Experiments with atomic and molecular ions in ASTRID
4. Experience with electrostatic elements
5. Mature technical design and workshops

Some "pre-historic" developments will be presented, as will some of the early physics results at ELISA. I will not give an overview of the field, but mention some of the little and bigger "sister" rings and "cousin" traps.

Laser probing of metastable Ba^+ for lifetime measurements

U Bērziņš, A. Ciniņš[1], A.Bžiškjans[1,], H.Hartman[2], M Burheim[2], H.Nilsson[2,] D.Hanstorp[3],
[1]Institute of Atomic Physics and Spectroscopy, University of Latvia
[2]Department of Materials Science and Applied Mathematics, Malmo University
[3]Department of Physics, University of Gothenburg.

Metastable levels are responsible for parity forbidden lines occuring in many low-density astrophysical plasmas, found in e.g gaseous nebulae, planetary nebulae, protostars, stellar chromospheres. Line ratios from forbidden lines are the most reliable tools for diagnostics of temperatures and density of these regions. Measurements of metastable lifetimes is direct importance for the use of forbidden lines. Such a lifetimes can be about 100sek long and therefore the low temperature and low pressure experimental chambers are demanded in order to avoid the depopulation of metastable levels due to collisions and thermal radiation. The facility Double ElectroStatic Ion-Ring ExpEriment, DESIREE [1, 2] at Stockholm University demonstrated capacity for such a measurements.

The laser probing technique (LPT) was derived by Mannervik and his group at the CRYING storage ring, and successfully applied to a number of ions of varying complexity [3] For several complex ions, the measured lifetimes were combined with astrophysical line ratios to derive experimental transition rates [4].

We propose to further develop the laser probing technique to measure lifetimes for stored positive ions using DESIREE. One of the most favorable ions to develop the technique of laser probing of a stored ion beam is Ba^+. The atomic structure is simple with few levels and the metastable energy levels are located at low excitation energies. This allows for a high population and increased fluorescence signal, making Ba^+ an ideal target ion.Recently Lifetime of Ba^+ metastable state $5d^2\ D_{5/2}$ was measured in Paul trap [5] and this can be used as reference

In our poster we will report a results of our first effort in the development of a LPT for DESIREE, and will discuss the next proposed experiment, what we are going to start on DESIREE in August 29, just after this Symposium

Acknowledgements
(UB) was supported ERDF project No. 1.1.1.5/19/A/003 “The Development of Quantum Optics and Photonics at the University of Latvia”,

References
[1] Schmidt H. T. et. al., *First storage of ion beams in the Double Electrostatic Ion-Ring Experiment: DESIREE* Review of Scientific Instruments 84, 055115 (2013).
[2] Bäckström E., et al’;. *Storing keV Negative Ions for an Hour: The Lifetime of the Metastable P-2(1/2)o level in S-32(-)”*D. Phys. Rev. Lett. 114, 143003 (2015).
[3] Mannervik, S *Studies of Metastable Levels in Singly Charged Ions by Laser Techniques in an Ion Storage Ring,* S, Physica Scripta, Volume 100, pp. 81-87
[4] Hartman, H, et. al.,*Experimental Oscillator Strengths for Forbidden Lines in Complex Spectra,* Hartman, H, Johansson, S, Lundberg, H, Lundin, P, Mannervik, S, Schef, P, Physica Scripta, Volume T119, pp. 40-44 (2005).
[5] Mohanty, A., *et al.* Lifetime measurement of the $5d^2\ D_{5/2}$ state in Ba^+. *Hyperfine Interact* **233,** 113–119 (2015).

Ion source based on combined RF frequency powered inductively coupled plasma and hollow cathode discharge

A.Ūbelis, U.Bērziņš, A.Apsītis, A. Bžiskjans, A.Pumpurs

Institute of Atomic Physics and Spectroscopy, University of Latvia

Radiofrequency powered inductively coupled plasma discharge *(RF-ICP)* is a well-known source of very intensive atomic resonance spectra where resonance lines are up to 10 times more intensive /1/.
There are still problems in production spectra sources for atomic analytical spectroscopy, but ICP is widely applicable in sophisticated experimental research /2,3,4/. Hollow cathode (HC) discharge is broadly used commercially in atomic analytical instrumentation to get atomic resonance spectra line for atoms of many elements of Mendeleev periodic system including hardly volatile elements, e.g. boron. HC lamps alongside atomic emmit sufficiently intensive resonance lines of ionized atoms, which rarely is the case for RF ICP plasma.

Based on our long-term expertise in manufacturing of various light sources /5,6/ we designed the device where both RF-ICP and HC plasma forms a hybrid system. The coil of the RF-ICP source is positioned just next to the cathode of the modified commercial hollow cathode lamp. As a result, we obtained amplification of intensities of emitted HC spectra by 3-5 times for atomic and ionic resonance lines of the selected element. We applied the hybrid system for Cd and Zn because their atomic and ionic resonance lines are closely positioned in the UV spectra region (210-240nm), and it is very suitable to measure and optimize the ratio of the number of atoms to the number of ions in the plasma. Presence of intensive ionic spectra lines evidences the abundance of ions for selected elements in the plasma produced by the hybrid system.

We adapted our hybrid system to serve as an ion source and attached it to our ion beam setup GRIBA (Gothenburg Riga Ion Beam Apparatus) /7/. Currently, the investigations of the positive ion flow extracted from our hybrid ion source are on the agenda in dependence on gas flow, the power of the HC lamp and RF-ICP source, and the geometry of the position of RF-ICP coil and HC.

Our main interest is to apply such a hybrid system for the generation of the boron ion beam, which could be implemented into an innovative implantation device. This work is inspired by Baltic Scientific Instruments /8/, worldwide known as a producer and supplier of ionizing radiation detectors based on high purity Germanium crystals.

Acknowledgement. This work is supported by ERDF project No. 1.1.1.1/19/A/144 “Technologic rese-arch for elaborating the next generation boron ion implantation apparatus with TRL level near to 4"

References:

1. S. A. Kazantsev, V. I. Khutorshchikov, G. H. Guthohrlein. L. Windholz, Practical Spectroscopy of High-Frequency Discharges, Plenum Press, New York and London, 1998, 339 pages.

*2. Spietz P., Gross U., Smalins E., Orphal J., Burrows J. P. 2001 Estimation of the Emission Temperature of an Electrodeless Discharge Lamp and Determination of the Oscillator Strength for the I($^2P_{3/2}$) 183.038 nm Resonance Transition Spectrochimica Acta Part B **56** 2456-2478.*

*3. J.C.Gómez Martín, J.Blahins, U.Gross, T.Ingham, A.Goddard, A.S.Mahajan, **A.Ubelis**, and Saiz-Lopez Alfonso. In situ detection of atomic and molecular iodine using resonance and off-resonance fluorescence by lamp excitation: ROFLEX. Atmospheric Measurement Techniques, 2010 AMTD - Atmos.Meas. Tech., 4, 29-45, 2011.*

4. U.Berzins, A.Ubelis, and A. Bziskjans. Branching Fraction Measurements of Arsenic $4p^25s$-$4p^3$ transitions. Submitted to Journal of Quantum Sperctroscopy and Radiative Transfer. Reviewed in August 2021.

5. S.J.Putninya, A.J.Skudra, A.P.Ubelis. Gaseous discharge source of resonance emission. Soviet patent certificate. CCCP No 1551162. 3 May, 1988.

6. SU patent SU1642537A12: Gaseous-Discharge Electrodeless Lamp. B.Khuzmieva Bella, M.Khuzmiev Marat,A.Ubelis A.Skudra date: 04/15/1991.

7. U.Berzinsh et.al., 2014 Gothenburg Riga Ion Beam Apparatus, GRIBA- Status and Perspectives, 72nd LU Annual Scientific Conference, Riga 2014.02.07.

***8.** Baltic Scientific Instruments has specialized in the development and fabrication of devices for spectrometric analysis based on semiconductor and scintillation radiation detectors. http://bsi.lv/en/about-us/*

A community platform for just atomic computations

S. Fritzsche

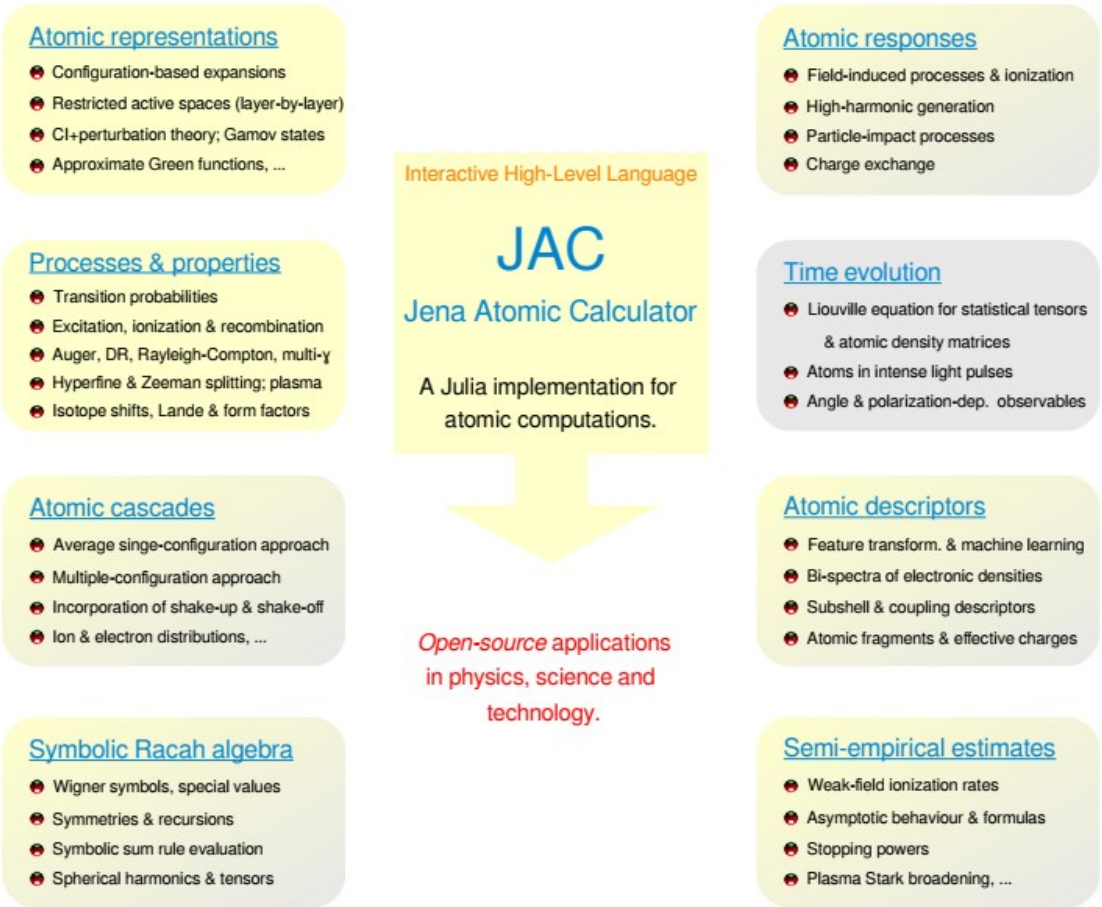
Helmholtz Institut, Jena, 07743, Germany
Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität, Jena, 07743, Germany
**email: s.fritzsche@gsi.de*

Electronic structure calculations of atoms and ions have a long tradition in physics with applications in basic research and spectroscopy. With the Jena Atomic Calculator (JAC), I here present a new implementation of a (relativistic) electronic structure code for the computation of atomic amplitudes, properties as well as a large number of excitation and decay processes for open-shell atoms and ions across the periodic table. JAC [1] is based on Julia, a new programming language for scientific computing, and provides an easy-to-use but powerful platform to extent atomic theory towards new applications.

A primary guiding philosophy in designing JAC was to develop a general and easy-to-use toolbox for the atomic physics community, including an interface that is equally accessible for working spectroscopists, theoreticians and code developers. In addition, I also wish to provide a modern code design, a reasonable detailed documentation of the code and features for integrated testing [2].

References

[1] S. Fritzsche, Comp. Phys. Commun. 240, 1 (2019); https://github.com/OpenJAC/JAC.jl
[2] Fritzsche, User Guide & Compendium to JAC (unpublished, 2019).



Dissociative recombination of internally cold CH^+ molecules

Daniel Paul[1,2], Manfred Grieser[1], Florian Grussie[1], Robert von Hahn[1], Leonard W. Isberner[3,1], Ábel Kálosi[1,2], Claude Krantz[1], Holger Kreckel[1], Damian Müll[1], David A. Neufeld[4], Daniel W. Savin[2], Stefan Schippers[3], Patrick Wilhelm[1], Andreas Wolf[1], Mark G. Wolfire[5], and Oldřich Novotný[1]

[1] Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany
[2] Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA
[3] I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Gießen, Germany
[4] Department of Physics & Astronomy, Johns Hopkins University, Baltimore, MD 21218, USA
[5] Department of Astronomy, University of Maryland, College Park, MD 20742, USA
E-Mail: daniel.r.paul@t-online.de

Heavy ion storage rings provide an ideal environment for internal state preparation of atomic and molecular ions and subsequent collision experiments over a large range of collision energies using the merged-beams technique. We have studied the dissociative recombination (DR) of CH^+ in the electrostatic Cryogenic Storage Ring (CSR; [1]). In the cryogenic environment of CSR ($T < 20$ K), CH^+ ions radiatively decayed toward their lowest rovibrational states [2,3] and the internally relaxed ions were used for DR experiments. Merging an electron beam in the CSR electron cooler with the ion beam, low energy (meV) collisions could be probed. Measurements for different internal state populations enabled us to extract the rate coefficient for the (v=0, J=0) ground state.

DR reactions for CH^+(v=0, J=0) at meV collision energies are an important part of the chemistry in diffuse interstellar clouds, out of which stars and planets can form [4]. The DR rate coefficient is needed to model this chemistry and interpret astronomical observations. Theoretical calculations are not yet reliably able to produce the required DR data due to the large number of intermediate states involved in the dynamics. Thus, laboratory studies of DR are needed to understand the CH^+ chemistry. With our experimental results at diffuse cloud conditions, we have significantly increased the reliability of the CH^+ diffuse cloud astrochemical models.

References

[1] von Hahn et al., Rev. Sci. Instrum. **87**, 063115 (2016)
[2] O'Connor et al., Phys. Rev. Lett. **116**, 113002 (2016)
[3] Kálosi et al., Phys. Rev. Lett. **128**, 183402 (2022)
[4] Krumholz, Phys. Rep. **539**, 49 (2014)

On absolute dating with ^{14}C and ^{41}Ca

Walter Kutschera
University of Vienna, Faculty of Physics – Isotope Physics, 1090 Vienna, Austria

Michael Paul
The Hebrew University of Jerusalem, Racah Institute of Physics, Jerusalem, 91904 Israel

^{14}C

It is well-known that ^{14}C ($t_{1/2}$ = 5,700 yr) requires a calibration curve to determine an absolute age from the measurement of the ^{14}C content in a material to be dated. Global calibration curves have been established for the entire ^{14}C dating range of about 50,000 years from the measurement of ^{14}C in absolutely dated archives [1-3]. However, sometimes 'plateaus' in the calibration curve hamper considerably the determination of a precise ^{14}C date, such as for the famous Minoan eruption of the Greek Island of Santorini some 3500 years ago [4].

Direct absolute ^{14}C dating would require the measurement of both ^{14}C and its stable beta-decay product $^{14}N^*$. The age of an object can thus be determined from a measured abundance ratio of $^{14}N^*/^{14}C$ and the known half-life. Although this is considered to be impossible because the feeble radiogenic $^{14}N^*$ signals are always overwhelmed by the omnipresence of nitrogen on Earth, an attempt at absolute ^{14}C dating has been discussed before [5].

^{41}Ca

Another radioisotope of considerable interest for archaeological dating is ^{41}Ca ($t_{1/2}$ = 100,000 yr). Bones contain a considerable amount of Ca, and the longer half-life would be ideal for dating the remains of hominides back to about 1 million years. This would make radiocalcium dating a particularly interesting tool [6]. Since a global calibration curve cannot be established for ^{41}Ca (it doesn't form a globally distributed gas like $^{14}CO_2$ from cosmogenic ^{14}C in the atmosphere), absolute dating through measurement of $^{41}Ca/^{41}K^*$ ratios would be required. Again, there is the problem of the omnipresence of potassium on Earth.

In this presentation we will discuss the possibility for absolute dating of ^{14}C and ^{41}Ca by utilizing the kinematics of the beta decays leading to recoil energies of $^{14}N^*$ and $^{41}Ca^*$ of only $\leq$6.9 and $\leq$2.2 eV, respectively. A major question in the decay process is the probability of retention of the radiogenic isotopes within the original molecule, e.g. benzene ($^{12}C_5{}^{\mathbf{14}}\mathbf{C}$) changing to $^{12}C_5{}^{\mathbf{14}}\mathbf{N^*}$ or bone hydroxyapatite ($^{40}Ca_4{}^{\mathbf{41}}\mathbf{Ca}$ $(PO_4)_3OH$) changing to $^{40}Ca_4{}^{\mathbf{41}}\mathbf{K^*}$ $(PO_4)_3OH$.

^{14}C and ^{41}Ca can both be measured by accelerator mass spectrometry (AMS). But assuming that a retention of the decay products is likely, a sensitive method of detecting the minute amounts of stable radiogenic isotopes has to be found. We hope for stimulating discussions on these questions at the Symposium.

[1] P. J. Reimer et al., "The Intcal20 northern hemisphere radiocarbon age calibration curve (0-55 cal kBP)," Radiocarbon **62/4** (2020) 725-757.
[2] A. G. Hogg et al., "SHCal20 southerm hemisphere calibration, 0 – 55,000 years cal BP," Radiocarbon **62/4** (759-778.
[3] T. J. Heaton et al., "Marine20 – the marine radiocarbon age calibration curve (0 – 55,000 cal BP)," Radiocarbon **62/4** (2020) 779-820.
[4] W. Kutschera, "On the enigma of dating the Minoan eruption of Santorini," Proc. Nat. Acad. Sci. USA **117** (2020) 8677-8679.
[5] J. Szabo, I. Carmi, D. Segal, E. Mintz, "An attempt at absolute ^{14}C dating," Radiocarbon **40/1** (1998) 77-83.
[6] Kutschera et al., "Studies towards a method for radiocalcium dating of bones," Radiocarbon **31/3** (1989) 311-323.