A 2: Collisions, Scattering and Correlation Phenomena

Time: Monday 11:00–13:00 Location: F107

A 2.1 Mon 11:00 F107

Scattering of twisted electron wave packets by crystals — •Sophia Strnat[1,2], Dmitry Karlovets[3], and Andrey Surzhykov[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland — [2]Technische Universität Braunschweig, Braunschweig, Deutschland — [3]Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland

The transmission electron microscopes (TEM) is one of the main tools in material studies. Nowadays TEMs provide beam sizes down to the sub-angström scale [1]. Further, electron beams carrying non-zero angular momentum with energies up to few hundred keV can be produced. These so-called twisted electron beams posses a magnetic moment which allows for additional probing of magnetic properties of materials. We describe the twisted electrons as spacially localized wave packets to take the finite beam size in TEMs into account. In particular, we investigate the elastic scattering of a Bessel-Gaussian electron mode by graphene in a generalized Born approximation (developed in [2, 3]). We study the scattering of a 80 keV electron wave packet with a size ranging from 0.5 Å to 5 Å and show that a non-zero orbital angular momentum projection significantly alters the scattering pattern.

References
[1] P. E. Batson *et al.*, *Nature***418**,617-620 (2002)
[2] D. V. Karlovets *et al.*, *Phys. Rev.* **A** 92, 052703 (2015)
[3] D. V. Karlovets *et al.*, *Phys. Rev.* **A** 95, 032703 (2017)

A 2.2 Mon 11:15 F107

Radiation-field-driven ionization in laser-assisted slow atomic collisions — •Andreas Jacob, Carsten Müller, and Alexander Voitkiv — Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf

It is generally assumed that for ionization processes, which occur in slow atomic collisions, the coupling of the colliding system to the quantum radiation field is irrelevant. We show [1], however, that – contrary to expectations – such a coupling can strongly influence ionization of a beam of atomic species A slowly traversing a gas of atomic species B excited by a weak laser field. Our results imply furthermore that the Breit interaction can, in fact, dominate over the Coulomb interaction at very low energies.

[1] A. Jacob, C. Müller, and A. B. Voitkiv, arXiv:2208.09812 (2022).

A 2.3 Mon 11:30 F107

Entanglement created in collisions governed by the Coulomb interaction — •Yimeng Wang, Karl P. Horn, and Christiane P. Koch — Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

Entanglement or inseparability is central to quantum physics. However, the test for separability can be rather hard to implement with increasing Hilbert space dimension, especially for entanglement in motional degrees of freedom where the von Neumann entropy as well as other quantum entropies are divergent or ill-defined. The goal of this work is to quantify the entanglement of the scattering between an electron and a proton, by calculating the momentum uncertainty of either particle, extending earlier work [1,2] on entanglement in low-energy hydrogen bound states. We inspect both Rydberg states and scattering states and evaluate the behavior of entanglement versus energy near zero, to study the analytical properties of the "spectrum of entanglement" across the ionization threshold. The quantification of entanglement for scattering states will provide a new perspective on quantum scattering states, and demonstrate the difference between the weakly-bound states, a flat continuum, and shape resonances.

[1] Paolo Tommasini, Eddy Timmermans and A. F. R. de Toledo Piza, Am. J. Phys. 66 881 (1998).
[2] Sofia Qvarfort, Sougato Bose and Alessio Serafini, New J. Phys. 22 093062 (2020).

A 2.4 Mon 11:45 F107

Calculations of Delbrück scattering to all orders in αZ — •Jonas Sommerfeldt[1,2], Vladimir Yerokhin[3], and Andrey Surzhykov[1,2] — [1]Physikalisch Technische Bundesanstalt, D-38116 Braunschweig, Germany — [2]Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [3]Max-Planck Institut für Kernphysik, D-69117 Heidelberg, Germany

Delbrück scattering is the process in which photons are elastically scattered by the electric field of an atomic nucleus via the production of virtual electron-positron pairs. It is one of the few non-linear quantum electrodynamical processes that can be observed experimentally [1] and, hence, testing the respective theoretical predictions serves as an important test of QED in strong electromagnetic fields. Despite the strong motivation for the theoretical analysis of Delbrück scattering, most of the previous studies have been limited to some approximation regarding the coupling between the virtual electron positron pair and the nucleus leading to large disagreements between theory and experiment for certain parameter regimes [2]. In this contribution, therefore, we present an efficient approach to calculate amplitudes for Delbrück scattering that accounts for the interaction with nucleus to all orders including the Coulomb corrections [3].

[1] M. Schumacher, Radiat. Phys. Chem. 56 (1999) 101-111
[2] P. Rullhusen et al., Z Physik A 293 (1979) 287-292
[3] J. Sommerfeldt et al., Phys. Rev. A 105 (2022) 02280

A 2.5 Mon 12:00 F107

First Dielectronic Recombination Measurements with Low-Charged Heavy Ions at the Cryogenic Storage Ring — •Leonard W. Isberner[1,2], Manfred Grieser[2], Robert von Hahn[2], Zoltán Harman[2], Ábel Kálosi[3,2], Christoph H. Keitel[2], Claude Krantz[4], Daniel Paul[3,2], Daniel W. Savin[3], Suvam Singh[2], Andreas Wolf[2], Stefan Schippers[1], and Oldřich Novotný[2] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Gießen, Germany — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Columbia Astrophysics Laboratory, Columbia University, New York, NY, USA — [4]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

Accurate plasma modeling, e.g. for astrophysical environments, requires detailed information on fundamental processes such as the recombination of free electrons with atomic ions. Although electron-ion recombination has been investigated in magnetic heavy ion storage rings over the past three decades, those studies were restricted to ions with low to moderate mass-to-charge ratios due to the relatively high residual gas pressure in magnetic storage rings. The electrostatic Cryogenic Storage Ring (CSR), located at the Max-Planck-Institut für Kernphysik in Heidelberg, provides excellent vacuum conditions and thus offers a unique environment for recombination studies with high mass-to-charge ratio ions. Here we report on the first recombination measurements with atomic ions at CSR. Our observations of resonant recombination features for Ne^{2+} and Xe^{3+} demonstrate the feasibility of atomic recombination studies with low-charged heavy ions at CSR.

A 2.6 Mon 12:15 F107

Hyperfine-induced effect on angular and polarization behaviors of the $K\alpha_1$ line following electron-impact excitation of He-like Tl^{79+} ions — •Zhongwen Wu[1,2,3], Ziqiang Tian[1], Jun Jiang[1], Chenzhong Dong[1], and Stephan Fritzsche[2,3,4] — [1]Northwest Normal University, P. R. China — [2]Helmholtz-Institut Jena, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany — [4]Friedrich-Schiller-Universität Jena, Germany

For atoms or ions with nonzero nuclear spin, the hyperfine interaction of nuclear magnetic moment with those of bound electrons leads to splitting of their fine-structure levels and, thus, affects their excitation and decay properties. In this contribution, we studied angular and polarization behaviors of the $K\alpha_1$ line following electron-impact excitation of He-like spin-1/2 Tl^{79+} ions using the multiconfigurational Dirac-Fock method and relativistic distorted-wave theory. Special attention was paid to the effect of the hyperfine interaction on the behaviors. It was found that the hyperfine-induced effect depends dominantly on impact electron energy. For low energies close to the excitation threshold, the hyperfine interaction contributes to making the $K\alpha_1$ line more anisotropic and polarized. In contrast, such an effect diminishes quickly with increasing energy and even vanishes at medium and high energies, which is rather different from the case of radiative electron capture. The present study is accessible at both electron-beam ion traps and ion storage rings and thus accurate angular or polarization measurements of the $K\alpha_1$ line at low energies are expected to probe the hyperfine interaction in highly charged few-electron ions.

A 2.7 Mon 12:30 F107

Search for Exotic Molecules in Rydberg Positronium-Neutral Atom Mixtures — •Milena Simić and Matthew Eiles — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The interaction between a Rydberg atom and a distant ground-state atom can bind the two atoms together into a long-range Rydberg molecule. The mechanism behind this interaction is the scattering of the low-energy Rydberg electron off of the ground-state atom. By replacing the Rydberg atom with Rydberg positronium, an additional interaction plays a role. This interaction, between the positron and the neutral atom, is also determined by low-energy scattering phase shifts, but now of the positron off of the ground state atom. These phase shifts, like those of electrons, have been computed for a variety of atoms. In this talk, we discuss the prospects of forming exotic long-range Rydberg molecules composed of both matter and antimatter. Compared to normal long-range Rydberg molecules, the replacement of the heavy atomic core with a positron brings new physics into play: the molecular bond is now determined by two scattering processes instead of one, the reduced mass of the molecule is very light, and the decay channel opened by annihilation could be significant.

A 2.8 Mon 12:45 F107

Berechnung der Ruhemassen von Elementarteilchen durch Polynome mit der Basis π — •Helmut Schmidt — LMU München

Lösungen der Schrödingergleichungen können in ein Polynom mit der Basis 2π transformiert werden. Für jedes Objekt ergibt die Energie als Polynom $E = r(t)(2\pi)^d + xy(t)(2\pi)^{d-1} + z(t)(2\pi)^{d-2}$. Jeder Koeffizient führt zu einer archimedische Spirale. Besitzen 2 Objekte und eine Beobachter einen gemeinsamen Schwerpunkt, können die Energien durch ein einziges Polynom in Beziehung gesetzt und berechnet werden. Die ganzzahligen Quantenzahlen r, xy, z und d bewirken einen Zusammenhalt und führen zu den vier fundamentalen Wechselwirkungen. Davon ist unser Weltbild, mit 3 isotropen Dimensionen x, y und z und Rotationen mit 2π, zu unterscheiden. Die Polynome werden durch einfache Operatoren (Addition) für die Parität, Zeit und Ladung umgeformt. Zahlreiche Rechnungen zu Elementarteilchen werden angeführt.

$m_{neutron}/m_e = (2\pi)^4 + (2\pi)^3 + (2\pi)^2 - (2\pi)^1 - (2\pi)^0 - (2\pi)^{-1} + 2(2\pi)^{-2} + 2(2\pi)^{-4} - 2(2\pi)^{-6} + 6(2\pi)^{-8} = 1838.6836611$

Ladungsoperator für alle Teilchen:
$\widehat{C} = -\pi + 2\pi^{-1} - \pi^{-3} + 2\pi^{-5} - \pi^{-7} + \pi^{-9} - \pi^{-12}$.

Protonenmasse:
$m_{proton} = m_{neutron} + \widehat{C} m_e = 1836.15267363 m_e$

Feinstrukturkonstante:
$1/\alpha = \pi^4 + \pi^3 + \pi^2 - 1 - \pi^{-1} + \pi^{-2} - \pi^{-3} + \pi^{-7} - \pi^{-9} - 2\pi^{-10} - 2\pi^{-11} - 2\pi^{-12} = 137.035999037$

Gravitationskonstante: $hGc^5 s^8/m^{10} \sqrt{\pi^4 - \pi^2 - 1/\pi - 1/\pi^3} = 1.00000$