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15TH ASIAN INTERNATIONAL SEMINAR ON ATOMIC AND MOLECULAR PHYSICS

AUGUST 19 - 23, 2024

KAIST, KI-BUILDING FUSION HALL, **DAEJEON, KOREA**

KPS AMPD The Korean Physical Society Atomic & Molecular Physics Division

KAIST Korea Advanced Institute of Science and Technology

KRISS Korea Research Institute of Standards and Science

PUSAN NATIONAL UNIVERSITY

KOREA UNIVERSITY

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Zurich Instruments

Agency for Defense Development

PASQAL

Invited talks

[PLENARY]

Collisions

(Mon 1) 2024-08-19
09:00 AM

Calculation of atomic and molecular collisions

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Abstract

Collisions on the atomic scale are governed by the ubiquitous long-ranged Coulomb interaction. Accordingly, such collisions could not be universally mathematically formulated as in the case of ionising ones the interactions between residual charged particles extended out to infinite distances. Curiously, this problem was solved computationally first, with the correct mathematical formulation following some ten years later! We shall discuss this unusual journey in the development of the Convergent Close-Coupling (CCC) theory for calculating collisions involving (anti)electrons, (anti)protons and photons with atoms and molecules.

[PLENARY] Collisions (Mon 2) 2024-08-19 9:35 AM

A brief overview of HCI collisions with molecules and applications

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Abstract

Various features of of atomic molecular physics can be conveniently investigated using fast-ions obtained from a low or high energy accelerators on a wider energy range of keV to MeV or even to GeV. Atomic collisions find many applications towards radiobiology, plasma physics, astrochemistry of intersteller medium as well as fundamental quantum mechanical issues. Particular interest is the collective plasmon resonance which is common thread among the different many body systems namely, fullerenes (C60) , PAH molecules (e.g. C24H12) , nano-particles, and nanosensitizers (such as iodo-uracil). It has been shown electron emission from simple molecules like H2 or N2 can reveal the double-slit nature of the molecules giving rise the Young type e-interference due to spatial coherence. The basic processes like single and multiple electron capture, ionization, fragmentation, plasmon excitation besides recently discovered electron-interference and inter-Coulombic decay are known to influence the dynamics of ion-molecule collisions. The recent studies on the ion-dimer collisions also provide new insights to these directions. The e-emission cross sections from DNA/RNA bases and water, or radio-sensitizers like halo-uracils are important for the study of radiation damage in high energy proton therapy of cancer. Similarly, the recent studies on the ionization and multi-fragmentation, in particular the dehydrogenation of different PAH molecules are shown to provide valuable information towards the astro-chemistry of inter stellar medium, such as, the abundance of H2 in ISM or astrophysical extinction curve. The elegant technique of using highly charge ions with large perturbation strength has been shown to be extremely useful probe to excite the dipole and quadrupole plasmon excitations in fullerenes or smaller PAH molecules. There has been a huge progress in this field in last two decades and I will summarize some of our recent contributions towards this.

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[KEYNOTE] Collisions (Mon 3) 2024-08-19 10:10 AM

Ionization process of cold molecules in superfluid helium nanodroplets

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Abstract

Helium nanodroplets are nano-size droplets of superfluid helium (4He) that provide an almost completely isolated environment for studying atoms and molecules at a temperature below 1 Kelvin. Atoms and molecules are easily trapped in the droplets through collisions. The droplets have transparent and homogeneous properties, making them ideal for spectroscopic studies on a wide range of captured species. The technique is not limited to neutral species; it has also been used for molecular ions. Neutral molecules captured in the droplets are ionized through charge transfer after the droplets are ionized by electron impact. The rapid cooling provided by the helium surroundings allows for producing metastable structural isomers of molecular ions and their complexes. Here, we discuss our recent results on the ionization of water clusters in the droplets. Generally, the ionization of the hydrogen-bonded neutral water dimer is an essential process in the radiation chemistry of water, and its product only known was the proton-transferred water dimer cation. In our study, we identified spectroscopically the production of another type of dimer cation, the hemibonded water dimer cation, in the droplets after electron-impact ionization. The production of this metastable structure requires the efficient removal of the excess energy upon ionization, which is made possible in the droplets. We will also discuss other examples from our recent studies of molecular ions produced in the droplets.

[PLENARY] Strong Field/Structure (Mon 4) 2024-08-19 10:50 AM

Ultrafast nonadiabatic excited state dynamics in the liquid/gas phase

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Abstract

Most photophysics and photochemistry processes occurs in the liquid phase, but the effects of a liquid environment on ultrafast dynamics of excited-state dynamics are not well understood. We first presented a direct comparison of ultrafast excited-state dynamics in the gaseous and liquid phases using the femtosecond time-resolved photoelectron spectroscopy in the XUV domain. Our observations indicates the persistence of vibrational coherence from exited states to the ground states in the liquid environment. In this case, the underlying existed state dynamics of those photochemical reaction beyond Born-Oppenheimer approximation pose a great of challenge for accurate simulations. We developed new experimental approaches to shoot molecular movie of the exited states basing on the strong-field tunneling and recollision ionization processes. This will allow the real-time imaging of transient structure of the electronic excited state, which is fundamentally critical to understand and control ultrafast chemical reactions. By establishing the new laser induced electron recollision-assisted Coulomb explosion imaging approach, snapshots of the vibrational wavepackets of the excited (A) and ground states (X) of D_2O^+ are captured simultaneously with sub-10 picometer and few-femtoseconds precision. We also developed an elliptical laser-induced electron diffraction method to achieve the tomography imaging of complex molecules with few-femtoseconds and picometer resolution. The incident angle-resolved molecular frame DCS of molecular ion has been first time obtained with this new approach. These results provide comprehensive structural information for studying the fascinating molecular dynamics of complex molecules, and pave the way towards to make a movie of excited state-resolved ultrafast molecular dynamics and light-induced chemical reaction.

[KEYNOTE] Strong Field/Structure (Mon 5) 2024-08-19 11:25 AM

Ion momentum imaging with extreme ultraviolet laser pulses

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Abstract

Extreme ultraviolet (XUV) and X-ray wavelength free-electron lasers (FELs) have enabled the determination of fine structures in protein nanocrystals and the observation of nonlinear X-ray optical phenomena. Furthermore, using FELs with pulse widths of tens of femtoseconds or less as probe light allows for real-time tracking of processes such as chemical bond formation and ligand exchange reactions. We are working on molecular movie filming of photochemical reactions in isolated molecular systems using XUV-FEL [1,2]. To capture transient molecular structures, we perform imaging measurements of the momentum distribution of ions emitted by the Coulomb explosion of molecules induced by XUV-FEL irradiation. The ion momentum imaging allows us not only to capture the molecular structures but also to reveal the fragmentation dynamics of multiply charged molecular ions. Given the ongoing advances in FEL technology, the continued study of the fragmentation dynamics of multiply charged molecular ions is of great interest. To study the photoionization and photofragmentation dynamics of 1-iodopropane (1-C3H7I) and 2-iodopropane (2-C3H7I) following interaction with XUV photons with energy above the iodine 4d ionization edge, we coupled covariance analysis with three-dimentional (3D) velocity map imaging [3]. We measured the ion momentum distribution by using XUV-FEL pulses (95 eV) provided by SACLA BL1. The localized multiple charges at the iodine atomic site, due to Auger-Meitner decays following selective photoionization of the 4d inner shell, lead to charge transfer to the propyl (C3H7) site, resulting in the sequential or simultaneous fragmentation of iodopropane into multiple ions. By incorporating native frame analysis into 3D covariance imaging, we extracted contributions from both sequential and simultaneous three-body fragmentation. Simulations based on a classical Coulomb explosion model reproduced the angular distributions of dissociation ion fragments emitted from each isomer molecule and revealed that C-I bond dissociation in the sequential three-body fragmentation of 2-C3H7I induces vibrational dynamics in the long-lived C3H7 ion. This demonstrates the effectiveness of combining 3D covariance imaging with native frame analysis to observe the dynamics of quasi-stable polyatomic intermediate ions during the fragmentation of multiply charged molecular ions.

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[EARLY CAREER] Strong Field/Structure (Mon 6) 2024-08-19 11:45 AM

Ultrafast carrier dynamics of perovskite-based functional materials

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Abstract

Organo-lead (Pb) halide perovskites are emerging as promising materials for the next generation of solar cells, achieving power conversion efficiencies (PCE) exceeding 26%. However, due to the growing concern about Pb toxicity, the development of lead-free perovskite solar cells (PSCs) has become urgent for environmental reasons. Among the Pb-free alternatives, tin (Sn) is the most used metal cation to replace Pb. Unfortunately, Sn PSCs typically exhibit lower PCE compared to their Pb counterparts. Since carrier recombination is the primary factor limiting the PCE of solar cells, it is essential to thoroughly understand the carrier dynamics of Sn PSCs to enhance their PCE. In this study, we investigate the ultrafast carrier dynamics of formamidinium ($CH(NH_2)_2^+$, FA+) tin triiodide (FASnI3) perovskite thin films using femtosecond transient absorption spectroscopy. By verifying the pump-power dependence of the ultrafast carrier dynamics, we found that trap-assisted recombination is the major recombination pathway that limits the carrier lifetime of FASnI3. Additionally, the trap-assisted recombination rate of FASnI3 is three orders of magnitude faster than its Pb counterpart, indicating a need for improved fabrication procedures for FASnI3 thin films. Furthermore, we examined the ultrafast carrier dynamics of Rb+-doped FASnI3. Although we observed that trap-assisted recombination is even more prominent in Rb+-doped FASnI3, it exhibits higher photoluminescence brightness compared to pristine FASnI3. This result suggests that Rb+-doped FASnI3 could be a promising material for near-infrared light-emitting diodes.

[KEYNOTE] Strong Field/Structure (Mon 7) 2024-08-19 12:05 PM

Cavity-free quantum electrodynamic chemistry

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Abstract

In this talk, I will briefly introduce my recent development in an emerging field "QED chemistry". How to employ quantum-electrodynamic (QED) effects to control chemical reactions is a grand challenge in chemistry. First of all, to capture the effect of infinite photonic modes on electron-transfer reactions, we incorporate molecular quantum electrodynamics into the electron transfer processes, develop a unified theory for describing radiative and non-radiative (Marcus) electron transfer, and establish the concept of "electron transfer overlap". Furthermore, we demonstrate that electron transfer rates can be significantly enhanced by several orders of magnitude without cavities under weak light-matter interactions, which is implicitly supported by several experimental reports. Second, to better describe the effect of dielectric medium in QED electron transfer reactions, we start from macroscopic quantum electrodynamics and then derive an explicit Marcus-type expression in terms of dyadic green's functions, which help us to capture the vacuum fluctuations of electromagnetic fields led by plasmonic modes and cavity photonic modes.

[EARLY CAREER] Ultracold Quantum Gas (Mon 8) 2024-08-19 2:30 PM

Mediated interaction between impurities in Bose-Einstein condensates

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Abstract

Mediated interaction plays a crucial role for our understanding of nature. They are central to Landau's widely used quasiparticle theory, and all interactions are mediated by gauge bosons at a fundamental level. In this talk, I will present our recent work on mediated interaction between impurities in Bose-Einstein condensates (BECs). In the first part, I discuss the interaction between two trapped ions mediated by a surrounding quantum degenerate Bose gas and show that the induced interaction leads to substantial and observable shifts in the ion phonon frequencies. In the second part, I discuss the interaction between mobile impurities immersed in a BEC in a two-dimensional square lattice and predict the formation of the long-sought bipolaron, which should be detectable using high resolution quantum gas microscopy in optical lattices.

[KEYNOTE] Ultracold Quantum Gas (Mon 9) 2024-08-19 2:50 PM

Robust Identification of phase transitions and their properties without a priori theories through self-supervised learning

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Abstract

We develop a self-supervised ensemble learning (SSEL) method to accurately classify distinct types of phasetransitions by analyzing the fluctuation properties of machine learning outputs. Employing the 2D Potts model and the 2D Clock model as benchmarks, we demonstrate the capability of SSEL in discerning first-order, second-order, and Berezinskii-Kosterlitz-Thouless transitions, using in situ spin configurations as the input features. Furthermore, we show that the SSEL approach can also be applied to investigate quantum phase transitions in 1D Ising and 1D XXZ models upon incorporating quantum sampling. We argue that the SSEL model simulates a special state function with higher-order correlations between physical quantities, and hence provides richer information than previous machine learning methods. Consequently, our SSEL method can be generally applied to the identification/classification of phase transitions even without explicit knowledge of the underlying theoretical models.

[KEYNOTE] Ultracold Quantum Gas (Mon 10) 2024-08-19 3:10 PM

Universal Kibble-Zurek scaling in an atomic Fermi superfluid

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Abstract

In systems undergoing symmetry-breaking phase transitions, spatial domains of the ordered phase can randomly develop, potentially leading to the formation of topological defects at their interfaces. The Kibble-Zurek mechanism (KZM) offers a universal framework for predicting the formation of these defects, establishing a power-law relationship between the number of defects and the rate of the phase transition. In this talk, I will present our experimental observations of Kibble-Zurek scaling in a homogeneous, strongly interacting Fermi gas during a superfluid phase transition. We explored this transition using two distinct control parameters: temperature and interaction strength. Although the microscopic dynamics of condensate formation differed significantly between these parameters, evidenced by a two orders of magnitude difference in formation timescales, the Kibble-Zurek exponent was consistently observed around 0.68 across both scenarios, aligning well with theoretical predictions for superfluid phase transitions. Additionally, I will discuss phenomena beyond the KZM, including defect saturation in rapid quenches and the early-time coarsening dynamics observed in the developing condensate.

[KEYNOTE] Ultracold Quantum Gas (Mon 11) 2024-08-19 3:30 PM

Far from equilibrium dynamics and quantum Kelvin-Helmholtz instability in strongly ferromagnetic spinor condensates

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Abstract

Understanding and classifying out-of-equilibrium dynamics in a closed quantum many-body system have been outstanding problems in modern physics. In this talk, we will introduce our recent experimental results on the universal coarsening dynamics in spin-1 Bose-Einstein condensate. Initially prepared polar condensate is quenched to ferromagnetic phases by microwave dressing. Right after the quench, we observe the emission of spin 1/-1 pairs due to dynamical instability, forming microdomains, which are coarse to form a larger domain as time evolves. We find distinctive scaling behavior depends on the symmetry of the Hamiltonian and associated dynamics of topological defects like domain walls and spin vortices. In the second part of this talk, I will also introduce our recent experiment on the quantum Kelvin Helmholtz instability (KHI). After preparing a single magnetic domain wall, we impose a counterflow by applying a magnetic field gradient. The flutter-finger pattern, the hallmark of the KHI, is observed on the magnetic domain boundary. In the nonlinear dynamic stage, a magnetic droplet is emitted from the tip of the figure, and further analysis shows that it has a fractional skyrmion charge with breaking axis symmetry.

[PLENARY] Precision Measurement (Tue 1) 2024-08-20 9:00 AM

Laser spectroscopy of two-electron systems with 10-digit precision

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Abstract

Precision spectroscopy of the hydrogen atom, a microscopic two-body system, historically led to the development of quantum mechanics and quantum electrodynamics (QED). Nowadays, more complex many-body systems, such as the helium atom (three-body) and the hydrogen molecule (four-body), are also amenable to full quantum calculations with very high precision based on QED and a few fundamental physical constants. Comparisons between theory and precision measurements of these systems can test QED, determine physical constants, and constrain new theories beyond the *Standard Model*. However, discrepancies have also been found between results obtained with different methods in different laboratories around the world. In this talk I will present our recent progress in laser spectroscopy of the helium atom and molecular hydrogen. Techniques developed in these studies are now also finding various applications.

[KEYNOTE] Precision Measurement (Tue 2) 2024-08-20 9:35 AM

Precision determination of isotope shifts in ytterbium and implications for new physics

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Abstract

Different isotopes of the same atom produce slightly different spectra, mainly due to the changes in mass and charge distribution of the nucleus. The advent of ultra-high precision optical spectroscopy allows us to extract subtle effects that go beyond these leading causes of isotope shift. We can use the differential isotope shift measurements to search for a hypothetical low-mass boson that would couple neutrons to electrons. Strong limits have been placed on the coupling strength of such a boson using Hz-level optical spectroscopy of isotope chains in calcium and ytterbium. Higher-order nuclear effects can also be uncovered using isotope shift spectroscopy. Yb nuclei are prolate spheroids rather than spherical, and this causes large changes in the higher-order charge distribution between isotopes. Isotope shift spectroscopy allows us to extract changes in this nuclear deformation along the whole isotopic chain. Moreover, we can use data-driven methods to suppress this effect and extract bounds on new physics.

[EARLY CAREER] Precision Measurement (Tue 3) 2024-08-20 9:55 AM

Narrow-Line mediated Sisyphus Cooling for enhanced performance in quantum sensors

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Abstract

Quantum sensors using optical clocks hold immense promise for applications like redefinition of the second and detecting gravitational waves. In this talk, I will present a variety of novel cooling techniques centering on narrow-line mediated Sisyphus cooling of alkaline-earth(-like) neutral atoms. This method significantly improves the performance of both state-of-the-art optical lattice clocks and next-generation continuous atomic sources for zero-dead-time quantum sensors. For 1D optical lattice clocks, our cooling technique achieves sub-recoil temperatures, potentially leading to reduced ac-Stark shift uncertainty. For continuous atomic sources, Sisyphus cooling scheme demonstrates a 10-fold improvement in cooling rate, enabling higher flux in a continuous magic-wavelength lattice-guided atomic beam.

[KEYNOTE]

Precision Measurement

(Tue 4) 2024-08-20
10:15 AM

Laser spectroscopy of triply charged thorium-229 isomer for a nuclear clock

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Abstract

Thorium-229 has an excited nuclear state (isomer) at only 8.4 eV from the nuclear ground state, which enables direct laser spectroscopy of the thorium-229 nucleus. A nuclear clock based on the transition frequency between the nuclear ground state and isomer is expected to achieve high accuracy due to its small sensitivity to fluctuations of external electromagnetic fields. Successful laser excitation of thorium-229 nuclei embedded in crystals has been reported recently. We aim to realize highly accurate nuclear clocks based on isolated thorium-229 ions in a trap. To this end, a triply charged thorium-229 ion is suitable due to the availability of closed electronic transitions enabling laser cooling, laser-induced fluorescence detection, and state preparation of ions. However, essential parameters of thorium-229 isomer ions for a nuclear clock, such as its nuclear decay lifetime, were unknown. We trapped triply charged thorium-229 isomer ions obtained as recoil ions from a uranium-233 source, where the isomer ions were produced with a branching ratio of about 2% (the remaining 98% of the nuclei were in the ground state). We developed a laser spectroscopy technique to extract signals from isomer ions and determined nuclear decay lifetime of thorium-229 isomer ions. Furthermore, by measuring the hyperfine constants, we determined various nuclear properties of thorium-229 isomer. We also developed a technique to enrich isomer ions up to more than 90% in a trap for future research on thorium-229 isomer, such as precise determination of the sensitivity of nuclear clocks to variations in the fine structure constant and investigation of unique nuclear decay via an electron bridge.

[PLENARY] Structure (Tue 5) 2024-08-20 10:55 AM

First Principle Reactivity Exploration Using Artificial Forces

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Abstract

Understanding the behavior of atoms in molecules and complexes during chemical reactions from first-principles calculations is a long-standing topic in theoretical chemistry and physics. We have worked to develop a systematic and automated approach. Our reaction path network representation of chemical reactions identifies not only the kinetically accessible region on the potential energy surface, but also the boundary between kinetically accessible and inaccessible regions, thus providing rich information, including how and why the reaction occurs selectively among many possible side channels. I will present its technical details, applicability, recent applications to the discovery of new synthetic methods in collaboration with synthetic chemists, and future prospects.

[KEYNOTE] Structure (Tue 6) 2024-08-20 11:30 AM

Benchmark Accuracy in Thermochemistry, Kinetics, and Noncovalent Interactions

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Abstract

Twenty-five years ago, composite ab initio theories were recognized with a Nobel Prize in Chemistry awarded to John Pople. This recognition sparked intense theoretical developments in this field. Due to major advances in quantum chemical theory, composite ab initio methods have advanced to the level where they can predict challenging thermochemical and kinetic properties with confident sub-kJ/mol accuracy. Powerful supercomputers further empower these theories, enabling them to tackle chemical processes involving molecules with dozens of atoms. Today, composite ab initio methods are revolutionizing various branches of chemistry. This presentation delves into the top end of these procedures, focusing on applications in thermochemistry, kinetics, and noncovalent interactions.

[KEYNOTE] Structure (Tue 7) 2024-08-20 11:50 AM

Unexpectedly large electron correlation induced effects in highly charged ion systems

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Abstract

Highly charged ions (HCIs) play an important role in astrophysics and fusion plasmas. Comparing with the relativistic effects (scale as Z^2 and higher), it was thought that the electron correlation effects (scale as Z) are generally less prominent in the HCIs than that in the lowly charged ions. However, considering the strong coulombic field within the HCIs, the orbital energies within the same n-shell would be very close to those of the hydrogen-like ions with degenerate energies and a strong intra-shell electron correlations could be expected [1], which may cause some new dynamical features comparing with the lowly charged ions. I will report the progress of our group that we pursue along this direction in recent years, including the prominent enhancement on the radiative branching ratio of the KLL resonant states due to the giant retardation effect in electron-electron interaction [2,3], and the unexpectedly large quantum interference between dielectronic and radiative recombination [4,5]. By the success collaboration with the Shanghai and Tokyo EBIT experimental groups, the mechanisms of these unexpectedly large electron correlation induced effects have been elucidated, which should be beneficial for applications such as the x-ray plasma spectroscopy.

References

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[EARLY CAREER] Precision Measurement (Tue 8) 2024-08-20 2:00 PM

Precision Measurement of Highly charged ions in Penning Traps

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Abstract

Highly charged ions (HCIs) are of great importance for investigating fundamental physics in extremely strong fields. A Penning trap is an experimental apparatus that confines charged particles, allowing for precision measurements in various research fields. In recent years, trapping single HCIs in Penning traps and measuring their mass, magnetic moment (g-factor), and other properties have provided an avenue for testing the building blocks of the standard model such as quantum electrodynamics (QED) with ultra-high precision and paved the way to explore underlying new physics [1,2].

We present the latest precision g-factor measurements of HCIs performed by the ALPHATRAP experiment. In this study, hydrogen-like $^{118}Sn^{49+}$ ions were produced in a high-energy electron beam ion trap (HD-EBIT). Subsequently, the ions were extracted and subjected to deceleration through a pulsed drift tube, finally being captured by a Penning trap apparatus. With the help of cryogenic pumping, the single highly charged $^{118}Sn^{49+}$ ion can be stored for more than one month. Employing microwave resonance techniques, the g-factor of the bound electron of $^{118}Sn^{49+}$ was precisely measured with an experimental uncertainty of 0.5 ppb, which agrees with state-of-the-art theory [3]. The result provides a stringent test of bound state QED in the extremely strong field of about 10^{15} V/cm.

Furthermore, we will also introduce progress in establishing a new Penning trap apparatus in Shanghai, China, aimed at the precision measurement of ultra-long-lived atomic or nuclear levels of highly charged ions [4,5], which holds promising applications for various fundamental studies, such as lifetime measurement of electronic metastable states and probing nuclear excitation by electron capture.

Key words: Highly charged ions; Penning Trap; Precision measurement; g factor

References

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[EARLY CAREER] Precision Measurement (Tue 9) 2024-08-20 2:20 PM

Multiphoton hyperfine Raman transitions based-multidimensional matter-wave beam splitters

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Abstract

Multidimensional beamsplitters play crucial roles in the development of multidimensional atom interferometers. Different one-dimensional beamsplitters are composited into one multidimensional beamsplitter, sharing the same external magnetic field as the quantization axis. The quantization axis defines the local interaction between the electromagnetic fields and the atoms. We studied both theoretically and experimentally the hyperfine Raman transition with different quantization axes and found a four-photon Raman transition that happened when the quantization axis was shifting from being parallel to perpendicular to the Raman beams' direction. Therefore, we present different configurations of multidimensional beamsplitters using both conventional two-photon Raman transitions and the newly discovered four-photon Raman transitions. These are pertinent to the future design and optimization of multidimensional atom interferometry systems.

[EARLY CAREER] Precision Measurement (Tue 10) 2024-08-20 2:40 PM

Rotation sensing using a multiply-orbiting-ion interferometer

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Abstract

Quantum wave nature-based sensors are anticipated as high-performance sensing technologies of the next generation. Atoms and ions are ideal for these sensors due to their precise quantum state control via optical methods. Laser-cooled ions in ion traps are particularly suitable for quantum sensing because of their stable, controllable, and isolated quantum systems. Our objective is to develop a gyroscope using a matter wave interferometer of ions trapped in an ion trap. This presentation introduces our research results towards realizing an ion gyroscope. The ion trap gyroscope, theoretically proposed by Campbell and Hamilton, uses a Sagnac interferometer with a single trapped ion in a two-dimensional isotropic potential, achieved through interferometry of ion wave packets propagating in clockwise and counterclockwise directions. Several key elements are required for the single trapped ion Sagnac interferometer, and we have developed the following technologies: first, preparing a two-dimensional circular potential and trapping the ion. By applying a laser pulse, we generate a spin-motion entangled state, known as the Schrödinger Cat state, to create a one-dimensional matter wave interferometer. Next, we achieved a non-adiabatic trap potential shift perpendicular to the momentum kick, realizing a two-dimensional interferometer. Recently, we successfully measured the Aharonov-Bohm phase with this two-dimensional interferometer. The experimental and calculated values of the phase shift of the matter wave interference signal, obtained by an ion orbiting multiple times in a magnetic field, matched. Furthermore, due to the trapping potential not being perfectly isotropic, the ion's trajectory forms a Lissajous figure, with its rotation direction reversing over time. This reversal in rotation direction results in a corresponding change in the interference phase. In this presentation, we will discuss the developed key technologies and the recent measurement results of the Aharonov-Bohm phase.

[KEYNOTE] Precision Measurement (Tue 11) 2024-08-20 3:00 PM

Calculations and applications of atomic polarizabilities

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Abstract

Atomic electronic dipole (E1) polarizability is a fundamental parameter for the atomic structure. It indicates the extent to which the electron cloud of an atom shifts away from its charge center in an external electric field. They have been used in many areas, such as the determination of magic and tune-out wavelengths in cold atom physics, the study of long-range interactions, the evaluation of Stark shifts and blackbody radiation shifts in high-precision measurements, and so on. The E1 polarizabilities can be theoretically determined by calculating the energy levels and E1 transition matrix elements. At present, there are many methods, such as the explicitly correlated Gaussian, relativistic all-order, many-body perturbation theory, relativistic coupled-cluster, and relativistic configuration interaction plus core polarization (RCICP) methods are widely used to calculate the E1 polarizability. Recently, we have developed a RCICP method. The static and dynamic polarizabilities of Sr+, Ca+, Ba+, Yb+ ions, and K, Rb, Cs, Be, Ca, and Cd atoms have been calculated. A number of tune-out wavelengths, as well as magic wavelengths of the clock transitions in the case of linearly polarized and circularly polarized light are obtained. In addition, taking into account the hyperfine interactions, we have predicted the dynamic polarizabilities and tune-out wavelengths for the hyperfine ground states of 39,40,41K,85,87Rb and 133Cs atoms. Good agreement with the recent experimental measurements is found. Furthermore, considering the magnetic dipole, electric quadrupole interactions, as well as the nonlinear interactions for the clock transition states of Be atoms, we have theoretically predicted the experimental conditions for realizing fractional Stark shifts of the clock transition to the 10E-19 level. Meanwhile, the triple magic trapping of the 5s2 1S0 → 5s5p 3P0 and 5s2 1S0 → 5s5p 3P2 transitions of Cd atoms are studied.

[KEYNOTE] Precision Measurement (Tue 12) 2024-08-20 3:20 PM

Multielectron effects in high harmonic generation: from frequency shift to odd-even intensity modulation

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Abstract

Fully comprehending the manifestations of multielectron effects in high-order harmonic generation (HHG) is essential to studying and extracting information about the core electrons. A prominent manifestation of the multielectron effect is the multielectron polarization (MEP) of the core electrons. Recently published studies have demonstrated the MEP effects on the intensity of the HHG spectra [1,2] and, more specifically, the even-to-odd ratio, i.e., the ratio between the intensities of the even and adjacent odd harmonics [3]. However, besides the HHG intensity, another important aspect of HHG spectra is the harmonic frequency [4]. The question is whether the MEP affects this feature and whether there is any relation between the MEP effects on the even-to-odd ratio and on the harmonic frequency. In this report, we found out the MEP effect induces harmonic frequency shifts compared to the case of neglecting MEP when a molecule CO interacts with a few-cycle laser pulse. The MEP-induced frequency shift is considerably large, about 0.7 harmonic order. In additional, we indicate the MEP effect transforms from the harmonic frequency shift to the odd-even modification as the results of increasing the laser pulse duration. Moreover, we reveal that these two MEP-induced effects are the consequence of the same origin: the MEP influence in the difference phase between the two adjacent harmonic emission bursts in the time domain.

Reference

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[PLENARY] Quantum Information (Wed 1) 2024-08-21 9:00 AM

Narrow-linewidth and high-spectral-brightness biphotons generated from hot atomic vapor

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Abstract

Biphotons are pairs of time-correlated single photons. One utilizes the first photon of a pair to herald the coming of the second photon in the same pair. Thus, the former is called the heralding photon, and the latter is called the heralded photon. It is convenient to employ the heralded photons in a subsequent quantum operation. We generated biphotons with the spontaneous four-wave mixing process in the double-Lambda configuration, consisting of a Raman transition and an EIT one. For the first time, the all-copropagation scheme was utilized in our systems, resulting in an excellent phase match. The phase-match scheme enables us to make the linewidth of the single-photon wave packets as narrow as 290 kHz. This is the world record for the narrowest linewidth of single-mode single photons generated from room-temperature or hot media, which can only be surpassed by that of our cold-atom single photon source with a linewidth of 50 kHz. Using the hot atomic vapor, we increased the spectral brightness of biphotons to 380,000 pairs/s/MHz. This spectral brightness is the best result to date among all kinds of room-temperature or hot media. Compared with other kinds of biphoton sources, The hot-atom source of biphotons developed by us: (1) Its frequency is stable and not controlled by temperature. The source has a continuously adjustable mode ranging more than 500 MHz and is very suitable for quantum repeaters. (2) Its linewidth is highly tunable, narrower than 300 kHz or broader than 3 MHz. The source is compatible with quantum devices with different characteristics. (3) Its ultrahigh spectral brightness is close to the ultimate limit. The source can achieve a high success rate in quantum communication.

This work was supported by Grant Nos. 112-2112-M-007-020-MY3 and 113-2119-M-007-012 of the National Science and Technology Council.

[KEYNOTE] Quantum Information (Wed 2) 2024-08-21 9:35 AM

Trapping Light via Electromagnetically Induced Transparency in a Superconducting Circuit

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Abstract

Recent progresses in Josephson-junction-based superconducting circuits have propelled quantum information processing forward. To further develop an extensive quantum network based on these circuits, photonic quantum memory is needed to synchronize flying qubits and distribute quantum states among various nodes within the network. However, lacking a metastable state in most superconducting artificial atoms hinders developments in photonic quantum memory based on electromagnetically induced transparency (EIT). In this presentation, we report a superconducting qubit-resonator circuit setting up a three-level artificial atom under the waveguide quantum electrodynamics architecture. The strong coupling qubit-like dressed state and high coherence resonator-like dressed state form an excited state and a metastable state, respectively, and the parametric modulation of the qubit frequency bridges otherwise the first-order dipole-forbidden transition between them. This artificial atom system, therefore, resembles a Λ-type atom and exhibits an EIT-like phenomenon. A probe pulse interacting with this artificial atom slows down. On-demand microwave storage and retrieval are also realized through dynamical controls of the parametric modulation within this single atom. These findings underscore the potential of our straightforward superconducting circuit design to attain photonic quantum memory in the microwave regime.

[EARLY CAREER] Quantum Information (Wed 3) 2024-08-21 9:55 AM

Atom interferometry inertial sensing based on a cold atomic source

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Abstract

Quantum sensors based on cold atom interferometers provide high-accuracy inertial measurement with exquisite sensitivity and stability. This capability has led to increasing interest in atomic inertial sensors such as gravimeter, gradiometer, and gyroscope for field uses. However, it is challenging to implement atom interferometry inertial sensors in a small volume without increasing complexity. Here, we present on a point-source atom interferometry (PSI) multi-axis inertial sensor which uses a velocity distribution of an expanding atomic source. We also introduce on a grating magneto-optical trap based atomic gyroscope in KRISS.

[PLENARY] Spectroscopy (Wed 4) 2024-08-21 10:55 AM

Intermediates in Singlet Fission and Triplet Fusion

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Abstract

The photophysical processes of singlet fission and triplet fusion have numerous emerging applications. They respectively involve the separation of a photo-generated singlet exciton into two dark triplet excitons and the fusion of two dark triplet excitons into an emissive singlet exciton. The role of the excimer state and the nature of the triplet-pair state in these processes have been a matter of contention. We have carefully analysed the room temperature time-resolved emission of a neat liquid singlet fission chromophore. It exhibits three spectral components: two that correspond to the bright singlet and excimer states, and a third component that becomes more prominent during triplet fusion. This spectrum is enhanced by magnetic fields, confirming its origins in the recombination of weakly-coupled triplet pairs. It is tentatively attributed to strongly coupled triplet pair state. These observations unite the view that there is an emissive intermediate in singlet fission and triplet fusion, distinct from the broad, unstructured excimer emission.

[KEYNOTE] Spectroscopy (Wed 5) 2024-08-21 11:30 AM

Molecular movie spectroscopy of van der Waals clusters : High-resolution spectra and image-based assignments

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Abstract

High-resolution spectroscopy of molecular complexes is one of the powerful tools to study dynamics and structures governed by intermolecular interactions. It is, however, difficult to measure pure rotational (microwave) and intermolecular vibrational (THz) spectra with a single setup, although rich information on intermolecular interaction can be deduced in these frequency regions. Recently, we have developed broad bandwidth (>3 THz), high-resolution (~50 MHz), spectroscopy for weakly-bound molecular clusters. Our method relies on high-precision rotational/vibrational wave packet imaging. , Rotational/vibrational wave packet of a molecular dimer is created upon broadband femtosecond pump, and subsequent dynamics is tracked by real-time Coulomb explosion imaging. Rotational/vibrational Raman spectrum can be obtained as a Fourier transform of a time trace of an observed wave packet movie. We applied the method to Ar2, (N2)2, (CH4)2, (C2H4)2,3, and other important systems which have been difficult targets of typical microwave spectroscopy. We also succeeded in measuring rotationally-resolved vibrational spectra for the first time. Details on experimental setup and selected results will be presented.

[KEYNOTE] Spectroscopy (Wed 6) 2024-08-21 11:50 AM

Spectrally Resolved Energy Transfer Length in Photodesorption of Astrophysical Ice

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Abstract

The overabundance of gas molecules in the coldest regions of space suggests the presence of a nonthermal desorption process. Laboratory simulations have demonstrated the efficient desorption of CO ice when exposed to vacuum ultraviolet (VUV) radiation, a process known as photodesorption. Fayolle et al. (2011) showed that the photodesorption of CO is dependent on its vibrational and electronic transition strengths, implying that desorption is induced by electronic transitions (DIET). Furthermore, Bertin et al. (2013) proposed that this mechanism is indirect, involving energy transfer between molecules with non-coinciding electronic transition states. Sie et al. (2022) indicated that the photodesorption yield of CO ice driven by broadband irradiation (using a microwave-discharged hydrogen lamp, MDHL) is not merely the sum of wavelength-dependent photodesorption yields. This suggests that multi-energy photon irradiation must consider the effects of photo-products. Additionally, Sie et al. (2022) provided the photon energy transfer length for VUV-irradiated CO ice at 15 K, approximately 9 monolayers (ML, where 1 ML = 1015 molecules/cm^2). In this study, we irradiate pure 13CO ice with tunable, monochromatic synchrotron radiation. By conducting experiments with different thicknesses of pure 13CO ice, we can determine the energy transfer length for each electronic transition. However, when applying these energy transfer lengths to the MDHL experiment, we find that the predicted energy transfer length is smaller than the experimental result from Sie et al. (2022). This reveals a discrepancy in the photodesorption yield of CO ice between narrow and broad energy irradiation, as well as in the energy transfer length.

[EARLY CAREER] Spectroscopy (Wed 7) 2024-08-21 12:10 PM

Absolute line strength measurements of transient free radicals with high-resolution time-resolved dual-comb spectroscopy

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Abstract

Transient free radicals, such as hydroxyl (OH) and hydroperoxyl (HO2) radicals play the crucial roles in atmospheric, combustion, and environmental sciences. Quantitative spectral studies of these key free radicals are important for estimation of their concentrations both in field observations and laboratory experiments to further explore their reactivity and impacts in the atmosphere. Herein, we report a new approach to perform line strength measurements of the fundamental transitions of OH and HO2 radicals using mid-infrared high-resolution time-resolved dual-comb spectroscopy. By simultaneous determination of multiple species including precursor, radical, and byproduct molecules, the absolute line strength of the OH and HO2 ro-vibrational transitions are measured with the small uncertainty of <10% and compared with the values from HITRAN database. Accurate line strength measurements of the key radicals achieved in this work are important to improving the accuracy of the simulated values in the database and to perform direct monitoring of these free radicals using mid-infrared absorption spectroscopy in various applications.

[PLENARY] Spectroscopy (Thu 1) 2024-08-22 9:00 AM

Development of a TW-class single-cycle laser and its applications to attosecond science

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Abstract

A new form of optical parametric amplification with two kinds of nonlinear crystals demonstrates a multi-TW carrier-to-envelope phase-stable single-cycle laser pulse in the mid-infrared region. Owing to the energy scalability of this new scheme, the prospects of the multi-terawatt sub-cycle laser pulses are also discussed.

[KEYNOTE] Strong Field (Thu 2) 2024-08-22 9:35 AM

Ultrahigh fidelity measurement of laser field using atomic tunneling ionization

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Abstract

The precise characterization of the temporal shape of laser pulses is crucial in numerous optics applications. Traditional temporal characterization techniques predominantly employ frequency domain methods, leveraging the nonlinear response of materials. A novel technique, termed Tunneling Ionization with a Perturbation for the Time-Domain Observation of an Electric Field (TIPTOE), has emerged as a promising alternative. TIPTOE utilizes sub-cycle tunneling ionization for pulse characterization and is effective across a broad spectral range, including UV, visible, and IR spectra. The sub-cycle tunneling ionization that serves as a fast temporal gate hinges on the extreme nonlinearity of the ionization process, allowing direct observation of the pulse's temporal shape. However, this high nonlinearity also renders the ionization yield highly sensitive to power fluctuations, resulting in noisy modulation and a poor signal-to-noise ratio (SNR). The nonlinearity of ionization in air (mostly O2 molecules) is 6. This means that the fluctuation of the ionization yield is approximately 6 times larger than the power fluctuation of the laser pulse. Thus, it is difficult to measure a laser pulse with good accuracy when the laser is unstable. In this work, we present an innovative approach to enhance the SNR of TIPTOE measurements. By collecting ionization yields through multiple electrodes and superposing two laser pulses at a small angle, we achieved phase-opposite ionization yield modulation. This phase-opposite modulation allowed for the subtraction of background noise, significantly improving measurement accuracy. Consequently, the temporal shape of the laser pulse can be measured with high precision.

[KEYNOTE] Strong Field (Thu 3) 2024-08-22 9:55 AM

Attosecond time delay in photoionization studied via strong-field multiphoton transition interferometry

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Abstract

Ultrafast dynamic measurement of strong-field ionization processes can enhance the understanding of laser-matter interactions. Strong-field multiphoton transition interferometry (SMPTI) is a crucial experimental technique for studying the strong-field photoionization with attosecond time-resolution. The main principle of SMPTI can be visualized as follows: using a strong 400 nm laser field to induce above-threshold multiphoton ionization of atomic and molecular targets, followed by the introduction of a weaker 800 nm laser. This induces a sequential absorption or release of one 800 nm photons in the ionization continuum, establishing a quantum interference and ultimately generating photoelectron spectra in the ionization channels. A structure of photoelectron peaks known as 'sidebands' is created in the photoelectron spectrum for one or few ionization channels. The sidebands record the formation time or phase of the ionization state, thus the phase information of the sidebands can be used to extract the relative time information for the corresponding channels during ionization. Based on the SMPTI method, we studied the REMPI processes for noble gases and some small molecules, and discussed the origin of the attosecond time-delay observed in the channel-resolved photoelectron spectra during REMPI.

[EARLY CAREER] Strong Field (Thu 4) 2024-08-22 10:15 AM

Realtime observation of light-induced dynamics in polyatomic molecules by ultrafast soft x-ray spectroscopy

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Abstract

Nonadiabatic transition (NAT) drives x-ray induced radiation damage of many bio- and x-ray functional molecules. These molecules contain aromatic rings in their skeleton and the NAT time constant for aromatic molecules is therefore a fundamental parameter to understand the mechanisms of the radiation damage. Recent advances in the two-color operation of femtosecond/attosecond x-ray free electron laser open the door for the real-time observation of x-ray induced NAT dynamics. To clarify the x-ray-induced NAT dynamics, we performed surface hoppling nonadiabatic molecular dynamics simulations on electronically excited tropone (C7H6O) dication created by the carbon normal Auger-Meitner decay. The final states of the Auger-Meitner decay were investigated by the two-hole population analysis. The liner-vibronic coupling model Hamiltonian for the fast nonadiabatic dynamics simulations was constructed by the complete active-space self-consistent field theory including the all valence two-hole states (210 singlet and 190 triplet states). The tropone dication undergoes the NAT cascade via ~10-100 states with time constants of 200-400 fs. We observed population traps in the highly excited electronic states in ~100 fs during the NAT cascade. The population trap is originated from the quasi-degeneracy of the highly excited electronic states and its time constant logarithmically increases by the number of valence electron. The fingerprint of this population trap can be extracted from C edge pump O pre-edge probe femtosecond transient x-ray absorption spectra measured by the O Auger-Meitner electron yield method (TR-AEYS) using intense narrow band femtosecond x-ray free electron laser pulses. Our coupled ionization rate equation model demonstrates that selective and saturable C core-ionization of tropone will realize a background-free measurement. These results indicate that the importance of NAT in x-ray photochemistry and photophysics in large molecules. The real-time tracking of the NAT dynamics using TR-AEYS shall be a powerful approach for deeper insight.

Reference: K. Yamazaki and K. Midorikawa, arXiv:2209.02874 (2022).

[PLENARY] Strong Field (Thu 5) 2024-08-22 10:55 AM

Attosecond science and technology in atomic and molecular systems

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Abstract

Attosecond science and technology in atomic and molecular systems Dong Eon Kim Physics Department, POSTECH and Max Planck Center for Attosecond Science, Max Planck POSTECH/KOREA Res. Initiative kimd@postech.ac.kr In the 21st century, quest has been growing about the study of how quantum systems evolve, and eventually, how to induce such quantum systems to behave as desired. In this sense, we are entering a new scientific paradigm, "Control Age." For example, scientists would like to move electrons around during chemical reaction processes that are far from equilibrium. The new era of science calls for new tools to control electron behavior in matters at the utmost time scale (femtosecond to attosecond) with atomic spatial resolution. The past two decades have witnessed the remarkable advance in the new metrology for ultrafast electron dynamics, which allows one to control material processes at electron level and study dynamics far away from equilibrium. This development was recognized by 2023 Nobel Prize in Physics. In this talk, I share the excitement, reviewing recent progress in the generation of ultrafast pulses (single cycle pulse, attosecond pulse, zeptosecond pulses) and their characterization and real time measurement and manipulation of electron dynamics in atoms, molecules and condensed matters. I hope that this provides the audience with the new insights and perspective that these tools have provided in aspects of both fundamental science and future technology.

[KEYNOTE] Strong Field (Thu 6) 2024-08-22 11:30 AM

Vortex electron generation by intense laser irradiation and its applications

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Abstract

Manifestations of and possibilities related to vortex electrons in strong-field physics are discussed. We present a theory which extends the foundation of a powerful method of target structure and dynamics imaging to vortex electrons. The theory enables one to extract the differential cross section (DCS) for elastic scattering of a vortex electron on the parent ion—a collision property introduced here—from the observable photoelectron momentum distribution (PEMD). We illustrate this by considering strong-field ionization from orbitals in two atoms, Xe and He+, and a molecule, O2. The vortex DCS is shown to be sensitive to the target structure. The PEMDs formed by vortex electrons are predicted to be sensitive to the chirality of the target. Extracting vortex DCSs from experimental PEMDs may open a new avenue for rescattering photoelectron spectroscopy.

[EARLY CAREER] Strong Field (Thu 7) 2024-08-22 11:50 AM

Orientation dependent tunneling ionization and dissociation of methane in two-color asymmetric intense laser fields

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Abstract

Intense laser pulses have large electric fields comparable to intramolecular Coulomb fields and drive ultrafast dynamics of electrons in atoms and molecules. Two-color intense laser fields, consisting of fundamental and second harmonic laser fields have spatial asymmetric electric fields, which has been used in selective breaking of equivalent chemical bonds of linear (CO_2, C_2H_2) and bent (H_2O) molecules from dication states. We present the three-dimensional momentum imaging of dissociative ionization and Coulomb explosion processes of tetrahedral molecules, CH_4 in two-color intense laser fields. The H^+ fragment produced from dissociative ionization, CH_4 → H^+ + CH_3 + e^-, is preferentially ejected on the larger amplitude side of the laser electric fields. To understand the asymmetric ejection of H^+, theoretical calculation of the tunneling ionization rate for the highest occupied molecular orbitals were carried out by the weak-field asymptotic theory. The calculation result showed that the orientation-selective tunneling ionization can occur for CH_4 having a high symmetry (T_d), which is consistent with the experimental asymmetry. A similar directional ejection of H^+ was also observed for the low kinetic energy components of the two-body Coulomb explosion, CH_4 → H^+ + CH_3^+ + $2e^-$. On the other hand, the fragment ejection in the opposite direction were observed for the high energy component, as well as H_2^+ produced from the Coulomb explosion CH_4 → H_2^+ + CH_2^+ + $2e^-$. Possible origins of the characteristic fragmentation are discussed.

Photoabsorption, photoionization and photodissociation studies of molecules using synchrotron radiation

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Electronically excited states of molecules play important roles in a variety of phenomena including atmospheric processes, formation and evolution of molecules in stellar and interstellar media, photobiological processes, etc. [1]. Studies of the structure and dynamics of excited states are crucial inputs in understanding intramolecular interactions and photon-induced reactions of molecules. Synchrotron radiation has proven to be a very powerful tool for such studies, with its high intensity and wide tunability across the vacuum ultraviolet (VUV) and soft X-ray regions of the electromagnetic spectrum, relevant for probing molecular photoionization and photodissociation. At the INDUS synchrotron radiation facility, at the Raja Ramanna Centre for Advanced Technology, Indore, India, a variety of studies on interaction of extreme UV photons with molecules are performed using two beamlines: The Photophysics beamline at the 450 MeV storage ring Indus-1 [2] and the recently installed Atomic Molecular and Optical Sciences (AMOS) beamline which is built at an undulator port of the 2.5 GeV ring Indus-2. Photoabsorption studies of several molecules of interest in environmental sciences, astrochemistry, industrial processes, etc. have been studied over the past few years [3,4] and spectroscopic data recorded using these beamlines is incorporated in international data bases [5]. Quantum chemical calculations are used as an indispensable tool to analyse the complex data, leading to a better understanding of the excited state electronic and vibrational structure of the molecules studied. In this talk, a few recent results and ongoing studies carried out using the Photophysics beamline will be presented, and future scope of molecular photoionization and photodissociation studies using the AMOS beamline will be briefly discussed.

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[KEYNOTE] Quantum Information (Thu 8) 2024-08-22 2:00 PM

Scalable graph states generations in an atom-nanophotonic interface

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Abstract

Graph states are essential for measurement-based quantum computation and many entanglement-assisted applications in quantum technologies. Here we proposed a general protocol using an atom-nanophotonic interface, which provides a high-fidelity generation of scalable graph states. We present a general recipe to weave graph states in one and two dimensions, where we provide a multiqubit state carving for linear and two-dimensional graph states at arbitrary sizes. This exquisite design protocol relies on the feature of contrasted single-photon reflection spectra allowed by the critical coupling regime in the interface. Via the state-carving technique, we are able to project the system into the target graph states with high fidelity. A sequence of single-photon probes further enhances the graph state probability, which is especially useful for large-size graph states and promises a near-term application in quantum engineering of multipartite entangled states. Our results illustrate the potential of an atom-nanophotonic cavity for generating linear and high-dimensional graph states, which sets the foundation for measurement-based quantum computation and many intriguing problem-specific applications.

[EARLY CAREER] Quantum Information (Thu 9) 2024-08-22 2:20 PM

Toward quantum simulations with Rydberg atoms

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Abstract

Quantum simulation is one of the promising experimental research that could provide quantum advantage. Hundreds of Rydberg atoms arranged in a two-dimensional space have recently shown remarkable experimental works in analog quantum simulations. Extending atomic arrays to three dimensions is expected to offer more diverse qubit connections, and therefore implementing various Hamiltonians. In this talk, we discuss the application of 3D Rydberg atom arrays for quantum simulations. As a relevant preliminary experiment, we observed the quantum dynamics of N=18 bilayer Rydberg atom clusters. We also observed antiferromagnetic spin correlations between interlayer Rydberg atoms, by varying the interlayer distance along the axial direction. We further discuss the potential implementation of a hybrid Ising- and XY-type Hamiltonians, such as Ising-type interactions at short-range and XY-type interactions at long-range interatomic distances. We introduce the current experimental progress for this purpose.

[EARLY CAREER] Quantum Information (Thu 10) 2024-08-22 2:40 PM

Quantum information processing with highly-connected ion qubits

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Abstract

TBA

[KEYNOTE] Collisions (Thu 11) 2024-08-22 3:20 PM

First Measurement of Fully Differential Cross Section for Ionization of Helium by Swift Iron Ions at the Cooling Storage Ring for Experiment (CSRe)

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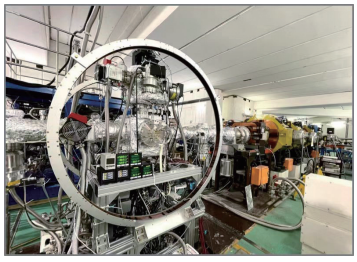
Abstract

Relativistic collisions between highly charged ions and atomic or molecular targets provide a powerful means to investigate the dynamics of correlated few-body quantum systems under strong electromagnetic fields. These collisions involve complex multi-electron dynamics, where electron correlations are crucial for understanding the underlying phenomena. Despite the well-established quantum electrodynamics (QED) framework describing these forces, the breakup processes in many-body correlated systems remain challenging, both experimentally and theoretically [1].

A comprehensive understanding of the collision dynamics necessitates detailed information on the kinematics of the final fragments, achievable through fully differential cross-section (FDCS) measurements. Storage rings have become indispensable for precise FDCS measurements, offering valuable data that elucidate processes such as ionization and charge exchange. These measurements, especially in the context of single ionization of atoms by highly charged ions, rigorously test theoretical models, particularly in the perturbative regime where higher-order effects are significant.

The new reaction microscope at the cooling storage ring in Lanzhou is designed to enhance the study of complex collision processes (see left panel of Fig. 1). Experiments with fast Fe^{26+} ions colliding with helium (He) and argon (Ar) atoms have demonstrated the potential of this apparatus. Preliminary results (right panel of Fig. 1) reveal promising insights into relativistic heavy ion-atom collisions. Ongoing research, supported by advanced experimental facilities in Lanzhou, aims to deepen our understanding of relativistic collision physics and shed light on fundamental interactions in relativistic quantum dynamics



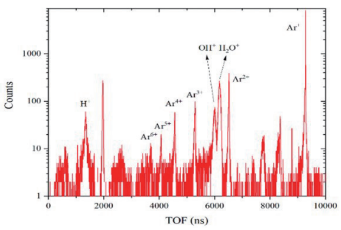


Fig. 1, (Left) the new reaction microscope at the CSRe. (Right) Time-of-flight spectra of the recoil ions in collisions between 120 MeV/u Fe^{26+} ions and Ar.

[1] H.-K. Kim, H. Gassert, J. **N.** Titze et al., Phys. Rev. A **89**, 022704 (2014); B. Najjari, Z. Wang and A. B. Voitkiv, Phys. Rev. lett. **127**, 203401 (2021)

[EARLY CAREER] Collisions (Thu 12) 2024-08-22 3:40 PM

Molecular science using electron impact spectroscopy

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Abstract

Electron impact spectroscopy has long been used for fundamental research in a broad range of science, and it has many applications by utilizing both photoelectric and Compton effects in electron scattering. In particular, Compton scattering has provided us several molecular spectroscopy techniques with unique abilities. For instance, electron-electron Compton scattering opened the door for the studies on the behavior of the outer, loosely bound valence electrons that are of central importance in chemical properties such as chemical reactivity and molecular recognition. In contrast to such study of intramolecular electrons, there was no way to directly observe intramolecular atomic motion, which governs chemical properties and functionalities of molecules. Under the circumstance, we have recently developed a completely new molecular spectroscopy technique by employing electron–atom Compton scattering. This technique, also known as atomic momentum spectroscopy (AMS), has the unique ability to map intramolecular motion of each constituent atom different masses; in other words, AMS is the complete electron analogue of the velocity speed gun in baseball games. In the talk, we will discuss not only our efforts of the experimental and theoretical developments of AMS but also molecular science using AMS.

[KEYNOTE] Collisions (Thu 13) 2024-08-22 4:00 PM

Study of electron induced processes on high Z atoms and ions relevant to plasma applications

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Abstract

Ionization of targets such as atoms, ions, and molecules by charged projectiles such as electrons / positrons has been studied from a long time and has various applications; few may be listed as diagnostics of fusion plasmas, modeling of physics and chemistry related to atmosphere, understanding the effect of ionizing radiation on biological tissues etc. The ionization cross sections are essential in the modeling of plasma in fusion research. Electron collision processes on the High Z atoms and their charged states play an important role in the fusion edge and diverter plasmas. The tungsten (W) and tungsten based materials have also been recommended as one of the materials to be used as plasma facing components for the International Thermonuclear Experimental Reactor (ITER) [1], and it is also been used in the number of current tokamaks such as JET, ASDEX-Upgrade and DIII-D. Electron induced processes are prevalent in such magnetic fusion devices in a wide range of energies. We report the results of our recent work on calculation of electron impact ionization cross sections for W and Mo atoms and charged states of W [2-4]. We also report elastic electron scattering differential cross sections of Pb atoms. The status of charged particle ionization processes from targets with introductory idea about the theoretical formalism involved will be reviewed and results for the electron induced processes of atomic and ionic targets will be discussed.

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[PLENARY] Spectroscopy (Fri 1) 2024-08-23 9:00 AM

Theoretical approaches to connect potential energy surfaces with vibrational spectroscopy

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Abstract

Vibrational spectroscopy is a commonly used experimental method to probe the structures and dynamics of molecular systems. To interpret vibrational spectra, the standard procedure is to use an accurate and efficient electronic method to locate local minima on the potential surface (PES), compute their second derivatives and linear terms of the dipole to simulate IR spectra for comparison. However, anharmonic coupling, such as Fermi resonance, are known to lead to non-trivial and complex features in the high-frequency part of experimentally observed spectra in mid-IR. There are several parallel developments on the theories and algorithms to address different aspects of anharmonic coupling and dynamical effects in linear and non-linear spectroscopy. In this talk, I will present a team effort to develop an integrative theoretical scheme to (i) extract simple effective Hamiltonian directly from PES without any fitting parameters covering a frequency range from THz, mid-IR to NIR and (ii) to enable direct simulations of the non-linear spectra and identification of specific spectral signals to elucidate the key roles of anharmonic coupling.

[KEYNOTE] Spectroscopy (Fri 2) 2024-08-23 9:35 AM

Formation dynamics of H^{3+} from small molecules

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Abstract

As the most prevalent molecular ion in interstellar space, the triatomic hydrogen ion H^{3+} plays a crucial role in astrochemistry due to its high activity in initiating various chemical reactions within interstellar clouds. H^{3+} acts as a proton donor through proton hopping reactions. Once protonated, these charged species are significantly more reactive than their neutral counterparts, initiating chains of reactions that lead to the formation of larger and more diverse molecules. Therefore, H^{3+} is often referred to as the "engine of astrochemistry." Traditionally, H^{3+} is known to form through collisions between H^{2+} ions and neutral hydrogen gas. Recently, we investigated pathways for H^{3+} formation involving the isomerization processes of dications of small organic molecules such as methanol, ethanol, and ethane. These experiments utilized electron impact ionization and photoionization techniques. The formation channels of H^{3+} were identified through multi-ion coincidence methods. Isomerization dynamics were further explored using ab initio molecular dynamics simulations. A two-step mechanism for H^{3+} formation emerged: first, a neutral H^2 is formed, which may undergo prolonged and extensive roaming or follow the potential energy surface of the transition state. In the second step, a proton transfers from the dication to H^2, forming H^{3+}. Further investigation focused on the environmental effects using methanol clusters as targets. It was observed that H^{3+} was suppressed by the chemical environment, suggesting a general phenomenon in dicationic clusters of organic molecules. These studies provide new insights into the dynamics of dicationic molecules/clusters and enhance our understanding of the mechanisms behind H^{3+} formation in the interstellar medium.

[EARLY CAREER] Spectroscopy (Fri 3) 2024-08-23 9:55 AM

Time-resolved plasma-assisted laser spectroscopy of highly charged ions

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Abstract

Visible transitions of highly charged ions(HCIs) can be used in various applications. For instance, spectroscopic observation of visible emissions in plasmas is one of the important diagnostic methods for astrophysical and fusion plasmas. Precision measurements of visible transitions in highly charged ions can provide important benchmarks for theoretical studies, such as the verification of QED effects, many-body recoil effects, and g-factor calculations of HCIs. Recently, various visible transitions of HCIs with many electrons have been proposed as candidates for next-generation atomic clocks. The proposals have also spurred the development of laser spectroscopy of highly charged ions. In addition, the accurate understanding of atomic structures of many-electron HCIs is of growing importance in realizing the HCI clock operation. In this talk, we present our recent demonstrations on time-resolved plasma-assisted laser spectroscopy of HCIs using a compact electron beam ion trap. This technique enabled us to study the atomic structures of many-electron HCIs accurately, which could not be experimentally observed. In particular, we successfully observed the hyperfine splitting in the laser excitation spectrum of ^{127}I^{7+}. In addition, the electric-quadrupole transition rate in I^{7+} and the intercombination transition rate in Ar^{14+} were measured by this technique. These results provide a benchmark for the theoretical calculations of relativistic atomic structures with many electrons and contribute to growing new applications.

[KEYNOTE] Spectroscopy (Fri 4) 2024-08-23 10:15 AM

A streamlined approach to measure the absolute photostability of molecular ions

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Abstract

Absolute photodetachment cross-section characterizes the photostability of anions against photodetachment. The measurement of this parameter is available only for simple atomic/molecular anions in literature. In 2006, Wester's group proposed a novel ion-trap-based technique to measure this parameter [S. Trippel, et al., Phys. Rev. Lett. 97, 193003 (2006)], independent of any normalization procedure. In the current work, we propose a simplified scheme by combining a single experimental rate measurement with simulated ion density distributions inside the trap, reducing the time required for the measurement by more than two orders of magnitude. We use this technique to report the first measurement for deprotonated indole at 405 nm.

[PLENARY] Quantum Information (Fri 5) 2024-08-23 10:55 AM

Recent progresses in single-atom superradiance

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Abstract

A superradiant state is a phase-correlated quantum state of atoms capable of undergoing superradiance immediately without a time delay. We can prepare a superradiant state in an optical cavity by exciting N atoms in the same superposition state of the ground and excited states with the same phase angle by using a nanohole array aperture. These correlated atoms generate superradiance in the cavity even when the mean number of intracavity atoms is much less than unity, and hence the name "single-atom superradiance" is given. As an application, the superradiant state can be used to realize the long-sought superabsorption, the opposite of superradiance, by reversing the superradiance process in time through the phase control of the superradiant state. As another application, we can also realize a photonic quantum engine, where the atoms entering the cavity act as a heat reservoir and the photons are an engine medium exerting radiation pressure on the cavity mirrors. Our engine operates between a thermal state and a superradiant state of a single reservoir at a fixed reservoir temperature. In our experiment, the effective engine temperature rose up to 150,000K because of the large ergotropy transfer from the reservoir through superradiance, resulting in the engine efficiency as high as 98%, the highest ever achieved in quantum engines so far. Our recent effort to replace the nanohole array with traveling-wave interaction with an extracavity phase-matched pump field on a high-density high-speed Ca+ ion beam is also discussed.

[EARLY CAREER] Quantum Information (Fri 6) 2024-08-23 11:30 AM

Quantum reservoir engineering through light-matter interactions

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Abstract

Quantum systems are inevitably influenced by their environment, leading to dissipative behaviors that cause decoherence and the loss of quantum properties. Quantum reservoir engineering aims to transform these usually harmful interactions into useful resources. By strategically coupling a quantum system with its environment, we can observe intriguing dynamics and exotic steady states, which can be leveraged for novel quantum applications. In this talk, we will present a quantum reservoir engineering approach that couples a quantum system to a dissipative cavity mode. Through typical light-matter interactions, we show that the quantum system can achieve atypical steady states, with potential applications in dissipative entanglement generation and the quantum simulation of open quantum system dynamics.

[EARLY CAREER] Quantum Information (Fri 7) 2024-08-23 11:50 AM

Quantum science with ultracold polar molecules

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Abstract

Ultracold polar molecules, with their rich internal structure and strong long-range dipolar interactions, hold the promise to become a highly scalable and programmable platform for quantum science research. In this talk, I will present our experimental efforts to create ultracold Bose and Fermi gases of strongly dipolar NaK molecules. This involves the atom-by-atom assembly of molecules from sodium and potassium atoms at nano-Kelvin temperatures. The potential application of ultracold polar molecules will also be highlighted, such as in quantum many-body research, including the quantum simulation of extended Hubbard models, the realization of molecular qubits for stable quantum information processing, and precision quantum chemistry.

Poster presentations

01

Photo-dressed states generating unidirectional pi-electron rotation in an aromatic ring molecule

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Abstract

In this talk we theoretically demonstrate that the helical-photon dressed state determines the direction of rotation of pi electron in aromatic rings using elliptically polarized (EP) or circularly polarized (CP) laser. We consider minimum three-electronic states model, which consists of the ground state and a doubly degenerate electronic excited state or two nondegenerate excited states. Three helical-photon dressed states are derived by solving the time-dependent Schrödinger equation within the semi-classical treatment of light-molecule interactions and rotating wave approximation. To examine the characteristic feature of the helical-photon dressed states mentioned above, benzene (D6h) and toluene (CS) are adopted as typical aromatic ring molecules with a doubly degenerate, and two nondegenerate excited states, respectively. The angular momentum of one of the three helical-photon dressed states represents an intuitive pi-electron rotation, and the rest represent the opposite rotation, i.e., counter-intuitive rotation. Intuitive rotation means that the direction of pi-electron rotation is the same as that of the given helical electric field vector, i.e., the electron rotation follows the classical equation of motion in the helical electric field. Whereas the counter-intuitive rotation means that the rotational direction of pi-electron is opposite to that of the given helical electric field vector, i.e., this is a purely quantum behavior of the pi-electron rotations. It has been rigorously proven that the sum of the angular momentums of all three dressed states is conserved and zero for aromatic ring molecules with high or low symmetry, irrelevant to the laser parameters such as detuning.

02

Nuclear spin dependent parity violation in ^{133}Cs

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Abstract

It is widely believed that Standard Model (SM) of particle physics is an intermediate manifestation of a complete theory that needs to be uncovered. Direct test of physics beyond the SM (BSM) is not successful yet through accelerator based experimental probe, though there have been substantial evidence of existence of such physics in nature. To explain and support the BSM physics, indirectly many table-top based experiments are carried out in the laboratories around the world. To extract meaningful signatures of BSM physics from these measurements, it is necessary to combine them with very high-precision atomic calculations. Studies of atomic parity violation (APV) is such an example, and it has been measured in $^{\{133\}}$Cs to 0.35% accurately. Study of APV can also probe a possible existence of nuclear anapole moment (NAM). In this work, we shall discuss the present status of the APV studies and highlight some of the issues related to the atomic calculations. We shall also present the new result on NAM.

03

Electric-field-tuned energy levels for Förster Resonance in thermal Rydberg atoms - Toward demonstrating giant Rydberg blockade

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Abstract

Rydberg atoms with high polarizability and strong dipole momentum are sensitive to the electric field, which induces the Stark effect. Through this effect, the energy level of the two Rydberg atoms can be controlled, facilitating the strong interaction that causes a Förster resonance. This phenomenon can significantly enhance the Rydberg blockade radius, which is crucial to developing quantum computing. The van der Waal interaction, which is the interaction between the Rydberg atoms, was calculated using the Alkali Rydberg Calculator package. We found that the blockade radius can significantly increase with large initial quantum numbers, especially in certain transition channels that can achieve more than 50 μm. However, applying an electric field to Rydberg atoms presents challenges due to the shielding effect caused by photo-desorption, particularly in the low-frequency electric field. By modulating the electric field, we observe variations in the Rydberg electromagnetic induction transparent (EIT) signal corresponding to the Stark effects. We systematically adjust the laser power and electric field strength to control the shielding effect so that a low-frequency electric field is possible.

04

Multielectron effects in High harmonic generation of HCN: Depending on laser pulse parameters

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Abstract

In recent decades, the progress of laser technologies has resulted in the discovery of various nonlinear effects [1-4]. These nonlinear effects, such as above-threshold ionization (ATI), high-energy ATI (HATI), nonsequential double ionization (NSDI), and high-order harmonic generation (HHG) [1-4], have potential to imply extracting time-resolved imaging and investigating dynamics within atoms and molecules [5, 6]. As a result, a deep physics understanding and accurate theoretical explanations of these nonlinear effects that are consistent with experimental observations are required. Solving time-dependent Schrödinger equation (TDSE) using the single active electron (SAE) model which is a low-cost method is a common way for investigating these phenomena theoretically [7-9]. Previous works ansatz highest occupied molecule orbital (HOMO) dominantly contributes to highly nonlinear spectra, such as HHG, compared to lower-lying orbitals [10-12]. However, subsequent studies have revealed the imprint of lower-lying orbitals. The coupling between HOMO and lower-lying orbitals leads to electron-electron interactions between MOs, called the multielectron effect. This effect offers to extract electron-electron dynamics on attosecond time scales, a significant topic in Strong-field Physics. To determine the contribution of each MO, an advanced approach such as time-dependent density-functional theory (TDDFT) is applied [13-15]. However, due to the new target, HCN molecules, there is disagreement in these researches about the contribution of HOMO and HOMO-1 [13, 15]. Furthermore, these simulations did not consider the permanent dipoles of each MO, which is required for dissymmetrical molecules like HCN. In this work, we discerned the contribution of HOMO and HOMO-1 in HHG spectra of HCN by solving the TDSE with SAE approximation that mimics the energies and permanent dipoles of both HOMO and HOMO-1. We explored the imprint of multielectron and the competition in contributing to HHG spectra of HOMO and HOMO-1 depending on the laser parameters. This explained the disagreement in previous studies [13, 15].

05

Auger Meitner(AM) electron emission Ar^{q+}–Ar atom collisions

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Abstract

When an atom undergoes inner shell excitation due to collisions with ion, one electron from of the inner shell (such as K-shell or L-shell) absorbs energy and goes to a higher energy level or continuum. Understanding of this process falls into two categories: (1) Coulomb ionization (for proton and bare-ion projectile) (2) Excitation or ionization of a quasi-molecule. For Coulomb ionization, it is assumed that orbital velocity (u$_{e}$) of electron in target atom is only marginally perturbed by either the fast-moving (v$_{p}>>u_{e}$) or lighter (Z$_{p}<<="" td="">>

06

Spectral properties of a superradiant laser with injected atomic coherence

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Abstract

It is known that superradiant lasing via quantum coherence of atoms can have a narrow linewidth compared to that of the conventional lasing. When atoms with controlled phase via a nano-hole array traverse a high-Q cavity, the strong interaction between the atoms and the cavity field results in superradiant lasing. We measured the spectrum of such superradiant lasing by using the heterodyne-style photon-counting second-order correlation spectroscopy (PCSOCS). Specifically, the second-order correlation function of the heterodyne signal formed by the lasing output and a local oscillator was measured in order to obtain the autocorrelation function, and the spectrum was then obtained by performing a Fourier transform of it. We confirmed that the frequency of the superradiant laser matched the frequency of the pump laser instead of the atomic or cavity resonance frequency. We experimentally demonstrated that the linewidth of superradiant light depends on the linewidth of the pump laser, which injects coherence, rather than the number of atoms in the cavity. When the pump laser linewidth was much narrower than the cavity linewidth, superradiant laser linewidth was the same as the pump laser linewidth. But as the pump linewidth became larger than the cavity linewidth, the linewidth of superradiant lasing approached the cavity linewidth. This indicates that the role of the quantum coherence reservoir shifts from the atoms to the cavity photons as the pump laser linewidth increases.

07

Programming higher-order interactions of Rydberg atoms

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Abstract

Representing higher-order interactions is crucial for complex spin models. Recently, Rydberg blockade-based quantum systems have demonstrated the capability to solve quadratic unconstrained binary optimization (QUBO) problems, a characteristic graph coloring problem. By utilizing auxiliary atom sets as gadgets, we can represent both quadratic and higher-order interactions. In this study, we develop an architecture to effectively represent higher-order interactions, enabling Rydberg atom systems to solve higher-order unconstrained binary optimization (HUBO). We estimate the scaling of an N-spin system as O(N^K), where K denotes the highest order of interaction.

08

Shortcut-to-Adiabaticity transport of single atoms by optical tweezers

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Abstract

Optical tweezers are instrumental in the precise manipulation of individual atoms, which is a crucial step in the rearrangement of atom arrays and the entanglement of qubits in neutral atom quantum computers. Therefore, we report the experimental realization of Shortcut-to-Adiabaticity (STA) transport of single atoms by optical tweezers introduced in E. Torrontegui et al., Physical Review A {83}, 013415 (2011). The results show that STA-based path maintain the atomic energy distributions as Maxwell-Boltzmann distributions for a 12.6(3) μm transportation distance within 58.5 μs with a success probability of 0.98(1) , while the other transportation along constant velocity path collapse this distribution and increase the average atomic energy with a success probability of 0.80(2). Moreover, we have demonstrated that STA paths can be achieved for complex and general curved paths through the utilization of the STA method, which involves the STA-based rotation of atoms in two dimensions and the concatenation of STA paths. To illustrate this, an S-shaped path was considered, and the transportation success rates of paths that satisfy the STA criterion as 0.99(1) were compared to those that do not as 0.25(2). Also, the findings revealed that the temperature of the atoms may be maintained on an STA path as 15(3) μK from 10(3) μK.

09

Neighboring and polarization effects on line shape profiles of the modulation transfer spectroscopy in F_g=2 of ^{85}Rb and F_g=1 of ^{87}Rb

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Abstract

Effects of neighboring transition are proven to be crucial in interpreting spectral line profiles due to the interactions between closely spaced energy levels in electromagnetically induced absorption (EIA) and electromagnetically induced transparency (EIT). In this work effects of neighboring transition have been applied to modulation transfer spectroscopy (MTS) for the first time. The asymmetric dependencies in the MTS spectra due to neighboring effect for the F_g=2 → F_e=1 transition was explained by altering the hyperfine energy separation. There are two ground states in lower hyperfine states which are F_g=2 of ^{85}Rb and F_g=1 of ^{87}Rb. We have investigated detailed MTS line profiles of the F_g=2 → F_e=1, 2, and 3 transitions due to neighboring hyperfine transitions depending on four different polarization configurations such as linear parallel, perpendicular configurations and circular parallel, perpendicular configurations. We also have studied detailed MTS line profiles of the F_g=1 → F_e=0, 1 and 2 transitions of ^{87}Rb depending on four different polarizations considering effects of neighboring transition. Theoretical line profiles of those transitions using optical density matrix match well with the observed ones.

10

Single Neutral Atom Collision by Atom Throw and Catch

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Abstract

In this study, we investigate the dynamics of neutral atom collisions using a method of atom throw and catch via optical tweezers [1]. We specifically focus on collisions involving rubidium (87Rb) atoms in Rydberg states. By employing optical tweezers, we accelerate and decelerate individual atoms, allowing us to control their velocities and interaction parameters. Our experimental setup begins with cooling two rubidium atoms in a magneto-optical trap (MOT), and from the magneto-optical trap two single atom trapped by each optical tweezer. One of this atom is held stationary, while the other is accelerated towards it using a dynamic optical tweezer before being excited to a Rydberg state. After acceleration we employ two Rydberg quench pulses at variable velocity and principal number n to study the interactions of Rydberg state. The primary variables under investigation include the velocities of the atoms v = 0.5(1) and 3.0(5) m/s and the Rydberg principal numbers n = 36, 45 and 53. The collision probabilities were measured as functions of the impact parameter and the principal quantum number. Also in weak interaction regime we saw single atom trajectory change due to Rydberg interaction. These findings provide new way to controlled dynamics of neutral atom collisions using optical tweezers. This approach demonstrates potential manipulation in cold chemistry or cold collision experiments, paving the way for new method in cold atomic and molecular collision physics research [2].

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[2] Yoshida, S., Burgdörfer, J., Fields, G., Brienza, R., & Dunning, F. B. "Giant cross sections for L changing in Rydberg-Rydberg collisions." Physical Review A 102.2 (2020): 022805.

11

Towards ultracold Rb-Yb mixtures

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Abstract

We aim to generate a mixture of alkali rubidium atoms and alkaline-earth-like ytterbium atoms and study the mixture physics in an optical lattice. The distinct properties of these two atoms allow for the engineering of species-selective potentials, enabling the independent control of different atomic species. This independent controllability provides us with the ability to manipulate the density and momentum of the two atoms in mixture experiments. By adjusting the mixture imbalance and interactions, we intend to explore new phases induced by mixture behaviors and study exotic phenomena that arise in this system, such as polaronic physics and phase separation. We have apparatuses capable of generating ultracold atomic gas samples for both Rb and Yb, and we are combining these two machines to create a mixture apparatus. We will present our design of the Rb-Yb mixture apparatus and the progress in building it.

12

Dynamic similarity of vortex shedding in atomic Bose-Einstein condensate

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Abstract

We numerically investigate the dynamic similarity of vortex shedding in atomic Bose-Einstein Condensates (BECs) using the two-dimensional Gross-Pitaevskii equation with a moving Gaussian potential. By comparing the local sound velocity with the flow speed around the potential barrier, we estimate the dynamic effective diameter of the Gaussian potential for both penetrable and impenetrable potentials. As the velocity of the flow around the potential barrier increases, the dynamic effective diameter correspondingly increases further, which aligns with the vortex formation region observed in real space. Furthermore, we investigate the drag and lift forces exerted by the Gaussian potential, relating them to the superfluid Reynolds number derived from the estimated dynamic effective diameter. The drag force is proportional to the velocity minus the critical velocity at which vortex shedding initiates, and the modified drag coefficient demonstrates a universal behavior with respect to the superfluid Reynolds number, paralleling its counterpart in classical fluid dynamics. The frequency of the oscillation in the lift force also exhibits a universal trend, even in the penetrable potential. Our study enhances the understanding of quantum fluid in relation to classical fluid dynamics.

13

Chaos-assisted turbulence in spinor Bose-Einstein condensates

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Abstract

Turbulence, a ubiquitous phenomenon in fluids, poses a major challenge in physics owing to its complexity. While various methods exist to generate turbulence in a controlled manner, most of them are based on external forces and inertial energy cascades, which might limit the possibilities of exploring novel properties of turbulent states. In this talk, we propose an alternative approach to generate turbulence by harnessing the intrinsic chaos within the fluid itself. Specifically, we present numerical and experimental verification of the turbulence-sustaining mechanism in a spinor Bose-Einstein condensate, which is based on the chaotic nature of internal spin dynamics under magnetic driving. This chaos-assisted turbulence establishes the spinor condensate as an intriguing platform for exploring chaos and related superfluid turbulence phenomena.

14

Detection and Elimination of Defects in an Optical Tweezer Array using Reinforcement Learning

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Abstract

Optical tweezers are essential in the field of Atomic, Molecular, and Optical (AMO) physics, allowing for the precise trapping and manipulation of individual atoms and molecules. This tool enables the creation of desired geometries in both one-dimensional and two-dimensional configurations, as well as the real-time reconfiguration and rearrangement of qubits during computational processes. However, when groups of atoms, cooled to temperatures between a few to several tens of microkelvin, are confined within optical tweezers, random defects can sometimes occur. In quantum computing, accurately detecting and eliminating these defects is essential because they can significantly degrade performance. To eliminate the defects, it is necessary to choose the optical tweezers that have captured atoms and then rearrange them. Optimizing the rearrangement of optical tweezers in experimental setups poses significant challenges due to its complexity and the time required. To avoid atomic loss, it is crucial to rapidly identify these defects and compute optimal movement paths. Although machine learning is well-suited for such tasks, its application in this specific context has not been fully explored. Our algorithm, trained using the Proximal Policy Optimization (PPO) model, focuses on solving the shortest path problem to create defect-free optical tweezer arrays. Consequently, our research utilizes machine learning to determine optimal motion paths for optical tweezers in various scenarios, demonstrating effective model learning throughout the process. This approach not only leverages the strengths of machine learning but also has the potential to effectively rearrange defective optical tweezer arrays, enhancing efficiency and precision in experiments. Our findings offer new possibilities for the rearrangement of optical tweezer arrays, thereby advancing efficiency and accuracy in quantum computing research.

15

Transit-time effect on room-temperature transduction and amplification of infrared to visible photons

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Abstract

In this report, we present the frequency transduction mediated by lambda-type atoms. Barium-138 atoms have two bottom states, the ground state 1S0 and the metastable state 1D2, both connected through a common excited state 1P1. The transition 1S0-1P1 has a transition wavelength of 553 nm with a radiative decay rate of 18.9MHz whereas the 1S0-1D2 transition occurs at 1500 nm with a radiative decay rate of 40 kHz. By preparing the barium initially in 1D2 state, we can convert 1500-nm photons into 553-nm photons in the presence of a recycling laser. Since the radiative decay rate of the 1S0-1P1 transition is much stronger than that of the 1D2-1P1 transition, 1500nm incident photons can be transformed to 553nm photons with amplification factor as large as 330 in principle. We measured the reset efficiency, the ratio of the number of atoms returned 1S0 by the 1500nm laser to the initial number of atoms in 1S0 without the D-state pre-pumping. The observed maximum reset efficiency was up to 69.5(1) % due to the branching of the 1P1 state to 3D2 state. Our results were well described by the optical Bloch equations including the transit-time effect properly. The saturation intensity for the transduction was effectively determined by the transit time, inversely proportional to it. In addition, we observed that the minimum bandwidth of the transduction was given by the sum of all dephasing rates.

16

Laser slowing of a MgF buffer-gas beam

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Abstract

Among diatomic molecules, especially those of alkaline earth mono-fluoride molecules, magnesium monofluoride (MgF) is an unique species. Only MgF has both bosonic and fermionic isotopologues, and it also has a large electric dipole-moment. This gives a chance to study various quantum-based chemical reactions and quantum information science. Additional, it has light mass, UV transition lines, and a fast radiative decay rate and considering these three facts together, MgF should have a merit on the laser slowing. Here, we report our recent progress on the laser slowing of MgF. We confirmed that the initial forward velocity of the buffer-gas-cooled MgF beam is between 150 m/s and 200 m/s. This is done by gathering a light-induced fluorescence (LIF) signal from a laser that intersects with the molecules at 70 cm away from the ablation point . The forward velocity is then calculated from the doppler shift with respect to the resonant frequency. We used a white-light slowing method by modulating the frequency of slowing lasers with electro-optic modulators (EOM) and acousto-optic modulators (AOM). By comparing forward velocity distribution of the MgF beam with and without the slowing lasers, we can verify whether the forward velocity of the beam is slowed or not. By optimizing the slowing parameters, we will slow the forward velocity down to approximately 80 m/s, which is the expected capture velocity of the magneto-optical trap for MgF based on our simulations. The success of this will be the beginning of utilizing ultracold MgF as an experimental platform for quantum research.

17

Family-Vicsek scaling in 1D XX Heisenberg Chains

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Abstract

Family-Vicsek scaling has been thoroughly studied in classical hydrodynamics and surface dynamics. This type of the scaling law is also found in the quantum system. Recently, Kardar-Parishi-Zhang(KPZ) class scaling in XXZ Heisenberg chains is demonstrated. In this poster, I will introduce the observation of Family-Vicsek scaling in 1D XX Heisenberg chains. We prepare a charge density wave(CDW) state within optical lattices and measure the relaxation dynamics with a quantum gas microscope. In the limit of low filling and strong on-site interactions, the Bose-Hubbard model is mapped to the XX model. We measure the relaxation dynamics for different chain lengths L=8,10,12,14,16 to extract the scaling exponents as $\alpha=0.51(3)$, $\beta=0.4(1)$, $z=1.0(1)$. We plan to further investigate how the disorder can change the Family-Viscek scaling.

18

Motion-selective coherent population trapping in an optical tweezer

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Abstract

We report our ongoing experiment for subrecoil cooling of optically trapped atoms outside the Lamb-Dicke regime by combining Raman sideband cooling (RSC) with velocity-selective coherent population trapping (VSCPT). We call this hybrid approach motion-selective coherent population trapping (MSCPT). The MSCPT scheme utilizes a circularly polarized trap beam to create a state-dependent difference in vibrational frequencies, enabling selective tuning of the two-photon detuning so that only the motional ground states form a coherent population trapping (CPT) dark state. In a proof-of-principle experiment conducted in 2022 with atoms in an optical lattice, we demonstrated that MSCPT could achieve lower temperatures than RSC alone. Our current work focuses on optimizing the experimental parameters for the MSCPT scheme on rubidium atoms in an optical tweezer. Specifically, we use an optical tweezer with a small spot size and a wavelength closer to the D resonances, increasing the vibrational frequency difference (v12) to enhance motion selectivity. We are currently optimizing the loading efficiency of single atoms and preparing for further experimental validation. Numerical simulations indicate that MSCPT can achieve subrecoil temperatures outside the Lamb-Dicke regime under feasible conditions, outperforming RSC in producing colder atoms. This method has potential applications for cooling optically trapped diatomic polar molecules, which exhibit significant variations in Stark shift and vibrational frequency depending on their rotational quantum number.

19

Electronic excitation of He with anomalously large intensity in electron back scattering

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Abstract

It is well documented that physics behind inelastic scattering of high-energy (keV) electrons shifts away from the photoelectric effect to Compton scattering with the increase in scattering angle θ. This is the material reason why inelastic electron scattering has been used as various spectroscopic techniques for various targets including solids and surfaces. Nevertheless, to our knowledge, studies are still scarce for inelastic electron back scattering (θ > 90°) by gaseous atoms and molecules. This is probably because its cross-section is very small compared to the forward scattering case (θ < 90°). In this regard, our laboratory has recently developed a multi-channel apparatus for electron back scattering, which employs a spherical energy analyzer covering almost completely the available 2-pi azimuthal angle range, thereby increasing the signal count rate by a factor of about 1000 compared to the single-channel measurements. Based on this development, in this study, we aim to have a more complete and systematic understanding of electron inelastic scattering by conducting an electron energy loss spectroscopy experiment on He at θ = 135° and at an incident electron energy of 2 keV. It is found that relative magnitudes of bands due to the 1s-2s and 1s-2p electronic excitation transitions to the elastic band are both anomalously larger than the Born approximation theory widely used for forward scattering. In this contribution, we will report and discuss further details of the observations.

20

Molecular science using electron impact spectroscopy

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Abstract

Electron impact spectroscopy has long been used for fundamental research in a broad range of science, and it has many applications by utilizing both photoelectric and Compton effects in electron scattering. In particular, Compton scattering has provided us several molecular spectroscopy techniques with unique abilities. For instance, electron-electron Compton scattering opened the door for the studies on the behavior of the outer, loosely bound valence electrons that are of central importance in chemical properties such as chemical reactivity and molecular recognition. In contrast to such study of intramolecular electrons, there was no way to directly observe intramolecular atomic motion, which governs chemical properties and functionalities of molecules. Under the circumstance, we have recently developed a completely new molecular spectroscopy technique by employing electron–atom Compton scattering. This technique, also known as atomic momentum spectroscopy (AMS), has the unique ability to map intramolecular motion of each constituent atom different masses; in other words, AMS is the complete electron analogue of the velocity speed gun in baseball games. In the talk, we will discuss not only our efforts of the experimental and theoretical developments of AMS but also molecular science using AMS.

21

Observation of eccentric fractional skyrmion in ferromagnetic superfluid.

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Abstract

Eccentric fractional skyrmion is one of the nonlinear excitations with spin singularity which can be generated from quantum Kelvin-Helmholtz instability (KHI). In this poster, we present an experimental demonstration of quantum KHI in a ferromagnetic spinor Bose-Einstein condensate (BEC) and observation of eccentric fractional skyrmions. After preparing a ^{7}Li spinor BEC in the ferromagnetic phase, we applied a magnetic gradient, which imparted a relative velocity to the domain, generating a flutter-finger-patterned domain wall. By analyzing the domain wall, we quantitatively assessed the evolution of the waves and how it varies with different gradient strengths. Over time, we observed that a portion of the domain separated from the tip of the fluttering finger to form a magnetic droplet. Spin population measurements and matter-wave interference imaging methods were used to confirm the spin texture and phase around the droplet, thereby verifying the spin texture of skyrmions. To study stability of skyrmion, we measure skyrmion number after the gradient pulse. We will also discuss our current DMD setup and future plan.

22

Absolute cross sections for ionization and dissociation of planetary atmospheric molecules measured by electron impact from 350 to 8000 eV

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Abstract

The solar wind electrons and photoelectrons generated by solar ultraviolet light are important energy sources for planetary atmospheres, especially at night, where the deposition of hot electrons leads to energy deposition and ionization in the upper atmosphere and ionosphere. The absolute cross-section of electron impact ionization and dissociation is a key input parameter for modelling planetary atmospheres. It is of great significance for studying hot topics on planetary ionospheric formation, atmospheric escape, and atmospheric composition. The observation from the solar wind electron analyzers carried by many space missions indicates that the energy of electrons ranges from a few eV to several tens of keV, thus reliable cross-sectional data of the relevant energy range are demanded. However, most of the existing experimental absolute cross-section data are restricted to the relatively low electron impact energies less than 1 keV, and the data for higher energies above 1 keV are very scarce. Recently, we carried out the measurements on the ionization and dissociation of planetary atmospheric molecules such as molecular oxygen, carbon monoxide, carbon dioxide and methane by using 300 eV - 8 keV electron collisions. The presently obtained absolute partial and total ionization cross section data will play an important role in the models for exploring the planetary environment.

23

Development of an apparatus for the study on stereodynamics of electron-molecule collision

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Abstract

Electron–molecule collision has long been attracting a great deal of interest, because it is an elementary chemical reaction that allows various kinds of fundamental research and application. Nevertheless, there were no experiments for studying effect of the molecular orientation on electron–molecule collision due to the random orientation of gaseous target molecules. In 2005, we have pioneered electron-impact ionization experiments on fixed-in-space molecules. However, since coincident detection of axial recoil fragment ions was employed to determine the spatial orientation of the molecule, the target liberty has been restricted to dissociative electron-impact ionization processes of simple linear molecules. Under this circumstance, the purpose of the present study aims to deepen and expand the knowledge about stereodynamics of electron–molecule collision by extensively broadening the species range of the target molecules as well as their electronic transitions. For the purpose, we are now developing an apparatus that features additional use of the laser-induced molecular alignment technique, which enables to prepare spatially aligned molecules under the field free conditions and is applicable to a variety of molecules ranging from diatomic one to large one such as benzene derivatives. In the contribution, we will detail the progress of the development with the preliminary experimental results and the spectrum simulations.

24

Cost efficient Bi-metal optical cavity for stabilizing frequency of the laser.

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Abstract

To achieve cost-effective stabilization of the laser, we employ a bi-metallic cavity spacer constructed from invar and aluminum. The thermal expansion coefficients of invar and aluminum are approximately 2×【10】^(-5)/K and 2×【10】^(-6)/K at room temperature, respectively. The length of the cavity spacer for each material is proportional to its thermal expansion coefficient. Consequently, the thermal expansion of each material compensates for each other's deviation, thus maintaining a stable cavity length. The exact matching position is found experimentally by rotating 200 step/mm screw thread on the aluminum spacer. We anticipate frequency instability of less than 1 MHz from the target frequency at room temperature, with fluctuations within 1°C. This level of stabilization is adequate for various optical spectroscopic applications, such as the repumping laser for optical clocks. In this post presentation, we report on the progress of stabilizing a 1389 nm laser using the bi-metallic optical cavity for the Ytterbium (Yb) optical lattice clock.

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Partnership announced in July 2024

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