Technical Meeting on Compilation and Evaluation of Nuclear Charge Radii

Monday 27 January 2025 - Thursday 30 January 2025

IAEA Headquarters, Vienna

Book of Abstracts

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Isomeric mean-square charge radii changes

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A summary of isomers-shift measurements in the $Z = 50$ region will be made related to the unique-parity $h_{11/2}$ shell.

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Nuclear polarization in muonic atoms

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The most precise value of the top-left corner element of the CKM matrix V_{ud} is obtained from superallowed nuclear beta decays. Observed hints to a $2.5 - 3\sigma$ deficit in top-row CKM unitarity motivated a reanalysis of nuclear corrections. These latter use nuclear charge radii as input, and so do their uncertainties. An extraction of nuclear charge radii from atomic measurements entails a reliable calculation of the nuclear polarization (NP) which depends on the entire spectrum of nuclear excitations. Recently, this contribution has been re-scrutinized for the lightest systems ($\mu - H, D, He$) in a field-theoretical approach based on dispersion relations and input from experimental data on photoabsorption. For heavier atoms, NP is traditionally evaluated using the Rinker-Speth approach from 1970's. I revisit NP in medium-light muonic atoms, propose a simple phenomenological formula to evaluate its effect for the 1S states and compare to existing estimates.

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Roles of atomic many-body methods for accurate determination of isotope shift constants

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Isotope shift (IS) studies are traditionally used as tools to extract nuclear charge radii. Today their precise measurements also serve as the medium to probe physics supporting beyond the Standard Model (SM) of particle physics. These studies, however, demand high-accuracy calculations of IS constants that are combined with the IS measurements to infer nuclear charge radii as well as to trace fingerprints of any plausible new physics. Thus, it is imperative to employ a potential atomic many-body method to determine the IS constants reliably in multi-electron systems. However, accuracy of atomic calculations of the IS constants also depend on the adopted approach in a given atomic-body method. In this work, we intend to discuss the calculated IS constants for a number of atomic systems evaluated by employing different approaches in the relativistic coupled-cluster (RCC) theory framework and compare them with the values that are obtained from other atomic many-body methods. This would help to understand roles of atomic many-body methods for accurate determination of the IS constants.

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From total neutron cross sections to nuclear charge radii - Part 1

Author: IstvÃ¡n ANGELI[1]

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Historical overview. War and peace. The foundation of the International Atomic Energy Agency. Total neutron cross sections; **matter radii**; correlation with binding energy. Visit to Ioffe Institute: K_α Isotope Shift $\rightarrow \delta r^2_{charge}$; other methods. Fine structure in **charge radii** along isotopic series: shell effects, odd-even, deformation. Fine structure along isotonic, isobaric, isosymmetric series: **Table I**. Comparison of experiment to theory; neutron skins calculated. Difference between r_{el} and r_{mu}. Evaluation procedures investigated: **Table II**. Comparison of evaluation methods. **Table III**. With completion: **Table IV**. Application of constraints: **Table V**. Moments of the two-parameter Fermi charge distribution. Calculation of Fermi parameters from charge moments. **Table VI**. with $\delta\langle r^2\rangle$. Correlation of nuclear charge radii with other nuclear observables. The proton radius puzzle.

Problems. Dispersion correction in electron scattering. Consequences of the proton radius puzzle: a) normalized data; b) charge radius formulae. Recommendation of radius formulae.

Future: *Weak (*$\backslash approx$ *neutron) rms radii from parity violating electron scattering?*

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Vision and precision in radii estimations

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Finite nuclear size effects play an increasingly important role in precision atomic and nuclear physics. For example, they have been found to strongly affect the determination of the V_ud matrix element of the CKM matrix (arXiv:2309.16893)

Determining the absolute charge radius of some short-lived nucleus entails careful assembly of several pieces spanning different fields.
Measurements include optical isotope shifts, muonic atom x-ray energies, electron scattering cross-sections, while theoretical calculations span high-field QED and nuclear structure effects in muonic atoms and many-body calculation of isotope shift factors in atomic systems.

In this talk I will give an overview of the different pieces that go into a charge radius and discuss their current status and reliable uncertainty estimations. The talk will be biased towards medium mass numbers ($10 < A < 60$) relevant to the the study of mirror nuclei (arXiv:2409.08193).

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Charge Radii of Light Isotopes from Laser Spectroscopy of He-Like Atomic Systems

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Light nuclei exhibit many facets of nuclear structure, like halos and clustering, and are accessible for *ab-initio* nuclear structure calculations. The atomic structure of few-electron systems is well understood; it allows for accurate calculations of mass-shift and field-shift factors in non-relativistic quantum electrodynamics calculations (NR-QED) to extract precise nuclear charge radii from the measurement of transition frequencies and isotope shifts. We have started to determine absolute and differential charge radii, R_c and $\delta\langle r^2\rangle$ of the light elements from Be to N using collinear laser spectroscopy. Helium-like ions of these species provide laser-accessible atomic transitions that can be calculated with the required accuracy in the NR-QED approach. As a first step, the $1s2s\,^3S_1 \rightarrow 1s2p\,^3P_J$ transitions in $^{12,13,14}C^{4+}$ were determined using the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA) at the Technical University of Darmstadt. This represents the first optical charge radius measurements in the carbon isotope chain and will be the starting point for the necessary improvement of charge radii of the light-mass nuclei.

This project was supported by DFG (Project-ID 279384907 - SFB 1245) and by BMBF (05P21RDFN1).

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Recent improvements in the theory of heavy muonic atoms and their influence on nuclear radii

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For decades, muonic atom spectroscopy has provided absolute values of nuclear RMS radii. The recent restart of muonic atom measurements also led to refinements in theoretical predictions. In my presentation, I will show the latest results for heavy muonic atoms, comparing them with previous results and focusing on individual and overall uncertainties. Finally, I will discuss how recent theoretical advances may influence the established values RMS radii.

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Charge Radii of Nuclei by EUV and X-ray Spectroscopy of Highly Charged Ions

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Electron beam ion traps (EBITs) have proven to be a valuable tool for the spectroscopy of highly charged ions over the past few decades. Na-like and Mg-like ions are especially interesting in the context of nuclear charge radii sensitivity due to the enhanced overlap of their ground-state wave functions with the nucleus. Their strong 3s–3p emission can be measured with high precision experimentally in the extreme ultraviolet and x-ray spectral ranges. A careful assessment of the uncertainties in advanced atomic structure calculations makes these measurements competitive with standard nuclear charge radii determination techniques. We report on this method for determining the absolute nuclear charge radius of medium to high atomic number elements. The measurement utilizes only a few million ions stored in an ion trap, which is advantageous for measurements involving small quantities of sample nuclei. Preparations are underway to apply the technique to radioactive nuclei.

This work is funded by a NIST grant (Award Number 70NANB20H87) and by a National Science Foundation grant (Award Number 2309273).

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Precise nuclear charge radii via bound electron g factor measurements

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The gyromagnetic g-factor of bound electrons in highly charged ions is ideal for testing quantum electrodynamics (QED) in the strongest electric fields. In heavy highly charged ions (HCI) the innermost electrons experiences electric fields exceeding 10^{15} V/cm that are otherwise unreachable in laboratories, but in a system still simple enough to enable high-precision theory calculations.
Additionally, the bound electron g factor is significantly influenced by the nuclear properties due to the close vicinity of the electrons to the nucleus. This makes it possible to extract nuclear charge radii with similar or higher precision compared to muonic-atom spectroscopy.

The ALPHATRAP experiment is a dedicated cryogenic Penning-trap setup to measure these bound electron g-factor of single HCIs. By co-trapping two hydrogenlike neon ions ($^{20}Ne^{9+}$ and $^{22}Ne^{9+}$) we have determined their isotope g-factor shift with 13 digits precision in respect of g. This allows to test the QED recoil contribution to highest precision and to improve the mean square nuclear charge radius difference by an order of magnitude compared to the literature value. Furthermore, we set limits on hypothetical new physics beyond the standard model. Recently we measured the g factor of hydrogenlike tin ($^{118}Sn^{49+}$). Given agreement with theory calculation this allows the extraction of the tin nuclear charge radius with a precision, which is only a factor of four less precise compared to the current literature value. Finally, I will give an outlook on upcoming studies and prospects.

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radbase: codes for non-linear least-squares analysis of the nuclear radius network - towards next generation recommended values of nuclear charge radii

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Once measurements have been converted into nuclear radii data, the challenge remains to combine these measurements into a consistent set of radii. Given the high number of radii (>800) to optimize and the tight coupling of radii from relative measurements, care must be taken to make a completely accurate non-linear approach feasible. *radbase*, an open-source set of Python codes, analyzes the network formed by nuclear radius data and breaks the minimization into computationally simple steps. Additionally, *radbase* supports including correlations between different pieces of data, an aspect missing from previous evaluations. We present the techniques employed in the code and compare the results of our analysis with those of other compilations. Future work, such as calculating correlations between data and integration with a planned nuclear radius database, will also be discussed.

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Nuclear charge radii vs. other experimental observables

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The question about the relations of the nuclear charge radii to other experimental observables will be brought up and relations to nuclear quadrupole moments will be reflected on, illustrated with a few examples.

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From total neutron cross sections to nuclear charge radii - Part 2

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Historical overview. War and peace. The foundation of the International Atomic Energy Agency. Neutron cross sections; matter radii; correlation with binding energy, mass dependence. Semiclassical model (NASA), matter radius derived. Visit to Ioffe Institute: K_α Isotope Shift $\rightarrow \delta r^2_{charge}$; other methods. Tables of rms charge radii from electron scattering, muonic atom transitions, K_α isotope shifts, optical isotope shifts. Fine structure in charge radii along isotopic series: shell effects, odd-even, deformation. Fine structure along isotonic, isobaric, isosymmetric series.

I. Table of rms charge radii. Correlated shell effects in charge radii and binding energy. Comparison of experiment to theory; calculated neutron skins. Table of rms charge radii from electron scattering. Table of δr^2 from optical isotope shifts. Difference between r_{el} and r_{mu}; caused by dispersion effects? Effect of valence nucleons on charge radii; the P-factor.
II. Table of rms charge radii. Systematics of charge radii. **III. Table of rms charge radii. IV. Table of rms charg**
V. Consistent table of rms charge radii. Moments of the two-parameter Fermi charge distribution. The kink strength: a tool for search of structures in series. The proton radius puzzle.
VI. Table of $\delta < r^2 >$ and rms charge radii. Correlation of nuclear charge radii with other nuclear observables.

Problems. Dispersion correction in electron scattering. Consequences of the proton radius puzzle: a) normalized data; b) charge radius formulae. Recommendation of radius formulae.
Future: Weak (≈ neutron) rms radii from parity violating electron scattering?

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Introduction to the Nuclear Data Section

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An overview of the mission and activities of the Nuclear Data Section of the International Atomic Energy Agency will be presented.

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Nuclear databases and webtools at the IAEA

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Databases, web tools and applications developed at the Nuclear Data Section will be presented.

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Welcome

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Isotope Shift and Charge Radii Measurements with the CRIS experiment at ISOLDE

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Over the last decade the CRIS experiment has measured utilised a high resolution resonance ionisation spectroscopy technique (CRIS) to measure charge radii in exotic nuclei. The low background and high efficiency has allowed the technique to measure short-lived exotic systems with production yields down ~10 atoms/second. This presentation will summarise the technical developments, challenges and results from the last 10 years of activity.

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Nuclear charge radii of neutron-rich scandium and zinc isotopes

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The isotope shifts of neutron-rich Sc and Zn isotopes have been measured in recent years using high-resolution laser spectroscopy techniques. By taking advantage of advanced atomic theory calculations, the nuclear charge radii of these two isotopic chains have been determined or re-evaluated, providing valuable insights into their nuclear structure. This contribution will present the measured isotope shifts, as well as the extracted or re-evaluated charge radii for both isotopic chains.