Multi-coincidence spectroscopy on interatomic Coulombic decay

Kiyoshi Ueda

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The inner-shell ionized states in matter are subject to Auger decay. Auger spectra are considered as fingerprint images of the atom where the inner-shell hole is created. About a decade ago, Cederbaum and coworkers [1] proposed a new mechanism of electronic decay where the environment plays a role. For an isolated atom or molecule with an innervalence vacancy, Auger decay is often energetically forbidden but interatomic or intermolecular Coulombic decay (ICD) may occur when another species is in close proximity. Later, the experimental evidences of ICD were provided by electron spectroscopy [2] and by multi-coincidence spectroscopy [3].

ICD can take place also after Auger decay as second-step decay [4]. We have been investigating ICD after Auger decay in rare-gas dimers, such as Ar$_2$ [5], ArKr [6], and Ne$_2$ [7], as well as trimers [8] and larger clusters, using momentum-resolved electron-ion multi-coincidence spectroscopy. By this method, we can measure three-dimensional momentum of the photoelectron and/or ICD electron together with those of two or three ions in coincidence and extract angular and energy correlations between the photoelectron/ICD electron and fragment ions. This allows us to identify the ICD channels without any ambiguity and, furthermore, to classify the ICD channels into two classes, one via virtual photon exchange and the other via electron exchange.

The present work has been carried out in fruitful collaboration with a number of colleagues whose names can be found in the authors’ list of Refs. [5-8], with approval of JASRI, and supported by JSPS, MEXT, BMBF, and DFG.

A new time-dependent scattering theory and its application to the capture of antiprotons by atoms

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In this talk, we will present our recent works on the state-specified capture process of antiprotons by atoms. Rewriting the time-independent form scattering equation into a time-dependent scattering equation allows us to convert the very complicated boundary condition problem into a simple initial condition problem. The complete scattering wavefunction, which contains all the dynamic information, is obtained by solving the Chew-Goldberger type integral equation. The state-specified capture cross sections of antiprotons by hydrogen atoms and helium atoms are obtained in a full quantum, non-perturbative way. Differing from the capture of antiprotons by hydrogen atoms, the bumpy structures are revealed in the total angular momentum dependent capture cross sections by helium atoms. Further analysis shows that the bumps arise from the partial channel closing due to the removal of the energy degeneracy in the antiprotonic helium. The detailed numerical procedures will be presented in the conference and the possible applications of the time-dependent scattering theory to other problems will also be discussed.
Development of New Techniques to Study Collisional Reaction Dynamics and Interaction Potential Energy Surfaces

Koichi Ohno, Naoki Kishimoto and Satoshi Maeda

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Many chemical reactions are induced by collision of reactant species on the interaction potential energy surface. For the quantitative estimation of the chemical reaction even by single collision, one needs to know many aspects in the molecular reaction dynamics such as interaction potential energy surface, mechanism of the reaction process, branching probabilities and related opacity functions, steric effects in the collisional trajectory, etc. Since reaction probability of collisional ionization between metastable atoms and target molecules (Penning ionization, He*(23S) + M → He + M+ + e-) depends on collisional energy of metastable atoms, we can obtain information on the stereodynamics by collision-energy/electron-energy-resolved Penning ionization electron spectroscopy (2D-PIES) [1]. Observed collision energy dependence of partial ionization cross sections (CEDPICS) reveals anisotropic interactions between target molecules and metastable atoms. With the 2D measurement of collisional ionization, information on anisotropic interactions for the spatial region where the corresponding molecular orbital (MO) extends can be obtained. Theoretical simulation of CEDPICS with trajectory calculation of He* and optimization of model potential leads us to determine interaction potential between He* and a target molecule. On the other hand, we have developed an automated searching algorithm for equilibrium structures, transition structures, and dissociation structures on the interaction potential energy surface with the scaled hypersphere search (SHS) method [2]. An application of the SHS method to the simplest amino acid molecule of glycine (C₂H₅NO₂) has provided us new synthetic routes [3]. The reverse routes of calculated dissociation channels of glycine were discovered as two new synthetic routes with no byproducts.

Reference
Background gas collision shift for $^{88}$Sr $^1S_0-^3P_1$
spin-forbidden transition

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Optical clocks now reach an accuracy of $\sim 10^{-17}$ [1], requiring evaluations of various systematic shifts that have been so far neglected due to their small effects. One of potentially significant shifts which we have to start considering is background gas induced collision shifts. While frequency shifts due to perturber gas have been investigated for rather strong transitions (natural line width $> 100$kHz) in dense perturber environment ($>1$Torr), we performed saturation absorption spectroscopy for a narrow transition $^{88}$Sr $^1S_0-^3P_1$ (natural line width = 7.4kHz) in a vapor pressure of $10^{-4}-30^{-2}$ Torr. Absolute frequency of probe laser was always monitored by a frequency comb referenced to International Atomic Time (TAI). Thanks to this absolute frequency ruler, we successfully detected a few kHz level of background gas collision shifts as well as same level of Sr-Sr binary collision shifts. The binary collision shift of thermal atoms resulted in 10 times less effect than that of ultracold atoms which was carefully measured in JILA [2]. The observed buffer-gas induced collision shift in helium was +5 kHz at 0.01 Torr. If we assume linear scaling, the fractional shift would be $1e^{-18}$ at $1e^{-9}$ Torr where latest lattice clocks work. Our measurement is not directly on $(5s^2)^1S_0 - (5s5p)^3P_0$ clock transition. Nevertheless this measurement may put optical clock makers under the necessity of carefully evaluating collision shifts with various residual atom or molecule in chambers.

Investigations into Electron-Atom/Molecule Collisions with Multiparameter Experimental Techniques

Julian Lower (1), Susan Bellm (1), Erich Weigold (1), Stephen Buckman (1), Subhendu Mondal (1), Don Madison (2), Alison Harris (2), Klaus Bartschat (3), Bob McEachran (1), Dmitry Fursa (4) and Igor Bray (4)

(1) - Australian National University, Australia
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An accurate experimental and theoretical determination of cross sections for electron collisions with atoms and molecules is important for a number of reasons. From the perspective of technological progress, it is important for modelling the behaviour of plasmas and ionized gases where many collision processes are in competition. Applications include modelling the upper atmosphere, fusion reactors, lasers, radiation damage to biological material and potential candidates for new light sources to replace present mercury-based technologies. From the fundamental perspective, comparison of experimentally and theoretically derived cross sections enable underlying mechanisms for the interaction of charged particles with matter to be investigated and the predictive powers of theory to be honed.

In this talk I will review our recent work in the area of electron-atom and electron-molecule collisions. In particular, I will describe how state-specific measurements on heavy and light targets, in concert with theory, shed light on specific aspects of the collision dynamics including the role of exchange and relativity. I will also discuss recent developments in instrumentation, which promise new insight into the dynamics of molecular fragmentation.

References
Atomic collision and spectroscopy experiments with ultra-low-energy antiprotons

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(3) - V. G. Khlopin Radium Institute, St. Petersburg, Russia
(4) - CERN, Switzerland

Antiproton, the antiparticle of proton, is a unique projectile in the study of atomic collision physics, which can be treated theoretically either as a ‘negative proton’ or a ‘heavy electron’. Atomic capture of an antiproton will result in formation of a highly excited exotic atom. Antiprotonic helium atom has been studied intensively by means of precision laser spectroscopy, which has led to a stringent determination of antiproton mass and charge to a level of ppb. Comparison of these values with those of proton gives one of the best tests of CPT invariance, the most fundamental symmetry in physics. However, the dynamic processes of antiproton capture remain unclarified. With an aim to produce an antiproton beam at atomic-physics energies for ‘pure’ collision experiments, we have so far developed techniques to decelerate, cool and confine antiprotons in vacuo, using a sequential combination of the Antiproton Decelerator (AD) at CERN, a Radio-Frequency Quadrupole Decelerator (RFQD), and an electromagnetic trap. Our recent success in stable extraction of monoenergetic ultra-slow antiprotons, about 300000 in number available every 5 minutes, has opened up the possibility to study ionization and atomic capture processes between an antiproton and an atom under the single collision condition. Some results of our cross-beam experiments will be presented, as well as technical difficulties and challenges in the detection system to identify the rare events with a reaction rate of 1/10000, to be antiproton annihilation.
Electron Impact Near-Threshold Electronic Excitation Differential Cross Sections of Argon

S. Mondal, J.C.A. Lower and S. J. Buckman

Centre for Antimatter-Matter Studies, Research School of Physical Sciences and Engineering, Australian National University, Canberra, Australia

We have measured angle dependent cross sections for near-threshold electron impact excitation of the \(3p^54s\) and \(3p^54p\) states of argon using an advanced, low energy, time-of-flight (ToF) spectrometer. This spectrometer utilizes a large area position sensitive channel plate detector to precisely measure near-threshold angular differential excitation cross sections of atoms and molecules. The ToF technique has the advantage over conventional analysing techniques that the transmission of scattered electrons is independent of energy, resulting in improved reliability of the measurements. This work covers the measurement of differential cross sections in an angular range from \(55^\circ\) - \(125^\circ\) and the incident electron energy range from 12.5 - 15 eV.
Recent Progresses on Atomic Physics with Highly Charged Ions in Lanzhou

Xinwen Ma, Xiaolong Zhu, Shaofeng Zhang, Bin Li, Shenyue Xu, Dacheng Zhang, Wentian Feng, Dongbin Qian, Huiping Liu, Lingjie Meng, ShunCheng Yan, Liangting Sun, Jinuy Li, Xiaodong Yang, Guoqing Xiao, Hushan Xu, Hongwei Zhao, Jiawen Xia, Youjin Yuan and Wenlong Zhan

Institute of Modern Physics, Chinese Academy of Sciences, China

Storage rings, small accelerators, as well as experimental setups have been established during past few years in Lanzhou China, the commissioning of the heavy ion Cooler Storage Rings gained great success. These advances give good opportunities for atomic physics researches using (highly) charged ions. Researches such as ion-atom /molecule differential measurements, ion-surface interactions, ion induced fragmentation of bio-molecules, electron-ion recombination, mass measurements, laser related processes, and so on, made considerable progresses. In my talk the current status of the accelerators, some experimental setups will be introduced. And examples of some research results will be selected and reported at the conference. The future aspects of atomic physics related to ion –matter interaction will be outlined.


This work was supported by the key projects of Pilot Project of the Knowledge Innovation Program launched by the Chinese Academy of Sciences and partly by the National Nature Science Foundation of China under grant No. 10434100
Chaotic photo-ionization of the helium atom: partial cross sections

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The total photo-ionization cross section of helium shows chaotic signals, of which fluctuating part decreases in amplitude as the energy approaches the double ionization threshold from below. The fluctuations were interpreted as associated with the closed triple collision orbits, and a scaling law for the energy-dependence of the amplitude of fluctuating part was suggested by applying a semiclassical approximation to the Green's function for the closed triple collision orbits. We proposed that the same kind of fluctuation would be observed in the partial cross sections. Experimental results obtained by Doerner's group showed consistency with our proposition. However, due to small signal-to-noise ratios in the data, there were some ambiguities in the correspondence between the classical actions of the closed triple collisions and the peaks in the Fourier transformation of the partial cross sections. Now we will present results of quantum calculation of the partial photo-ionization cross sections of the collinear-eZr-helium atom, which clearly shows that fluctuations in the partial cross sections as well as the total cross section can be explained by the semi-classical closed orbit theory generalized to the system with an essential singularity such as triple collision.
Low energy positron scattering has long been plagued by the lack of energy resolution of typical positron beams. The advent of the buffer gas trap, pioneered by the group of Prof. Cliff Surko at UCSD, made available for the first time a relatively high intensity positron source with very good energy resolution (~25 meV) that could be used for low energy scattering measurements.

Measurements of low energy positron scattering have commenced at the Australian Positron Beamline Facility. Two beamlines are available, one each for materials analysis and atomic and molecular physics. The atomic and molecular physics beamline uses a Surko trap to produce a high resolution pulsed beam of positrons, tunable at energies below 100eV. The energy resolution of the beam is approximately 70 meV, allowing high precision measurement of atomic processes and also suitable for the investigation of threshold effects and the search for positron scattering resonances.

The first series of measurements has been on the noble gases, and data is available for positron scattering from helium, neon and argon. Operation of the beamline will be outlined, along with an explanation of the analysis techniques, which take advantage of the fact that the positron beam is confined in a 500 gauss magnetic field. The measurements of grand total and total positronium formation cross sections will be presented, with comparison to previous work, both experimental and theoretical. Prospects for future work will be outlined, including the measurement of different cross sections and scattering from different atomic and molecular targets.
Storage Modes in a Low Energy Charged Particle Storage Ring for Atomic & Molecular Experiments

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Specific storage modes have been identified and explored both experimentally and computationally for a new type of low energy charged particle storage ring for use in Atomic & Molecular Physics experiments [Tessier et al, Phys Rev Lett, 99, 253201, (2007)]. These modes offer the possibility of storing monochromatic charged particle beams injected into the ring. Alternatively, some of the storage modes identified may be appropriate for monochromating, within the ring, a stored charged particle beam. The ring is entirely electrostatic and has been shown experimentally to be capable of storing low energy electrons with storage lifetimes in the region 50 microseconds (~150 orbits) that are vacuum base pressure limited. The ring is constructed from two 180° hemispherical deflector analyzers which are interconnected by two identical cylindrical lens stacks. Each lens stack is primarily controlled by 3 voltages. The storage modes observed occur at specific combinations of these 3 voltages and are consistent with a multiple orbit charged particle optics model of the apparatus explored using both a matrix approach and trajectory integration in a 3 dimensional electrostatic model.
Reaction dynamics of transition metal atoms studied by crossed beam technique

Kenji Honma and Ryo Yamashiro

Graduate School of Material Science, University of Hyogo, Japan

Because transition metal atoms populate their electrons in almost degenerated ns and (n-1)d orbitals, there are several low lying electronic states which have different electronic configurations and/or spin multiplicities. On the last decade of the 20th century, a number of kinetic studies have been carried out to clarify the correlation between these electronic states/electron configurations and their reactivity. However, the kinetic studies can generally provide only qualitative information about the reaction mechanism and potential energy surfaces, and experimental studies such as a crossed-beam are required to clarify these points. Here, we would like to present recent crossed-beam studies of oxidation reactions of gas-phase transition metal atoms.

The left side of the first raw metals, Sc, Ti, V, and Cr, two reaction mechanisms have been proposed for their oxidation reactions, i.e. a direct O atom abstraction and a complex formation. For the former mechanism, the key property of metal atoms is the electron configurations, which determine the correlation between reactants and products, i.e. electronic states of metal atoms and those of metal oxides. The amount of the electronic energy is more important in the case of the complex formation via electron transfer. We have studied the following reactions by the crossed-beam laser-induced fluorescence/chemiluminescence technique, and observed that the product state distributions are well reproduced by the statistical energy partition.

\[
\begin{align*}
\text{Ti}(a^3F_{ij}) + O_2 & \rightarrow \text{TiO}^*(A^3\Phi) + O \\
\text{Ti}(a^5F_{ij}) + O_2 & \rightarrow \text{TiO}^*(A^3\Phi, B^3\Pi) + O \\
V(a^4F_{ij}) + NO & \rightarrow VO(X^4\Sigma) + N \\
V(a^4F_{ij}) + O_2 & \rightarrow VO^*(B^4\Pi) + O \\
\text{Cr}(a^7S_{ij}) + O_2 & \rightarrow \text{CrO}(X^5\Pi) + O
\end{align*}
\]

These results suggest that the oxidation reactions proceed via the complex formation. The crossing between covalent and ionic surfaces leads to the ionic intermediate, M\(^+\)-OX\(^-\), which lives long enough to randomize the available energy. However, the electron transfer occurs at rather short atom-molecule distance because of high ionization energies of these transition metal atoms compared with alkaline atoms. Significant repulsive interaction of the covalent surface at the short distance results in a barrier even for the crossing with highly attractive ionic potential.


Positronium formation for positron-sodium scattering at low and intermediate energies

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There have been various theoretical calculations for positron-sodium scattering that attempts to calculate accurate Ps formation cross sections at low and intermediate energies. The recent hyperspherical close-coupling (HSCC) calculations [1] has handled the contribution from the positronic bound states to a great extent. Their calculations has further strengthened the argument that the theoretical Ps cross sections at low energies deviate from the predictions of the experimental measurements [2]. The nagging question is that does the inclusion or the neglect of the positronic bound states in the calculation have any significant effects on the low energy Ps formation cross sections. Thus in this work, we attempt to investigate if large-scale CC calculations are deficient in this respect.

The present work uses two sets of calculations: The 12-states CC calculation uses nine atomic states (Na(3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 5d)) and three Ps states (Ps(1s, 2s, 2p)) whereas the 15-states CC consists of nine atomic (Na(3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 5d)) and six Ps (Ps(1s, 2s, 2p, 3s, 3p, 3d)) states to map out the low and intermediate scattering region. The trend of the present Ps cross section is in accord with the previous theoretical calculations. Furthermore, both the CC(9,6) and the CC(9,3) predict some structures within the energy region between 1 – 6 eV which is also observed in the two CC calculations by Ryzhikh and Mitroy [3] and Campbell et al [4].Thus, further experimental and theoretical studies are sorely needed at the lower energy regions.

The total Ps formation cross section is depicted in Figure 1. The present work is compared with other theoretical works (HSCC (SFG pot.) [1], HSCC (FCLXpol) [1], CC (5,6) [3] and Campbell et al [4]) and experimental data [2].

The funding of this work by the SAGA grant (Academy of Sciences Malaysia: Account No: 66-02-03-0077) under KR and MZMK is gratefully acknowledged.

(For an extended contribution see Attachment 11 on CD)
Cavity, Atom and the Cat

Kyungwon An

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Two-mode coupling plays an important role in physics. In chaotic optical microcavities nonintegrability induces mode-mode coupling and with openness it brings about avoided crossing of energy levels and the existence of an exceptional point. In cavity quantum electrodynamics (QED), a two-level atom and a high-Q cavity also couple strongly to each other and make possible to explore quantum information processing. I will review recent progresses made in my group related to two-mode coupling physics and introduce our efforts to generate a tamed Schroedinger's cat in the cavity-QED microlaser.
Controlled atom-cavity coupling constant in the cavity-QED microlaser with a nanopore-lattice aperture

Younghoon Song, Wontaek Seo, Moonjoo Lee, Hyun-Gue Hong, Jai-Hyung Lee and Kyungwon An

Seoul National University, Korea

In almost all cavity quantum electrodynamics (QED) experiments, atoms in an optical cavity experience position-dependent coupling constants because of the standing wave mode structure in the cavity. In the present work we demonstrate an experimental capability of precisely controlling the atom-cavity coupling constants by employing a nanopore lattice aperture. This aperture has nanometer-scale holes in the form of a two dimensional lattice with a 791-nm interval, which is the same as the transition wavelength ($\text{s}^1S_0 - \text{p}^3P_1$) of atomic barium, which interact with a high-Q cavity in the cavity-QED microlaser. Atoms that pass through this aperture meet the cavity field with an identical atom-cavity coupling constant. When the horizontal position of the aperture is translated so as to make the vertical columns of nanopores aligned with the antinodes of the cavity, the atoms experience the maximum coupling. If the columns of nanopores and the nodes of the cavity field overlap each other, on the contrary, the atom-cavity coupling vanishes. Besides, the cavity we newly fabricated has a special shape so that the aperture can be placed very close (up to a distance of 500 micron) to the cavity mode, resulting in reduction of spatial dispersion of the barium beam. We have demonstrated the controlled coupling constants by measuring the microlaser output as a function of the aperture translation. Our nanopore lattice technique provides a new opportunity to perform various cavity-QED experiments with continuously scannable atom-cavity coupling constants.
Stationary light pulses without Bragg grating

Yen-Wei Lin, Hung-Chih Chou, Thorsten Peters, Wen-Te Liao, Hung-Wen Cho, Pei-Chen Kuan and Ite A. Yu

National Tsing Hua University, Taiwan

The intriguing idea of creating stationary light pulses (SLPs), i.e., light pulses without motion via the retrieval of stored pulses with two counter-propagating coupling fields, has been proposed and experimentally demonstrated several years ago in Phys. Rev. Lett. 89, 143602 (2002) and Nature 426, 638 (2003). In both papers the underlying mechanism of the SLP is identified as a band gap being created by a Bragg grating formed by the two coupling fields of similar wavelength. In this paper we present a more general view on the formation of SLPs, namely several balanced four-wave mixing processes sharing the same ground-state coherence. From this point of view SLPs are not restricted to frequency components close to one center frequency, but can be formed from multiple components of large frequency differences. Utilizing this new concept we report the first experimental observation of a bichromatic SLP at wavelengths of 780 nm and 795 nm for which no Bragg grating can be established. Additionally, we demonstrate the production of a SLP directly from a propagating light pulse without prior storage. With these results SLPs become a very versatile tool for the already promising applications to low-light-level nonlinear optics and quantum information manipulation. This work was supported by the National Science Council of Taiwan under Grants No. 95-2112-M-007-039-MY3 and No. 97-2628-M-007-018.
The Hydrogenic Lamb Shift in Iron

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The Hydrogenic Lamb Shift in Iron, Fe 25+ and fine structure Lamb shift. 1s-2p Lyman α transitions in hydrogenic iron, Fe25+, have been observed from a beam-foil source in fourth order diffraction off ADP 101 and PET 002 crystals, simultaneously with the n=2 to n=4 Balmer β transitions diffracted in first order. Calibration of the local dispersion relation of the spectrometer using Balmer β lines provides measurements of Lyman α wavelengths. The novel approach of fitting the full two-dimensional dispersion relation, including other members of Balmer and Lyman series, limits random and systematic correlation of parameters. The development of a theory of X-ray diffraction from mosaic crystals was necessary for the accurate interpretation of the experimental data.

Several systematics are quantified for the first time for these medium-Z QED comparisons. 2s-1s and 4f-2p satellites are explicitly investigated. A dominant systematic is due to the variable location of spectral emission downstream of the beam-foil target. 1s-2p3/2, 1s-2p1/2 iron Lamb shifts are measured to be $35376 \pm 1900 \text{cm}^{-1}$ and $35953 \pm 1800 \text{cm}^{-1}$. These agree with but lie higher than theory. This represents a 5.7% measurement of the hydrogenic 1s-2p1/2 Lamb shift in iron. The technique also reports iron 2p3/2-2p1/2 fine structure as $171108 \pm 180 \text{cm}^{-1}$, representing a 51% measurement of the hydrogenic iron fine structure Lamb shift, and reports measurements of secondary lines.

The possibility for the fundamental constants to vary in space and time is predicted by theories unifying gravity with other interactions. Strong evidence that the fine structure constant $\alpha$ might be smaller about 10 billion years ago was found in the analysis of the quasar absorption spectra. The study of possible present-day time variation of the fine structure constant is conducted by comparing the rates of different most precise atomic clocks over long periods of times. In both cases the analysis requires input from atomic theory to link the changes in the spectra to variation of the fine structure constant. A set of methods and computer codes were developed and applied to a number of atomic transitions. The results were used in the analysis. The analysis of the quasar absorption spectra for the redshift parameter $z$ in the range from 0.2 to 4.2 gives $\frac{\Delta \alpha}{\alpha} = (\pm 0.543 \pm 0.116) \times 10^{-5}$, which under assumption of constant rate of change corresponds to $\frac{\Delta \alpha}{\alpha} = (6.40 \pm 1.35) \times 10^{-16}$ per year. Recent comparison of the Al$^+$ and Hg$^+$ optical frequency standards over a year leads to a constrain $\frac{\Delta \alpha}{\alpha} = (-1.6 \pm 2.3) \times 10^{-17}$ per year.
The dynamics of van der Waals molecule dissociation

Ula Alexander (1), Heather Holmes-Ross (1), Jason Gascooke (2) and Warren Lawrance (1)

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Non-covalent inter-atomic and intermolecular interactions govern behaviour in a wide variety of environments. For example, they determine the aggregation of atoms and molecules, govern the structure of polymers and biological molecules, determine solvation properties, and modify chemical reactions in solution. A fundamental understanding of these interactions can be gleaned via spectroscopic probing of van der Waals molecules, with small model systems providing insights into the essential interaction mechanisms.

Our group uses a combination of velocity map imaging and dispersed fluorescence to explore the dissociation energetics and dynamics of van der Waals molecules. Velocity map imaging measures the translational energy in the molecular fragments following severing of a van der Waals bond. In general, the maximum translational energy in the products is used to determine the binding energy of the van der Waals molecule, i.e. it reveals the strength of the intermolecular bond. The translational energy released, in combination with the spectroscopic probe of dispersed fluorescence, allows the distribution of rotational energy in the fragments to be determined, which provides insights into the dissociation process. In some systems it is possible to selectively ionise individual rotational states of the products, providing the ability to measure the translational distributions of individual product states.

We will present results for two systems currently under study by our group, NO-Ar and benzene-Ar\textsubscript{n} (n=1,2).
Stau atomic collision and big-bang nucleosynthesis

Yasushi Kino (1), Masayasu Kamimura (2), Koichi Hamaguchi (3), Tetsuo Hatsuda (3), Tsutomu Yanagida (3) and Emiko Hiyama (4)

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(2) - Kyushu University, Japan
(3) - University of Tokyo, Japan
(4) - RIKEN, Japan

A stau particle is a supersymmetric partner of tau lepton, and is expected to be found at LHC in the near future. The stau is heavier than an iron atom, and its lifetime is considered to be more than 1,000 s. From a viewpoint of atomic physics, the stau is a point particle and interacts by Coulombic interaction. The negatively charged stau behaves like a heavy electron, and forms stau atomic and molecular systems.

Though the stau have never found because of its heavy mass, it should be created in big-bang. Since the stau has a long lifetime, it could survive during the first three minutes when the nucleosynthesis occurred. The stau forms a stau atom and causes nuclear reactions as in the muon catalyzed fusion process. Since the stau binds nucleus too tight, collisional energies are one order of magnitude lower than the binding energy of the stau atom.

We, for the first time, calculate the nuclear reactions during the stau atomic collision in a full qantal manner. The results based on the atomic collision theory show that the nuclear reactions induced by the stau atomic collision can solve the lithium-6 and lithium-7 problems which are most crucial problem in the big-bang nucleosynthesis.
Low energy investigations of positron - He scattering

Peter Caradonna (1), Adric Jones (1), James Sullivan (1), Casten Makochekanwa (1), Daniel Slaughter (1), Stephen Buckman (1), Mark Stevenson (2) and Birgit Lohmann(2)

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Recent measurements of positron-He scattering will be presented over the energy range from 0.5 to 60 eV. A pulsed beam of positrons from a Surko-style, buffer gas trap is used, with a typical energy resolution of 70 meV. The beam is confined by a strong magnetic field (530 G) and the measurements of the cross sections take advantage of the positron motion in the field. This allows an unprecedented level of accuracy for investigation of the scattering processes, paving the way for a benchmark set of cross sections for positron scattering, as has been established in the case of electron scattering. Measurements of the grand total (GTCS) and positronium formation cross sections will be presented, along with preliminary data for differential cross section measurements. The low energy GTCS results can be compared with the earlier benchmark results of Mizogawa [1] and provide a validation of the experimental techniques used. Careful measurements were taken in the Ramsauer-Townsend minimum to resolve recent, controversial observations indicating the presence of resonance-like structures [2]. High resolution measurements around the threshold for positron formation and various other excitation processes shed light on the strength of channel coupling and provide a limit for the size of any scattering resonances. Positronium formation measurements will be compared to other experimental and theoretical work.

The talk will conclude by presenting future plans for positron scattering measurements using this apparatus.

References
Matter Antimatter Collisions in and without the presence of External Fields

Chandana Sinha

Indian Association for the Cultivation of Science, India

According to the standard model each of the fundamental particles making up the material Universe has an equivalent antimatter particles. It is mostly believed that at the same time of the Big Bang antiparticles and particles were created in equal numbers. But the question that why antimatter is then so rare today is one of the greatest challenge to the scientists. Probably the recent activation of the LHC at CERN could throw some light in this direction. Some underlying asymmetry (matter antimatter) should be there that has led the Universe to prefer matter to the antimatter. This has motivated scientists all over the world to work on the properties of the antiparticles.

The fundamental questions in physics regarding antimatter- matter interactions can be studied from the investigation of the properties and production of an antimatter, particularly the antihydrogen, a simplest ideal antimatter atom, due to its stability than any other exotic atoms, such as positron, muonium, protonium etc. Moreover, the CPT invariance theorem of the Standard Model can be verified from much investigations. Both ATHENA [1] and ATRAP [2] as well as some other Groups [3] are working hard towards the ultimate goal of making high precision spectroscopic comparison between the hydrogen and antihydrogen. To achieve this goal, cold or low velocity antihydrogen atom is highly needed in its ground state. The present talk will discuss different mechanisms for the production of antihydrogen in ground / excited states giving particular emphasis on the three body recombination process of an antiproton and positron plasma which is supposed to be the most efficient method for a significant production of cold antihydrogen . In the process of experimental confinement and trapping of the antiparticles / antimatter, an external magnetic field [3,4] is needed that might in turn influence the antihydrogen production yield. Further, irradiation by laser field might also enhance / suppress the antihydrogen production. The effects of the external fields (magnetic field as well as laser field) will also be discussed.

and see other references cited there in.
Effect of coupled bichromatic interference on the spatially uniform atom-cavity interaction in the cavity-QED microlaser

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The cavity-QED microlaser shows multiple threshold behavior due to the oscillatory gain produced by the coherent interaction between two-level atoms and a high-Q cavity. In spite of the wavelength-order modulation of the standing mode of cavity, spatially uniform atom-field interaction has been achieved in this system via deliberate tilt of the atomic beam, which makes use of the decomposition of the standing wave into two Doppler-shifted traveling waves. In the previous observation of the multiple thresholds of the microlaser, however, there was deviation from the prediction by a uniform atom-cavity coupling theory, notably the frequency-pushing behavior for high threshold regions. In the semiclassical limit, we have analyzed the effect of the tilted injection of atoms and show that the observed deviation originates from the interference between the two traveling components of the cavity field. The criteria for sufficiently reduced interference and thus uniform atom-cavity interaction are derived in analytic considerations. It turns out that the Doppler-shift should be larger than both the largest Rabi frequency involved and the transit-time broadening. The numerical calculation of gain for various position of injection verifies the criteria. We also present new experimental data which strongly supports our analysis.
Avoided level crossing in a coupled system of a single atom and a single cavity mode with an adjustable coupling constant

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Avoided crossing (AC) of energy levels is a characteristic feature of an open quantum system, which is described by a non-Hermitian Hamiltonian. For a coupled system with non-negligible damping, AC is associated with the existence of an exceptional point (EP), where both energy-level crossing and AC coalesce. A coupled atom-cavity system with non-negligible atomic and cavity damping can also be described by a non-Hermitian Hamiltonian, and thus with a proper choice of parameters it is possible to observe an EP and to study its singular characteristics experimentally. Toward this end, we have devised a coupled atom-cavity system with cold single atoms in a high-Q microcavity, where the atom-cavity coupling constant $g$ can be adjusted at will. We chose our experimental parameters as $(g_0, \kappa, \gamma) = (16, 19, 3)$ MHz (in frequency), respectively, so that AC is observed in the parameter space spanned by the (probe) laser-cavity detuning and the atom-cavity detuning with the maximum coupling constant $g_0$. We can reach the EP condition, $g = |\kappa - \gamma|/2$, by decreasing the coupling constant from $g_0$ to its half, which is made possible by changing the probe-laser polarization and/or by choosing high-order transverse modes of the cavity. Our cavity was constructed by two supermirrors separated by 0.16 mm with a resulting finesse of 25,000. We trapped 85Rb atoms in a magneto-optical trap (MOT) placed 5 mm above the cavity and dropped them toward the cavity by turning off the trap laser beams. By monitoring the transmission of a cavity probe beam, we could not only record individual single-atom transit events, but also sort out only the events with the maximal atom-cavity coupling under the given condition. By measuring the transmission spectrum while scanning the laser-cavity detuning for various atom-cavity detuning, we could map out the energy levels of the coupled system and could observe ACs, an EP and ordinary level crossings. As a future work we plan to measure the second-order correlation function $g^2(t)$ of the cavity transmission, which is expected to show characteristics features near the EP.