38th EGAS

ISCHIA (Naples) 7-10 June 2006

EUROPHYSICS CONFERENCE

Book of Abstracts

Editors:
Antonio Sasso, Giuseppe Pesce, Giulia Rusciano

LOCAL ORGANISING COMMITTEE
Antonio Sasso, G. Pesce, G. Rusciano
G. Abbate, S. Solimeno, N. Spinelli, R. Velotta

Structure of the Book of Abstracts

The abstracts are sorted in order of presentation within each category for each day. They are labelled according to the nature of the sessions, as follows:

- Plenary Talks: PL
- Progress Reports Talks: PR
- Short Reports: SRA and SRB
- Posters from the following categories:
  - Structure of atoms and molecules: theory
  - Atomic spectra and interactions with photons
  - Molecular spectra and interactions with photons
  - Instruments and techniques
  - Atomic and molecular collision processes
  - Quantum optics
  - Cold atoms and molecules
  - Laser spectroscopy and applications
  - Highly charged ions and X-ray spectroscopy
  - Plasma spectroscopy and diagnostics.
  - Clusters, Quantum Dots, ...
  - Others

  will be presented in sessions P1 and P2.

EUROPHYSICS CONFERENCE ABSTRACTS are published by the European Physical Society, 2005.

ISBN: 2-914771-35-5

The 38° Egas organizing committee gratefully acknowledges support by:

Physik Instrumente

Toptica Photoninc Inc.

Coherent Inc.

Crisel Instruments srl

Varian Inc.

Laser Optronic

Journal of Physics B

Springer Verlag

Goethe Institut

SIF: Società Italiana di Fisica

European Physical Society

Università di Napoli "Federico II"

Consiglio Nazionale delle Ricerche

Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia

Regione Campania

Provincia di Napoli

Comune di Ischia

Azienda autonoma di cura soggiorno e turismo di Ischia

EGAS Board

	Wednesday June 7th			Thursday June 8th			Friday June 9th			Saturday June 10th
8:30	OPENING									
9:00	Hänsch (PL1)		9:00	Delande (PL5)		9:00	Hinds (PL7)		9:00	Inguscio (PL11)
9:45	Julien (PL2)		9:45	Brixner (PL6)		9:45	Fritioff (PL8)		9:45	Esslinger (PL12)
10:30	Coffee Break		10:30	Coffee Break		10:30	Coffee Break		10:30	Coffee Break
11:00	Nörtershäuser (PR1)	Le Targat	11:00	Ostrovsky (PR3)	Pashayan-L.	11:00	Callegari (PR5)	Schmelcher	11:00	Schmidt (PL13)
11:15		Sorrentino	11:15		Sørensen	11:15		Fattori		
11:30	Pichler	Shabaev	11:30	Costello	Belfi	11:30	Velotta	Lahaye		
11:45	Weis	Le Gouët	11:45	Eschner	Viteau	11:45	Krstulović	Harris	11:45	CONFERENCE CLOSE
12:00	DeKieviet	Jentschura (PR2)	12:00	Blackwell-W.	Halfmann (PR4)	12:00	Grucker	Dalfovo (PR6)		
12:15	Dubois		12:15	Orlando		12:15	Glushkov			
12:30	L U N C H		12:30	L U N C H		12:30	EGAS General Assembly		12:30	L U N C H
						13:00	L U N C H			
14:00	Ullrich (PL3)		14:00	Excursion & Social Dinner						
14:45	Zajfman (PL4)					14:30	Pegg (PL9)			
15:30	Coffee Break & Poster Session 1					15:15	Gribakin (PL10)			
						16:00	Coffee Break & Poster Session 2			
19:00	Demtröder (EL)					19:00	Special Event			

PL_i	Plenary Lectures
PR_i	Progress Reports
EL	Evening Lecture
A_i, B_i	Short Reports

Contents

Wednesday, June 7th

The Heartbeat of Light

Theodor W. Hänsch

Max-Planck-Institut für Quantenoptik
Hans-Kopfermann-Str. 1, D-85748 Garching
and
Sektion Physik, Ludwig-Maximilians-Universität München
Schellingstr. 4/III, D-80799 München
E-mail: Hansch@physik.uni-muenchen.de

For three decades, precision spectroscopy of the simple hydrogen atom has motivated advances in laser spectroscopy and optical frequency metrology.
Recently, femtosecond laser optical frequency comb synthesizers have arrived as revolutionary tools for ultraprecise optical spectroscopy.
A new absolute frequency measurement of the hydrogen 1S-2S two-photon resonance sets upper limits for possible slow variations of the time structure constant α. Frequency comb techniques are also making it possible to control the electric field of ultrafast laser pulses, opening intriguing opportunities in attosecond physics.

From spectroscopy of atomic hydrogen to metrology of fundamental constants

P. Cladé[1], O. Arnoult[1], M. Cadoret[1], E. de Mirandes[1], S. Guellati-Khélifa [2], C. Schwob[1], F. Nez[1], L. Julien[1] and F. Biraben[1]

[1] *Laboratoire Kastler Brossel, ENS, CNRS, UPMC, 4 place Jussieu, 75252 Paris cedex 05, France*
[2] *Institut National de Métrologie, Conservatoire National des Arts et Métiers, 61, rue du Landy, 93210 La Plaine Saint Denis, France.*

High resolution spectroscopy and optical frequency measurements in atomic hydrogen permit accurate confrontation of experiment and theory (mainly the QED). Combining the results obtained in Garching on the 1S-2S transition and the ones obtained by our group in Paris on the 2S-nS/nD two-photon transitions, one can deduce precisely the Rydberg constant and the 1S Lamb shift [1]. The comparison is now limited by the knowledge of the 2S-nS/nD and of rms charge radius of the proton. As the precision on the 2S-nS/nD frequencies is mainly limited by the light shifts, we have undertaken a measurement of the 1S-3S two-photon frequency for which the light shift is negligible. In this experiment, the frequency is measured using a femtosecond frequency comb and the second-order Doppler effect is partially compensated using a magnetic field perpendicular to the 1S atomic beam [2]. A determination of the proton radius with relative a uncertainty of $10\{-3\}$ is possible by measuring the 2S Lamb shift in muonic hydrogen. An ambitious experiment is going on at the Paul Scherrer Institute in Switzerland in the frame of an international collaboration. A search for the 2S-2P resonance line at $6\mu m$ was performed in 2003 [3]. The statistics of the data, collected during 3 weeks, was too low to prove or to disprove the existence of a resonance signal. We concentrate now on an improvement of the laser chain [4] to increase the event rate. Another test of QED can be done by comparing the different accurate values of the fine structure constant α deduced either from the electron magnetic moment anomaly a_e measurement and its complicated theoretical expression or from other methods. A competitive one is to determine α from the ratio h/M deduced from the measurement of the recoil velocity of cold atoms sample. A pioneering work has been done by S. Chu et al. by atomic interferometry with Cs. Recently, our group has performed an accurate measurement of the recoil velocity of ^{87}Rb atoms based on Bloch oscillations in a vertical accelerated optical lattice. We transfer about 900 recoil momenta to the atoms with an efficiency of 99.97% per recoil. The deduced value of $\alpha(^{87}Rb)$, with a relative uncertainty of 6.7 ppb [5], is in good agreement with the two other best determinations $\alpha(Cs)$ [6] and $\alpha(a_e)$ [7]. Another motivation for a precise measurement of α is the recent proposal of the redefinition of the kilogram by fixing the value of the Planck constant h [8]. The realization of the kilogram would be achieved using the Watt balance and it is based on the validity of the relation giving the von Klitzing constant characterizing the quantum Hall effect : $R_K = h/e2 = \mu_0/2\alpha$. To test the validity of this relation, independent accurate measurements of α are needed.

References

[1] B. de Beauvoir et al., Eur. Phys. J. D 12, 61 (2000).
[2] G. Hagel et al, Phys. Rev. Lett. 89, 203001 (2002).
[3] R. Pohl et al., Can. J. Phys. 83, 339 (2005).
[4] A. Antognini et al., Opt. Comm. 253, 362 (2005).
[5] P. Cladé et al., Phys. Rev. Lett. 96, 033001 (2006).
[6] A. Wicht et al., Physica Scripta T102, 82 (2002).
[7] T. Kinoshita and M. Nio, Phys. Rev. D 73, 013003 (2006).
[8] I.M. Mills et al., Metrologia 43, No. 3, 227 (2006).

From Atto- to Femtoseconds

Joachim Ullrich

Max-Planck-Institut für Kernphysik
Heidelberg - Germany
E-mail: Joachim.Ullrich@mpi-hd.mpg.de

Highly-charged ions at velocities close to the speed of light generate extremely strong (I$\simeq 10^{15}$-10^{23} W/cm^2), attosecond (t>0.1 as) electromagnetic pulses when passing target atoms, molecules or clusters [1,2]. State-of-the-art commercial Ti:Sa laser systems deliver femtosecond (t > 5 fs) optical pulses at power densities 10^{15} to 10^{17} W/cm^2 with records up to 10^{22} W/cm^2. Attosecond-laser pulses at similar power-densities might be expected in the future.
How do super-strong electromagnetic fields couple to matter, to single atoms or molecules at these very different ultra-short time scales? What are the dynamic mechanisms of atto- or femtosecond single [3,4] and multiple ionization [5,6] occurring e.g. with megabarn cross sections for the removal of all 18 electrons from Argon atoms in heavy ion collisions? Can we trace [7] and possibly control [8] the correlated femto- or sub-femtosecond quantum dynamics of electrons and ions in such fields and might we be able to have a glimpse on the attosecond bound-state correlated motion in many-electron atoms or molecules? Using *Reaction Microscopes* [9] such questions are being explored in unprecedented detail at heavy ion accelerators as well as with lasers and will be elucidated in the talk.

References

[1] Ionization of Helium in the Attosecond Equivalent Light Pulse of 1 GeV/u U92+ Projectiles R. Moshammer, W. Schmitt, J. Ullrich, H. Kollmus, A. Cassimi, R. Drner, O. Jagutzki, R. Mann, R.E. Olson, H.T. Prinz, H. Schmidt-Bcking, L. Spielberger Phys. Rev. Lett. 79 (1997) 3621
[2] Radiation Field and Resonant Two-Centre Dielectronic Transitions in Relativistic Ion Atom Collisions A.B. Voitkiv, B. Najjari, and J. Ullrich Phys. Rev. Lett. 94 (2005) 163203
[3] Three-Dimensional Imaging of Atomic Four-Body Processes M. Schulz, R. Moshammer, D. Fischer, H. Kollmus, D.H. Madison, S. Jones, and J. Ullrich Nature 422 (2003) 48
[4] Re-scattering of Ultra Low-Energy Electrons for Single Ionization of Ne in the Tunneling Regime? R. Moshammer, J. Ullrich, B. Feuerstein, J. R. Crespo Lopez-Urrutia, A. Dorn, D. Fischer, C.D. Schrter, W. Schmitt, H. Rottke, C. Trump, M. Wittmann, G. Korn, K. Hoffmann, W. Sandner Phys. Rev. Lett. 91 (2003) 113002-1
[5] On the Charge-Sign Dependence of Four-Particle Dynamics in Helium Double Ionization D. Fischer, R. Moshammer, B. Feuerstein, A. Dorn, C.D. Schrter, J.R. Crespo Lopez-Urrutia, C. Hhr, H. Kollmus, S. Hagmann, and J. Ullrich Phys. Rev. Lett. 90 (2003) 243201-1
[6] Momentum Distributions of Nen+ Ions Created by an Intense Ultrashort Laser Pulse R. Moshammer, B. Feuerstein, W. Schmitt, A. Dorn, C.D. Schrter, J. Ullrich, H. Rottke, C. Trump, M. Wittmann, G. Korn, K. Hoffmann, W. Sandner Phys. Rev. Lett. 84 (2000) 447
[7] Correlated Multi-Electron Dynamics in Ultrafast Laser Pulse - Atom Interactions A. Rudenko, K. Zrost, B. Feuerstein, V.L.B. de Jesus, C.D. Schrter, R. Moshammer, J. Ullrich Phys. Rev. Lett. 93 (2004) 253001
[8] Time-Resolved Imaging and Manipulation of H2 Fragmentation in Intense Laser Fields Th. Ergler, A. Rudenko, B. Feuerstein, K. Zrost, C.D. Schrter, R. Moshammer, and J. Ullrich Phys. Rev. Lett. (accepted)
[9] Recoil-Ion and Electron Momentum Spectroscopy: Reaction-Microscopes J. Ullrich, R. Moshammer, A. Dorn, R. Drner, L. Ph. H. Schmidt, H. Schmidt-Bcking Reports on Progress in Physics 66 (2003) 1463

Reaction Dynamics with Stored and Cold Molecular Ions

D. Zajfman[1,2], A. Wolf[1], D. Schwalm[1], H. Kreckel[1]

[1] *Max-Planck Institute for Nuclear Physics, Heidelberg, Germany*
[2] *Weizmann Institute of Science, Dept. of Particle Physics, Rehovot, Israel*
E-mail:Daniel.Zajfman@weizmann.ac.il

The detailed study of reaction involving molecular ions requires good control of their internal degrees of freedom, as well as of the kinematics of the reactants. In particular, for reaction involving molecular ions and electrons, the possibility to control both the initial vibrational and rotational states of the molecular ions, and the kinetic energy of the electrons are of utmost importance.
Heavy-ion storage rings with merged electron beam devices offer a clean environment for studies of reactions involving molecular ions with precise control of the relative collision energy and efficient detection of reaction products on a single molecule basis. Due to the long storage time available (tens of seconds), complete vibrational cooling (through radiative transitions) can be achieved for most of the non-symmetric molecular species. However, due to the final temperature of the ring walls, only partial rotational cooling is possible (usually down to 300 K).
Recently, it has become possible to overcome the above limitation by using a pre-storage scheme which allow to inject directly rotationally cold molecular ions. In a recent experiment [1] carried out at the Test Storage Ring (TSR) located at the Max-Planck Institute for Nuclear Physics, in Heidelberg, we have performed an experiment with rotationally cold (10-20 K) H_3^+ ions which allow to disentangle, on a partial basis, the contribution of the ortho and para state to the dissociative recombination process, which leads to the neutralization and fragmentation of the molecular ion. Thus, direct nuclear spin effect on the reaction rate could be analyzed, and compared to theoretical prediction. Additionally, we have performed a direct measurement of the angular dependence of the recombination process for the simplest asymmetric molecular ion (HD^+), and found a very large anisotropy.
In order to overcome the fundamental rotational temperature limitation, a new cryogenically cooled electrostatic storage ring (CSR) is under design and construction in Heidelberg. The main feature of this instrument, as well as a glimpse into the scientific program will be presented as well.

References

[1] H. Kreckel *et al.*, Phys. Rev. Lett. **95**, 263201 (2005).

Progress in High Resolution Laser Spectroscopy: From Atoms in Beams to Molecules in Bose-Einstein-Condensates

W. Demtröder

Fachbereich Physik, Universität Kaiserslautern

This is a review on the development of high resolution laser spectroscopy over the past 40 years. Besides some research on the spectroscopy of the active laser medium in the He-Ne-laser, the "Doppler-free" laser spectroscopy got its real impetus about 40 years ago by the invention of tunable single mode lasers. First examples of their applications were investigations of atomic hyperfine structures by linear laser spectroscopy, based on laser-induced fluorescence. The second step forward was the introduction of nonlinear techniques, such as saturation- and polarization-spectroscopy, allowing Doppler-free resolution of atoms and molecules in cells. Doppler-free two- and three-photon spectroscopy opened the access to high lying energy levels of atoms and molecules and started a revival of atomic and molecular Rydberg state spectroscopy. This research laid the basis for the realization of the one-atom maser. Resonant two-photon spectroscopy in molecular beams in combination with mass spectrometry allowed spectroscopists the isotope-selective spectroscopy of molecules and clusters with high sensitivity. Also the detection techniques have experienced a rapid progress. For example, cold Bolometers are used for very sensitive detection of molecules in long-lived excited vibrational states. The experimental realization of Bose-Einstein condensation of atoms opened the way to ultra-high resolution of molecular levels closely below the dissociation energy, using laser-induced recombination of atoms in a BEC. Recently even BEC of diatomic molecules has been reported, where magnetic field tuning through Feshbach resonances was used to stabilize molecules from atoms with ultrasmall relative velocities. This talk illustrates the different developments by some selected examples taken from the literature as well as from our own research.

High-Precision Atomic Spectroscopy of Halo Nuclei

Wilfried Nörtershäuser[1,2]

[1] *Institute of Nuclear Chemistry, Johannes Gutenberg - Universität Mainz, Germany*
[2] *GSI Darmstadt, Germany*
E-mail:W.Noertershaeuser@gsi.de

Halo nuclei have an exotic nuclear structure arising from the very weak binding of the last one or two valence nucleons. They have been discovered more than 20 years ago in nuclear reaction studies [1] and exhibit a huge matter radius, much larger than those of neighboring isotopes. This is because the valence nucleons, which are bound to a well-defined core-nucleus that contains all the other nucleons, are tunnelling into the classically forbidden region far away from the nuclear core. The best studied halo isotopes are ^{11}Li, ^{6,8}He and ^{11,14}Be. Even though nuclear charge radii are of great interest for these systems since they provide direct insight into the nuclear core - they have not been measured until recently. The only available source of model-independent nuclear charge radii for short-lived isotopes are laser spectroscopic measurements of isotope shifts. But for light isotopes like helium and lithium, the differences in nuclear mass causes a mass-dependent isotope shift that is 10,000 times larger than the small nuclear volume shift; thus, it is very difficult to extract accurate nuclear information.

A few years ago it became possible to calculate the mass-based portion of the isotope shift in three-electron systems with relative accuracy of approximately 10^{-6} [2] - sufficient to extract the change in the nuclear charge radius between isotopes - provided that the total isotope shift can be experimentally determined with comparable accuracy. However, this task is complicated because halo isotopes are produced only in tiny amounts at radioactive-beam facilities like TRIUMF or ISOLDE, and once produced, they decay away with half-life as short as a few ms. Thus, the applied method must be both fast and sensitive.

The talk will present recent work in this field with emphasis on the first determination of the ^{11}Li charge radius using laser spectroscopy on the $2s \rightarrow 3s$ Doppler-free two-photon transition combined with sensitive resonance ionization detection. An outlook on planned experiments to determine the charge radius of radioactive beryllium isotopes will also be given.

References

[1] I. Tanihata *et. al.*, PRL 55, 2676 (1985).
[2] Z.-C. Yan and G.W.F. Drake, PRA 61, 022504 (2000).

Quantum Electrodynamics of Light Atomic Systems and Fundamental Constants

Ulrich D. Jentschura

Max–Planck–Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg
E-mail: jentschura@mpi-hd.mpg.de

European physics has certainly attained an internationally leading role in high-precision experimental atomic structure physics. This talk will be focused on the theory behind the measurements. In general, the combination of relativistic atomic theory and quantum field theory is commonly referred to as bound-state quantum electrodynamics. It belongs to the most developed tools in the arsenal of theoretical physics. Among other applications, this powerful tool may be used for the determination of fundamental constants, for the verification of quantum field theory in atomic systems, and for the investigation of the potential time variation of fundamental quantities on the basis of laboratory measurements. Calculable frequency standards are appearing on the horizon. The recent progress in the field is the result of a fortunate and fruitful combination of high-precision theory and highly accurate experiments, some of which are performed using laser spectroscopic techniques and some of which profit from high-precision traps.

The topics covered in the talk include:

- the theory of the hydrogen and deuterium spectra and the determination of the Rydberg constant, and of the proton and deuteron charge radii, based on a least-squares analyis, as well as the theory of the hydrogen and deuterium hyperfine structure,
- the theory of the bound-electron g factor and the determination of the electron mass, as well as potential further applications regarding the nuclear g factor and a potential alternative determination of the fine-structure constant based on the *bound*-electron g factor,
- the structure of helium and the determination of the fine-structure constant, as well as high-precision measurements along the helium isoelectronic sequence, where interesting discrepancies of theory and experiment have been observed recently.

Emphasis will be laid on the use of a generalized least-squares analysis which enables optimal use of a large number of measurements of theoretically related quantities (such as different transitions in the same atomic system) for the determination of constants. This method, in particular, allows to quantify possible discrepancies of theory and experiment in situations where many related experimental results have to be confronted simultaneously with theory. A short survey of other bound systems such as muonium (which yields the electron-muon mass ratio), and the theoretical foundations governing the conceivable variation of fundamental constants, complement the other topics of the talk. Finally, an outlook will be given, and emphasis will be laid on the potential increase in the demand for accurate theoretical calculations in the area, because frequency combs have dramatically increased the feasibility of high-precision and ultra-high-precision measurements in University laboratories as opposed to a few government-funded institutions on the national level. The possibilities opened by the new techniques are nearly endless. As Heinz Maier–Leibnitz put it, "Whenever you invent a method ten or a hundred times better than existing ones, you can be sure that this will lead to new science!"

Treating cesium resonance lines with femtosecond pulse train

N. Vujicic, S. Vdovic, T. Ban, D. Aumiler, H. Skenderovic and G. Pichler

Institute of physics, Bijenika 46, Zagreb, Croatia
E-mail:pichler@ifs.hr

We present results of recent experiments when cesium vapor were illuminated by the femtosecond laser frequency comb centered at either D2 line at 852 nm or D1 line at 894 nm. This action changed the usual Doppler profile into very peculiar profile in which periodic structure can be observed by cw laser scanning probe. The periodic structure reflected the frequency spectrum of the pulse train consisting of a series of fringes separated by the pulse repetition rate. In cesium system the atomic coherence relaxation time is longer than the laser pulse repetition period. Cs atoms interact with the spectrum of the pulse train, and not with the spectrum of a single pulse. This open up a possibility for the high resolution spectroscopy [1,2], where the observed linewidths are much less than the Fourier- transform limit of the individual pulse in the train.
In our recent papers [3,4] we presented the observation of the velocity selective population transfer between the Rb ground state hyperfine levels induced by fs pulse train excitation. We developed a modified direct frequency comb spectroscopy (DFCS) which uses a fixed frequency comb for the ^{85,87}Rb $5^2S_{1/2} \rightarrow 5^2P_{1/2,3/2}$ excitation (Tsunami mode-locked Ti:sapphire laser with pulse duration of 100 fs and pulse repetition of 80 MHz) and a weak cw scanning probe (TOPTICA DL100, ECDL at 780 nm) for ground levels population monitoring. The Rb($5^2P_{1/2,3/2}$) excited atomic levels have the relaxation times greater than the fs laser repetition period.
We shall present velocity selective optical pumping of the ground hyperfine levels in cesium atoms achieved by femtosecond laser oscillator. Modulations in the hyperfine absorption line profiles are observed as a direct consequence of the velocity selective optical pumping induced by the frequency comb excitation. In addition, we show the results of the use of a hyperfine Cs filter, which selectively absorbs frequency comb lines over the Doppler profile.

References

[1] A. Marian, M. C. Stowe, J. R. Lawall, D. Felinto and J. Ye, Science 306, 2063 (2004).
[2] A. Marian, M. C. Stowe, D. Felinto and J. Ye, Phys. Rev. Lett. 95, 023001 (2005).
[3] D. Aumiler, T. Ban, H. Skenderovic and G. Pichler, Phys. Rev. Lett. 95, 233001 (2005).
[4] T. Ban, D. Aumiler, H. Skenderovic and G. Pichler, to be published in Phys. Rev. A (2006).

Electric tensor polarizability and Stark shift of the clock transition in cesium

A. Weis, S. Ulzega, A. Hofer and P. Moroshkin

Physics Department, Université de Fribourg, Fribourg, Switzerland
E-mail:antoine.weis@unifr.ch

The quadratic Stark effect of atomic levels is commonly parametrized by scalar (α_0) and tensor (α_2) polarizabilities. While the former leads to an equal shift of all magnetic sublevels, the latter lifts their degeneracy in a characteristic way. In second order perturbation theory, tensor polarizabilities only exist for states with angular momenta $J > 1/2$. As a consequence, the spherically symmetric $n^2S_{1/2}$ ground states of alkali atoms exhibit only a scalar Stark shift. However, it was shown already in the 1960s that a static electric field can lift the Zeeman degeneracy of the hyperfine structure in alkali ground states [1,2]. Sandars [3] explained the finite value of the corresponding tensor polarizability by extending the perturbation theory to third order including the hyperfine interaction. Unfortunately, that model was not able to reproduce the experimental values. In a recent all-optical experiment we have confirmed the early experimental results [4].

In this paper we present an extension of Sandars' theory by including not only diagonal, but also off-diagonal hyperfine matrix elements in the third order calculation of α_2. As a result we obtain a reasonable agreement between experiment and theory, thereby solving a 40-year-old open question. Our analysis has revealed a sign error in Sandars' formulas. The error does not affect the absolute value of the polarizability, but the relative sign of $\alpha_2(F = 4)$ and $\alpha_2(F = 3)$. We present experimental evidence for the correctness of our sign.

Our calculation also yields a theoretical value for the static Stark shift of the clock transition frequency in cesium. The frequency shift of primary frequency standards by blackbody radiation (a dynamic Stark shift) can be parametrized in terms of the transition's static Stark shift. The blackbody shift is one of the dominating systematic uncertainties of atomic clocks. Our theoretical value is in excellent agreement with a recent experimental measurement of the static shift [5] but disagrees with the value [6] commonly used by the clock community for correcting the primary frequency standards. It is to be noted here that a many different types of hyperfine matrix elements contribute to both the polarizability and the clock shift, however, with strongly differing weights. In the case of the clock transition 95% of the contributions can be expressed in terms of experimentally determined quantities which gives a particularly high level of confidence in the result.

References

[1] J. P. Carrico et al., Phys. Rev. 170, 64 (1968).
[2] H. Gould et al., Phys. Rev. 188, 24 (1969).
[3] P. G. H. Sandars, Proc. Phys. Soc., 94, 857 (1967).
[4] C. Ospelkaus at al., Phys. Rev. A67, 011402 (2003).
[5] A. Godone et al., Phys. Rev. A71, 063401 (2005).
[6] E. Simon et al., Phys. Rev. A57, 436 (1998).

Measurement of the Lamb shift of n=2 exited states in helium-like uranium using crystal spectroscopy methods

M. Trassinelli[1] D. Banaś[2], P. Jagodziński[2], M. Pajek[2], U. Spillmann[1] and Th. Stöhlker[1]

[1] *Gesellschaft für Schwerionenforschung, Darmstadt, Germany*
[2] *Świętokrzyska Academy, Kielce, Poland*
E-mail:m.trassinelli@gsi.de

We present a new experiment for the precise study of the inner-shell transition $1s2p\ ^3P_2 \rightarrow 1s2s\ ^3S_1$ in helium-like uranium in the few keV range (4.5 keV) using a Johann-type Bragg spectrometer with a spherically bent crystal [1]. Due to the focusing properties of the crystal bending, such instruments is characterized by a high efficiency (about 10^{-6}) and it will enables, for the first time, to evaluate precisely the Lamb shift for $n = 2$ states in highly charged helium-like ions. The data will be acquired at storage ring ESR of GSI using a fast He-like uranium beam colliding with a gas target. This measurement will provide the most sensitive test for the relativistic electron-electron interaction in highly charged ions.

References

[1] H.H. Johann, Zeitschrift für Physik **69**, 185 (1931)

Interferences phenomena in ion-molecule collisions

N. Sisourat[1], P.D. Fainstein[2] and A. Dubois[1]

[1] *Laboratoire de Chimie Physique-Matière et Rayonnement, Université Pierre et Marie Curie, 75005 Paris, France*
[2] *Comisión Nacional de Energía Atómica, Centro Atómico Bariloche, 8400 Bariloche, Argentina*
E-mail: Alain.Dubois@upmc.fr

Scattering experiments between charged particles and molecules have recently displayed novel many-body phenomena involving coherent interplay between electrons and nuclei. For example, in fast $A^{q+} - H_2$ collisions, doubly-differential cross sections for electron emission have been measured in a wide range of impact energy and for different projectile charges [1,2] : the energy-distributions of the secondary electrons presented different structures which have been explained by the coherent emission of electrons from both nuclei of the diatomic molecules [3]. The wide structures observed in the spectra were therefore interpreted by first-order interferences, in analogy with the ones observed in the famous Young's slits experiment. Higher frequency oscillations superimposed on the former structures were also observed [2] and tentatively interpreted through second-order effects. On the other hand, different theoretical analysis based on the Born approximation, CDW-EIS treatment, classical and semiclassical models confirmed qualitatively the existence of the first-order structures but did not predict the higher frequency ones.
For intermediate collision energies, corresponding to projectile velocities similar to the average velocity of the target electron, these effects are smeared out since the the electron dynamics is completely entangled in an attosecond transient multi-center structure. However new kind of dynamical features may be observed for electron transfer and are extremely sensitive to the detailed electronic structure of the molecular target, the projectile and the geometry of the collision complex [4].

In the conference we shall discuss interference effects in ion-molecule collisions observed for electron transfer in the intermediate impact energy range and for ionisation at higher velocities. We present two original semiclassical approaches to solve such problems, based on the numerical solution of the time-dependent Schrödinger equation [5,6] : (i) a basis expansion approach and (ii) a full numerical grid-method. The basis state method is most suitable for studies of geometrical effects for bound-bound transitions as the final channels are here correctly described. The grid method is perfect for collisions where charge transfer plays a minor role (ie. when ionization dominates) and an analysis in function of the energy and angle of ejection of the electron is required. In both cases we display strong interference effects with unique signatures of the two- and three-center dynamics of the electron cloud during the collision.

References

[1] N. Stolterfoht *et al*, Phys. Rev. Lett. **87**, 023201 (2001).
[2] N. Stolterfoht *et al*, Phys. Rev. A **69**, 012701 (2004).
[3] M. E. Galassi, P. D. Fainstein and R. D. Rivarola, Phys. Rev. A **70** 032721 (2004).
[4] I. Reiser, C. L. Cocke and H. Bräuning, Phys. Rev. A **67** 062718 (2003).
[5] J. Caillat, A. Dubois, I. Sundvor, and J. P. Hansen, Phys. Rev. A **70** 032715 (2004).
[6] J. Caillat *et al*, Phys. Rev. A **73**, 014701 (2006).

Higher order effects in a strontium optical lattice clock

R. Le Targat, A. Brusch, X. Baillard, M. Fouché and Pierre Lemonde

SYRTE, Observatoire de Paris, 61 Avenue de l'observatoire 75014 Paris, France
E-mail:rodolphe.letargat@obspm.fr

The recent advent of optical lattice clocks opens a promising way towards frequency standards with improved accuracy [1]. With a large number of atoms probed in the Lamb-Dicke regime these clocks combine the advantages of traditional optical standards which use either a trapped single ion or a large number of free falling neutral atoms. A crucial concern for this new type of clocks is the level of cancellation of the effects of the trapping potential on the clock transition. The first order perturbation is intrinsically cancelled by tuning the lattice to the "magic wavelength", this is however not the case for higher order terms. Though theoretical predictions indicate that these effects should be compatible with a 10^{-18} accuracy goal [2], they do not properly account for two photon resonances at the vicinity of the magic wavelength. In Sr, the $5s5p\,^3P_0 \rightarrow 5s7p\,^1P_1$ and $5s5p\,^3P_0 \rightarrow 5s4f\,^3F_2$ transitions lie respectively 7×10^{-2} nm and 5 nm away from the magic wavelength.
We report here the first observation of higher order effects in a strontium optical lattice clock. Non linear frequency shifts of several kHz are observed by operating the clock at a very high trapping intensity of $10^5\,\mathrm{W/cm^2}$ and by tuning the trap laser some 100 MHz away from the $P \rightarrow F$ resonance. No effect of the $P \rightarrow P$ transition could be observed to within the present accuracy of our measurements. When tuning the laser at the magic wavelength, which we determine to be 813.428 (1) nm, higher order effects are compatible with zero to within a few Hz. This demonstrates that they will not constitute a limitation to the accuracy at the 10^{-18} level for a Sr optical lattice clock operated at a reasonable lattice depth in the range of $10^3\,\mathrm{W/cm^2}$ [3].

References

[1] M. Takamoto, F.-L. Hong, R. Higashi, and H. Katori, Nature **435**, 321 (2005).
[2] H. Katori, M. Takamoto, V. G. Pal'chikov, and V. D. Ovsiannikov, Phys. Rev. Lett. **91**, 173005 (2003).
[3] P. Lemonde and P. Wolf, Phys. Rev. A **72**, 033409 (2005).

A strontium sample for ultracold atomic physics, high-precision spectroscopy and quantum sensors

F. Sorrentino, G. Ferrari, N. Poli, R. Drullinger and G. M. Tino

Dipartimento di Fisica and LENS, Istituto Nazionale Fisica Nucleare, Istituto Nazionale Fisica della Materia,
Polo Scientifico-Università di Firenze, 50019 Sesto Fiorentino, Italy
E-mail:sorrentino@fi.infn.it

Recently, laser-cooled atomic strontium has been the subject of active research in several fields spanning from all-optical cooling towards quantum degeneracy for bosonic and fermionic isotopes, cooling physics, continuous atom laser, detection of ultra-narrow transitions, multiple scattering, and collisional theory.
Much of that interest relies on the features of the electronic level structure of alkali-earth atoms, that make them ideal systems for laser manipulation and realization of quantum devices. Among the alkali-earths, strontium summarizes most of the useful properties both for the preparation of ultracold samples and for applications.
We describe the production of atomic strontium samples at ultra-low temperature and at high phase-space density, and their possible use as quantum sensors for frequency metrology and highly sensitive devices.
Our apparatus allows for simultaneous loading of a far-off-resonant optical dipole trap with different isotopes[1]. We performed collisional studies in the μK temperature domain. Our analysis proves that the ^{88}Sr isotope has a remarkably small s-wave scattering length, in agreement with results from photoassociation spectra[2,3]. It also shows the occurrence of ^{88}Sr-^{86}Sr interspecies elastic collisions. We exploited such fact to implement an optical sympathetic cooling scheme, thus increasing the phase-space density by one order of magnitude[4].

Part of our experiment concerns with high-resolution spectroscopy and accurate optical frequency measurements[5]. Here we also present our recent advances towards the realization of an optical frequency standard based on the highly forbidden $^1S_0$-$^3P_0$ intercombination line at 698 nm on the even Sr isotopes.

In ground-state ^{88}Sr atoms, the combination of small elastic cross-section and virtual immunity from stray magnetic fields may represent a critical advantage for the realization of quantum sensors, by reducing the possible sources of perturbation. We actually observe persistent Bloch oscillations[6] of ^{88}Sr atoms in a vertical 1-D optical lattice up to 10 seconds. As an example, we determine the gravitational acceleration in our lab[7]. We discuss the possible applications of our system to measure forces at micrometer scale.

References

[1] N. Poli, R. E. Drullinger, G. Ferrari, J. Léonard,F. Sorrentino and G. Tino, Phys. Rev. A 71, 061403(R) (2005).
[2] M. Yasuda, T. Kishimoto, M. Takamoto and H. Katori, arXiv:physics/0501053 (2004).
[3] P. G. Mickelson, Y. N. Martinez, A. D. Saenz, S. B. Nagel, Y. C. Chen and T. C. Killian, Phys. Rev. Lett. 95, 223002 (2005)
[4] G. Ferrari, N. Poli, R. E. Drullinger, F. Sorrentino and G. Tino, Phys. Rev. A. 73, 023408 (2006).
[5] G. Ferrari, P. Cancio, R. Drullinger, G. Giusfredi, N. Poli, M. Prevedelli, C. Toninelli and G. M. Tino, Phys. Rev. Lett. 91, 243002 (2003).
[6] F. Bloch, Z. Phys. 52, 555 (1929).
[7] G. Ferrari, N. Poli, F. Sorrentino and G. Tino, to be published.

g-factor of heavy ions: a new access to the fine structure constant

V.M. Shabaev[1], D.A. Glazov[1], N.S. Oreshkina[1], A.V. Volotka[1,2], G. Plunien[2], H.-J. Kluge[3] and W. Quint[3]

[1] *Department of Physics, St.Petersburg State University, Oulianovskaya 1, Petrodvorets, St.Petersburg 198504, Russia*
[2] *Institut für Theoretische Physik, TU Dresden, Mommsenstrasse 13, D-01062 Dresden, Germany*
[3] *Gesellschaft für Schwerionenforschung, Planckstrasse 1, D-64291 Darmstadt, Germany*
E-mail: shabaev@pcqnt1.phys.spbu.ru

A possibility for a determination of the fine structure constant in experiments on the bound-electron g-factor is examined. It is shown that studying a specific difference of the g-factors of B- and H-like ions of the same spinless isotope in the Pb region to the currently accessible experimental accuracy of 7×10^{-10} would lead to a determination of the fine structure constant to an accuracy which is better than that of the currently accepted value. Further improvements of the experimental and theoretical accuracy could provide a value of the fine structure constant which is several times more precise than the currently accepted one. The feasibility of the theoretical calculations to the required accuracy is discussed.

Investigation of the sensitivity limits of an atomic gravimeter

J. Le Gouët, J. Kim, D. Holleville, A. Clairon, A. Landragin, F. Pereira Dos Santos

LNE-SYRTE, CNRS UMR 8630
Observatoire de Paris, 61 av. de l'Observatoire, 75014 Paris, France
E-mail:julien.legouet@obspm.fr

We use atom interferometry to perform an absolute measurement of the gravitational acceleration g with ^{87}Rb free falling atoms. A cold atomic sample is prepared by 2D- and 3D-MOT loading within 50 ms. After a short σ_+-σ_- cooling phase, the molasses lasers are adiabatically shut off, and the final temperature is about 2 μK. While the atoms are falling, a sequence of three stimulated Raman transitions separates and recombines the atomic wave function, using vertical counter-propagating lasers. These two photons transitions address the two hyperfine sublevels F=1 and F=2 of the $^5S_{1/2}$ ground state via a virtual excited state. Each time the atoms experience a light pulse, the phase difference of the lasers is imprinted onto the atomic phase. The phase shift between the two paths depends on g, and scales with the square of the time interval between two consecutive pulses [1]. This phase shift is deduced from a fluorescence measurement of the atomic state at the output of the interferometer. The previous experiment based on this principle [2] demonstrated an excellent sensitivity of $2 \times 10^{-8} g/Hz^{1/2}$ [3], better than the best absolute gravimeter commercially available today [4], for a comparable accuracy of $3 \times 10^{-9} g$. With respect to this atomic fountain where the interaction time can be increased up to about 1 s, our experiment was developed to be transportable. Its compactness limits the maximum interaction time to 120 ms, but allows us to operate the interferometer with a high repetition rate of 5 Hz.

First interference fringes were obtained with our experiment a year back. We reduced the influence of the vibration noise by combining a passive isolation and a post-correction based on the independent measurement of the vibrations with a low noise seismometer. This allows us to reach the sensitivity of $2.5 \times 10^{-8} g/Hz^{1/2}$. I will present a detailed investigation of the influence of the different sources of noise on the measurement of our interferometer [5], as well as the undergoing studies on the various systematic effects that shift the measured value of g.

References

[1] C.J. Bordé, "Atomic Interferometry and laser spectroscopy", in *Laser Spectroscopy X*, World Scientific, 239-245 (1991)
[2] M. Kasevich, S. Chu, *Phys. Rev. Lett.*, **67**, No 2, 177-180 (1991)
[3] A. Peters, K. Y. Chung, S. Chu, *Metrologia*, **38**, 25-61 (2001)
[4] T.M. Niebauer et al., *Metrologia* **32**, 159 (1995)
[5] P. Cheinet, B. Canuel, F. Pereira Dos Santos, A. Gauguet, F. Leduc, A. Landragin, submitted to *IEEE. Trans. Instrum. Meas.*, arXiv:physics/0510197

Ab initio calculations of the Sulfur electron-affinity: the atomic and molecular approaches

T. Carette, M.R. Godefroid, J. Liévin and O. Scharf

Service de Chimie Quantique et Photophysique, CP 160/09
Université Libre de Bruxelles, B-1050 Bruxelles, Belgium
E-mail:mrgodef@ulb.ac.be

The photodetachment microscopy, relying on the analysis of electron interferograms obtained by photodetachment of a negative ion in the presence of an electric field, appears as the most accurate method for electron affinity measurements [1]. Its high accuracy, combined with a high sensitivity that allows the electron images to be recorded even for the rarest isotope, opens the possibility of measuring the isotope shift in the electron affinity [2]. Although not as accurate for many-electron systems, the theoretical investigation of the isotope shifts in the electron-affinity is worthwhile, shedding some light on electron correlation that can be strong enough to make it "anomalous" [3,4]. With this respect, Chlorine remains an interesting challenge for which the many-body calculations failed to reproduce the experimentally observed anomalous specific mass shift for the isotope pair ^{35,37}Cl [5]. Almost reaching the many-body complexity of Chlorine, the S^-/S is another interesting atomic pair for which the ^{32}S electron-affinity has been revisited recently by photodetachment microscopy experiments [1]. However, before tackling the evaluation of the expectation value of the mass-polarization term for the negative and neutral systems respectively – their difference making the mass specific shift for a given isotope pair –, it is needed to assess the theoretical description of the electron-affinity itself.

We will report ab initio calculations of the electron-affinity of the infinite-mass systems S^-/S, adopting two different methods. We use the numerical multi-configuration Hartree-Fock approach (MCHF) combined with configuration-interaction (CI), using the ATSP-2K package [6] and adopting different correlation models inspired from similar electron-affinity studies [3,4]. A molecular approach is also attempted, using MOLPRO [7], a complete system of ab initio programs for molecular electronic structure calculations, that has been shown already to be efficient for estimating atomic electron-affinities [8]. Although the use of the abelian D_{2h} point group might appear as a strong disadvantage for dealing with the spherical atomic symmetry, the desired degeneracies of the $(2L+1)$ components belonging to a given irreducible representation $\mathcal{D}^L$ can be obtained in the state-averaging multiconfiguration scheme. Moreover, this package allows for an extensive treatment of the electron correlation problem through the multi-reference CI.

References

[1] C. Blondel, W. Chaibi, C. Delsart and C. Drag, J. Phys. B 39, 1409 (2006).
[2] C. Blondel, C. Delsart, C. Valli, S. Yiou, M. Godefroid and S. Van Eck, Phys. Rev. A 64, 052504 (2001).
[3] M. Godefroid and C. Froese Fischer, Phys. Rev. A 60, R2637 (1999).
[4] M. Nemouchi, A. Taleb and M. Godefroid, J. Phys. B 37, 865 (2004).
[5] U. Berzinsh, M. Gustafsson, D. Hanstorp, A.E. Klinkmüller, U. Ljungblad and A.-M. Mårtensson-Pendrill, Phys. Rev. A 51, 231 (1995).
[6] C. Froese Fischer, G. Tachiev, G. Gaigalas, M. Godefroid and P. Jönsson, "The ATomic Structure Package - Version 2K", http://atoms.vuse.vanderbilt.edu/
[7] H.-J. Werner, P. J. Knowles, R. Lindh, M. Schütz *et al*, MOLPRO, a package of ab initio programs, http://www.molpro.net
[8] G. de Oliveira, J.M.L. Martin, F. de Proft and P. Geerlings, Phys. Rev. A 60, 1034(1999).

New approach for determination two-body effects on the hyperfine structure of the complex atoms in multiconfiguration approximation. Illustration of the case of Ta I

J. Dembczyński, M. Elantkowska and J. Ruczkowski

Chair of Quantum Engineering and Metrology,
Faculty of Technical Physics, Poznań University of Technology,
Poznań, Poland
E-mail: Jerzy.Dembczynski@put.poznan.pl

The electrostatic and spin-orbit coupling with distant configurations is defined for example as:

$$\begin{aligned} S_{\mathbf{FS-HFS}}(\psi,\psi') = \\ -\sum_{\psi'''\neq\psi,\psi'} \left\langle nl^N n_1 l_1^{N_1} n_2 l_2^{N_2}; SLJFM \,|\mathbf{FS}|\, nl^{N-1} n'''l''' n_1 l_1^{N_1} n_2 l_2^{N_2}; S'''L'''JFM \right\rangle \times \\ \left\langle nl^{N-1} n'''l''' n_1 l_1^{N_1} n_2 l_2^{N_2}; S'''L'''JFM \,|\mathbf{HFS}|\, nl^N n_1 l_1^{N_1} n_2 l_2^{N_2}; S'L'JFM \right\rangle \\ -\sum_{\psi'''\neq\psi,\psi'} \left\langle nl^N n_1 l_1^{N_1} n_2 l_2^{N_2}; SLJFM \,|\mathbf{HFS}|\, nl^{N-1} n'''l''' n_1 l_1^{N_1} n_2 l_2^{N_2}; S'''L'''JFM \right\rangle \times \\ \left\langle nl^{N-1} n'''l''' n_1 l_1^{N_1} n_2 l_2^{N_2}; S'''L'''JFM \,|\mathbf{FS}|\, nl^N n_1 l_1^{N_1} n_2 l_2^{N_2}; S'L'JFM \right\rangle \end{aligned} \tag{1.1}$$

where **FS** denotes electrostatic or spin-orbit operator and **HFS** states for one from many hyperfine structure (hfs) operators.
The terms of the formulae (1) can be written for each kind of considered excitations of the one or two electrons and moreover these terms can be presented as the product of the angular part and the radial part. On this way, the one- and two-body hfs interactions can be expressed as a set of the linear equations for each hfs constants A and B :

$$A(\psi) = \sum_{\kappa k, nl} \alpha_{nl}^{\kappa k}(\psi)\, a_{nl}^{\kappa k} + \sum_{\kappa k, i} \alpha_i^{\kappa k}(\psi)\, P_i^{\kappa k} R^t\left(nln_1l_1, n'''l'''n_1l_1\right)\left(nl, n'''l'''\right) \tag{1.2}$$

$$B(\psi) = \sum_{\kappa k, nl} \beta_{nl}^{\kappa k}(\psi)\, b_{nl}^{\kappa k} + \sum_{\kappa k, i} \beta_i^{\kappa k}(\psi)\, P_i^{\kappa k} R^t\left(nln_1l_1, n'''l'''n_1l_1\right)\left(nl, n'''l'''\right) \tag{1.3}$$

where $a_{nl}^{\kappa k}$ and $b_{nl}^{\kappa k}$ are the Sandars-Beck one-body radial parameters [1], R^t are the possible kinds of the Slater integrals and $P_i^{\kappa k}$ are the different kinds of the two-body hfs radial parameters.
The method has been applied to the atomic tantalum, where more than 250 experimental hfs A and B constants are known [2-4]. Our hfs analysis allows to determine quantitatively the hfs two-body contributions to each experimentally observed A and B constants.

This work was supported by Poznań University of Technology under project BW-63-028/06

References

[1] P.G.H. Sandars, J. Beck, Proc. R. Soc. (London) A 289, 97 (1965)
[2] L. Windholz, G.H. Guthoehrlein, Physica Scripta T105, 55 (2003)
[3] D. Messnarz et al., Physica Scripta 68, 170 (2003)
[4] N. Jaritz et al., Physica Scripta 69, 441, (2004); 71, 611, (2005)

Stark effect on radiation transition probabilities in the region of anticrossing between atomic multiplet levels

A. A. Kamenski and V. D. Ovsiannikov

Department of Theoretical Physics, Voronezh State University, 394006, Voronezh, Russia
E-mail: San40@bk.ru

The dependence of radiative characteristics on the external field is the basic problem in describing interaction between an atomic system and field. In a dc electric field, together with the shift and splitting of levels, forbidden lines may emerge and allowed lines may vanish.

An important feature of the Stark effect on multiplet states of many-electron atoms is the anticrossing of two (doublet) sublevels with equal principal and angular quantum numbers nL, which may appear if the polarizability of the upper state α_{nLJ_2M} with energy E_{nLJ_2} is greater than the polarizability of the lower state α_{nLJ_1M} with energy $E_{nLJ_1} < E_{nLJ_2}$. The "doublet" levels interacting in pairs may exist among states with arbitrary spin (not only $S = 1/2$) and specific magnetic quantum number, for example with $|M| = L + S - 1$. We have determined the influence of a static electric field $\mathbf{F}_0 = F_0\mathbf{e}_0$ on the wave functions, energies and probabilities of dipole transitions between the "doublet" atomic states near the anticrossing regime with $F_0 \approx F_A$. Our calculations are based on the integral Schrödinger equation for close levels,

$$\Psi(\mathbf{r}) = \sum_{i=1}^{k} a_{J_iM} \left[1 + G^{(nL)}(\mathbf{r}, \mathbf{r}') \left(\hat{V}(\mathbf{r}') - \Delta E\right)\right]^{-1} |\phi_{nLJ_iM}(\mathbf{r}')\rangle, \tag{1.4}$$

where $G^{(nL)}$ is the completely reduced Green function with the mean energy of multiplet [1]. The zero-order wave function resolved in doublet wave functions of the field-free atom

$$\Psi^{(0)}_{nLM,\pm} = a^{\pm}_{J_1M}|\phi_{nLJ_1M}\rangle + a^{\pm}_{J_2M}|\phi_{nLJ_2M}\rangle,$$

already in the superposition coefficients contains the dependence on the field strength [2]

$$a^{\pm}_{J_1M}(f) = \left|a^{\mp}_{J_2M}(f)\right| = \sqrt{\frac{1}{2}\left(1 \mp \frac{1 - f^2\,\xi^2}{\sqrt{1 + f^2(f^2-2)\,\xi^2}}\right)}, \tag{1.5}$$

where the "+" ("−") sign corresponds to the greater (the smaller) eigenvalue $\Delta E_{\pm}$, and ξ is a dimensionless parameter depending on quantum numbers of doublet atomic states. For $f = F_0/F_A \to 0$ only one of the two coefficients (1.5) is nonzero.

We have derived analytical expressions for the dipole transition probability between arbitrary atomic doublet states in the electric field F_0. E.g., for π-transition from the state $|nLM, \pm\rangle$ to the isolated state $|n'L' = L-1\, J'M\rangle$ the probability ratio to the total probability of the doublet transitions in a field-free atom is:

$$R^{\pi}_{\pm}(F_0) = \frac{1}{2}\left\{1 \pm \frac{\xi(f^2-1)\,\mathrm{sign}\,(\alpha^t_{nL})}{\sqrt{1 + f^2(f^2-2)\xi^2}}\right\}. \tag{1.6}$$

Near anticrossing, $F_0 \approx F_A$, the both probabilities become equal to one another, $R_+(F_A) = R_-(F_A) = 1/2$, as was observed in helium n^3P_J states with $M = 0$ [2]. The strong field, $f \to \infty$, breaks down the spin-orbit structure of atomic states so as to transform transition probabilities into those of a spin-less atom, with only one of the two values $R_{\pm}(\infty)$ remaining nonzero.

References

[1] I.L. Bolgova, *et al*, JETP, **96**, 1006 (2003).
[2] A.A. Kamenskii and V.D. Ovsyannikov, JETP, **100**, 487 (2005).

Dipole transition probabilities for atoms in electric field

A.A. Kamenski A.A.[1], V.D. Ovsiannikov[1] and A.A. Tarusin[1]

[1] *Department of Physics, Voronezh State University, 394006, Voronezh, Russia*
E-mail: san40@bk.ru

The field-induced dipole-forbidden transitions, which may be conveniently described in the second-order approximation by components of the "transition polarizability" tensor [1], are accompanied by the basic transformations for probabilities of allowed transitions between multiplet sublevels due to the field-induced reconstruction of atomic multiplets ultimately resulting in breakdown of the spin-orbit structure in strong field [1,2]. Also the variations in probabilities for the dipole-allowed transitions between singlet states in a static electric field $\mathbf{F}_0 = F_0\mathbf{e}_0$ may provide essential information on characteristics of both the internal atomic structure and the ambient external fields.

In this communication we present theoretical data for the second-order electric-field-induced corrections to the wave functions, matrix elements and probabilities of the dipole radiation transitions between singlet atomic states. E.g., the probability for transition between an initial $n_i\,{}^1S_0$ and final $n_f\,{}^1P_1$ states, supported by a field of wave with the unit polarization vector $\mathbf{e}$, may be presented as

$$W_{fi} = W_{fi}^{(0)}\left\{1 + F_0^2\left[w_\perp + \left(w_\parallel - w_\perp\right)|\mathbf{e}_0\cdot\mathbf{e}|^2\right]\right\},$$

where $W_{fi}^{(0)}$ is the probability of transition without the dc field, $w_\parallel$ ($w_\perp$) is the coefficient for the second-order correction to the probability of the π-(σ-)transition in the dc field with $\mathbf{e}_0 \parallel \mathbf{e}$ ($\mathbf{e}_0 \perp \mathbf{e}$). These coefficients include the second-order corrections to the transition frequency and to the matrix element. We demonstrate, that the first-order in F_0 matrix elements of the field-induced E2 and M1 transitions do not interfere with the field-free dipole matrix element and also contribute to the second-order correction for the π-transition $n_i\,{}^1S_0 \to n_f\,{}^1P_1$ in the wave propagating perpendicular to the dc-field vector. The non-dipole corrections to the σ transitions also appear in $w_\perp$, if the wave propagates collinear with $\mathbf{e}_0$. However, the numerical computations for helium and alkaline-earth atoms have demonstrated the E2-M1 corrections to be negligibly small in comparison with contribution from the interference between the second-order correction and the field-free E1 matrix elements.

The coefficients $w_{\parallel(\perp)}$ are rapidly increasing functions of the upper-level energy. On the basis of numerical computations, we have derived asymptotic extrapolation equations for transitions to highly excited $n_f\,{}^1P_1$ states with the effective principal quantum number $\nu_f = 1/\sqrt{-2E_{n_fP}}$. For helium the three-term extrapolation polynomial is:

$$w_\parallel \approx -3300\,\nu_f^{10} + 11500\,\nu_f^9 - 165000\,\nu_f^8,$$

with coefficients very smoothly dependent on the initial $n_i\,{}^1S_0$ state. This function gives the w values with 3 significant figures in a wide range of the $n_f\,{}^1P_1$ state principal quantum numbers, up to $\nu_f \approx 1000$.

References

[1] A.A. Kamenski and V.D. Ovsiannikov, JETP 100, 487 (2005).
[2] A.A. Kamenski and V.D. Ovsiannikov, J.Phys.B 39 (2006), in print.

Relativistic many-body calculations of the Stark-induced amplitude of the $6P_{1/2} - 7P_{1/2}$ transition in thallium

M. S. Safronova[1], W. R. Johnson[2], U. I. Safronova[3] and T. E. Cowan[3]

[1]*Department of Physics and Astronomy, University of Delaware, Newark, Delaware, USA*
[2]*Department of Physics, University of Notre Dame, Notre Dame, Indiana, USA*
[3]*Physics Department, University of Nevada, Reno, Nevada, USA*
E-mail: msafrono@udel.edu

Stark-induced amplitudes for the $6P_{1/2} - 7P_{1/2}$ transition in Tl I are calculated using the relativistic SD approximation in which single and double excitations of Dirac-Hartree-Fock levels are summed to all orders in perturbation theory. Our SD values $\alpha_S = 368\ a_0^3$ and $|\beta_S| = 298\ a_0^3$ are in good agreement with the measurements α_S=377(8) a_0^3 and $\beta_S = 313(8)\ a_0^3$ by D. DeMille, D. Budker, and E. D. Commins [Phys. Rev. A**50**, 4657 (1994)]. Calculations of the Stark shifts in the $6P_{1/2} - 7P_{1/2}$ and $6P_{1/2} - 7S_{1/2}$ transitions are also carried out. The Stark shifts predicted by SD calculations agree with the most accurate measured values within the experimental uncertainties for both transitions.

Relativistic Nuclear Recoil, Electron Correlation and Quantum Electrodynamic Effects in Be- and B-like Ar Ions

Z. Harman[1], U. D. Jentschura[1], C. H. Keitel[1], A. Lapierre[1], R. Soria Orts[1], J. R. Crespo López-Urrutia[1], H. Tawara[1], J. Ullrich[1], A. N. Artemyev[1,2], I. I. Tupitsyn[1,2], A. V. Volotka[2], V. M. Shabaev[2]

[1]*Max Planck Institute of Nuclear Physics, Saupfercheckweg 1, D-69117 Heidelberg, Germany*
[2]*Department of Physics, St. Petersburg State University, Oulianovskaya 1, Petrodvorets, 198504 St. Petersburg, Russia*
E-mail: harman@mpi-hd.mpg.de

The isotope shift [1] and the radiative decay rate [2,3] of the $1s^22s^22p\ ^2P_{3/2} - {}^2P_{1/2}$ forbidden M1 transition in B-like argon ions has been determined with high accuracy using the Heidelberg electron beam ion trap (EBIT). This transition, which is of fundamentally relativistic origin, provides unique possibilities for performing precise studies of correlation and quantum electrodynamic effects in many-electron systems. Our isotope shift calculations, which rely on a fully relativistic formulation of the nuclear recoil operator, are in excellent agreement with the experimental results and confirm that it is indispensable to include relativistic recoil corrections when predicting mass shift contributions in medium-Z ions. A calculation applying the nonrelativistic operator only would yield values for the isotope shift which are smaller than the experimental result by a factor of roughly three. The lifetime corresponding to the above transition has been measured with an accuracy on the order of one per thousand and is confirmed very recently by an independent measurement [3]. Theoretical calculations predict a lifetime that is in significant disagreement with this high-precision experimental value.

*Isotope shift.*The wavelengths of the $1s^22s^22p\ ^2P_{3/2} - {}^2P_{1/2}$ transition in Ar^{13+} and the $1s^22s2p\ ^3P_1 - {}^3P_2$ transition in Ar^{14+} were compared for the isotopes ^{36}Ar and ^{40}Ar. The observed isotopic effect has confirmed the relativistic theory of nuclear recoil effects in many-body systems, which corrects major inconsistencies in earlier theoretical methods. Theoretical transition energies and their isotope shifts, including the contributions due to the relativistic recoil operator, have been determined by large-scale configuration interaction Dirac–Fock–Sturm (CI–DFS) calculations and quantum electrodynamic many-body theory. Nonrelativistic normal mass shift and specific mass shift contributions were also evaluated in the framework of the multiconfiguration Dirac–Fock method. To the best of our knowledge, the relativistic nuclear recoil effect has never been observed experimentally thus far.

*Lifetime.*The lifetime of the Ar^{13+} $1s^22s^22p\ ^2P_{3/2}$ metastable state was determined to be 9.573(4)(5) ms (stat)(syst). The accuracy level of one per mill makes this measurement sensitive to quantum electrodynamic corrections like the electron anomalous magnetic moment and to relativistic electron-electron correlation effects. Theoretical predictions, including the result of a recent calculation based on the CI–DFS method combined with higher-order electron interaction and QED corrections [4], cluster around a lifetime that is approximately 3σ shorter than the experimental result. At present there is no explanation for this discrepancy. It is interesting to mention that a similar disagreement was also found for the lifetime of the Al-like Fe XIV $3s^23p\ ^2P_{3/2}$ level. Experimental and theoretical work is underway to confirm.

References

[1] R. Soria Orts *et al.*, *to be published.*
[2] A. Lapierre *et al.*, Phys. Rev. Lett. 95, 183001 (2005).
[3] A. Lapierre *et al.*, *submitted to* Phys. Rev. A (2006); J. R. Crespo López–Urrutia, private communication (2006)
[4] I. I. Tupitsyn *et al.*, Phys. Rev. A 72, 062503 (2005).

Bound States Composed of Positroniums and One-valence-electron Atoms

Mohamed Assaad Abdel-Raouf

Physics Department, Faculty of Science, UAEU Al Ain 17551, United Arab Emirates

The interest in the construction of exotic molecules containing positroniums has been rapidly increasing in the last few years. In the present work are reviewed both experimental and theoretical efforts made in this direction. Particularly, we demonstrate our treatments of chemical compounds containing positronium and one-valence-electron atoms. The compounds are considered as four-body systems in which nuclei and core electrons are frozen. Calculations are mainly concentrated on the formation of ground states. However, it is also explored possible existence of these molecules with excited positroniums.

Fine-structure energy levels and lifetimes in Mn XIII

G. P. Gupta[1] and A. Z. Msezane[2]

[1] *Department of Physics, S. D. (Postgraduate) College, Muzaffarnagar - 251 001, (Affiliated to Chowdhary Charan Singh University, Meerut - 250 004), INDIA*
[2] *Department of Physics and Center for Theoretical Studies of Physical Systems, Clark Atlanta University, Atlanta, Georgia 30314, USA*
E-mail: g_p_gupta1@yahoo.co.in

We have performed large scale CIV3 calculations of excitation energies from ground states for 98 fine-structure levels as well as of oscillator strengths and radiative decay rates for all electric-dipole-allowed and intercombination transitions among the fine-structure levels of the terms belonging to the $(1s^2 2s^2 2p^6)3s^2$3p, 3s3p^2, $3s^2$3d, $3p^3$, 3s3p3d, $3p^2$3d, 3s3d^2, $3s^2$4s, $3s^2$4p, $3s^2$4d, $3s^2$4f, and 3s3p4s configurations of Al-like Manganese, using very extensive configuration-interaction (CI) wave functions [1]. The important relativistic effects in intermediate coupling are incorporated by means of the Breit-Pauli Hamiltonian which consists of the non-relativistic term plus the one-body mass correction, Darwin term, and spin-orbit, spin-other-orbit, and spin-spin operators [2]. The errors, which often occur with sophisticated *ab initio* atomic structure calculations, are reduced to a manageable magnitude by adjusting the diagonal elements of the Hamiltonian matrices. In this calculation we have investigated the effects of electron correlations on our calculated data, particularly on the intercombination transitions, by including orbitals with up to n=5 quantum number. We considered up to three electron excitations from the valence electrons of the basic configurations and included a large number of configurations (1164) to ensure convergence.

Our adjusted excitation energies, including their ordering, are in excellent agreement with the available experimental results [3] and the recommended data by the National Institute of Standard and Technology (NIST). In our CIV3 calculation we identify the levels by their dominant eigenvector [4,5]. In this calculation the mixing among several fine-structure levels is so strong that the levels $3p^2(^1S)$3d($^2D_{1.5}$) and $3p^2(^1D)$3d($^2P_{1.5}$) are designated by the second largest and the third largest eigen vectors respectively. Due to this enormous mixing among several fine-structure levels, it is very difficult to identify these levels correctly. Perhaps, this may be the reason that no experimental results are available for these levels. Our very extensive calculations may assist the experimentalists in identifying these fine-structure levels. From our transition probabilities, we have also calculated radiative lifetimes of the fine-structure levels in Mn XIII. Our calculated lifetime for the level $3s^2$4s($^2S_{0.5}$) is found in good agreement with available theoretical and experimental results [6,7]. We predict new data for several levels where no other theoretical and/or experimental results are available.

References

[1] A. Hibbert, Comput. Phys. Commun. 9, 141 (1975). [2] R. Glass and A. Hibbert, Comput. Phys. Commun. 16, 19 (1978). [3] T. Shirai et al., J. Phys. Chem. Ref. Data 23, 179 (1994). [4] G. P. Gupta, K. M. Aggarwal and A. Z. Msezane, Phys. Rev. A 70, 036501 (2004). [5] G. P. Gupta and A. Z. Msezane, At. Data Nucl. Data Tables 89, 1 (2005). [6] J. F. Thornbury et al., Physica Scripta 42, 700 (1990). [7] J. F. Thornbury, A. Hibbert and E. Trabert, Physica Scripta 40, 472 (1989).

Oscillator strengths and lifetimes in Mg-like germanium

G. P. Gupta[1] and A. Z. Msezane[2]

[1] *Department of Physics, S. D. (Postgraduate) College, Muzaffarnagar - 251 001, (Affiliated to Chowdhary Charan Singh University, Meerut - 250 004), INDIA*
[2] *Department of Physics and Center for Theoretical Studies of Physical Systems, Clark Atlanta University, Atlanta, Georgia 30314, USA*
E-mail: g_p_gupta1@yahoo.co.in

Emission lines from multiply charged Mg-like ions are frequently observed in the spectra of astrophysical plasma and laboratory plasmas. Accurate absorption oscillator strengths for these ions are needed in astrophysical observations and in the study of laboratory plasmas both for diagnostic purposes and for the determination of the effects of impurities on controlled thermonuclear fusion.
We have calculated excitation energies from the ground state for 53 fine-structure levels as well as oscillator strengths and radiative decay rates for all electric-dipole-allowed and intercombination transitions among the $(1s^22s^22p^6)3s^2(^1S)$, 3s3p($^{1,3}P^o$), 3s3d($^{1,3}D$), 3s4s($^{1,3}S$), 3s4p($^{1,3}P^o$), 3s4d($^{1,3}D$), 3s4f($^{1,3}F^o$),$3P^2(^1S,^3P,^1D)$,3p3d($^{1,3}P^o,^{1,3}D^o,^{1,3}F^o$), 3p4s($^{1,3}P^o$), and $3d^2(^1S,^3P,^1D,^3F,^1G)$ states of Ge XXI. These states are represented by extensive configuration-interaction (CI) wave functions obtained using the CIV3 computer code of Hibbert [1]. The important relativistic effects are incorporated through Breit-Pauli Hamiltonian [2]. Small adjustments to the diagonal elements of the Hamiltonian matrices have been made. These adjustments improve the accuracy of the mixing coefficients which depends in part on the accuracy of the eigenvalues. This is a justifiable [3] fine-tuning technique and is particularly useful for the calculation of intercombination lines [4]. These adjustments also affect the composition of the eigenvectors slightly. In a way, they correct the *ab initio* approach for the neglected core-valence correlation, which has been shown to contribute significantly in neutral magnesium [5].
Our excitation energies, including their ordering, are in excellent agreement with the available experimental results [6]. In our CIV3 calculation we identify the levels by their dominant eigenvector [7,8]. The enormous mixing among several fine-structure levels makes it very difficult to identify them correctly with the result that their positions in other calculations are interchanged compared to our results and the experimental values. From our transition probabilities, we have also calculated radiative lifetimes of some fine-structure levels. Our calculated oscillator strengths and the lifetimes are found to be in good agreement with the experimental and other theoretical results (wherever available). In this calculation we also predict new data for several fine-structure levels where no other theoretical and/or experimental results are available. We believe that the new oscillator strengths will be useful in many astrophysical applications and in technical plasma modeling.

References

[1] A. Hibbert, Comput. Phys. Commun. 9, 141 (1975). [2] R. Glass and A. Hibbert, Comput. Phys. Commun. 16, 19 (1978). [3] D. McPeake and A. Hibbert, J. Phys. B: At. Mol. & Opt. Phys. 33, 2809 (2000). [4] A. Hibbert, J. Phys. B 12, L661 (1979). [5] P. Jnsson, C. Froese Fischer, and M. R. Godefroid, J. Phys. B 32, 1233 (1999). [6] T. Shirai et al., J. Phys. Chem. Ref. Data 24, 1577 (1995). [7] G. P. Gupta, K. M. Aggarwal and A. Z. Msezane, Phys. Rev. A 70, 036501 (2004). [8] Vikas Tayal and G. P. Gupta, J. Phys. B: At. Mol. Opt. Phys. 38, 4135 (2005).

Classical calculation of radiative lifetimes and branching ratios for hydrogenic Stark states

M.W. Horbatsch, E.A. Hessels, M. Horbatsch

York University, Department of Physics and Astronomy,
Toronto, Ontario, Canada M3J 1P3
E-mail:marko@yorku.ca

Recently we obtained accurate lifetime expressions for hydrogenic states on the basis of a classical Larmor radiation calculation [1]. Branching ratios (BRs) were obtained in good agreement with quantum mechanics when the Fourier components were collected to correspond to allowed final states. Accurate lifetimes were subsequently obtained for diamagnetic states using the framework of classical time-dependent perturbation theory [2].

Here we turn to the problem of lifetimes and BRs for Stark states of hydrogen. Classical expressions for these BRs were obtained in 1917 by H.A. Kramers. In order to go beyond that, we transform from the space of two Fourier indeces that characterize the motion in parabolic coordinates to (Δn, $\Delta\mu$), which represent changes in the principal and electric quantum numbers. Using this method, we find a good correspondence between the classical predictions and quantum mechanical results even for large $\Delta n/n$ for which the old calculation fails. A lifetime formula and comparisons of partially summed BRs with quantum mechanical results will also be presented.

This work allows one to draw several conclusions. The quantum-mechanical branching ratios for transitions between different Stark states are quantities with interesting structures as the final-state quantum numbers are varied. Our classical calculations which are based on a Fourier decomposition of the initial-state trajectory obtain many of these structures with good accuracy. The complicated dependencies appear for different reasons in both calculations: in the quantum case the matrix elements are determined by the nodal structures in the initial and final state wave functions.

From a practical perspective it is worthwhile to explore to what extent classical-quantum correspondence can be used in cascade calculations, e.g., for high-n initial states for which the calculation of quantum transition matrix elements becomes tedious [3]. Such calculations are of interest for plasma simulations both in atom trapping and in astrophysical applications.

References

[1] M.W. Horbatsch, E.A. Hessels, M. Horbatsch, Phys. Rev. A 71, 020501(R) (2005).
[2] M.W. Horbatsch, E.A. Hessels, M. Horbatsch, Phys. Rev. A 72, 033405 (2005).
[3] M.R. Flannery, D. Vrinceanu, Phys. Rev. A 68, 030502(R)(2003).

Electromagnetically induced transparency and light slowdown for Lambda - like systems with a structured continuum

S. Zielinska-Kaniasty[1],A. Raczynski[2], M. Rzepecka[2] and J. Zaremba[2]

[1]*Instytut Matematyki i Fizyki, Akademia Techniczno-Rolnicza, Aleja Prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland*
[2]*Instytut Fizyki, Uniwersytet Mikolaja Kopernika, ulica Grudziadzka 5, 87-100 Torun, Poland*
E-mail:sziel@atr.bydgoszcz.pl

Electric susceptibility of a laser-dressed atomic medium is calculated for a model Lambda-like system including two lower states and a continuum structured by a presence of an autoionizing state or a continuum with a laser-induced structure. We give analytic expressions for the susceptibility in the case of the bound-continuum dipole matrix elements being modelled according to Fano autoionization theory. We examine the shape of the transparency window depending on the amplitude of the control field.

We consider a generalization of a Λ system including two lower states $|b>$ (initial) and $|c>$, the bare continuum $|E>$ and an autoionizing state $|a>$. The state $|a>$ is coupled with the continuum by an additional coupling U, e.g. configurational or one due to a third laser. The autoionizing state and the continuum are coupled with the state $|b>$ by a weak probe field and with the state $|c>$ by a relatively strong control field. Depending on the strength of a control field, it is possible to obtain a significant reduction of the light velocity in a narrow frequency window in the conditions of a small absorption.

We find a qualitative similarity to the case of EIT in a typical Λ system, provided that the asymmetry parameter $|q_b| > 1$. In the case of a flat continuum the magnitudes of both the real and imaginary parts of the medium susceptibility are by many orders smaller and the transparency window is by a similar factor narrower than in a typical Λ system driven by the same control field. For not too large values of the Fano parameters we obtain the values of Reχ and Imχ much larger than in the case of a flat continuum but still by 6-7 orders of magnitude smaller than in the case of a typical Λ system. The transparency window is here much wider than in the case of a flat continuum, but by a few orders of magnitude narrower than for a typical Λ, for the same control fields. Our results are thus located in an intermediate region between the two limiting cases. Additionally, in the case of continuum the point of zero absorption is in general slightly shifted. It is shown that increasing the values of the asymmetry parameters leads to an increase of the values of both real and imaginary parts of the medium susceptibility and to an increase of the width of the transparency window, compared with the case of a flat continuum. A smooth transition is shown between the case of a flat continuum and that of a discrete state serving as the upper state of a Lambda system.

The work has been partly supported by Polish budget funds allocated for the years 2005-2007 as a research grant No. 1 P03B 010 28.

The binomial potential of electron-proton interaction alternative to the coulomb law

V.K. Gudym[1] and E.V. Andreeva[2]

[1]*Space National Agency of Ukraine, Kyiv, Ukraine*
[2]*Institute of Physics of Semiconductors of the NASU, Kyiv,Ukraine*
E-mail:vgudym@mail.ru

On the basis of only classical assumptions, we have shown earlier [1,2,3] that an electron and a proton interact by the binomial law

$$V = -\frac{e^2}{r} + \frac{\Gamma}{r^2} \tag{1.7}$$

and have determined the value of the constant Γ as $6.10276 \times 10^{-28}\ CGSE\ units$.
Potential (1.7) has been verified by us in the analysis of both the Kepler task of a hydrogen atom where the energy takes the form

$$E = \frac{m\dot{r}^2}{2} + \frac{M^2}{2mr^2} - \frac{e^2}{r} + \frac{\Gamma}{r^2} \tag{1.8}$$

and the Schrödinger equation

$$\Delta\Psi + \frac{2m}{\hbar^2}\left(E + \frac{e^2}{r} - \frac{\Gamma}{r^2}\right)\Psi = 0\ . \tag{1.9}$$

We have also analyzed the scattering of an electron by a proton, as a special case of the Kepler task. Below, we give the formula for the deflection angle φ_{0b} as a function of the impact parameter ρ:

$$\varphi_{0b} = \sqrt{\frac{E\rho^2}{E\rho^2 + \Gamma}}\arccos\left[\left(1 + \frac{4E(E\rho^2 + \Gamma)}{e^4}\right)^{-1/2}\right]\ . \tag{1.10}$$

The calculations have shown that the formula describing the scattering of electrons in the binomial potential well represents the process within the range of impact parameters down to $10^{-13}cm$ for the energies of an electron from several eV up to hundreds of MeV. Further, on the basis of potential (1.7), we have shown the basic opportunity for the solution of the classical task concerning the movement of an electron in the field of a proton for a hydrogen atom. On this way, we were succesful to clarify the nature of the Bohr postulates, the Planck constant, and some other constants which were not treated earlier within the framework of classical mechanics. For the theory of Schrödinger, we have demonstrated, with the use of potential (1.7), the opportunity to understand and to resolve a number of its internal contradictions. In particular, it turns out to be possible to derive, for the first time, a wave package being stable in time in the problem concerning a hydrogen atom and to explain the mechanism of birth of a quantum in the classical interpretation.
Generally, potential (1.7) can be considered as a link between the classical and quantum theories.

References

[1] Gudym V.K. 2001, Visnyk Kyiv. Univ., N. 3, P. 254. [2] Gudym V.K., Andreeva E.V. 2003, Poverkhn., N. 5, P. 59-63. [3] Gudym V.K., Andreeva E.V. 2006, Poverkhn., N. 3, P. 113-117.

Radiative parameters for some transitions in Cu II spectrum

R. Mayo[1], M. Ortiz[1], P. Quinet[2,3], E. Biémont[2,3], G. Malcheva[4] and K. Blagoev[4]

[1]*Department of Atomic, Molecular and Nuclear Physics, Univ. Complutense de Madrid, 28040 Madrid, Spain*
[2]*IPNAS (Bât. B15), University of Liège, Sart Tilman, B-4000 Liège, Belgium*
[3]*Astrophysics and Spectroscopy, University of Mons-Hainaut, B-7000 Mons, Belgium*
[4] *Institute of Solid State Physics, 72 Tzarigradsko Chaussee, BG - 1784 Sofia, Bulgaria*
E-mail: bobcheva@issp.bas.bg, kblagoev@issp.bas.bg

Accurate determination of transition probabilities in Cu II spectrum is of great interest for plasma physics, laser physics, astrophysics and for the construction of new light sources. Most of the Cu II transition probabilities, available so far in the literature, concern states belonging to the low-lying $3d^9 4p$ and $3d^9 5s$ configurations.

In this contribution we report on Cu II radiative parameters for some transitions arising from $3d^9 4d$ and $3d^8 4s^2$ configurations.

A plasma produced by laser ablation was employed as a source of Cu II ions. A focused Nd:YAG laser beam was used to generate the plasma on the surface of a copper target in a controlled argon atmosphere (8 Torr). The Nd:YAG laser generated 240 mJ pulses of 7 ns duration at 20 Hz frequency and 1064 nm wavelength. The recording of the spectrum was performed with a monochromator (0.3 Å spectral resolution) and an OMA III detection system. The set up allows to register the spectra with different delays after the laser pulse, which gives the opportunity to choose the best experimental conditions for relative intensity measurements. The system was calibrated by an etalon tungsten lamp in the visible spectral region and by an etalon deuterium lamp in the UV spectral range.

Theoretical calculations of transition probabilities and radiative lifetimes have also been performed by a relativistic Hartree-Fock approach (HFR method)[1], in which core-polarization effects and extensive configuration interaction between $3d^{10}$, $3d^9 4s$, $3d^9 5s$, $3d^9 4d$, $3d^9 5d$, $3d^9 5g$, $3d^8 4s^2$, $3d^8 4p^2$, $3d^8 4d^2$, $3d^8 4s4d$ (even parity) and $3d^9 4p$, $3d^9 5p$, $3d^9 4f$, $3d^9 5f$, $3d^8 4s4p$, $3d^8 4s4f$, $3d^8 4p4d$ (odd parity) have been included.

Experimental relative transition probabilities were normalized to an absolute scale using the calculated lifetimes data of the corresponding states.

The experimental and the theoretical transition probabilities were found in good agreement.

This work was supported by Bulgarian National Science Foundation under contract 1516/05 and also by the Belgian National Fund for Scientific Research (FNRS).

References

[1] R. D. Cowan, "The Theory of atomic Structure and Spectra" (University of California Press, Berkeley, California, USA, 1981).

Radiative lifetimes and transition probabilities of astrophysical interest in Zr II

G. Malcheva[1], K. Blagoev[1], R. Mayo[2], M. Ortiz [2], H. L. Xu[3], S. Svanberg[3], P. Quinet[4,5] and E. Biémont[4,5]

[1]*Institute of Solid State Physics, 72 Tzarigradsko Chaussee, BG - 1784 Sofia, Bulgaria*
[2]*Department of Atomic, Molecular and Nuclear Physics, Univ. Complutense de Madrid, 28040 Madrid, Spain*
[3]*Department of Physics, Lund Institute of Technology, P.O. Box 118, S-221 00 Lund, Sweden*
[4]*IPNAS (Bât. B15), University of Liége, Sart Tilman, B-4000 Liége, Belgium*
[5]*Astrophysics and Spectroscopy, University of Mons-Hainaut, B-7000 Mons, Belgium*
E-mail: campos@fis.ucm.es, rmayo@fis.ucm.es

The determination of elemental abundances in the stars, including the Sun, requires a large number of accurate radiative transition probabilities for many ions including Zr II. In the present work, radiative lifetimes of excited levels and transition probabilities of Zr II transitions of astrophysical interest are reported.

Radiative lifetimes of 16 levels belonging to the $4d^25p$ configuration were measured using a time-resolved laser-induced fluorescence (TRLIF) technique [1] with a laser single-step excitation process either from the ground state or from appropriate metastable states. These states are: x $^2P_{3/2}$, $^2D_{3/2,5/2}$, $^2F_{5/2,7/2}$; y $^4P_{3/2,5/2}$, $^2D_{3/2,5/2}$, $^2F_{7/2}$, $^2G_{7/2}$; z $^2S_{1/2}$, $^2P_{1/2}$, $^2F_{5/2,7/2}$, $^2G_{9/2}$. Free singly ionised zirconium atoms were generated by laser ablation. 12 levels were investigated for the first time.

The relativistic Hartree-Fock (HFR) method, as described by Cowan [2], but modified for the inclusion of core-polarization effects, was used to compute the radiative lifetimes and the transition probabilities. The following interacting configurations were explicitly introduced in the calculations: $4d5s^2 + 4d5p^2 + 4d5d^2 + 4d4f^2 + 4d5f^2 + 4d5s6s + 4d5s5d + 4d5s6d + 4d5p4f + 4d5p5f + 4d^25s + 4d^26s + 4d^25d + 4d^26d + 4d^3 + 5s^26s + 5s^25d + 5s^26d$ (even parity) and $4d5s5p + 4d5s6p + 4d5s4f + 4d5s5f + 4d5p5d + 4d5d4f + 4d5d5f + 4d^25p + 4d^26p + 4d^24f + 4d^25f + 5s^25p + 5s^26p + 5s^24f + 5s^25f$ (odd parity).

A good agreement is observed between our experimental and theoretical values.

Experimental relative transition probabilities were normalized to an absolute scale by theoretical data of the radiative lifetimes of the corresponding states.

The values of the experimental and theoretical transition probabilities are in good agreement.

This work was supported by the EC under the program "Access to Research Infrastructures" under the grant RII3-CT-2003-506350, by the National Fund for Scientific Research (FNRS) of Belgium and by the National Science Foundation of Bulgaria under contract 1516/05.

References

[1] Z. G. Zhang, S. Svanberg, P. Quinet, P. Palmeri, E. Bimont, Phys. Rev. Lett. 87, 273001 (2001).
[2] R. D. Cowan, "The Theory of atomic Structure and Spectra" (University of California Press, Berkeley, California, USA, 1981).

Solution of integral equations for radiative energy transfer using a generalized Fokker-Planck method

T. Kharchuk[1], N. Bezuglov[1], A. Klucharev[1], A. Ekers[2], K. Miculis[2], F. Fuso[3] and M. Allegrini[3]

[1] *Fock Institute of Physics, St Petersburg State University, 198904 St Petersburg, Russia*
[2] *Institute of Atomic Physics and Spectroscopy, University of Latvia, LV-1586 Riga, Latvia*
[3] *Dipartimento di Fisica, Universita' di Pisa, Largo Bruno Pontecorvo, 3 56127 Pisa, Italy*
E-mail:lidael@bk.ru

Integral equations describing energy transfer are broadly used in various areas of physics, astrophysics, and chemical physics. A general approach to their solution involves the reduction to differential equations using the Fokker-Planck (FP) method [1]. However, the applicability of the FP method is subject to limitations. Firstly, the mean free path $<\lambda>$ of the energy transfer processes must be much smaller than the characteristic size L of the reaction zone Ω. Secondly, the energy spectrum of integral equations must be limited, while the differential operators can acquire arbitrarily large (infinite) energy values.

Here, we present a modification of the FP method, which allows one to bypass the above limitations. We consider the Biberman-Holstein radiation trapping equation [2], which governs the evolution of the population $n^*(\vec{r},t)$ of excited atoms in the spatial point $\vec{r}$:

$$\frac{\partial n^*(\vec{r},t)}{\partial t} = -\Gamma n^*(\vec{r},t) + \Gamma \int_\Omega G\left(|\vec{r} - \vec{r'}|\right) n^*\left(\vec{r'},t\right) d^3r'; \quad G(\rho) = \frac{k_0}{4\pi\rho^2}\exp(-k_0\rho). \tag{1.11}$$

The absorption coefficient κ_0 is assumed to be independent of frequency and Γ denotes the radiative decay constant. Equation (1) can be rewritten in an equivalent form [3] by introducing the Fourier transform $V(\vec{p})$ for the kernel $G(|\vec{r}|)$ and using the momentum representation $\vec{p} = -i\vec{\nabla}$ in the coordinate space:

$$\frac{\partial n^*(\vec{r},t)}{\partial t} = -\Gamma V(-i\vec{\nabla}) n^*(\vec{r},t); \quad V(\vec{p}) = 1 - \frac{k_0}{|\vec{p}|}\arctan(\frac{|\vec{p}|}{k_0}). \tag{1.12}$$

In optically dense media ($k_0 L \gg 1$), the FP method uses the substitution of $V(p)$ by its Taylor expansion for small p : $V(p) \to p^2/3$. Such substitution is, however, associated with a wrong behavior of $V(p)$ at large p, where $V(p \to \infty) \to 1$ is expected, since at small opacities ($k_0 \to 0$) no photons can be absorbed. A correct asymptotic behaviour of $V(p)$ can be ensured, if it is substituted by the function $p^2/(3+p^2)$. Equation(2) is then transformed into the form

$$\frac{1}{\Gamma}\frac{\partial n^*(\vec{r},t)}{\partial t} = \frac{\widehat{\Delta}}{3k_0 - \widehat{\Delta}}\, n^*(\vec{r},t). \tag{1.13}$$

Here, $\widehat{\Delta}$ is the Laplace operator. Equation(3) correctly reflects all mathematical properties of the master integral operator in Eq.(1); its solution is more comfortable and easy, which will be demonstrated for a number of examples.

The work was supported by: Russian Found. for Basic Research, Grants 05-02-16216, 05-03-33252; INTAS Grant 05-1000008-8013; EU TOK project LAMOL; NATO Grant EAP.RIG.981378.

References

[1] H. Risken, *The Fokker-Plank Equation* (Springer, Berlin, 1984).
[2] A. F. Molisch and B. P. Oehry, *Radiation Trapping in Atomic Vapours* (Oxford, 1998).
[3] N. N. Bezuglov et al. J. Chem. Phys. 119, 7094 (2003).

Binding energy, Mass Defect and $\Delta E = Ac^2\ \Delta m$ in Deuteron.

Ajay Sharma

Fundamental Physics Society. His Mercy Enclave. Post Box 107 The Mall Shimla 171001 INDIA.
Email physicsajay@rediffmail.com

The masses of nucleons are same universally (inside and outside the nucleus) and secondly nuclei possess Binding Energy i.e. masses of nucleons are different. To explain these observations of deuteron (BE = 2.2244MeV), the difference in masses must be 0.002388 u or about 0.11854% of mass of outside nucleus. Thus masses of nucleons must be different, which is not justified. $\Delta E = Ac^2\ \Delta m$, explain BE successfully as small mass defect (24×10^{-14} u) can yield BE= 2.2244MeV.

Effect of atomic charge on atomic and molecular polarizabilities

F. Torrens[1] and G. Castellano[2 , 3]

[1]*Institut Universitari de Ciència Molecular, Universitat de València, València, Spain*
[2]*Departamento de Química, Universidad Politécnica de Valencia, València, Spain*
[3]*Facultad de Ciencias Experimentales Edetania, Universidad Católica de Valencia San Vicente Mártir, València, Spain*
E-mail: francisco.torrens@uv.es

The dependence of atomic polarizabilities α on effective charges q has been studied. A number of theoretical plots $\alpha - q$ have been analyzed in the q range $(-1) - (+3)$. The obtained trend has been applied to the atoms H, Li, C, N, O, Na, S, K and Ca in the total q range $(-0.719) - (+2.000)$. The objective is to analyze de dependence of atomic α on q in order to improve molecular intra and intermolecular force fields. The q can be obtained in a self-consistent field (SCF) calculation or can be adapted from the results of calculations for their fragments or related systems and the dipole polarizabilities are available for all the neutral atoms and ions of interest [1] and interpolated values can be used in correspondence with the charge of the atom. The analysis of the results show that most elements approximately multiply α by 3.7 as the effective charge approaches -1 whereas α essentially halves as the effective charge approaches $+1$. The interpolated α have been implemented in programs AMYR for the theoretical simulation of molecular associations and chemical reactions [2] and POLAR for the theoretical simulation of molecular polarizabilities [3]. The following improvements have been implemented in AMYR. (1) AMYR can read effective charges from input (X-ray diffraction, Mulliken population analysis from SCF or post-SCF). (2) AMYR can renormalize the effective charges in order to reproduce either the experimental dipole moment μ (for molecules with $q = 0$) or quadrupole moment (for apolar molecules with $q = \mu = 0$). (3) AMYR allows a fractional formal molecular charge. (4) AMYR can interpolate the dipole polarizabilities as a function of effective charges making use of the Lagrange interpolated polynomial. POLAR can interpolate the dipole polarizabilities according to a new equation.

References

[1] S. Fraga, J. Karwowski, K. M. S. Saxena, Handbook of Atomic Data, Elsevier, Amsterdam, 1976.
[2] F. Torrens, M. Rubio, J. Sánchez-Marín, Comput. Phys. Commun. 115, 87 (1998).
[3] F. Torrens, J. Phys. Org. Chem. 15, 742 (2002).

The Recalculation of the Magnetic Dipole Splitting Constants With New Measurements of Neutral Manganase

İpek K.Öztürk[1], F. Gülay Acar[2] , Gönül Başar[1], Günay Başar[2] and Sophie Kröger[3]

[1]*Istanbul University, Faculty of Science, Physics Department, 34118 Vezneciler, Istanbul, Turkey*
[2]*Istanbul Technical University, Faculty of Science and Letters, Physics Engineering Department, 34469 Maslak, Istanbul, Turkey*
[3] *Technische Universitat Berlin, Institut fur Atomare Physik und Fachdidaktik, Hardenbergstr. 36, 10623 Berlin, Germany*
E-mail:ikanat@istanbul.edu.tr

The element Manganese has just one stable isotope, which has an odd mass number 55, a nuclear spin of I = 5/2. In our first paper, experimental and theoretical studies of the hyperfine structure in the even configurations of atomic manganese have been performed [1].
In the second one a parametric analysis of the odd configurations has been carried out [2]. The most recent hyperfine structure measurements on Manganase were done by Blackwell-Whitehead et.al. in 2005 [3]using Fourier transform spectroscopy of hollow cathode discharges.
In this study, a renewed parametric analysis of hyperfine structure for even and odd configurations is performed with the new experimental results in [3]. Theoretical predicted values for the unknown magnetic dipole hyperfine structure constants A of all levels are given. The comparison between experimental and calculated values shows good agreement.

References

[1] Gü. Başar,Gö. Başar,G. Acar, İ.K.Öztürk, S. Kröger, Physica Scripta 67 p.476-484, (2003).
[2] G. Acar,Gü. Başar,Gö. Başar, İ.K.Öztürk, S. Kröger, Physica Scripta 71 p.245-250, (2005).
[3] R.J. Blackwell-Whitehead et.al., The Astrophysical Journal Supplement Series, 157:402-409,2005

On the competition between radiative and Auger decays of the 1s2s2p $^4P^\circ_{5/2}$ metastable state in Li-like ions

M.R. Godefroid[1], P. Indelicato[2], C. Mendoza[3], P. Palmeri[4], P. Quinet[4,5] and N. Vaeck[1]

[1] *Chimie Quantique et Photophysique, CP 160/09, Université Libre de Bruxelles, B-1050 Bruxelles, Belgium*

[2] *Laboratoire Kastler Brossel, Ecole Normale Supérieure, CNRS et Université Pierre et Marie Curie, 75252 Paris Cedex 05, France*

[3] *Centro de Fisica, Instituto Venezolano de Investigaciones Cientificas (IVIC), PO Box 21827, Caracas 1020A, Venezuela*

[4] *Astrophysique et Spectroscopie, Université de Mons-Hainaut, B-7000 Mons, Belgium*

[5] *IPNAS, Sart Tilman B15, Université de Liège, B-4000 Liège, Belgium*

E-mail:quinet@umh.ac.be

The K-vacancy states in Li-like systems represent an unusually versatile workbench for the magnetic interactions. Indeed, in addition to their dipole allowed manifold, these states can also decay via strong magnetic transitions, some of them being almost as large as their E1 counterparts as shown recently by Bautista *et al.* [1] in the case of Fe^{23+}. The situation becomes critical for the 1s2s2p $^4P^\circ_{5/2}$ metastable state which radiatively decay mainly through both M1 and M2 transitions to $1s^2 2p\ ^2P^\circ_{3/2}$ and $1s^2 2s\ ^2S_{1/2}$, respectively. Moreover, the 1s2s2p $^4P^\circ_{5/2}$ level autoionizes through the reaction 1s2s2p $^4P^\circ_{5/2} \rightarrow 1s^2\ ^2S_0 + e^-$ that ends up in the ground state of the He-like child ion, this autoionization being only possible via the spin-spin magnetic interaction.

A little more than 20 years ago, relativistic Auger and X-ray emission rates of the 1s2s2p configuration in some Li-like ions ($13 \leq Z \leq 92$) using Dirac-Hartree-Slater wavefunctions were published by Chen *et al.* [2]. More recently, Bautista *et al.* [1] reported detailed calculations of atomic data for the K-vacancy states of Li-like iron using different theoretical approaches. While these latter authors found a good agreement with Chen *et al.* for the *A*-value of the dominant M2 radiative transition depopulating the 1s2s2p $^4P^\circ_{5/2}$ state, their Auger rate, obtained using the AUTOSTRUCTURE code in a Breit-Pauli relativistic framework, was a factor of 3 smaller than the previous calculation [2].

In the present work, we employ three different computational packages to study the properties of the 1s2s2p $^4P^\circ_{5/2}$ metastable state in Li-like ions, i.e. the AUTOSTRUCTURE program [3,4], the relativistic multiconfigurational Dirac-Fock (MCDF) approach as implemented in the code developed by Grant and coworkers [5,6] and in the code of Desclaux and Indelicato [7]. Our calculations are compared with the few available previous theoretical and experimental studies.

References

[1] M.A. Bautista, C. Mendoza, T.R. Kallman, P. Palmeri, Astron. Astrophys. 403, 339 (2003).
[2] M.H. Chen, B. Crasemann, H. Mark, Phys. Rev. A 24, 1852 (1981).
[3] N.R. Badnell, J. Phys. B 19, 3827 (1986).
[4] N.R. Badnell, J. Phys. B 30, 1 (1997).
[5] I.P. Grant, B.J. McKenzie, P.H. Norrington, D.F. Mayers, N.C. Pyper, Comput. Phys. Commun. 21, 207 (1980).
[6] B.J. McKenzie, I.P. Grant, P.H. Norrington, Comput. Phys. Commun. 21, 233 (1980).
[7] J.-P. Desclaux and P. Indelicato , *"The relativistic atomic program MDFGME "* (2006) http://dirac.spectro.jussieu.fr/mcdf/index.html

Transition probabilities in actinides: the case of Am I

V. Fivet[1], P. Quinet[1,2] and E. Biémont[1,2]

[1] *Astrophysique et Spectroscopie, Université de Mons-Hainaut, B-7000 Mons, Belgium*
[2] *IPNAS, Sart Tilman B15, Université de Liège, B-4000 Liège, Belgium*
E-mail:quinet@umh.ac.be

It has been suggested recently [1] that the envelop of some magnetic stars could be enriched in radioelements with short lifetimes such as those of the actinide group. A confirmation of this suggestion would establish that spallation processes could affect in a significant way the chemical composition of the outer layers of some stars. The available observations are however affected by large uncertainties mostly due to the lack of atomic data for these elements or ions. In view of their radioactivity, the actinides (atoms or ions) are very difficult to study in the laboratory. Up to now, experimental data are available only for two elements of the group (Np I [2] and Am I [3]).
As an extension of our recent studies devoted to lanthanides [4,5], we have started an investigation of the atomic structures of selected elements in these heavy rare earths, concentrating upon the radiative parameters (transition probabilities and lifetimes). The theoretical analysis of these very complex structures has however to face many problems. Among them, let us mention the fact that the 5f orbital is less embedded in the core than the 4f orbital in the lanthanides, the predominancy of the relativistic effects in the excitations of the type $nf - (n+1)d$, the fact that the spectra show many rather weak lines and the presence of isotopic shifts or hyperfine structure effects. Nevertheless, these elements are an interesting challenge for the calculation of atomic structures.
We will discuss during the meeting the particular case of Am I and we will show some preliminary results obtained in this atom.

References

[1] C.R. Cowley *et al.*, Astron. Astrophys. 419, 1087 (2004).
[2] E.F. Worden and J.G. Conway, J. Opt. Soc. Am. 68, 733 (1979).
[3] Th. Arndt *et al.*, Phys. Rev. A 38, 5084 (1988).
[4] E. Biémont and P. Quinet, Phys. Scr. T 105, 38 (2003).
[5] E. Biémont, Phys. Scr. T 119, 55 (2005).

Transition probabilities and lifetimes in Au I and Au II

V. Fivet[1], P. Quinet[1,2], E. Biémont[1,2] and H.L. Xu[3]

[1] *Astrophysique et Spectroscopie, Université de Mons-Hainaut, B-7000 Mons, Belgium*
[2] *IPNAS, Sart Tilman B15, Université de Liège, B-4000 Liège, Belgium*
[3] *Department of Physics, Lund Institute of Technology, P.O. Box 118, S-221 00 Lund, Sweden*
E-mail:quinet@umh.ac.be

Radiative lifetimes of three levels of neutral gold (Au I) and one level of singly ionized gold (Au II) have been measured using time-resolved laser-induced fluorescence technique [1-3]. The new results have been used to assess the accuracy of calculations with a Hartree-Fock-plus-Relativistic-corrections model that takes configuration interaction and core-polarization effects into account [4-5]. Theoretical lifetimes agree well with the experimental results. These results, combined with theoretical and experimental branching fractions have allowed to deduce a reliable set of transition probabilities for Au I and Au II lines, some of them being of astrophysical interest [6]. The results will be stored in an extension of the database D.R.E.A.M. [7] to be created on a website of the University of Mons-Hainaut in Belgium.

References

[1] P. Palmeri, P. Quinet, E. Biémont, H.L. Xu ans S. Svanberg, Mon. Not. R. Astr. Soc. 362, 1348 (2005).
[2] E. Biémont, P. Palmeri, P. Quinet, Z. Dai, S. Svanberg and H.L. Xu, J. Phys. B: At. Mol. Opt. Phys. 38, 3547 (2005).
[3] V. Fivet, P. Palmeri, P. Quinet, E. Biémont, H.L. Xu and S. Svanberg, Eur. Phys. J. D 37, 29 (2006).
[4] R.D. Cowan, *The Theory of Atomic Structure and Spectra*, Univ. of California Press, Berkeley, USA (1981).
[5] P. Quinet, P. Palmeri, E. Biémont, M.M. McCurdy, G. Rieger, E.H. Pinnington, M.E. Wickliffe and J.E. Lawler, Mon. Not. R. Astr. Soc. 307, 934 (1999).
[6] V. Fivet, P. Quinet, E. Biémont and H.L. Xu, Eur. Phys. J. D (to be submitted).
[7] E. Biémont and P. Quinet, Phys. Scr. T 105, 38 (2003).

Experimental hyperfine structure investigation of atomic Nb

Günay Başar[1], Gönül Başar[2] and Sophie Kröger[3]

[1] *Technical University of Istanbul, Faculty of Science and Letters, Physics Engineering Department, 80626 Maslak, Istanbul, Turkey* [2] *Istanbul University, Faculty of Science, Physics Department, 34459 Vezneciler, Istanbul, Turkey*
[3] *Technische Universität Berlin, Institut für Atomare und Analytische Physik, Hardenbergstr. 36, 10623 Berlin, Germany*
E-mail:basar@itu.edu.tr

Nb possesses only one stable isotope with the odd mass number 93 and a nuclear spin I = 9/2. Because of the large nuclear magnetic dipole moment of $\mu_I = 6.1705(3)\mu_N$, in many transitions it is adequate to apply Doppler limited experimental techniques such as optogalvanic spectroscopy for an accurate determination of the magnetic dipole hyperfine interaction constants A. The comparatively small value of the electric quadrupole moment, Q = -0.36(7)b, leads to small quadrupole interaction constants B and corresponding weak deviations from the interval rule in hyperfine structure investigations. Therefore, the electric quadrupole constants B can not be determined precisely from Doppler limited spectra.

In this work Doppler reduced saturation absorbtion spectroscopy has been applied to study the hyperfine structure of excited levels of Nb I for the partially resolved lines measured with optogalvanic spectroscopy. In the wavelength range from 645 nm to 675 nm 11 transitions were measured using a hollow cathode discharge and a tunable single-mode cw ring dye laser. Precise values for the magnetic dipole hyperfine structure constants A and electric Quadrupole hyperfine structure constants B of investigated levels were determined.

Hyperfine structure measurements utilizing a laser and RF double resonance technique

P. Schef[1], M. Bjorkhage[2], P. Lundin[1], S. Mannervik[1]

[1] *Physics Department, Stockholm University, Stockholm, Sweden*
[2] *The Manne Siegbahn Laboratory, Stockholm, Sweden*
E-mail:schef@physto.se

A new experimental setup used for high precision measurements of hyperfine structure of metastable levels has been constructed at the Manne Siegbahn Laboratory[1] in Stockholm, Sweden. The setup utilizes a tunable ring dye laser in combination with a RF transmitter to induce transitions between hyperfine levels in a beam of ions. Since the Doppler width is proportional to the frequency, transitions induced by radio waves result in spectral lines with very narrow widths. These narrow lines make very accurate determinations of hyperfine structure constants possible. In order to observe the RF transition the population of one specific hyperfine level is depleted by laser excitation. In a subsequent interaction region the result of the RF excitation is monitored.

Recently the first results originating from this setup were published[2]. In this publication the magnetic dipole hyperfine structure constants as well as the electric quadrupole hyperfine structure constants of the level $5d6s\ b^1D_2$ level in La II are presented with a superior accuracy compared to all the previous studies of this level. The results of this recent measurement, $A = 48.3118 \pm 0.0016 MHz$ and $B = 39.043 \pm 0.013 MHz$ are in good agreement with two previous studies done with a Fast Ion Beam LAser Spectroscopy (FIBLAS) method[3],[4].

References

[1] Manne Siegbahn Laboratory homepage at http://www.msi.se
[2] P. Schef et al. Physica Scripta 73, 217 (2006)
[3] L. Maosheng et al. Physica Scripta 61, 449 (2000)
[4] C. Hohle et al. Zeitschrift fur Physik A 304, 279 (1981)

Precision measurement of the radiative screening correction and the hyperfine splitting in lithiumlike scandium

M. Lestinsky[1], E. W. Schmidt[2], D. A. Orlov[1], S. Schippers[1], E. Lindroth[3], A. Müller[2], A. Wolf[1]

[1]*Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany*
[2]*Institut für Atom- und Molekülphysik, Justus-Liebig-Universität, D-35392 Giessen, Germany*
[3]*Atomic Physics, Fysikum, Stockholm University, S-10691 Stockholm, Sweden*
E-mail:A.Wolf@mpi-hd.mpg.de

The radiative (QED) correction in the excitation energy $2s_{1/2}$-$2p_{3/2}$ of the lithiumlike ion Sc^{18+} was determinded in a combined experimental and theoretical study to ±0.25%, yielding by far the most precise result to-date for the radiative screening correction on this line in lithium-like systems. Autoionizing Rydberg resonances formed by binding an additional electron to the excited lithiumlike core were detected using electrons incident on Sc^{18+} from a new photocathode electron beam [1] and a high-quality stored Sc^{18+} ion beam. The autoionizing Rydberg resonances occur at ∼68.8 meV and the center of the observed hyperfine array was measured with a precision of ±0.2 meV, strongly improving on previous results on this system [2].
The resonance position plus the binding energy of the Rydberg resonant state yield the $2s_{1/2}$-$2p_{3/2}$ excitation energy. Present high-level relativistic many-body perturbation theory (RMBPT) allows the Rydberg binding energy (∼44.24 eV) to be calculated to better than ±0.3 meV [2]; this yields for the present measurement the $2s_{1/2}$-$2p_{3/2}$ excitation energy (∼44.31 eV) to better than ±0.4 meV. The analysis, in progress, yields a preliminary result of 215.3(5) meV (±0.25%) for the total radiative correction and of $\Delta E = 33.0(5)$ meV (±1.5%) for the screening part of the radiative correction. Its scaled value $F(Z\alpha) = \Delta E/[\alpha^2(Z\alpha)^3 mc^2]$ then amounts to 0.337(5).
A reproduction of the experimental result with this accuracy in the Z range where the radiative screening correction dominates over higher-order one-electron radiative corrections still under study should improve the result for the one-electron two-loop correction from the recent measurements [3] on U^{89+}, where a 3% variation between several theoretical results for the radiative screening correction limits the determination of the one-electron correction. A comparison to theories for the $2s_{1/2}$-$2p_{3/2}$ radiative screening correction (mostly screened self-energy) will be presented at the conference.
At the high energy resolution of the present electron collision experiment the hyperfine structure of the $2s_{1/2}$ level ($F = 3$ and 4 for the Sc nuclear spin of 7/2) is resolved. The energy splitting is extracted within ±0.1 meV in agreement with the prediction [4] by considering in detail its effect on the Rydberg resonances in dielectronic recombination.

References

[1] D. A. Orlov *et al.*, J. Phys.: Conf. Ser. 4, 290 (2005);
D. A. Orlov *et al.*, Appl. Phys. Lett. 78, 2721 (2001).
[2] S. Kieslich *et al.*, Phys. Rev. A 70, 042714 (2004).
[3] P. Beiersdorfer *et al.*, Phys. Rev. Lett. 95, 233003 (2005)
[4] S. Boucard and P. Indelicato, Eur. Phys. J. D 8, 59 (2000).

Theoretical study of Stark width and shift parameters of Sn II and Pb II transitions. Regularities and systematic trends

C. Colón[1], A. Alonso-Medina[1], C. Rivero[2], F. Fernández[3], J. Albéniz[3] and J. Madueno[3]

[1]*Departamento de Física Aplicada, EUIT Industrial, Universidad Politécnica de Madrid (UPM), Madrid, Spain*
[2]*Departamento de Tecnologías Especiales, ETSI Telecomunicación, (UPM) , Madrid, Spain*
[3] *Departamento de Química Industrial y Polímeros, EUIT Industrial,(UPM) , Madrid, Spain*
E-mail:cristobal.colon@upm.es

Measurements of Stark-broadening parameters provide means for diagnosis laboratory and astrophysical plasmas. Stark broadening data for a large number of transitions in many atomic and ionic spectra are needed for the modelling of stellar plasma, the investigation of its physical properties and abundance determinations. When calculating opacities of large-scale plasmas of stellar atmospheres, the Stark-broadened line profiles of resonance transitions are of the utmost importance because they give a relatively large contribution to radiative energy transport. Quite a large number of articles have been published that use different theoretical approximations to calculate these parameters, and to study their dependence on the nuclear charge number, effective ionization potential, atomic polarizability or principal quantum number. In order to provide astrophysicists with the relevant data needed for the theoretical modelling of stellar spectra and stellar atmospheres, we made an effort to determine the relevant Stark broadening parameters with the semi-classical formalism of Pb II and Sn II.

In this work we present theoretical calculated Stark widths for 80 lines of Sn II and 43 lines of Pb II arising from ns $^2S_{1/2}$, np $^2P_{1/2,3/2}$, nd $^2D_{3/2,5/2}$ and nf $^2F_{5/2,7/2}$ levels of Sn II and Pb II. Stark shift of 5610.4 Å of Pb II and 6845.4 Å of Sn II are present.

The data have been obtained using Griems semiclassical calculations. Stark widths are presented as functions of temperature for an electron density of 10^{17}cm^{-3}.

The atomic matrix elements were obtained using relativistic Hartree-Fock calculations and configuration interaction in an intermediate coupling (IC) scheme. The Cowan code was selected for this purpose. To provide level energies for our calculations, the table of Moore has been used. The relatively good agreement between experimental transition probabilities and our theoretical results obtained with this method shows that our IC mixing accounts the correlation effects.

We use the effective Gaunt factors which are calculated and tabulated by Griem.

The theoretical values obtained in this work are compared with the experimental ones published by the others authors. The calculated values are in good agreement with the experimental data. We have studied the dependence of the Stark width ω (Å) on principal quantum number, n, for several series of Pb II and Sn II. Regularities of this parameter versus temperatute has been studied.

References

[1] R. D. Cowan in "Theory of Atomic Structure and Spectra" (University of California Press-Los Angeles) (1981).
[2] C. Colon, A. Alonso-Medina, J. Phys. B:At.Mol.Opt.Phys. 35, 1143-1153 (2002).
[3] C. Colon, A. Alonso-Medina, J. Phys. B:At.Mol.Opt.Phys. 36, 2141-2143 (2003).
[4] C. Colon, A. Alonso-Medina, C. Rivero, F. Fernandez, Physica Scripta (in press) (2006).

Experimental Stark widths and transition probabilities of neutral and ionized lead and tin

A. Alonso-Medina[1] and C. Colón[1]

[1] *Departamento de Física Aplicada, EUIT Industrial, Universidad Politécnica de Madrid (UPM), Madrid, Spain*
E-mail:aurelia.alonso@upm.es

Data on atomic parameters (transition probabilities, Stark width,...) are relevant not only for atomic structure reserarch, but also for applications to astrophysics, plasma and laser physics, and also for analisys and industrial techniques. Laser produces plasma (LPP) is one of the habitual methods forthe experimental determination of different atomic and molecular parameters ain in particular the transition probabilities and the Stark width.

In this work we present measurements of transition probabilities for 39 lines of Pb I, 31 lines of Pb II, 10 lines of Pb III, 36 lines of Sn II, whose values have been previously published by these authors, and broadening measurements that are presented normalized to a electron density of $10^{16}\mathrm{cm}^{-3}$ for various temperatures, corresponding to several transitions of the Pb II and Sn II, that are in publication roads.

The optical emission from a LPP obtained by a 10640 Å laser irradiation with a flux of $2 \times 10^{10} W\,\mathrm{cm}^{-2}$, on Pb-Sn targets. Spectra were recorden and analized in a range from 1900 to 7000 Å. Pulses of 270 mJ and 7 ns of a Q-switched Nd:YAG laser were focused using a 12 cm focal lens onto several samples of lead and tin placed in a vacuum chamber evacuated with a turbomolecular pump which was filled with argon at a pressure of 6-12 Torr. The ligtt emitted by te LPP was focused on a quartz optical fiber,wich transmited the ligth to the input slit of a 1m Czerny-Turner monochromator. The resolution of the spectroscopic system in first order was 0.17 Å of half width half maximum (HWHM) for 5593 Å. A time-resolved optical multichannel analyzer (OMA) system allowed the detection and digital analysis of each spectrum. Spectra were obtained with different time gates. Spectral response calibration of the experimental system was made usin a deuterium lamp in the range from 1900 to 4000 Å and a tungsten lamp in the range from 3500 to 7000 Å.

Each observed spectrum was adjusted, taking in mind the instrumental profile, using Voigth profiles. The profile area of each line studied were recorded in order to obtain their total intensity and the contribution of Lorentz profile to their HWHM was obtained.

The population levels distribution and the corresponding temperatures for each considered atomic species were obtained using Boltzmann plots. Self-absorption of the atomic species were studied. The plasma electron densities were determined using well-known Stark broadening parameters of spectral lines.

References

[1] A. Alonso-Medina, Physica Scripta 55, 49-53 (1997).
[2] C. Colon, A. Alonso-Medina, C. Herran-Martinez, J. Phys. B:At.Mol.Opt.Phys. 32, 3887-3897 (1999).
[3] A. Alonso-Medina, C. Colon, Physica Scripta 61, 646-651 (2000).
[4] A. Alonso-Medina, C. Colon, C. Herran-Martinez, J. Quant. Spectrosc. Radiat. Transf. 68, 351-362 (2001).

Combined excitation of the bismuth atom resonant level by electron impact and optical pumping in the Bi-Xe-NaCl mixture discharge

R.B. Riyves, Yu.V. Zhmenyak, V.A. Kelman, Yu.O. Shpenik, Plekan O.I.

Institute of Electron Physics, Ukr. Nat. Acad. Sci., Universytetska St. 21, Uzhhorod, Ukraine 88017
E-mail:vkel@mail.uzhgorod.ua

In [1] we demonstrated the high efficiency of excimer XeCl molecules formation in the non-toxic NaCl-Xe mixture excited by a low pressure longitudinal pulse-periodic discharge. The radiation spectra of this emission source is characterized by a dominant band of B → X transition of the XeCl molecule with maximum at 308 nm where the larger part of the discharge emission is concentrated. High intensity and narrow bandwidth (5 ns) of the XeCl excimer band allows to use this source for selective optical pumping of atomic and molecular levels which are important in laser physics. Using the unique properties of the developed excimer lamp we tried to demonstrate the possibility of additional pumping of excited states by gas discharge atomic levels for which the absorption lines from the ground state lie in the spectral range of the excimer 308 nm band.

The bismuth atom was tested as an object for investigation. First of all, the resonant transition of BiI with λ 306,8 nm is close to the centre of the XeCl molecule B → X transition, secondly the additional optical pumping of the upper laser level of the well-known bismuth-vapor laser on self-terminating 472.2 nm transition [2] can improve the output parameters of this laser. This paper presents our investigations of the spectral and time-dependent parameters of the discharge radiation of Bi-Xe-NaCl and Bi-Ne-NaCl mixtures to study the influence of the excimer molecules and their emission on the excitation of bismuth atoms in the discharge.

The experimental setup, similar to [2], where pulse periodical longitudinal discharge with 400 mm length, 12 mm ID and temperature stabilization of the discharge zone by an external heater was used for the excitation of the abovementioned mixtures. The emission spectra of the discharge were investigated by a time-resolved spectral registration system.

The Bi-Ne-NaCl mixture emission spectra demonstrate the domination of BiI spectral lines from the first resonant state to the ground (306.8 nm) and metastable (472.2 nm) states. By changing the buffer gas neon to xenon in the discharge tube we observed an intense excimer band of XeCl molecule (308 nm) with the 15 percents growth of the intensity of the BiI abovementioned lines. To our opinion this is an evidence of additional pumping of the BiI resonant state. This process is possible due to the compliance of the optimal temperature intervals for maximal intensity of the XeCl molecule radiation and the bismuth lines which is the effect of always similar values for the saturated vapor pressure of Bi and NaCl. The time-dependent forms of the discharge current pulses and BiI spectral lines also demonstrate higher intensities, faster growth and longer pulses by changing Ne to Xe.

References

[1] Riyves R.B., Svetlichnij E.A., Zhmenyak Yu.V., Kelman V.A., Shpenik Yu.O. J. Tech. Phys. (Russia) 74, 90 (2004).

[2] Zhmenyak Yu.V., Kelman V.A., Shpenik Yu.O. Optics and Spectroscopy (Russia) 90, 811 (2001).

Three-photon laser spectroscopy of even-parity states of samarium atom

A. Gomonai, O.I. Plekan

Institute of Electron Physics, Ukranian Academy of Siences,
Uzhgorod, Ukraine
E-mail: vkel@mail.uzhgorod.ua, kudelich@rambler.ru

Multi-photon resonance ionization spectroscopy is one of the most highly sensitive and precise methods of studying the complex structure of electron spectra in atoms and molecules [1].
Samarium atom (Sm) is characterized by an extremely complicated energy level spectrum resulted from the presence of less than half-filled $4f^6$ – shell not studied up to date. Especially this holds true for high-lying even-parity bound states. In the literature, the overwhelming majority of the data on the above states have been obtained by a multi-step spectroscopy method, in which the number of excited states is limited by the choice of specific excitation scheme. Therefore to obtain more complete information on the even-parity higher-lying states of Sm one needs to perform the spectroscopic studies with the use of different excitation schemes.
In this paper, using the multi-photon one-color resonance ionization spectroscopy the spectrum of high-lying even-parity bound states of samarium atom lying in the $E > 33000\ cm^{-1}$ energy range has been studied.
High-lying even-parity bound states were excited by two-photon absorption from the different ground ${}^7F_{0-6}$ – levels. Note that since all the seven ground-term levels are populated even at relatively low temperatures, the resonance structure in the three-photon ionization spectrum is an aggregate of the maxima due to the transitions from different initial levels. The energies E and the total momenta J of the above states were determined by observing the groups of maxima corresponding to the two-photon transitions from different lower levels to the same upper excited level. Therefore in order to identify correctly the resonance structure we have compared the spectra measured at different laser beam intensities.
We have determined the energies and the total momenta of 305 even-parity higher bound states of samarium atom lying within the $E = 33036.0 - 40526.7\ cm^{-1}$ energy range. A comparison of our data (i.e. the energies E and the total momenta J with those obtained by other methods [2–4] shows a fairly good agreement.

References

[1] D.S.Kliger. Ultrasensitive laser spectroscopy. (1983).
[2] T.Jayasekharan, M. A. N. Razvi, G.L.Bhale. JOSA B. 17, 1607 (2000).
[3] T.Jayasekharan, M. A. N. Razvi, G.L.Bhale. JOSA B. 13, 641 (1996).
[4] H.Park, Hyun-chae Kim, Yi Jong-hoon, Jae-Min Han, Jongmin Lee. JKPhS. 30, 453 (1997).

Photodouble ionisation studies of the Ne($2s^2$) state

P. Bolognesi[1], A. Kheifets[2], S. Otranto[3], M. Coreno[1,4], V. Feyer[1,5], F.D. Colavecchia[6], C.R. Garibotti[6] and L. Avaldi[1,4]

[1] *CNR-IMIP, Area della Ricerca di Roma 1, Monterotondo Scalo,, Rome, Italy*
[2] *Research School of Physical Sciences and Engineering, Australian National University, Canberra, Australia*
[3] *Physics Department, University of Missouri-Rolla, Rolla MO, USA*
[4] *CNR-TASC, Gas Phase Photoemission Beamline at Elettra, Area Science Park, Trieste, Italy*
[5] *Institute of Electron Physics, National Academy of Sciences, Uzhgorod, Ukraine*
[6] *CONICET and Centro Atmico Bariloche, 8400 S.C. de Bariloche, Argentina*
E-mail:feyer@tasc.infm.it

The study of the photodouble ionisation (PDI) of He via photoelectron-photoelectron or photelectron-recoil ion coincidence experiments is the most suited approach to the study of the few-body Coulomb problem, a fundamental process in atomic physics. Indeed, the PDI of the He atom, with the simple 1Po symmetry of the electron pair and just a bare nucleus with no internal structure in the final state, is the prototypical example of the three-body Coulomb problem and the most suited process to study the electron-electron correlations. Since the first experiments in 1994 [1] the study of PDI in He via coincidence experiments has made noticeable progresses and a satisfactory experimental description and a good theoretical understanding have been reached [2]. In this contribution we show that the same experimental technique provides valuable information on the PDI process in the heavier rare gases. In particular the triple differential cross section (TDCS) of Ne($2s^2$) state at 20 eV above its double ionisation threshold has been measured in equal and unequal energy sharing conditions and perpendicular geometry and compared with the one of the He($1s^2$). The dynamical quantities which govern the photodouble ionisation (PDI) process, i.e. the squared moduli of the gerade and ungerade complex amplitudes and the cosine of their relative phase, have been extracted from the experimental data. The results from the two targets have been compared between themselves as well as with the theoretical predictions of the SC3 [3] and CCC calculations [4]. Despite the two targets share the same initial and final state symmetries some qualitative differences are observed in the TDCS. In equal energy sharing the differences can be explained as an initial state effect. The predictions of both the theoretical models are in reasonable agreement with the experiment when an accurate Ne 2s initial state wavefunction, which accounts for 2s-2p intrashell correlation, is used. At variance in the case of the unequal energy sharing the use of the same wavefunction does not improve the agreement. This finding suggests that a complete description of the observed TDCS implies an extension of the used models to account properly for the correlation between the ejected electrons and the bound ones in the final state.This work represents a joint experimental and theoretical approach to the investigation of PDI of atomic systems with more than two electrons.

References

[1] O. Schwarzkopf, B. Krssig, J. Elmiger and V. Schmidt, Phys. Rev. Lett. 70, 3008 (1993).
[2] A. Huetz and L. Avaldi, J. Phys. B: At. Mol. Opt. Phys. 38, S861 (2005).
[3] S. Otranto and C.R. Garibotti, Eur. Phys. Jour.D 21, 285 (2002).
[4] A. Kheifets and I. Bray Phys. Rev. Lett. 81, 4588 (1998).

Experimental investigation of the hyperfine structure of atomic La

Gönül Başar[1], Günay Başar[2], Alev Er[1] and Sophie Kröger[3]

[1] *Istanbul University, Faculty of Science, Physics Department, 34459 Vezneciler, Istanbul, Turkey*
[2] *Technical University of Istanbul, Faculty of Science and Letters, Physics Engineering Department, 80626 Maslak, Istanbul, Turkey*
[3] *Technische Universität Berlin, Institut für Atomare und Analytische Physik, Hardenbergstr. 36, 10623 Berlin, Germany*
E-mail:gbasar@istanbul.edu.tr

Lanthanum is the first element of the rare-earth series in the periodic table, the so-called Lanthanides. It has two naturally occurring isotopes ^{138}La and ^{139}La with a natural abundance of 0.090% and 99.910%, with nuclear spins 5 and 7/2 respectively.

Although the hyperfine structure of La has been investigated extensively, the knowledge about experimental hyperfine structure constants is far from being complete. The aim of the present work was to extend the data to energetically high lying levels of odd parity.

Optogalvanic laser spectroscopy has been applied to measure the hyperfine structure of 20 spectral lines of La I in the wavelength regions of 570 nm to 590 nm and 700 nm to 825 nm. Experimental hyperfine structure constants A and B of the isotope ^{139}La have been measured for 17 levels of odd parity. Out of them six magnetic dipole and ten electric quadrupole constants have been determined for the first time. Some disagreements with previous values are discussed.

Precise structure of dark resonance in ^{87}Rb atomic vapor

G. Kazakov, B. Matisov

St. Petersburg State Polytechnic University,
Polytechnicheskaya 29, St. Petersburg 195251, Russia
E-mail:kazjor@rambler.ru

The importance of the frequency stabilization presently becomes more profound, because of the newly emerging tasks that require building of relatively cheap, compact and stable atomic clocks and new technologies entering this branch of metrology. One of the particularly promising ways is an optical method of frequency stabilization by means of so-called dark resonance [1]. This dark resonance manifests the destructive interference of different excitation channels in real (multilevel) atoms irradiated by coherent multicomponent (two-component, in the simplest case) electromagnetic fields. The atoms are thus optically pumped into a coherent superposition state immune to excitation by the given laser radiation. This effect is called the coherent population trapping (CPT). If the two-photon (Raman) resonance condition is fulfilled, and the radiation intensity exceeds certain value determined by the relaxation of the CPT state, the system exhibits a sharp resonance (called the dark resonance) that is characterized by anomalously small absorption coefficient and, therefore, by suppressed light scattering.

The dark resonance parameters sufficiently depend on the excitation scheme. The simple excitation scheme using a two-frequency σ^+-polarized laser light has the disadvantage of putting most of the atoms in a "trap state" (or "pocket state") that does not contribute to the clock resonance signal. It leads to the decrease of the dark resonance amplitude and therefore to the worsening of the stability. To avoid this effect, different methods can be proposed [2-5]. Most of these methods are related to the use of laser light with linearly polarized components, their polarization planes can be either orthogonal ("lin $\perp$ lin") [2,3] or parallel ("lin $\parallel$ lin") [4,5]. The "lin $\perp$ lin" configuration was proposed for the creating of Raman-Ramsey fringes using the CPT in an atomic ensemble combined with pulsed optical radiation [2]. "Push-pull" technique based on the intensity-modulated laser light and combination of σ^+- and σ^- pulses was considered in [3]. These methods require quite sophisticated experimental technique and therefore are not favorable for applications that impose restrictions on the volume of the standard.

On the contrary, we propose a standard that operates in the continuous wave regime. We show that for the gas cell with the dimensions of about 1 cm and containing a buffer gas at 10 - 30 Torr, the short-term stability, which is one better by an order of magnitude than that of a standard based on the σ^+-polarized laser light, can be achieved. We present the results of the theoretical and numerical analysis of the dark resonance in ^{87}Rb atomic vapor for different configurations of co-propagating, linearly-polarized laser beams. We show that dark resonance structure is more complicated than it is usually assumed. We demonstrate that qualitatively different dark resonance line shapes can occur in both the "lin $\perp$ lin" and "lin $\parallel$ lin" cases, depending on the magnetic field strength, the choice of the resonant hyperfine sublevel of the excited state ($F_e = 1$ or $F_e = 2$), the buffer gas pressure etc. Some our conclusions are corroborated by experimental results.

This work is supported by the INTAS-CNES project 03-53-5175.

References

[1] J. Vanier, Appl. Phys. B 81, 421 (2005).
[2] T. Zanon, S. Guerandel, E. de Clerq et. al. Phys. Rev. Lett. 94, 193002 (2005).
[3] A.B. Post, Y.-Y. Jau, N. N. Kuzma et. al. Phys. Rev. A 72, 033417 (2005).
[4] G. Kazakov, B. Matisov, I. Mazets et. al. Phys. Rev. A 72, 063408 (2005).
[5] A. V. Taichenachev, V. I. Yudin, V. L. Velichansky et. al. Pis'ma v ZhETF, 82, 7, 449 (2005)

Ionization of Rb and Na Rydberg atoms by blackbody radiation.

I.I. Beterov[1], D.B. Tretyakov[1], I.I. Ryabtsev[1], A. Ekers[2], N. Bezuglov[3]

[1] *Institute of Semiconductor Physics, Department of Quantum Electronics, Novosibirsk, Russia*
[2] *University of Latvia, Institute of Atomic Physics and Spectroscopy, Riga, Latvia*
[3] *St.Petersburg State University, Fock Institute of Physics, St. Petersburg, Russia*
E-mail:beterov@isp.nsc.ru

The photoionization of Rydberg atoms by blackbody radiation (BBR)

$$\mathrm{Na}^{**} + \hbar\omega_{\mathrm{BBR}} \rightarrow \mathrm{Na}^{+} + e^{-} \tag{1.14}$$

has been found to be an important source of ions leading to spontaneous formation of ultracold plasma from the dense samples of cold Rydberg atoms [1]. In this work we present the results of the theoretical calculations of BBR-induced ionization rates of Rb and Na Rydberg nS, nP and nD atoms with $n = 8 - 100$ at the ambient temperatures of 77, 300 and 600 K, taking into account the effects caused by BBR-induced transitions between Rydberg states prior to the ionization. The results of our experimental measurements of BBR-induced photoionization rates of sodium nS and nD Rydberg atoms with n=8-20 [2] are compared with theory.

Blackbody radiation induces not only direct transitions from Rydberg states to the continuum, but also transitions between neighboring Rydberg states which are also ionized by BBR. In addition, blackbody radiation populates high Rydberg states that can be field ionized by the extracting electric pulses usually applied to collect and detect ions in the experiments. Our calculations have shown that these effects strongly affect the measured BBR ionization rates.

A semi-classical model [3] was used to calculate the bound-bound and bound-free matrix elements. This method gives orthogonal and normalized continuum wavefunctions. The calculated photoionization cross-sections were found to be in a good agreement with the more sophisticated quantum-mechanical calculations [4].

The comparison of our experimental results with theory demonstrates a good agreement for Na nD states with $n < 20$ and for nS states with $n < 15$.

Acknowledgements

This work was supported by INTAS Young Scientist Fellowship No. 04-83-3692, Russian Foundation for Basic Research (grant No. 05-02-16181), Russian Science Support Foundation and Siberian Branch of RAS.

References

[1] M.P.Robinson, B.Laburthe Tolra, Michael W.Noel, T.F.Gallagher and P. Pillet, Phys. Rev. Let. 85, 4466 (2000).
[2]I.I.Ryabtsev, D.B.Tretyakov, I.I.Beterov, N.N.Bezuglov, K.Miculis and A.Ekers 2005 J. Phys. B 38, S17 (2005).
[3]L.G.Dyachkov and P.M.Pankratov, J. Phys. B 27, 461 (1994).
[4]M.Aymar J. Phys. B 11, 1413 (1978).

Laser-induced-fluorescence excitation and emission spectra of the $1\,^3\Sigma_u^+$–$1\,^3\Pi_g$ ($1\,^3\Sigma^+$–$2\,^3\Pi$) transition in K_2, Rb_2 (KRb) on the surface of superfluid helium droplets

O. Allard, G. Auböck, J. Nagl, C. Callegari, and W. E. Ernst

Institute of Experimental Physics, TU Graz, Petersgasse 16, 8010 Graz, Austria/EU
E-mail:wolfgang.ernst@tugraz.at

We measured laser induced fluorescence and emission spectra of the $1\,^3\Sigma_u^+(0_u^-, 1_u)$–$1\,^3\Pi_g(0_g^+, 0_g^-, 1_g, 2_g)$ transition of K_2, Rb_2, and the corresponding $1\,^3\Sigma^+(0^-, 1)$–$2\,^3\Pi(0^+, 0^-, 1, 2)$ transition of KRb, on the surface of superfluid helium droplets. The spectra are relatively well reproduced, quantitatively, by simulations making use of the gas phase potentials [1,2]. For an exact agreement, however, one needs to assume: (1) that the $1 \leftarrow 0^-$ excitation is strongly suppressed, (2) that the spin-orbit coupling constant is increased (K_2, KRb), and (3) an adjustable broadening factor. (1) points to a yet-unexplained lack of population of the 0^- state after dimer formation, (2) and (3) can be justified qualitatively as due to the presence of the droplet, but are difficult to predict quantitatively. As the interaction of the molecules with helium may influence the symmetries valid in free molecules, an alternative explanation has to take into account the state-specific interactions and correlate free-molecule states with a new set of on-droplet states. Data analysis and corresponding theoretical modelling are in progress. Emission spectra, sharp, confirm that the molecules emit from the gas phase after having been ejected from the droplet; they can be used to test existing potential energy surfaces. We are in the process of acquiring new data and improving our analysis of vibrational populations in the excited state.

References

[1] K_2: A. R. Allouche. Potential energy curves available at lasim.univ-lyon1.fr/allouche/pec.html
[2] Rb_2, KRb: M. Aymar and O. Dulieu private communication

Identification of alkali-oligomer spectra on helium nanodroplets by laser depletion

O. Allard, G. Auböck, J. Nagl, C. Callegari, and W. E. Ernst

Institute of Experimental Physics, TU Graz, Petersgasse 16, 8010, Graz, Austria/EU
E-mail:wolfgang.ernst@tugraz.at

We have used a pump-probe scheme to identify spectra of alkali oligomers physisorbed on the surface of cold helium droplets. Most of them desorb from the droplet upon resonant laser excitation. We exploit this fact to selectively deplete dimers or trimers from the helium droplet beam by exciting known transitions. A few centimeters downstream of the depletion laser, laser induced fluorescence from the excitation of an unidentified band is recorded and the spectra with and without depletion laser are compared. A decrease of the fluorescence is observed when the depleted species and the one to be identified are the same and the two transitions being excited share the same initial state. New bands of the potassium trimer have been identified in this way. We have been able, as well, to separate strongly overlapping dimer and trimer spectra and solve the assignment problem discussed by Brühl *et al.* [1].

References

[1] F. R. Brühl, R. A. Miron, and W. E. Ernst, *J. Chem. Phys.* **115** 10275 (2001)

Effects of anisotropy of a host crystal and the nearness to surface on spontaneous emission rate of pentacene in p-terphenyl

I. Rebane

Institute of Physics, University of Tartu, Estonia
E-mail:inna@fi.tartu.ee

Due to anisotropy of a birefringent host crystal the isoenergetic surface in the **k**-space is not spherical. This circumstance leads to the different values of the spontaneous emission rate of a single-impurity molecule depending on the orientation of the transition dipole moment in the host crystal.
The spontaneous emission rate of a single-impurity molecule in a birefringent host crystal depends on the angles between the transition dipole moment and the principal axes of the dielectric (permittivity) tensor as well as on the main dielectric constants of a host crystal (this problem was considered in Ref.[1] for the dipole and Ref.[2] for the quadrupole transitions). The transition dipole moment of a single pentacene impurity in p-terphenyl crystal can have four different orientations depending on the spectroscopic sites O_1 to O_4[3]. Here the orientation of the transition dipole moment is defined by the angle between the projection of the transition dipole moment to the a'/b'-plane of the crystal and the b'-axis. The relative spontaneous emission rates of the electric dipole and quadrupole transitions are calculated for these four spectroscopic sites in dependence on unknown component of the transition dipole moment which is normal to the a'/b'-plane of the crystal. Possible differences in the spontaneous emission rate for the electric dipole transition of pentacene in p-terphenyl crystal are up to 24%[4] and for the quadrupole transition, up to 8%.
Effects caused by the nearness to the plane surface between crystal and air are calculated using the theory of Ref.[5]. For dipoles which are parallel to the surface maximal changes in the spontaneous emission rate are 18% for distances less than 270 nm from the surface and less than 8% for distances more than 400 nm from the surface. For dipoles which are perpendicular to the surface maximal changes in the spontaneous emission rate occur in the near vicinity of the surface. Changes in the spontaneous emission rate are less than 24% for distances more than 70 nm from the surface and less than 8% for the distances more than 100 nm.
This work was supported by Estonian Science Foundation – grants no. 5547 and 6545.

References

[1] I. Rebane, Optics Commun. 217, 265 (2003).
[2] I. Rebane, J. Lumin. 107, 38 (2004).
[3] F. Güttler, M. Croci, A. Renn, U.P. Wild, Chem. Phys. 211, 421 (1996).
[4] I. Rebane, J. Lumin. 000, 000 (2006).
[5] K.H. Tews, J. Lumin. 9, 223 (1974).

Calculations of relative spontaneous emission rates of a single-impurity molecule in uniaxial host crystals

I. Rebane, R. Koch[1]

Institute of Physics, University of Tartu, Estonia
E-mail:inna@fi.tartu.ee; koch@fi.tartu.ee

In the single molecule spectroscopy the main object of studies is the zero-phonon line - the narrowest and the most intense line in the spectrum. We have taken into account a factor which up to now has not been considered in the theories of zero-phonon line - the influence of the anisotropy of the host crystal on the spontaneous emission rate of the single-impurity molecule and thus also on the radiative line width. The anisotropy reveals itself in the dependence of the spontaneous emission rate on the orientation of the radiative transition dipole moment in the crystal. The relative spontaneous emission rate of the electric dipole transition for a uniaxial crystal is the following[1]:
$\gamma(\beta)/\gamma(0) = R\sin^2\beta + \cos^2\beta$,
where γ is spontaneous emission rate and β is a angle between the direction of the optical axis and the transition dipole moment vector. In this work the dependence of the coefficient R on the extraordinary refractive index n_e is calculated for the ordinary refractive index n_o from 1.2 to 3.2. For example, possible differences in the spontaneous emission rate of the electric dipole transition of single-impurity molecule in cinnabar (HgS) crystal ($n_o = 2.8224$, $n_e = 3.1489$, at $\lambda = 700$ nm[2]) are up to 24.5%.
Effects caused by the nearness to the plane surface between cinnabar and air are calculated using the theory from Ref.[3]. Changes in the spontaneous emission rate of the dipole in the cinnabar are less than 24.5% when the dipole is in the distance of 65 nm or more from the surface.
This work was supported by Estonian Science Foundation – grants no. 5547 and 6545.

References

[1] I. Rebane, Optics Commun. 217, 265 (2003).
[2] F.I. Fedorov, V.V. Filippov, Reflection and Refraction of the Light by Transparent Crystals, Nauka i Tehnika, Minsk, 1976 (in Russian).
[3] K.H. Tews, J. Lumin. 9, 223 (1974).

Shell Model Calculations for Alkali Halide Molecules

S.Y. Yousif Al-mulla

College of Engineering, University of Borås, Sweden

This work applies the shell model to study the behaviour of the internuclear interactions of diatomic alkali halide molecules from data given by the dynamical models for alkali halide crystals. Our interest is to test the breathing shell model when core holes have been introduced. This will provide another source of information on the nature of the interaction potential between anion and cation systems and give insight into the rate of relaxation in determining shifts in Auger and photoelectron spectroscopy.

Screening effects in the ionization of molecules by positrons

L. Nagy[1], I. Tóth[1], R. I. Campeanu[2], V. Chiş[1] and A. D. Stauffer[2]

[1]*Faculty of Physics, Babeş-Bolyai University, 400084 Cluj, Romania*
[2]*Department of Physics and Astronomy, York University, 4700 Keele Street, Toronto, ON Canada*
E-mail:lnagy@phys.ubbcluj.ro

In the last years several experimental data have been published for the ionization of molecules by positron impact. Direct ionization and positron formation have been also investigated. Previously we have performed theoretical calculations in order to describe the direct ionization process for several molecules [1-5]. Our method was based on the Born approximation, called CPE (Coulomb plus plane waves with full energy range), tested successfully for atoms [6]. In order to give a reliable description of the target, we have adopted Gaussian-type molecular wavefunctions. The two-center or multi-center wavefunctions have been expanded in terms of Legendre polynomials (or spherical functions in the case of nonlinear molecules) in order to perform the angular integrals analytically.
The results for the H_2 [1] and the CO [4] molecules were in very good agreement with the experimental data, while for N_2 [2], CO_2 [4] and CH_4 [5] the obtained results were higher. For the O_2 [3] the comparison with the experiment is not conclusive, because there are no experimental data for direct ionization.
In order to improve these results now we have used more realistic wavefunctions for the incoming and outgoing positron and the ejected electron, leading to the more sophisticated DWBA (Distorted Wave Born Approximation). The real potential created by the nuclei and the electrons has been spherically averaged, and the wavefunctions of the continuum states have been calculated numerically in these screened potentials. By this modification of our previous method the results were generally improved, obtaining lower values than with the CPE. For CO and N_2 the results are in very good agreement with the experimental data, and in case of the CH_4 we have found also improvement. The only problem is the CO_2 molecule, for which present results are also much higher (by 80%) than the experimental data. The explanation for this discrepancy could be the large size of the molecule and the fact, that in our method we have calculated the continuum wavefunction in a spherically symmetric (one-center) potential. This approximation seems to be valid for diatomic molecules and the CH_4, but does not hold for a 'long' molecule like CO_2. As we have shown previously [5], in this case the independent atom model (with the addition rule) lead to better results. Improvement may be obtained by using multi-center continuum wavefunctions.

References

[1] R. I. Campeanu, V. Chis, L. Nagy and A.D. Stauffer, Phys. Lett. A **310** (2003) 445.
[2] R. I. Campeanu, V. Chis, L. Nagy and A.D. Stauffer, Nucl. Instr. Meth. B **221** (2004) 21.
[3] R. I. Campeanu, V. Chis, L. Nagy and A.D. Stauffer, Phys. Lett. A **325** (2004) 66.
[4] R. I. Campeanu, V. Chis, L. Nagy and A.D. Stauffer, Phys. Lett.A **344** (2005) 247.
[5] R. I. Campeanu, V. Chis, L. Nagy and A.D. Stauffer, Nucl. Instr. Meth. B, in press.
[6] R. I. Campeanu, R. P. McErhan and A. D. Stauffer, Can. J. Phys. **79** (2001) 1231.

Resonance effects in quantum transitions induced by ultrashort laser pulses with high repetition rate

S. Borbély and L. Nagy

Faculty of Physics, Babeş-Bolyai University, 400084 Cluj, Romania
E-mail:lnagy@phys.ubbcluj.ro

Due to the recent technological development many experiments are performed with laser pulses of various intensities, repetition rates and durations. They interact with targets such as atoms, molecules, clusters and solids [1]. There is a basic need for reliable theoretical models in order to interpret the experimental data.
The interaction of the external laser field and a quantum-mechanical system can be described by the time dependent Schrödinger equation (TDSE). In most of the cases this equation may be solved only numerically [3-4]. The main disadvantage of the fully numerical approaches is that they need very high computational power, consequently for complex systems (with two or more active particles) other methods based on the approximate solution of TDSE are used [5-7].
In the present work our goal is the qualitative study of the transitions induced by a train of ultrashort laser pulses. In the previous theoretical studies [6-7] the laser pulses are treated separately, while we study the entire pulse train. The calculations were performed using a simple approach based on time dependent perturbation theory, and the laser field was considered to be of rectangular shape.
The constant repetition rate of the laser pulses yield to the appearance of resonance effects: we have significant transition probability only if $E_f = E_i + \frac{2k\pi}{\tau_0}$ is satisfied, where E_f and E_i are the energies of the final and of the initial state respectively, while $\frac{1}{\tau_0}$ is the repetition rate of the used laser and k is an arbitrary integer. In most of the practical cases we are interested in quantum transitions where the final state is a continuum state. In this case the shown resonance pattern could be observed only if the following condition is satisfied $\delta E < \frac{2\pi}{\tau_0}$ (δE being the spectral resolution of the used electron spectrometer), otherwise the resonance pattern vanishes due to the averaging effect of the measurement.

References

[1] U. Saalmann, Ch. Shiedschlag and J. M. Rost, J. Phys. B: At. Mol. Opt. Phys. **39** (2006) R39.
[2] E. Cormier and P. Lambropoulos , J. Phys. B: At. Mol. Opt. Phys. **30** (1997) 77.
[3] C. E. Dateo and H. Metiu, J. Chem. Phys. **95** (1991) 7392.
[4] M. Pont, D. Proulx and R. Shakeshaft, Phys. Rev. A. **44** (1991) 4486.
[5] K. Andrae, P. G. Reinhard and E. Suraud, J. Phys. B: At. Mol. Opt. Phys. **35** (2002) 4203.
[6] P. A. Macri, J. E. Miraglia and M. S. Gravielle, J. Opt. Soc. Am. B. **20** (2003) 1801.
[7] R. Gayet, J. Phys. B: At. Mol. Opt. Phys. **38** (2005) 3905.

Time-Resolved Imaging of H2(D2) Nuclear Wave Packet Dynamics

Th. Ergler, A. Rudenko, B. Feuerstein, K. Zrost, C.D. Schroeter, R. Moshammer and J. Ullrich

Max-Planck-Institut fuer Kernphysik, Saupfercheckweg 1, 67119 Heidelberg, Germany
E-mail: j.ullrich@mpi-hd.mpg.de

Time-resolved laser-induced Coulomb explosion (CE) imaging technique is one of the most direct ways to map moving nuclear wave packets of molecules [1]. However, if the conventional pump-probe schema is applied for the mapping of bound wave packets, it requires laser pulses which match the vibrational timescale of the molecule. In this respect the break-up of the simplest molecule, $H_2(D_2)$, which attracts much attention due to its relative simplicity for theory, represents an experimental challenge since one needs to use few-cycle laser pulses [2]. Here we present the results of time-resolved analyses of $H_2(D_2)$ fragmentation induced by intense 750 nm laser radiation. We use a combination of a pump-probe setup providing two 6-25 fs pulses with variable delay of 300 as accuracy and a 'reaction microscope' spectrometer, which allows coincident detection of several charged particles with excellent momentum resolution. The time evolution of the wave packet prepared by the first (pump) pulse can be visualized by removing the second electron at different internuclear distances, thus, projecting the wave packet onto the Coulomb repulsive potential curve, and measuring the corresponding Coulomb energy. Using two 25 fs laser pulses we map the propagation of the free (dissociating) wave packet of H_2^+ (D_2^+) created by the first pulse. In contrast to earlier studies [3] we resolve two different channels of this 'delayed' ionization, corresponding to the dissociation induced by net absorption of one or two photons. In addition, we demonstrate that by using an interferometrically stable pump-probe setup, which allows one to control the electric field shape in the region of overlapping pulses, a clear pump-probe experiment can be carried out even in this regime by selecting only those delays for which both pulses interfere destructively. The molecular ions that remain bound after the first pulse, manifest themselves as a delay-independent band around 3 eV [1]. Using 6-7 fs pulses, we were also able to map the time evolution of bound nuclear wave packet in H_2^+ and D_2^+. Ionizing the neutral molecule with the pump pulse, we prepare a coherent superposition of several vibrational states of the molecular ion. After a few oscillations, the anharmonicity of the potential curve, i.e., the non-equal spacing of the vibrational levels, leads to the dephasing, or 'collapse' of the wave packet. However, due to the long-time preserved coherence, after a certain time the wave packet regains its original form. The possibility to observe this partial revival of the wave packet using time-resolved Coulomb explosion imaging was recently predicted theoretically [4], and the calculated revival times are in perfect agreement with the experiment both for H_2 and D_2.

References

[1] Th. Ergler et al., Phys. Rev. Lett., 95 093001 (2005)
[2] A.S. Alnaser et al., Phys. Rev. A. 72 030702 (2005) (R)
[3] C. Trump, H. Rottke and W. Sandner, Phys. Rev. A 59 2858 (1999)
[4] B. Feuerstein and U. Thumm, Phys. Rev. A 67 063408 (2003)

Study of electron impact single ionization of alkali earth atoms Be, Mg and Ca

G. Purohit[2], R. Choubisa[3], U. Hitawala[1] and K. K. Sud[1]

[1] *Department of Physics, University College of Science, M. L. S. University, Udaipur-313002, India*
[2] *Department of Physics, Mody Institute of Technology and Science, Lakshmangarh-33311, Dist-Sikar, Rajasthan, India*
[3] *Physics Group, Birla Institute of Technology and Science, Pilani-333031,India*
E-mail:g_vpurohit@yahoo.com

The ionization of atoms, ions and molecules by electron impact are the basic processes of atomic and molecular physics, with fundamental applications in different areas as fusion physics, plasma physics, advanced fusion technologies, condensed matter physics, surface science etc. Electron coincidence experiments in which an incoming electron knocks out a bound electron in a collision with target, the two outgoing electrons are then detected in coincidence with defined kinematics are known as (e, 2e) experiments. Such types of investigations have been done to study the momentum distribution of valence electrons in atoms and molecules [1]. Extensive studies of (e, 2e) processes have been reported on various targets including hydrogen, helium, rare gases and alkali targets [2-3]. Recently, Purohit et al [4-5] have calculated triple differential cross sections (TDCS) and spin asymmetry in (e, 2e) processes for lithium like ions and helium like ions using distorted wave Born approximation (DWBA) formalisms. We present in this communication the results of our calculation of TDCS in (e, 2e) processes for alkaline earth targets Be, Mg and Ca atoms in coplanar symmetric geometry. We have performed the calculation in DWBA [1] formalism using spin averaged static exchange potential. We compare the results of our calculation of TDCS for Ca atom with the available experimental data[6]. We will discuss the salient features observed in the TDCS of alkali earth atoms Be, Mg and Ca.

References

[1] I. E. McCarthy and E. Weigold, Rep. Prog. Phys. 54, 789 (1991) [2] W Nakel and C T Whelan, Phys. Rep. 315, 409 (1999) [3] A Lahmam-Bennani, J. Phys. B24, 2401 (1991) [4] G Purohit, R Choubisa, Vinod Patidar and K K Sud, Physica Scripta 69, 208 (2004) [5] G Purohit, R Choubisa, D K Sharma and K K Sud, Ind. J. Phys. 78 (10), 1067 (2004) [6] A. J. Murray and D. Cvejanovic, J. Phys. B36, 4875 (2003).

Measuring the atom-surface van der Waals interaction in a vapour nanocell

I. Maurin, P. Todorov, I. Hamdi, A.Laliotis, A. Yarovitski, G. Dutier, S. Saltiel, M.-P. Gorza, M. Fichet, D. Bloch and M. Ducloy

Laboratoire de Physique des Lasers, Université Paris13, 93430 Villetaneuse, France
E-mail:bloch@galilee.univ-paris13.fr

Although the dipole-dipole attraction between neutral bodies is a key phenomenon in the ultimate cohesion of the matter, experimental measurements have remained scarce, most probably because at very short distances, higher order terms are involved, while the decay with the distance is quite rapid. The atom-surface interaction provides one of the simplest prototype of this dipole-dipole interaction through the electrostatic image model. Its scaling, in $C_3\ z^{-3}$ (z: the atom-surface distance), is usually expected to cover a distance range 1-1000 nm. Although this attraction law should cover about 10 orders of magnitude in energy, little has been done to test this predicted dependence in an effective situation. The various developments in nanotechnologies and nanosciences should make it more important to measure effectively these remote forces, as for the Casimir force already known to be a possible limiting factor in MEMS technology. At longer distances, and after pioneering principle experiments with deflection of an atomic beam [1], the only accurate experiments allowing a test of the spatial vW dependence were conducted on a beam of Rydberg atoms channeled between two plates, for plate separation in the 500-3000 nm range [2]. The recent blossom of experiments sensitive to the vW interaction, has actually an applicability restricted to ground states, while the most sensitive effects connected to the real nature of the surface - e.g. dielectric surface- appear only for excited states, as the possible conversion of attraction into a vW repulsion [3].
Following our long investment in the development of reflection spectroscopy techniques [4], that had enabled us to measure the vW interaction at an interface, new possibilities have arisen with the recent development of vapour nanocells [5], whose nanometric thickness varies locally. Our report is on a detailed analysis of a simultaneous transmission and reflection spectroscopy through a nanocell [6]. These two signals, that can be traced back to two linearly independent spatial combination of the atomic response, are processed independently, and yield consistent results. A major originality is that the C_3 coefficient could be extracted for various cell thicknesses, varying from 40 to 130 nm, exploring a distance range smaller by one order of magnitude than that explored previously. Until now, the measurement [7] was performed for the excited level Cs ($6D_{5/2}$) and the C_3 coefficient appears to be constant for all thickness within our experimental accuracy, with C_3 = 7.5-2.5 $kHz.\mu m^3$. This is only in fair agreement with the common theoretical value ($\simeq 15\ kHz.\mu m^3$) predicted in the ordinary atom-surface model, but could be related with subtleties of the pumping step Cs ($6S_{1/2}$-$6P_{3/2}$), that may exhibit anisotropy. Complementary experiments are now under way on the elementary D_1 resonance line, whose interpretation is in the principle simple, but whose smaller vW interaction make experiments more delicate.

References

[1] D. Raskin, P. Kusch, Phys. Rev. 179, 712 (1969).
[2] V. Sandoghdar et al., Phys. Rev . Lett. 68, 3432 (1992); Phys. Rev. A 53, 1919 (1996).
[3] H. Failache et al., Phys. Rev. Lett. 83, 5467 (1999); Eur. Phys. J. D 23, 237 (2003).
[4] D. Bloch, M. Ducloy, "Atom-wall interaction" in Adv. At. Mol. Opt. Phys. 50, (Bederson B. and Walther H. eds.), 91 Elsevier-Academic Press (2005).
[5] D. Sarkisyan et al, Opt. Comm. 200, 201 (2001).
[6] G. Dutier et al., Europhys. Lett. 63, 35 (2003); J. Opt. Soc. Am. B 20, 793 (2003).
[7] For a preliminary account, see I. Hamdi et al., Laser. Phys 15, 987 (2005).

The spectral and polarization analysis of Zeeman - specific cross sections for radiative atomic collisions

E. Chesnokov

Institute of Physics, St. Petersburg State University, St. Petersburg, Russia
E-mail:tchesn@ec8174.spb.edu

The Zeeman - specific total and differential cross sections for processes of the type

$$A(^1S_0) + B + \hbar\omega \leftrightarrow A(^1P_1/^3P_2) + B$$

have been analysed in the framework of semiclassical approach for the case of linear and circular light polarizations in scattering plane. In this order a simple model including three adiabatic states has been considered. Two excited states of Σ and Π symmetry ($0^+ - 1^+$ for $^1P_1$ state and $1^+ - 2^+$ for $^3P_2$ state) are coupled by the Coriolis interaction while the radiative coupling between the ground and the excited states is weak. If the difference potential between two excited states admits an exponential approximation and is essentially larger than the mean difference potential between the excited and the ground states, the Rosen-Zener-Demkov model is suitable to describe the evolution of the excited states and closed analytical expressions can be obtained for the total (Coriolis + radiative) transition amplitude.

For an allowed atomic transition $^1S_0 - ^1P_1$ the dipole moment is nearly independent on the internuclear distance R and equals to its atomic value. In this case the final formula for the transition amplitude related to the total collision has been derived in terms of the generalized hypergeometric function ${}_3F_2$. This formula takes into account the interference of amplitudes for in-going and out-going radiative transitions and reproduces the Stueckelberg oscillations. Another formula for the transition amplitude related to the half of collision has been derived in terms of gamma function. The last one implies any average procedure over the Stueckelberg oscillations and is more suitable for total cross sections, but it is valid also for an asymptotically forbidden transition $^1S_0 - ^3P_2$ when the dipole moment decreases exponentially with R increasing.

As an specific example some $Ca - RG$ and $Hg - RG$ quasi-molecules have been considered. The results obtained demonstrate a reasonable qualitative agreement with the available experimental and theoretical data in the fields of the spectral line shapes and the polarization analysis of collisionally redistributed light. The dependence of the orientation of atoms in the metastable $^3P_2$ state on the frequency and polarization of light has been investigated for the first time side by side with the analogous dependence for atoms in the resonance $^1P_1$ state in differential scattering conditions. The oscillation structure of the differential cross sections and the left - right scattering asymmetry have been interpreted in terms of the Condon and decoupling radii. It was shown that the polarization analysis together with the analysis of oscillation structure yield an important information about interaction of the excited atoms.

Spectroscopy of heavy multi-charged ions and exotic atomic systems: Quantum mechanical perturbation theory approach to spectra calculation

A.V. Glushkov, E.P. Gurnitskaya, O.Yu. Khetselius, V.N. Khokhlov and L.A. Vitavetskaya

Odessa University, P.O.Box 24A, Odessa-9, 65009, Ukraine
E-mail: glushkov@paco.net

A consistent theoretical approach, based on the relativistic density functional (DF) approach and quantum electrodynamics perturbation theory (QEPT), is developed for the calculation of the exotic atomic and nuclear systems. One of the main purposes is establishment of a quantitative link between quality of the nucleus structure modelling and accuracy of calculating energy and spectral properties. Another one is application of our atomic-nuclear numerical code to calculation of spectra of the hadronic (pion, kaon, hyperon) atoms. A new, highly exact approach [2] to relativistic calculation of the spectra for multi-electron super heavy ions with an account of relativistic, correlation, nuclear, radiative effects on the basis of gauge-invariant quantum electrodynamics perturbation theory is used. Zeroth approximation is generated by the effective functional, constructed on the basis of the comprehensive gauge invariance procedure [2]). The wave functions zeroth basis is found from the Klein-Gordon (pion atom) or Dirac (kaon, hyperon) equation. The potential includes the effective core potential, the electric and polarization potentials of a nucleus (the Fermi model, the gaussian form of charge distribution in the nucleus and the uniformly charged sphere are considered) [1, 2]. For low orbits there are important effects due to the strong hadron-nuclear interaction (pion atom). The energy shift is connected with length of the hadron-nuclear scattering (scattering amplitude under zeroth energy). There have taken into account all correlation corrections of the second order and dominated classes of the higher orders diagrams (particles screening, particle-hole interaction, mass operator iterations). The magnetic inter-electron interaction is accounted in the lowest (on α constant of hyperfine structure), the Lamb shift polarization part- in the Uhling-Serber approximation, self-energy part of the Lamb shift is accounted effectively with the use of the Green functions method. We carried out calculations: Shifts and widths of transitions (2p-1s, 3d-2p, 4f-3d) in some pionic and kaonic atoms.

References

[1] P. Kienle, Phys. Scr. 46, 81 (1993).
[2] A. Glushkov, L. Ivanov, Phys. Lett. A 170, 33 (1992); Preprint ISAN N1 Moscow 1992; A.V. Glushkov, JETP Lett. 55 108 (1992); A.V. Glushkov, Nucl. Phys. 708 (2004); E. Ivanova, L.N. Ivanov, A.V. Glushkov, A.S. Kramida, Phys. Scr. 32, 512 (1985); A.V. Glushkov *et al.*, In: Nuclear Projects and New lines of Research in Nuclear Physics, Eds.: G. Fazio and F. Hanappe, World Sci. Publ., Singapore, 126 (2003).

Collisional shift of the Tl hyperfine structure lines in atmosphere of inert gases

A.V. Glushkov, S.V. Ambrosov, A.V. Loboda, V.P. Polischuk and T.A. Florko

Odessa University, P.O.Box 24A, Odessa-9, 65009, Ukraine
E-mail: glushkov@paco.net

New relativistic approach, based on the gauge-invariant perturbation theory [1, 2] with using the optimized wave functions basis's in zeroth order, is proposed to calculation of the inter atomic potentials, spectra, hyperfine structure (hfs) collision shift for heavy atoms in atmosphere of inert gases and diatomic quasi molecules. It is carried out detailed studying and calculation of the inter atomic potentials, collision shifts of the hyperfine transition lines for Tl atom in atmosphere of inert gases for systems Tl-He, Tl-Ar and Tl-Xe. To calculate the spectral lines hyperfine structure collision shift we use the following known expression from kinetical theory of spectral lines form (see [1, 3]) with effective potential of the inter atomic interaction, which has a central symmetry in a case of the systems Tl-B (B=He, Ar). To calculate an effective potential of the inter atomic interaction we used a method of the exchange perturbation theory [1, 3]. The experimental (observed) and calculated values of the relative local shift of the hyperfine structure lines for system Tl-He are presented and compared with calculation results of ref. [3], which are obtained within non-gauge-invariant perturbation theory with Hartree-Fock like orbital basis's. New data for systems of Tl-Ar and Tl-Xe are presented. The important feature of our scheme is a correct account of the correlation and polarization effects with using special effective potentials from ref. [4].

References

[1] A.V. Glushkov, N. Loboda, V. Polischuk *et al.*, Optics Spectr. 84, 670 (1998); J. Struct. Chem. 39, 220 (1998).
[2] A.V. Glushkov, L.N. Ivanov, Phys. Lett. A 170, 33 (1992).
[3] V.V. Batygin, I.M. Sokolov, Optics Spectr. 55, 30 (1983).
[4] A. Glushkov, E. Ivanova, J. Quant. Spectr. Rad. Transfer. 36, 127 (1986); E.P. Ivanova, L.N. Ivanov, A.V. Glushkov, A.E. Kramida, Phys.Scripta 32, 512 (1985).

Resonances in Electron Scattering with State Selected Rovibrational Exited Diatomic Molecules

S.Pozdneev

Department of Quantum Radiophysics, Laboratory of Photochemical Processes, P.N.Lebedev Physical Institute, Leninsky pr.53, Moscow 117924, Russia

A theoretical method is proposed for the investigation of the initial rovibrational exitation of diatomic molecules by electron impact.
This method is based on the treatment of the collision as a few- body processes, using quantum theory of scattering in few particles system.
The results of the calculation of the cross sections of the different elastic and inelastic processes are compared with available experimental data and another calculations are discussed.

Three-body approximation in electron scattering on diatomic molecules

S.Pozdneev

Department of Quantum Radiophysics, Laboratory of Photochemical Processes, P.N.Lebedev Physical Institute, Leninsky pr.53, Moscow 117924, Russia

The quantum theory of few-body scattering based on the Faddeev-Yakubovsky equations is applied to the calculation of the electron scattering with the diatomic initial rovibrational exiting molecules hydrodgen, nitrogen, lithium, sodium and hydrogen halide The results of this calculations are compared with available experimental data and the results of other calculation.

First negative and meinel band system excitation at the collisions electrons with nitrogen molecules

M Gochitashvili, R Lomsadze, R Kvizhinadze, K Gongadze

Physics Department, Tbilisi State University,Chavchavadze av3
Tbilisi,0128, Georgia
E-mail:mgochitashvili@hotmail.com

Absolute emission cross section for the first negative(1NG) $B^2\Sigma_g^+ - X^2\Sigma_g^+$ and Meinel ($A^2\Pi_u - X^2\Sigma_g^+$) bands system of N_2^+molecule have been measured at the collisions of electrons with N_2 molecules in the $100eV - 1500eV$ projectile energy range. The measurement was performed by optical spectroscopy method in the visible $400 - 800nm$ spectral region. The relative excitation rates of the Meinel bands were measured by scanning the spectrum of the Meinel bands between 600 and $800nm$ at pressures sufficiently low (roughly $0.50mTorr$) to minimise the effects of quenching [1]. Number of Experimental works in which the Meinel bend system are measured are very limited. The experimentally determined cross section for the formation of N_2^+ions in the $A - state$ is known only to within about $50percent$, which can be attributed to the long radiative lifetime of the state [2-4]. Particularly the excitation functions of $(0,0),(0,1),(0,2),(1,1),(1,2),(1,3)$ bands of 1NG and $(2,0),(3,0),(4,1),(5,2)$ bands of Meinel systems was measured respectively. The measured A-state and B-state vibrational level distribution agrees well with the relative Franck-Condon factors. The analize of results given that the ratio of the Meinel bends$[(2,0),(3,0),(4,1),(5,2)]$ to $1NG[(0,0),391.4nm]$ band cross sections is invariant with electron energy.

References

[1] Piper L G, Green B D, Blumberg W A M and Wolnik S J 1985 J. Chem. Phys. 82 3139

[2] Holland R F and Meier W B 1972 J. Chem. Phys. 56 5229

[3] Peterson J R and Moseley T J 1973 J. Chem. Phys. 58 172

[4] Piper L G, Green B D, Blumberg W A M andWolnik S 1986 J. Phys. B: At. Mol. Opt. Phys. 19 3327

The ionization, charge exchange and excitation in $Na^+ - Ar$ collisions.

R Lomsadze, M Gochitashvili,R Kvizhinadze, N Mosulishvili, B Lomsadze

Physics Department, Tbilisi State University,Chavchavadze av3
Tbilisi,0128, Georgia
E-mail:Lomsadze86@hotmail.com

In the present work the value of absolute cross section of ionization, charge exchange and excitation function for $Na^+ - Ar$ colliding pairs in the $0.5 - 10keV$ energy range are obtained.
The measurements are carried out by modified transverse electric field and optical spectroscopy methods. The error in the determination of the ionization and charge exchange cross sections was 15percent. The relative uncertainty for excitation processes was 5percent, and absolute one did not exceed - 10percent.
The data obtained allow us to draw certain conclusion about the mechanisms of the relevant processes. In discussing these data the schematic correlation diagram of the diabatic quasimolecular terms of systems of colliding particles was used. The diagram was plotted using the $Barat - Lichten$ rules [1].
In case of charge exchange processes two nonadiabatic region are revealed where transitions can results in charge transfer. At low energy ($E \approx 2,5keV$) the most probable transition is from the ground state of the system to a state corresponding to the capture of an electron by the ground state of the sodium atom. The process is considered as a result of direct interaction of the corresponding $\Sigma - \Sigma$ terms of the quasimolecular $(NaAr)^+$ system. The $\Sigma - \Pi$ transition is characterized for the energy $E > 3keV$ and it is connected with rotation of internuclear axis.
The contributions made by the various processes to the total cross sections of an electron emission in the $Na^+ - Ar$ collision are estimated. It was established that the ionization processes is determined by the autoionization of the Ar atoms. The main exit channel for autoionization is due to two optical electron excitation of Ar atoms.
For the excitation function the quasimolecular character of interaction is revealed. The mechanism of excitation for both colliding partners is established. Significant portion in the excitation of argon 4s state is due to cascade transition from upper $(4p, 3d)$ level. On the excitation function of an argon atom lines ($\lambda = 104,8nm; 106.7nm$) the oscillatory structure are observed.

Reference

[1] Barat M., Lichten W. Phys.Rev.A 1972, v.6. p. 211.

Closed-form expressions of the second-order Faddeev three-body charge-transfer amplitudes

E. Ghanbari Adivi[1] and M. A. Bolorizadeh[2,3]

[1] *Physics Department, Yazd University, Yazd, Iran*
[2] *Physics Department, Shahid Bahonar University, Kerman, Iran*
[3] *Flinders University, Adelaide, Australia*
E-mail: eghanbari@yazduni.ac.ir

The three-body atomic process has been studied in which an energetic projectile ion impinges on a neutral target atom and scatters off it after an electron capture. The Faddeev-Watson-Lovelace formalism (FWL)has been used, in a second-order approximation. The rearrangement transition T-matrix includes five partial components; i.e. the first-order Born amplitude, A_{B1}, the second-order nuclear-electronic amplitude, $A_e^{(2)}$, the first-order inter-nuclear term, $A_n^{(1)}$, and two second-order internuclear components, $A_n^{(2a)}$ and $A_n^{(2b)}$.The first-order Born amplitude is independent of the two-body interaction potential. A closed-form expression is reported for this term in the literature (see for example [1]). Here, the most general integral forms of the other partial amplitudes have been derived:

$$A_e^{(2)} = C_1 \int_0^\infty dx x^\tau e^{iax} \int_0^\infty dk_i k_i^2 R_{nl}(k_i) j_l(k_i x)(k_i^2 - 2\varepsilon_n)^{-\rho} \times \int_0^\infty dk_f k_f^2 R_{n'l'}(k_f) j_{l'}(bk_f x)(k_f^2 - 2\varepsilon_{n'})^{-\mu} \quad (1.15)$$

$$A_n^{(1)} = C_2 \int_0^\infty dk_i k_i^2 R_{nl}(k_i)(k_i^2 - 2\varepsilon_n)^{\delta} + C_3 \int_0^\infty dk_f k_f^2 R_{n'l'}(k_f)(k_f^2 - 2\varepsilon_{n'})^{\delta} \quad (1.16)$$

$$A_n^{(2a)} = C_4 \int_0^\infty dk_i k_i^2 R_{nl}(k_i)(k_i^2 - 2\varepsilon_n)^{\delta} \int_0^\infty dk_f k_f^2 R_{n'l'}(k_f)(k_f^2 - 2\varepsilon_{n'})^{-\mu} \quad (1.17)$$

$$A_n^{(2b)} = C_5 \int_0^\infty dk_i k_i^2 R_{nl}(k_i)(k_i^2 - 2\varepsilon_n)^{-\rho} \int_0^\infty dk_f k_f^2 R_{n'l'}(k_f)(k_f^2 - 2\varepsilon_{n'})^{\delta} \quad (1.18)$$

The present work reports the exact analytical expressions for these partial amplitudes in a typical transition in which the active electron suffers a transition from the initial hydrogen-like state, $i \equiv nlm$, to the final hydrogen-like state $f \equiv n'l'm'$. In our method, the Gegenbauer polynomials, therein radial parts of the initial and final wave functions in momentum space, are expanded in terms of the powers of their arguments in an especial and efficient manner. Using the integral representation of the Gamma functions and performing the integrals analytically, one leads to the closed-forms of the nuclear-electronic and internuclear amplitudes. The calculated electron-capture differential cross-sections are discussed and compared with other calculations from B2F [2], CDW [3, 4], DWB [5] and SPB [6] formalisms as well as experimental data [7].

References

[1] E. Ghanbari Adivi and M. A. Bolorizadeh, J. Phys. B 37, 3321 (2004).
[2] P. S. Vinitsky and Yu. V. Popov, Phys. Rev. A 71, 012706 (2005).
[3] H. F. Busnengo, A. E. Martínez, R. D. Rivarola and L. J. Dubé, J. Phys. B 28, 3283 (1995).
[4] P. N. Abufager, P. D. Fainstein, A. E. Martínez and R. D. Rivarola, J. Phys. B 38, 11(2004).
[5] K. Taulbjerg and J. S. Briggs, J. Phys. B 16, 3811 (1983).
[6] S. Alston, Phys. Rev. A 38, 3124 (1988).
[7] H. Vogt, R. Schuch, E. Justiniano, M. Schulz and W. Schwab, Phys. Rev. Lett. 57, 2256 (1986).

Shift and Width Calculations in the Case of Radiating ^{7}Li$(2p-2s)$ Perturbed by ^{4}He

K. Alioua and M. Bouledroua

Faculté de Médecine and Laboratoire de Physique des Rayonnements, Badji Mokhtar University, B.P. 12, Annaba 23000, Algeria
E-mail: boulmoncef@netscape.net

The importance of the collisional processes in the astrophysical environments, such as in the stellar mediums and the planetary ionospheres, is now well established [1]. The discovery in 1995 of Gliese 229B has provoked a series of observations and theoretical studies of the brown dwarfs. Calculations of photochemical equilibrium in the atmospheres of these cold dwarfs have been reported and the resonance lines of the alkali-metal atoms have been shown to be powerful tools to diagnose the dwarf atmospheres [2,3]. More specifically, Burrow, Marley, and Sharp [4] have concluded that the lithium, sodium, and potassium lines may play a remarkable role in the spectra of the T dwarfs.
In this study, we have focused our attention on the pressure broadening of the lithium line core, namely the width w and the shift s of the resonance line $2p-2s$, when the ^{7}Li atoms are perturbed by helium ^{4}He monatoms. The calculations have been carried out by using the Baranger method which assumes the impact approximation [5]. To do so, we have constructed from reliable and recent data points the potential energy curves through which a ground or an excited lithium atom interacts with a helium atom.
For the temperatures ranging from 200 K to 3000 K, the results we have obtained of the width and shift rates, i.e. w/n and s/n, with n is the perturbing gas number density, are compared with those already published [6-9].

References

[1] A. Dalgarno and S. Lepp; P.D. Feldman; J.L. Fox, in *Atomic, Molecular, and Optical Physics Handbook*, G.W.F. Drake, Ed., (AIP Press, Woodbury, New York, 1996).
[2] K. Lodders, Astrophys. J. **519**, 793 (1999).
[3] C.A. Griffith and R.V. Yelle, Astrophys. J. **532**, L59 (2000).
[4] A. Burrows, M.S. Marley, and C.M. Sharp, Astrophys. J. **531**, 438 (2000).
[5] J. Szudy and W.E. Baylis, Phys. Rep. **266**, 127 (1996).
[6] A. Gallager, Phys. Rev. A **12**, 133 (1975).
[7] C. Bottcher, T.C. Cravens, and A. Dalgarno, Proc. R. Soc. Lond. A **346**, 157 (1975).
[8] J. Kielkopf, J. Phys. B **9**, L547 (1976).
[9] G. Smith and B.S. Collins, J. Phys. B **9**, L117 (1976).

Self-Broadening and Shifting of the $4s - 4p$ Line of Potassium

L. Reggami[1], M. Bouledroua[2], F. Bouchelaghem[1], M. Aubert-Frécon[3], and A. Ross[3]

[1] *Physics Department, Badji Mokhtar University, B.P. 12, Annaba 23000, Algeria*
[2] *Faculté de Médecine and Laboratoire de Physique des Rayonnements, Badji Mokhtar University, B.P. 12, Annaba 23000, Algeria*
[3] *LASIM, 43 Bd. du 11 Novembre 1918, Villeurbanne F-69622, France*
E-mail: boulmoncef@netscape.net

The aim of this study is the quantum-mechanical computation of the width γ and the shift d of the resonance line $4s - 4p$ of potassium ^{39}K atoms evolving in their parent monatomic gas. In the frame of the impact approximation method developed by Baranger [1,2], these two spectral parameters are given in terms of the phase shifts η_l caused by the ground $\mathrm{K}(4s) + \mathrm{K}(4s)$ and excited $\mathrm{K}(4p) + \mathrm{K}(4s)$ collisions

$$\begin{aligned} \gamma &= +n \left\langle v \left(\frac{1}{3} Q^{(w)}_{\Sigma\Sigma} + \frac{2}{3} Q^{(w)}_{\Pi\Sigma} \right) \right\rangle \\ d &= -n \left\langle v \left(\frac{1}{3} Q^{(s)}_{\Sigma\Sigma} + \frac{2}{3} Q^{(s)}_{\Pi\Sigma} \right) \right\rangle \end{aligned}$$

where the average $\langle \cdots \rangle$ is Maxwellian, v is the relative velocity, n is the number density, and

$$\begin{aligned} Q^{(w)} &= \frac{4\pi}{k^2} \sum_{l=0}^{\infty} (2l+1) \sin^2 \left(\eta'_l - \eta''_l \right) \\ Q^{(s)} &= \frac{\pi}{k^2} \sum_{l=0}^{\infty} (2l+1) \sin \left[2 \left(\eta'_l - \eta''_l \right) \right], \end{aligned}$$

k and l being the wave number and the angular momentum, respectively. The upper η'_l and lower η''_l phase shifts needed in the width and shift cross sections, $Q^{(w)}$ and $Q^{(s)}$, are calculated by solving numerically the Schrödinger equation for which we constructed the singlet and triplet potential energy curves from recent and reliable RKR and/or *ab initio* data points.

The results show that the linewidth and lineshift do not depend on temperature and may be reproduced by simple formulas, $\gamma \sim 1.394 \times 10^{-6}\ n$ and $d \sim 1.540 \times 10^{-7}\ n$, with n being in cm^{-3} and γ and d in s^{-1}. We also applied to this problem a semi-classical method as outlined in Mott and Massey [3]. From the calculations, it appears that the influence of the long-range R^{-3} forces are prominent.

References

[1] M. Baranger, Phys. Rev. **111**, 481 (1958).
[2] J. Szudy and W.E. Baylis, Phys. Rep. **266**, 127 (1996).
[3] Mott and H.S.W. Massey, *The Theory of Atomic Collisions*, (Oxford University Press, Oxford, 1965).

Viscosity of a Cold Cesium Plasma and its Variation Law with Temperature

M.T. Bouazza[1] and M. Bouledroua[2]

[1]*Physics Department, Badji Mokhtar University, B.P. 12, Annaba 23000, Algeria*
[2]*Faculté de Médecine and Laboratoire de Physique des Rayonnements, Badji Mokhtar University, B.P. 12, Annaba 23000, Algeria*
E-mail: boulmoncef@netscape.net

In this work, we have examined, within the frame of the Chapman-Enskog model [1], the thermophysical properties of a monatomic cesium Cs gas by using the most recent ground $^1\Sigma_g^+$ and $^3\Sigma_u^+$ Rydberg-Klein-Rees interatomic potentials. We have explored the viscosity and elastic cross sections and analyzed closely the resonance features they exhibit. We have particularly determined the viscosity η and thermal conductivity λ coefficients of the alkali-metal vapor as a function of the temperature T. The results we have found of the collision integrals $\Omega^{(2,2)}$ and of the coefficients η and λ agree quite well with some available experimental and/or theoretical data [2]. Besides, we have investigated the variation law with temperature T of the above thermophysical quantities. We have found that, for temperatures ranging from around 150 to 3000 K, the results of η and λ can be reproduced by simple formulas of the form $\sim aT^{\alpha}\exp(-\xi/T)$.

References

[1] J.O. Hirschfelder, C.F. Curtis, and R.B. Bird, *Molecular Theory of Gases and Liquids*, (Wiley and Sons, Inc., New York, 1964).
[2] C.A. Nieto de Castro *et al.*, Ber. Bunsengs. Phys. Chem. **94**, 53 (1990).

Inelastic scattering of photons in photoexcitation processes

V.A. Kilin[1], R.Yu. Kilin[1], M.Ya. Amusia[2], H. Schmoranzer[3], A. Ehresmann[4]

[1] *Department of Higher Mathematics, Tomsk Polytechnic University, Tomsk, Russia*
[2] *A.F. Ioffe Physico-Technical Institute of Academy of Sciences, St.Petersburg, Russia*
[3] *Technical University, Kaiserslautern, Germany*
Technical University, Kassel, Germany
E-mail:vak@tpu.ru

Conventionally, the single photon ionization (PI) or excitation is considered as a process of driving an electron out due to the interaction between an atom and low-intensive electromagnetic field (EMF). The absorption of a single photon of energy exceeding the multiple ionization potential may result in driving two, three and more electrons out of atom, so that the transition energy is continuously distributed between photoelectrons [1]. The multiple PI makes both the experimental measurements and the theoretical calculations of PI cross sections to be rather complicated problems. The dominating physical mechanisms of multiple PI are different and depend on the exciting photon energy. They are: (i) the direct multiple PI proceeding exclusively due to correlation effects; (ii) two-, three-, or more-step autoinization and irradiation transitions following the photoionization of an intermediate highly excited state. Note, that within a correct approach, the secondary photon ω_{irr} irradiated from an intermediate excited state should be considered as the inelastic scattered primary photon ω_{exc}. General consideration of the Raman scattering is presented, for example, in [2].Principal possibility to observe the irradiation transitions in a multi-step sequence (ii) in PIFS experiments is discussed in [3].

In this work, we report about first results on calculation of Ne 2p- and 2s-photoexcitation accompanied by irradiation of the secondary photon. For this process the relationship $\omega_{exc} = I + \omega_{irr} + \epsilon$, where I is the ionization potential and ϵ stands for the energy of excited electron, reflects both the energy conservation law and the continuous sharing of the transition energy $E_{tr} = \omega_{exc} - I$ between the secondary photon and excited electron. This is very similar to the continuous energy distribution between two electrons in such processes as double PI, double Auger transitions, double autoionization of resonantly excited states, and so forth, considered in our previous works.

The effect of inelastic photon scattering has been taken into account within the lowest nonvanishing order of the perturbation (with respect to low-intensive EMF) theory with the use of non-relativistic Hartree-Fock wave functions. This accounting has allowed us to directly calculate the profile of fluorescent lines and to reveal the significance of the scattering effect at different energies of exciting photon. It is also important to note that by accounting the scattering (i.e., considering the two-photon process) we automatically include a set of photoelectrons "forbidden" in traditional calculations of PI cross sections. This can also ascertain the data upon the photoelectron angular distribution.

The detailed results and calculated cross sections will be presented at the Conference.

References

[1] Kilin V.A., et.al. J.Phys.B.: Atom.Mol.Opt.Phys. 3, 4989, (2000). [2] Landau L.D. and Livshits E.M. Field Theory. V 2, (1988), in Russian [3] Ehresmann A., et.al. 26 EGAS IC, Spain, Barcelona (1994).

Prospects for photoassociation and formation of cold Fr_2, RbFr and CsFr molecules.

M. Aymar[1], O.Dulieu [1], F.Spiegelman[2]

[1] *Laboratoire Aimé Cotton, CNRS, Bât.505, 91405 Orsay, France*
[2]*IRSAMC, Université Paul Sabatier,118 route de Narbonne, 31062 Toulouse, France*
E-mail:mireille.aymar@lac.u-psud.fr

Among the alkali dimers, only those involving Francium atoms have not been investigated yet. However several groups have succeeded to trap Francium in a magneto-optical trap [1-3], and techniques are progressing so fast that in the near future it would be possible to produce alkali dimers involving Francium atoms. **We present, for the first time**, calculations concerning the potential curves, permanent and transition dipole moments of Fr_2 molecule and of some alkali heteronuclear dimers involving Fr atoms, namely RbFr and CsFr and of their cations [4]. Our aim is also to predict the rates for the photoassociation of these species and for the subsequent formation of cold molecules as we did previously for all mixed alkali dimers involving Li to Cs atoms [5]. Such predictions should help the experimentalists in their investigations. The method is based on a pseudopotential for the core representation, with ℓ-dependent effective core polarization potential and self-consitent calculation (SCF) combined with full valence configuration interaction calculation (CI). The theoretical methods are similar to the one used in our previous paper dealing with the determination of accurate permanent dipole moments of heteronuclear alkali dimers [6]. However, the Fr atom is described by a new pseudopotential with averaged relativistic effets, derived from all-electron relativistic Dirac-Fock SCF calculations [7] rather than from Hartree-Fock calculations. A perturbative approach is used to introduce spin-orbit coupling. As no experimental data is available, the accuracy of our results is discussed by comparison with the Rb_2, Cs_2 and RbCs systems.

References

[1] J. E. Simsarian *et al*, Phys. Rev. Lett., **76**, 3522 (1996).
[2] Z.-T. Lu *et al*, Phys. Rev. Lett., **79**, 994 (1997).
[3] Atutov *et al*, J. Opt. Soc. Am. B, **20**, 953 (2003).
[4] M. Aymar, O. Dulieu and F. Spiegelman,(Submitted to J. Phys. B)
[5] S. Azizi, M. Aymar and O. Dulieu, Eur. Phys. J. D, **31**, 195 (2004).
[6] M. Aymar, O. Dulieu, J. Chem. Phys., **122**, 204302 (2005).
[7] J. P. Desclaux, Computer Phys. Commun. **9**, 31 (1775).

Demagnetization cooling of Chromium atoms

M. Fattori, S. Götz, A. Griesmaier, T. Koch, J. Stuhler, and T. Pfau

Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany
E-mail: m.fattori@physik.uni-stuttgart.de

Adiabatic demagnetization is a very efficient cooling scheme which allows researchers in solid state physics to cool their samples by several order of magnitude in a single cooling step.
In a recent paper Hensler and co. [1] have proposed to apply this technique to a gas of atoms with non-zero spin. Starting from a cloud polarized in the lowest energy Zeeman state we can have depolarization of the sample through all the other sublevels. Such process is driven by binary inelastic dipolar collisions and is enhanced when the Zeeman energy splitting is of the order of the temperature of the sample. Energy is then transferred from the external kinetic reservoir to the internal spin reservoir with a consequent reduction of the temperature of the gas. Using optical pumping it is then possible to polarize again the atoms and prepare them for a further cooling step. In principle several iterations allow to reduce the temperature of the cloud down to the photon recoil limit.
It is important to stress that such technique doesn't lead to any atom loss and can also work close to quantum degeneracy.
In this paper we present our experimental results of demagnetization cooling applied to a gas of Chromium atoms. Chromium is in fact a good candidate thanks to its large magnetic dipole moment of 6 μ_B which leads to an inelastic dipolar collision rate ~ 200 times larger than in alkali atoms. At the moment we are able to cool 10^6 atoms, trapped in a single beam dipole trap, from 20μK to 11μK in 7 seconds. In order to quantify the efficiency of such technique we can evaluate the increase in phase space density over atom losses. The 10% reduction in the atom number results in a cooling efficiency $\chi = -d\log\rho/d\log N$ of ~ 11 much larger than 4, optimum value for evaporative cooling.

References

[1] S. Hensler, A. Greiner, J. Stuhler and T. Pfau, Europhys. Lett. 71, 918 (2005).

Feshbach molecules from an atomic Mott insulator

Stephan Dürr, Thomas Volz, Niels Syassen, Dominik Bauer, Eberhard Hansis, Gerhard Rempe

Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany
E-mail:stephan.duerr@mpq.mpg.de

Feshbach molecules from bosonic atomic species have proven to be short-lived with respect to inelastic collisions [1]. As a result the typical lifetime observed for a cloud of ultracold $^{87}Rb_2$ molecules stored in an optical dipole trap is limited to a few milliseconds.
We report the observation of long-lived Feshbach molecules in an optical lattice. A BEC of ^{87}Rb atoms is loaded into the lowest Bloch band of a 3D optical lattice operated at a wavelength of 830 nm. By ramping up the lattice depth, the atomic gas enters the Mott insulator regime. A magnetic-field ramp through the Feshbach resonance at 1007 G creates molecules [2]. Lattice sites initially occupied with more than 2 atoms experience fast inelastic collisional losses. The observed lifetime of the remaining molecules is $\sim$ 100 ms, which is much longer than for a pure molecular sample in an optical dipole trap. Similar results have recently been reported in Ref. [3].
The increased lifetime is an important step on the route to a BEC of molecules in the vibrational ground state [4].

References

[1] T. Mukaiyama et al., Phys. Rev. Lett. **92**, 180402 (2004).
[2] S. Dürr et al., Phys. Rev. Lett. **92**, 020406 (2004).
[3] G. Thalhammer et al., Phys. Rev. Lett. **96**, 050402 (2006)
[4] D. Jaksch et al., Phys. Rev. Lett. **89**, 040402 (2002).

Simultaneous Magneto-Optical Trapping of Bosonic and Fermionic Chromium Atoms - Towards quantum degeneracy for a new Boson-Fermion Mixture

R. Chicireanu, A. Pouderous, Q. Beaufils, B. Laburthe-Tolra, E. Maréchal, L. Vernac, J.-C. Keller, and O. Gorceix

Laboratoire de Physique des Lasers, UMR 7538 CNRS, Université de Paris Nord, 99 Avenue J.-B. Clément, 93430 Villetaneuse, France
E-mail:vernac@galilee.univ-paris13.fr

Bosonic ^{52}Cr has recently been cooled down to quantum degeneracy [1]. Its main specificity is its large magnetic moment of 6 μ_B in its ground state. Thus, Cr is a perfect candidate for studying new physics in the degenerate regime, where the interactions are dominated by the long range, anisotropic, dipole-dipole interactions [2], which are 36 times stronger than for alkalis. Additionally, the presence of a second, abundant (9%), fermionic isotope – ^{53}Cr – opens the way to producing ultracold Fermi-Bose degenerate mixtures.

We are building a cold atom experiment to trap these two chromium isotopes. Our first result was the obtention of a ^{53}Cr Magneto-Optical Trap. Using a high temperature oven operated at 1500 ° C, we were able to load, from a Zeeman-slowed atomic beam, up to 5×10^5 fermionic ^{53}Cr atoms in a steady-state MOT, with a loading rate of 3×10^6 atoms.s^{-1}. We measured unusually large inelastic, light-assisted collision rates, on the order of 10^{-9} cm$^3 s^{-1}$, similar to those of the bosonic ^{52}Cr, indicating a not yet understood long range loss mechanism.

Our experimental setup allows us to simultaneously capture both isotopes in a combined MOT. In order to obtain larger number of atoms, we used the presence of metastable D states for both isotopes, which are spontaneously populated from the MOTs by radiative decay, and are magnetically trapped in the gradient of the MOT coils. By repumping these metastable atoms back in the ground state, we could get enough atoms to study the inter-species light assisted collisions [3], which are as well very important. This metastable accumulation scheme provides in fact a good starting point for the evaporative cooling of both isotopes.

At present, we are working on accumulating as many atoms as possible in the metastable states. For this purpose we are developing new techniques to prevent the collisions with MOT atoms, which actually are the main limitations for this accumulation.

In the next weeks we are going to transfer the atoms in a crossed dipole trap, which eventually will allow us to reach quantum degeneracy. We will in particular try to find the optimal strategy for doing sympathetic cooling of the fermionic species by the bosonic one : the long term goal of the experiment is the study of a Fermi sea with dominant dipole-dipole interaction, and its transfer into optical lattices.

The poster will present all the experimental results obtained by the time of the conference.

References

[1] A. Griesmaier et al. Phys. Rev. Lett. 94, 160401 (2005)
[2] S. Giovanazzi et al., J. Opt. B. Quantum Semiclass. Opt. 5, S208-211 (2003)
[3] Chicireanu et al, http://lanl.arxiv.org/abs/quant-ph/0603028

Magnetoelectric Jones spectroscopy of alkaline-earth atoms

P.V. Mironova, V.D. Ovsiannikov and V.V. Tchernouchkine
Department of Physics, Voronezh State University, 394006, Voronezh, Russia
E-mail: pvmir@yandex.ru

Magnetoelectric birefringence, predicted by Jones [1], which was first observed in liquids [2], may also become a useful tool for determining spectroscopic properties of atomic systems [3,4].
We consider magnetoelectric-field-induced resonant Rayleigh scattering in a vapor of ground-state alkaline-earth atoms. The amplitudes of this process are bilinear in magnetic and electric fields. In particular, the amplitudes U_D and U_P, related to the resonance conditions on D and P levels, correspondingly, may be written as

$$U_D = \frac{A}{\varepsilon^2}(p_1+p_2)[2\varphi_0+\varphi_1+\varphi_2]; \qquad U_P = \frac{A}{\varepsilon'^2}(q_1+q_2)[\varphi_1+\varphi_2], \tag{1.19}$$

where the factor $A = -\alpha\omega F^2 F_0 B/240$ includes the product of laser wave F, static electric F_0 and magnetic B fields; $\alpha = 1/137$ is the fine-structure constant, ω is the laser wave frequency. Complex quantities ε and ε' include both resonance detunings for real parts and resonance level widths for imaginary parts. The polarization-dependent factors are

$$\varphi_0 = (\mathbf{e}_0 \cdot [\mathbf{n}\times\mathbf{e}_B])\,; \qquad \varphi_1 = (\mathbf{e}_0\cdot\mathbf{e})\,(\mathbf{e}^*\cdot[\mathbf{n}\times\mathbf{e}_B])\,; \qquad \varphi_2 = (\mathbf{e}_0\cdot\mathbf{e}^*)\,(\mathbf{e}\cdot[\mathbf{n}\times\mathbf{e}_B])\,, \tag{1.20}$$

where $\mathbf{e}_B$ and $\mathbf{e}_0$ are unit vectors of magnetic and electric fields, $\mathbf{e}$ and $\mathbf{n}$ are unit polarization and wave vectors of the laser wave, correspondingly. Factors p_1, p_2, q_1, q_2 are the products of the first-order and second-order radial matrix elements, which can be presented as follows:

$$p_1 = \langle n'D|r g_1^{\omega} r|nS\rangle\langle nS|r^2|n'D\rangle; \qquad p_2 = \langle n'D|r g_1^{0} r|nS\rangle\langle nS|r^2|n'D\rangle; \tag{1.21}$$

$$q_1 = \langle n'P|r^2 g_1^{0} r|nS\rangle\langle nS|r|n'P\rangle; \qquad q_2 = \langle n'P|r g_2^{\omega} r^2|nS\rangle\langle nS|r|n'P\rangle. \tag{1.22}$$

The Jones birefringence appears, when $\mathbf{e}_0 = \mathbf{e}_B$, due to the difference between the amplitudes (1) for $\mathbf{e} = \mathbf{e}^{(+)}$ and $\mathbf{e} = \mathbf{e}^{(-)}$, where $\mathbf{e}^{(\pm)} = (\mathbf{e}_0 \pm [\mathbf{n}\times\mathbf{e}_0])/\sqrt{2}$:

$$\Delta U_D^{(J)} = U_D^{(+)} - U_D^{(-)} = 2\frac{A}{\varepsilon^2}(p_1+p_2) \quad \text{and} \quad \Delta U_P^{(J)} = U_P^{(+)} - U_P^{(-)} = 2\frac{A}{\varepsilon'^2}(q_1+q_2). \tag{1.23}$$

When $[\mathbf{e}_B\times\mathbf{e}_0] \neq 0$, also the difference appears between the amplitudes (1) for $\mathbf{e} \parallel \mathbf{e}_0$ and $\mathbf{e} \perp \mathbf{e}_0$:

$$\Delta U_D^{(L)} = U_D(\mathbf{e}\parallel\mathbf{e}_0) - U_D(\mathbf{e}\perp\mathbf{e}_0) = 2\frac{A}{\varepsilon^2}(p_1+p_2)\,(\mathbf{e}_0\cdot[\mathbf{n}\times\mathbf{e}_B])\,; \tag{1.24}$$

$$\Delta U_P^{(L)} = U_P(\mathbf{e}\parallel\mathbf{e}_0) - U_P(\mathbf{e}\perp\mathbf{e}_0) = 2\frac{A}{\varepsilon'^2}(q_1+q_2)\,(\mathbf{e}_0\cdot[\mathbf{n}\times\mathbf{e}_B])\,. \tag{1.25}$$

In addition, amplitudes (1) discover also the difference between the amplitudes U_D for different directions of the laser wave propagation relative the vector $[\mathbf{e}_B\times\mathbf{e}_0]$, $U^{(\parallel)} = U\,(\mathbf{n}\parallel[\mathbf{e}_B\times\mathbf{e}_0])$ and $U^{(\perp)} = U\,(\mathbf{n}\perp[\mathbf{e}_B\times\mathbf{e}_0])$:

$$\Delta U_D^{(P)} = U_D^{(\parallel)} - U_D^{(\perp)} = 2\frac{A}{\varepsilon^2}(p_1+p_2), \quad \text{while} \quad \Delta U_P^{(P)} = U_P^{(\parallel)} - U_P^{(\perp)} = 0. \tag{1.26}$$

References

[1] R. C. Jones, J. Opt. Soc. Am. 38, 671 (1948).
[2] T. Roth and G. L. J. A. Rikken, Phys. Rev. Lett. 85, 4478 (2000).
[3] J. E. Stalnaker, D. Budker, D. P. DeMille, S. J. Freedman, and V. V. Yashchuk, Phys. Rev. A 66, 031403 (2002).
[4] D. Budker and J. E. Stalnaker, Phys. Rev. Lett. 91, 263901 (2003).

Measurement of the Lamb shift in hydrogen-like lead using crystal spectroscopy methods

M. Trassinelli[1], D. Attia[2], D. Banaś[3], F. Bosch[1], C. Brandau[1], K. Beckert[1], P. Beller[1], S. Chatterjee[1], Th. Krings[4], E. Förster[5], B. Franzke[1], A. Gumberidze[1], S. Hagmann[1], J. Hoszowska[6], P. Indelicato[2], H.-J. Kluge[1], Ch. Kozhuharov[1], É.-O. Le Bigot[2], D. Liesen[1], X. Ma[7], B. Manil[8], I. Mohos[4], F. Nolden[1], U. Popp[1], D. Protic[4], R. Reuschl[1], D. Sierpowski[9], A. Simionovici[10], U. Spillmann[1], Z. Stachura[9], M. Steck[1], Th. Stöhlker[1], S. Tashenov[1], S. Trotsenko[1], A. Warczak[9], O. Wehrhan[5], E. Ziegler[6], H.F. Beyer[1]

[1] *Gesellschaft für Schwerionenforschung, Darmstadt, Germany*
[2] *Laboratoire Kastler Brossel, Université Pierre et Marie Curie, Paris, France*
[3] *Świętokrzyska Academy, Kielce, Poland*
[4] *FZ Jülich, Institut für Kernphysik, Jülich, Germany*
[5] *Institut für Optik und Quantenelektronik, F. Schiller-Universität, Jena, Germany*
[6] *ESRF, Grenoble, France*
[7] *Institute of Modern Physics, Lanzhou, China*
[8] *CIRIL-GANIL, Caen, France*
[9] *Institute of Physics, Jagiellonian University, Cracow, Poland*
[10] *ENS, Lyon, France*
E-mail:m.trassinelli@gsi.de

We present the preliminary results on the evaluation of the ground state Lamb shift in hydrogen-like lead by the measurement of the $Ly\alpha$ transitions energy. For this propose we used two crystal spectrometer in a focusing compensate asymmetric Laue geometry [1] coupled with large area position sensitive germanium detectors [2,3]. The data have been collected for a period of two week at the storage ring ESR of GSI in March 2006. The analysis is still in progress. We expect a final accuracy of few eV for the measurement of the Pb^{81+} $1s$ level Lamb shift, which will allow for a test of Quantum Electrodynamic in strong field with unprecedented precision.

References

[1] H.F. Beyer *et al.*, Spectrochimica Acta B **59**, 1535 (2004)
[2] D. Protič *et al.*, IEEE Trans. Nucl. Sci. **48**, 1048 (2001)
[3] D. Protič *et al.*, IEEE Trans. Nucl. Sci. **52**, 3194 (2005)

From Newton to Casimir and back: fundamental physics using Atomic Beam Spin Echo.

M.F.M. DeKieviet

Physics Department, Heidelberg University, Heidelberg, Germany
E-mail:maarten@physi.uni-heidelberg.de

The quantum mechanical nature of (empty) space has far-reaching consequences in many branches of physics, ranging from (sub-)atomic physics to cosmology. The existence of electromagnetic vacuum fluctuations, for example, manifests itself most impressively in the Casimir force [1], a stochastic and feeble force, so hard to measure properly, that it was considered to be solely of academic interest for a long time. With the current revolution in nano-technology, however, there is a rising, yet even economic need for a quantitative understanding. I will present an experiment, in which the Casimir-Polder force between a *single* atom and the surface of a solid is determined quantitatively to better than the 1% level. It is based on the Atomic Beam Spin Echo method developed in Heidelberg [2], an atom interferometry method, in which we combine the exclusive surface sensitivity of thermal atom scattering with the resolution of in-beam magnetic resonance techniques. This technique will be introduced and its high resolving power (down to sub-neV) shown in some simple scattering experiments. Subsequently, I will turn to the phenomenon of quantum reflection and show how it may depend very sensitively on the long-range details of some *attractive* atom-surface interaction. Utilizing quantum reflection as a tool, we have been able to clearly identify the Casimir and the van der Waals branches for a variety of surfaces [3]. Finally, the potential of Atomic Beam Spin Echo is addressed in particular with respect to testing fundamental questions in physics concerning the Casimir force and beyond. I will show on-going measurements focussing on the dependency of the working of the vacuum fluctuations on temperature, geometry and spectral properties of the solid. For example, our data show the Casimir interaction can be significantly altered by heating the surface, or by using specifically nano-crafted ones. As an outlook, I will describe two possible experiments that may have the sensitivity for detecting parity violation in light atoms, respectively for testing gravity beyond Newton's law.

References

[1] H.B.G. Casimir and D. Polder, Phys. Rev. Lett. 73, 360 (1948).
[2] M.F.M. DeKieviet, D. Dubbers, Ch. Schmidt, D. Scholz and U. Spinola, Phys. Rev. Lett. 75(10), 1919 (1995).
[3] V. Druzhinina and M. DeKieviet, Phys. Rev. Lett. 91(19), 1 (2003).

High sensitivity spectroscopy for ambient-air trace gas detection using a portable difference-frequency source around 3 μm

P. Malara, P. Maddaloni, G. Gagliardi and P. De Natale

CNR - Istituto Nazionale di Ottica Applicata
Via Campi Flegrei 34 - Pozzuoli, Italy
E-mail: pietro.malara@inoa.it

Real-time, in-situ chemical analysis of trace gases based on optical absorption techniques is a relevant issue in several areas of research, from environmental monitoring to biomedical diagnostics. However, since most species of interest are naturally present in very low concentrations, ranging from parts-per-million (ppmv) to parts-per-trillion (pptv) by volume, the resulting absorbance can be extremely small. Hence for ambient-air monitoring field applications, a laser spectroscopic system must combine a compact and robust set-up with a high sensitivity technique. In our work, many efforts have been focused on the developement and use of coherent radiation sources operating at wavelengths where the strongest transitions occurr, in conjunction to high-sensitivity spectroscopy techniques particularly suitable for field applications. For this purpose, the window between 2.5 and 3.5 μm is particularly attractive, because it exhibits strong and well-isolated lines for a large number of molecules (C-H, N-H and O-H fundamental vibrations occur in this interval).

As a first step, we report the development of a compact, rugged and portable spectrometer for field applications based on difference-frequency generation (DFG) in a periodically-poled lithium-niobate crystal, between 2.9 and 3.5 μm, with an output power of several milliwatts. The performance in real-time gas monitoring is evaluated with a direct-absorption scheme in a 13-m multiple-reflection cell. Thanks to strong dipole moment of lines belonging to the fundamental ν_3 vibration, direct absorption profiles of natural-abundance methane at atmospheric pressure were recorded with a noise-equivalent absorption coefficient of $5.8 \cdot 10^{-7}$ cm$^{-1}/\sqrt{\text{Hz}}$, corresponding to a minimum detectable CH_4 concentration of 3 ppb$/\sqrt{\text{Hz}}$.

In order to further improve the spectrometer detectivity preserving the possibility of field measurements as well, a frequency modulation and a long-path technique were implemented and combined to the DFG source. In the first case, two-tone FM spectroscopy provided a significant noise reduction with a reasonable technical demand. As a proof of sensitivity, weak CH_4 ro-vibrational transition in ambient-air samples were detected, resulting in an enhancement of a factor 100 in the signal-to-noise ratio with respect to the direct absorption, and thus a minimum absorption coefficient of $5.3 \cdot 10^{-9}$ cm$^{-1}/\sqrt{\text{Hz}}$.

A different high-sensitivity scheme for quantitative gas detection was demonstrated with off-axis integrated-cavity-output spectroscopy (OA-ICOS). This cavity-based technique can be realized in a very simple set-up and, being intrinsically insensitive to small vibrations and misalignements, is particularly suitable for outdoor applications. Thanks to the high output power of our DFG spectrometer, we could successfully use OA-ICOS to perform direct ambient-air methane detection at atmospheric pressure. An 1.8-km effective cavity absorption pathlenght was demonstrated, yielding a minimum detectable concentration of 850 ppt$/\sqrt{\text{Hz}}$. Furthermore, an analytical model based on the integrated off-axis cavity-response enabled us to retrieve the absorber concentration directly from the area under the recorded absorption profile in a wide concentration range.

Investigations on the CPT effect in π configuration: the 'pseudo-resonance' mechanism and its application in compact atomic clocks

E. Breschi[1], C. Affolderbach[1], G. Mileti[1], G. Kazakov [2], B. Matisov [2], I. Mazets [3]

[1] *Observatoire Cantonal de Neuchâtel, Neuchâtel, Switzerland*
[2] *St. Petersburg State Polytechnic University,*
[3] *A. F. Ioffe Physico-Technical Institute St. Petersburg, Russia*
E-mail: evelina.breschi@ne.ch

Coherent Population Trapping represents a promising alternative for the realization of stable and small atomic clocks [1]. An important factor which limits the performances of CPT-based atomic clocks is the small signal contrast. To overcome this limit several excitation schemes have been proposed [2, 3] and references therein. In particular, in reference [2] the authors showed that a significant enhancement of the CPT amplitude is obtained when co-propagating laser waves with parallel linear polarization are resonant with the excited state $F_e = 1$. In this case, the reference transition for atomic clocks is between Zeeman sublevels with $|m_F \neq 0|$. To reduce the influence of external magnetic field, it has been proposed [4] to use as frequency reference a combination of CPT effect and signal discrimination at the maximum of absorption, referred to as a *pseudo-resonance*.
With the present communication we report on our CPT/pseudo-resonance experiment and model. We work with pure ^{87}Rb vapor in a sealed cell (few cm^3), and the laser source is tuned nearly in resonance with the D_1 line (795 nm). In order to increase the sensitivity of our setup, the noise on the detector has been measured to point out the main noise sources. The behavior of the pseudo-resonance parameters (amplitude, linewidth and central frequency) has been studied as a function of some relevant experimental parameters hereafter described. The optimal working conditions are determined by optimizing the Discriminator slope (D_s) of the pseudo-resonance. Optimum values have been found for the laser beam cross section, the longitudinal magnetic field and the cell temperature. This optimal values depend on the characteristics of the cell (mainly its volume and buffer gas pressure). The D_s maximum is reached when the laser radiation is resonant to the transition towards $F_e = 1$. We have analyzed the influence of the Doppler and pressure broadening of the D_1 line as well as the laser line-width on the pseudo-resonance signal. We have concluded that the amplitude of the pseudo-resonance is critically affected by the pressure broadening and the laser line-width. This two mechanisms, even if they have different physical origin and meaning, both contribute to increase the influence of the transitions towards $F_e = 2$, which considerably reduce the signal amplitude. On the other hand, their influence on the pseudo-resonance line-width is less critical: we can easily reach pseudo-resonance line-width below 1 kHz.
In this communication, we will present latest results comparing CPT resonance and pseudo-resonance under the same experimental conditions in view of application in atomic frequency standards.

References

[1] J. Vanier, Appl. Ph. B 340, 1905 2005.
[2] A. V. Taichenachev, V. I. Yudin, V. L. Velichansky, S. A. Zibrov, JETP Lett. 82, 398 2005
[3] G. Kazakov, I. Mazets, Yu. Rozhdestvensky, G. Mileti, J. Delporte, B. Matisov, Eur. Phys. J. D 35, 445 2005
[4] G. Kazakov, B. Matisov, I. Mazets, G. Mileti, J. Delporte, Phys. Rev. A 72, 063408 2005

Coherent effects in free-bound transitions in hydrogen/antihydrogen atom under the action of ultra-short strong-field laser pulse

M. Ryabinina, L. Melnikov

Department of Physics, Saratov State University, Saratov, Russia
E-mail:mvr@vtt.net

In present paper the results of the investigation of the dynamics of free-bound transitions in hydrogen/antihydrogen atom under the action of ultra-short strong laser pulse are presented. At ultra-low temperatures of antiproton-positron plasmas [1] energy distribution width is small enough and corresponding set of continuous states can be considered as single highly-degenerate level. Broadening of this level is similar to inhomogeneous broadening of spectral lines in plasma due to thermal movement. In this case something resembling Rabi oscillations and analog of π- pulse should be expected. Thus proper choice of pulse parameters allows to increase considerably the yield of atoms in laser recombination process. It may be useful for some international projects (ELENA, ALPHA, ATRAP) aimed the production and research of the atomic antihydrogen. This dynamics can be used for diagnostics of continuum states itself.

The wavefunction is assumed to be presented as sum of one discrete state (n, l, m) and a set of continuous states (k, l, m), where k is the wavenumber, l, m are orbital and magnetic quantum numbers. The probability amplitudes equations are as follows:

$$\mathrm{i}\dot{a}_{n,l,m} = \sum_{l',m'} \int \frac{dk}{2\pi} b_{k,l',m'}(t) e^{-\mathrm{i}(\frac{k^2}{2}+\frac{1}{2})t} \vec{E}(t) \langle n, l, m|\vec{r}|k, l', m'\rangle,$$

$$\mathrm{i}\dot{b}_{k,l,m} = a_{n,l',m'}(t) e^{\mathrm{i}(\frac{k^2}{2}+\frac{1}{2})t} \vec{E}(t) \langle k, l, m|\vec{r}|n, l', m'\rangle +$$
$$\sum_{l',m'} \int \frac{dk'}{2\pi} b_{k',l',m'}(t) e^{\mathrm{i}(\frac{k^2}{2}-\frac{k'^2}{2})t} \vec{E}(t) \langle k, l, m|\vec{r}|k', l', m'\rangle.$$

In this equation system the dipole approximation is used. a is the probability amplitude of one discrete state, b_k is the probability amplitude of continuous state with wavenumber k. The right part of first equation describes the recombination. The first term of right part of second equation describes an ionization, while second term describes free-free laser-stimulated transitions. If $n = 1$ then field frequency is slightly more than $\frac{1}{2}$. Hence laser radiation couples free states with $k'^2 = k^2 \pm 1$. Dipole moment matrix elements are nonzero when $l' = l \pm 1$, $m' = m + q$, where q is field polarization index. All matrix elements were analytically calculated using corresponding wavefunctions [2]. These equations were solved numerically replacing integrals by discrete sums. The initial conditions corresponds to thermal distribution according to k with characteristic width corresponding to temperatures 4 - 100 K.

As the results we have observed Rabi-like oscilations of $|a(t)|^2$ which period and amplitude nonmonotonically depend on pulse area and pulse amplitude. There exists the parameters set which gives the value of $|a(t)|^2$ comparable with the total population of continuous states with given orbital momentum.

References

[1] http://hussle.harvard.edu/ atrap/,http://alpha.web.cern.ch/alpha/
[2] L.D.Landau, E.M.Lifshits, Quantum Mechanics, Moscow. Nauka Publ. 1989.

Alignment to orientation conversion in Cs in a pure electric field: experiment theory and applications

M. Auzinsh, K. Blushs, R. Ferber, F. Gahbauer, A. Jarmola and M. Tamanis

University of Latvia, Department of Physics and Mathematics, Rainis Blvd. 19, Riga LV-1586, Latvia
E-mail:kblush@latnet.lv

We present a detailed theoretical model of experimentally measured signals of alignment to orientation conversion (AOC) in the $7D_{3/2}$ and $9D_{3/2}$ states of cesium atoms in the presence of an external dc electric field [1]. Alignment produced by linearly polarized light can be converted into orientation by the quadratic Stark effect in an electric field if the angle between the electric field and the polarization vector of the exciting radiation is neither 0 nor 90 degrees and if there are magnetic sublevels with $\Delta m = \pm 1$ that cross as the electric field is scanned. Orientation is verified by the observation of a net circular polarization in the laser induced fluorescence. The model is based on the optical Bloch equations and extends models previously developed to solve the rate equations for Zeeman coherences in single step [2] and double step [3] laser excitation of atoms. The agreement between the simulated and measured signals is excellent. The experimental signals are observed in cesium vapor in a sealed glass cell at room temperature. An electric field up to 2000 V/cm is produced by two polished Stark electrodes of 25 mm diameter, which are separated by a 5 mm gap. The $7D_{3/2}$ and $9D_{3/2}$ states of cesium are populated by two step excitation ($6S_{1/2} \longrightarrow 6P_{1/2} \longrightarrow nD_{3/2}$) with two counterpropagating laser beams. For the first step, a diode laser is used. For the second step, another diode laser is used in the case of $n = 7$, and a dye laser is used in the case of $n = 9$. Laser induced fluorescence (LIF) is observed at the $nD_{3/2} \longrightarrow 6P_{1/2}$ transition and the rate of circular polarization is measured by passing the light through a $\lambda/4$ plate and a linear polarizer. Circular polarization rates up to 10% are observed and the maximum of circular polarization corresponds to electric field values at which magnetic sublevels with $\Delta m = \pm 1$ cross. AOC has applications in experiments searching for fundamental physics as well as in practical applications. In certain types of experiments searching for a permanent electric dipole moment (EDM) of the electron [4], the deformation of the atomic angular momentum distribution caused by AOC could mimick signals stemming from an EDM. AOC could be introduced when the polarization vector of the exciting radiation is not perfectly parallel or perpendicular to the electric or residual magnetic fields used in the experiments. As EDM searches become ever more sensitive, it is useful to have an exact theoretical description of AOC that can be used to evaluate and subtract such potential backgrounds. AOC in an electric field could also be used in practical applications to deflect beams of light [5].

We acknowledge support from NATO Grant SfP-978029 "Optical Field Mapping" and the Latvian Government material science project Nr. 1-23/50 "Perspective inorganic materials for photonics and energetics." K. B., F. G., and A. J. thank the European Social Fund for support.

References

[1] Marcis Auzinsh, Kaspars Blushs, Ruvin Ferber, Florian Gahbauer, Andrey Jarmola, and Maris Tamanis, arXiv.org, physics/0603194

[2] K. Blushs and M. Auzinsh, Phys. Rev. A. 69. 063806 (2004).

[3] M. Auzinsh, K. Blushs, R. Ferber, F. Gahbauer, A. Jarmola, and M. Tamanis, Opt. Commun. (to be published), physics/0511035

[4] B. C. Regan, E. D. Commins, C. J. Schmidt, and D. DeMille, Phys. Rev. Lett. 88, 071805 (2002).

[5] R. Holzner, P. Eschle, S. Dangle, R. Richard, H. Schmid, U. Rusch, B. Röhricht, R. J. Ballagh, A. W. McCord, and W. J. Sandle, Phys. Rev. Lett. 78, 3451 (1997).

Highly efficient DNA-protein and protein-protein crosslinking induced by fs-UV laser pulses

C. Altucci[1,2], R. Velotta [1,2], L. Altucci[3], A. Nebbioso[3], L. Birolo[2], and G. Marino[2]

[1] *Dipartimento Scienze Fisiche, Università di Napoli "Federico II", CNISM, Napoli, Italy*
[2] *Facoltà di Scienze Biotecnologiche, Università di Napoli "Federico II", Napoli, Italy*
[3] *Dipartimento di Patologia Generale, Seconda Università di Napoli, Napoli, Italy*
E-mail:carlo.altucci@na.infn.it

UV laser cross-linking is a potentially powerful tool to investigate transient DNA-protein interactions and binding kinetics in intact cells. Biochemical methods have been developed to study stable protein-DNA interactions *in vivo* and chemical crosslinking has been used for less stable interactions, but the chemical agents are slow, damage cells and perturb native equilibria. To avoid these perturbations, UV laser crosslinking offers an alternative although, the above excitation being typically a two UV-photon process, the energies required for significant cross-linking cause extensive DNA damage. In fact, the crosslinking yield is still relatively low with the commonly used pulses in the nanosecond range. To attain higher crosslinking yields, laser parameters must be adjusted to the underlying two-photon process, which strongly depends on pulse intensity and pulse duration. The highest crosslink yields could be achieved using fs laser pulses, but these also result in higher DNA damage. Based on pioneering works on DNA-protein cross-linking induced by UV laser pulses [1,2], we have carried out single pulse (λ=263 nm, τ=250 fs, variable intensity) measurements on DNA-protein. In these first experiments we found that a key role is played by the interaction geometry of the laser beam and the irradiated solution. In particular, both capillarity properties of the solution and adhesion of the solution to the container walls made hard a uniform illumination of the sample. We have been able to physically cross-link U937 leukaemia cells irradiated in a 9 mm diameter cylindrical well by an unfocused laser pulse at the maximum available energy (300 μJ). It is worth emphasizing that the observed crosslink process yield has been even higher than that obtained by means of conventional chemical methods. Further experiments are planned, based on the pump/probe technique, in which a combination of UV pulses for the first excitation step and blue pulses for the second step will be also tried. This strategy has the advantage that the intensity of the UV pulse in the first step can be kept low, thus reducing DNA damage caused by the UV photons.

We have extended the UV laser technique to protein-protein cross-linking, for the first time to the best of our knowledge. Very satisfactory and encouraging results were obtained in preliminary experiments, regardless of the specific protein used and thus suggesting a wide applicability of the approach. As an example we mention alchool dehydrogenase (ADH) that was exposed at UV light at 266 nm at 30 Hz. Whenever the protein samples were irradiated, the formation of higher molecular weight species was observed by denaturant gel electrophoresis analysis and the yield of crosslinked proteins was exposure time dependent. These observations suggest crosslinking efficiency much higher than classical and well established chemical and photochemical protein crosslinking and foresee a wide range of applications of suitable shaped laser pulse.

References

[1] C. Russmann *et al.*, Nucleic Acids Res **26**, 3967-70 (1998).
[2] C. Russmann *et al.*, Nucleic Acids Res **25**, 2478-84 (1997).

Three-Level Laser Models with Incoherent Pumping

Avi Ben-Arie, Gennady Koganov and Reuben Shuker

Physics Department, Ben Gurion University of the Negev P.O.B. 653, Beer Sheva, 84105, Israel
E-mail: shuker@bgu.ac.il

The dynamics and statistics of three-level laser systems with incoherent pumping are investigated. Three theoretical models are studied: Λ , V and ladder in a comparative approach. The three models describe systems of three-level atoms interacting with a single mode of electromagnetic field inside an optical cavity. A critical value of the lasing threshold is obtained. In the V model, the pump excites the atoms from the lower lasing level. In the ladder model, two pumping processes are in action, one of which excites the atoms from the lower lasing level. This fact causes a second critical value of the pumping rate, in addition to the critical value of the lasing threshold. The second critical value, which does not exist in the Λ model, is the break point at which lasing ceases [1,2]. We call this point the turn-off threshold. Above this pumping rate threshold, the number of photons drops dramatically and the system no longer operates as a laser. At the two critical points, the lasing and the turn-off thresholds, the laser field behaves in a phase-transition-like manner: the photon number changes dramatically, the Fano factor has a strong peak and the second order correlation function changes significantly.

For each of the three models, the modified Maxwell-Bloch equations are presented and solved in steady state. The solutions are analyzed systematically. The dependence of the photon number on the pumping rate and on the main model parameters, for example, the spontaneous emission rate at the lasing transition and the dephasing rate, are investigated. For each model we derive explicit expression for the lasing threshold and the turn-off threshold, if exists. Moreover, the critical values of the main model parameters, beyond which lasing is impossible, are being calculated.

One of the main characteristics of the laser radiation is the photon number fluctuations or in other words, the noise. This characteristic is being studied for each model by two statistical measures: the Fano factor and the second-order correlation function. The dependence of these two measures on the pumping rate is presented and analyzed graphically based on the quantum Fokker-Planck equation. Special attention is given to the possibility to obtain "squeezed light", i.e. the possibility to get noise suppression below shot noise limit. In the Λ and V models the maximum noise suppression one can get is 25%, whereas in the ladder model one can achieve only 5% suppression.

References

[1] Yi Mu and C.M. Savage, Phys. Rev. A **46**, 5944 (1992).

[2] G.A.Koganov and R. Shuker, Phys. Rev. A **63**, 015802 (2001).

All-optical laser magnetometer based on the effect of coherent population trapping in Rb

D. Slavov, T. Karaulanov, S. Cartaleva, N. Petrov, G. Todorov

Institute of Electronics, Bulgarian Academy of Sciences,
72 Tzarigradsko shosse, 1784 Sofia, Bulgaria
E-mail: dilas@ie.bas.bg

Most of the commercially available optical magnetometers are based on the use of the optical pumping process in alkali atoms. Recently Coherent Population Trapping (CPT) phenomenon has been exploited, in order to realize new types of magnetometer and gradiometer. The approach based on the CPT resonance utilization allows building of an all-optical magnetic field (MF) sensor, thus expanding application fields of optical magnetometers. In the first systems some practical limitation is imposed by the needed laser frequency modulation in the GHz region.

The present communication concerns our results related to the development of a portable, all-optical-sensor atomic magnetometer based on the CPT prepared within a single hf transition in Rb. Here the Rb vapor is irradiated by frequency modulated circularly polarized laser light and the CPT resonances in the fluorescence dependence on the laser modulation frequency are observed, centered at the Larmor frequency and its harmonics. Here, the Larmor frequency is measured directly and the measure of it is the laser modulation frequency. The direct measurement of the Larmor frequency eliminates the need to calibrate the ground-state microwave transition, for precise and absolute MF measurements. Moreover, small oscillators that operate at the Larmor frequency (hundreds of kHz's, for most applications) are commercially available and consume much less power than those emitting in the GHz region.

A methodology for MF measurement has been elaborated and the measurements have been performed in the laboratory magnetic field, which is composed of the earth magnetic field and electromagnetic noise from the laboratory equipment. Despite the noisy laboratory environment, very good signal/noise CPT resonances are registered. Scanning the modulation frequency from 20 to 220 kHz, more than 12 coherent resonances are observed. The observed resonances are identified as prepared by the carrier, first and higher order harmonics of the frequency-modulated laser light.

The developed system has been tested for measurement of Earth MF fluctuations, when situated in laboratory of the Institute of Electronics at the Bulgarian Academy of Sciences. The test shows very good agreement with similar measurement performed in the professional L'Aquila geomagnetic station, Italy. The results are really encouraging because the measurement performed in Sofia is under the Electromagnetic pollution of the large city and large MF gradients.

In many applications such as testing of materials, real time monitoring of manufacture processes, it is important to use sensing element performing in hazardous and difficult to access environment. The developed methodology is suitable for application in this type of environment.

The authors acknowledge financial support of the EC (contract No G6RD/CT-2001-00642). We thanks: colleagues from University of Siena; Technical University of Graz; Optela Optical Technologies JSC, Plovdiv ; Optella Ltd, Sofia and ELO company, Sofia for fruitful collaboration. We appreciate also the Bulgarian NCSR for partial support (Grant No.F-1404/04)

Absorption and fluorescence spectra of Cs atomic vapour in Extremely Thin Cell

C. Andreeva[1], S. Cartaleva[1], L.Petrov[1].D. Slavov[1], D. Sarkisyan[2] T. Varzhapetyan[2]

[1]*Institute of Electronics, BAS boul. Tzarigradsko Shosse 72, 1784 Sofia, Bulgaria*
[2]*Institute for Physical Research, NAS of Armenia, Ashtarak-2, Armenia*

The spectroscopy of atomic layers in a thin cell has proven promising for the studies of atom-light, atom-atom and atom-surface interactions. Such layers are formed in the so called Extremely Thin Cells (ETC), whose longitudinal dimension L is below 1 μm [1]. The single light beam transmission reveals sub-Doppler features centered at the resonance frequency of the hyperfine (hf) transitions of alkali atoms. As shown in [2,3], two cases can be distinguished: at L=$\lambda/2$ (λ is the excitation wavelength) the hf transitions show sub-Doppler width enhanced absorption profiles, while for L=λ a Doppler-broadened absorption spectrum is registered [3].

In this paper is presented an experimental study of the sub-Doppler spectra at the D_2 line of Cs confined in ETC, using a narrow-band laser excitation. Well-resolved and good contrast sub-Doppler resonances in absorption and fluorescence are obtained and their behavior in dependence on the cell length L is examined.

For L=$\lambda/2$ strong narrowing of the hf transitions is observed due to absorption enhancement in the transition center relative to that in the wings. For L=λ, the coherent Dicke narrowing vanishes and at low power the hf structure is not resolved. However, at higher power well pronounced narrow dips of reduced absorption are registered, centered at all hf transitions and related to saturation and optical pumping. In the fluorescence, with laser power increase for the open transitions narrow reduced-fluorescence dips are observed superimposed on the fluorescence profiles. For the closed transition no fluorescence dip is registered, even at high light power. At L=$3/4\lambda$, for low laser intensities the absorption spectrum consists in three well-resolved enhanced-absorption resonances, hence, the behaviour is similar to that at L=$\lambda/2$. Increasing the laser power, small dips attributed to optical pumping and saturation appear superimposed on the absorption profiles. Thus, at higher light power the behaviour of the medium absorption is similar to that at L=λ. At the same time, no reduced fluorescence dips are registered. Therefore, the fluorescence behaviour is similar to that at L=$\lambda/2$. For cell width L=$5/4\lambda$, a very interesting behaviour is observed. In absorption, at very low power the three hf transition profiles are observed. Increasing the power, reduced absorption dips occur first at the open transitions, then also at the closed one. Increasing further the light power, first for the closed transition and then for the open ones a small peak in absorption, superimposed on the reduced absorption dip in the hf transition profile is registered. The origin of these absorption peaks is still not clear. The behaviour of the fluorescence is similar to that at L=λ.

The presented results contribute to the further knowledge of the behavior of confined alkali atomic vapour with importance for investigations of complex atomic and molecular spectra

The authors thank the Bulgarian NCSR (grant F-1404/04) and Rila (Grant 2/2). D.S. and T.V. thank ANSEF (Grant 05 – PS – opt – 0813 - 233).

References

[1] D. Sarkisyan, D. Bloch, A. Papoyan, M. Ducloy, Opt. Commun. 200, 201 (2001).
[2] D. Sarkisyan, et al., Phys. Rev. A69, 065802 (2004).
[3] G. Dutier, et al., Europhys. Lett. 63, 35, (2003).

Study of Atomic Transitions between Zeeman Sublevels in a Cell with Thickness of the Atomic Vapor Column $L = \lambda$

L. Petrov[1], D. Sarkisyan[2], A. Papoyan[2], M. Auzinsh[3], K. Blushs[3]

[1] *Institute of Electronics, BAS boul. Tzarigradsko Shosse 72, 1784, Sofia, Bulgaria*
[2] *Institute for Physical Research, NAS of Armenia, Ashtarak-2, 378410, Armenia*
[3] *Department of Physics, University of Latvia, 19 Rainis blvd., Riga, LV-1586, Latvia*
E-mail:lyubomir.p.petrov@gmail.com

Recently, the investigation of atomic vapour confined in Extremely Thin Cells (ETC) [1] is attracting increasing attention. As shown in [2], the narrowest sub-Doppler linewidth of resonant fluorescence (7-8 times narrower than the Doppler width) is achieved in ETC when the thickness of the vapor column is $L = \lambda/2$, where λ is the laser wavelength resonant with the atomic transition. It was demonstrated that the use of an ETC with $L = 400$ nm $\approx \lambda/2$ allows one to resolve a large number of individual transitions between Zeeman sublevels of Rb D_1 line in an external magnetic field of about 200 Gauss [3]. The good spectral resolution of these transitions allows one to observe both linear and nonlinear regimes of Zeeman effect. Recently it was demonstrated that velocity selective optical pumping (VSOP) peaks of reduced absorption centered at the hyperfine transitions occur in ETC transmission spectra at $L = n\lambda$, where n is an integer. The narrowest linewidth is achieved for $n = 1$ and is close to the obtained in saturation absorption (SA) spectroscopy [2]. The advantage of the "$L = \lambda$ technique" versus the "$L = \lambda/2$ technique" is that the linewidth of the VSOP peaks is $\sim$ 5 times narrower and also the laser power needed for VSOP formation is at least 10 times lower than that needed to produce a detectable fluorescence radiation. Note that since a single beam is used in the $L = \lambda$ technique in contrast with the SA technique, there are no crossover resonances in the spectrum. In addition, the contrast of the VSOP peaks is better. This allowed us to implement this technique for resolving a large number of individual transitions between Zeeman sublevels of Cs D_2 line (atomic transitions $F_g = 3 \rightarrow F_e = 2, 3, 4$, $F_g = 4 \rightarrow F_e = 3, 4, 5$) in an external magnetic field less than 100 Gauss. However, the most interesting results have been obtained for D_2 line of ^{87}Rb, for the $F_g = 1 \rightarrow F_e = 0, 1, 2$ transitions. In this case, a strong nonlinear Zeeman effect is observed for an external longitudinal magnetic field as low as 5 Gauss. In particular, for the case of excitation of the $F_g = 1 \rightarrow F_e = 0$ transition with circular laser polarization, the VSOP peak for σ^- (right-handed polarization) is about 3 times larger than that for σ^+ (left-handed polarization). This is a result of the fact that the transition probability modified by the magnetic field is about 3 times larger for σ^- excitation. For the atomic transition $F_g = 1 \rightarrow F_e = 2$ and σ^+ excitation in magnetic field $B =$ 30 Gauss, all three individual Zeeman transitions are fully resolved. The estimations show that the $L = \lambda$ technique could be successfully applied to the D_1 and D_2 lines of Na and K atomic vapors, too. A theoretical model has been developed, which takes into account the modification of transition probabilities due to the magnetic field, resulting in modification of the different Zeeman sublevels population at different VSOP regimes. Comparison with the experiment will also be presented.

The authors D.S. and A.P. thank SCOPES (Grant IB7320-110684/1). LP thanks also RILA program (grant No 2/2) and NCSR (grant F-1404/04).

References

[1] D.Sarkisyan, D.Bloch, A.Papoyan, M.Ducloy, Opt. Commun. 200, 201 (2001).
[2] D.Sarkisyan, T.Varzhapetyan, A.Sarkisyan et al., Phys. Rev. A 69, 065802 (2004).
[3] D.Sarkisyan, A. Papoyan,T. Varzhapetyan, K. Blush, M. Auzinsh, JOSA B 22, 88 (2005).

Measurement of light induced birefringence, electromagnetically induced transparency, and absorption in the cesium D_2 line

R.-H. Rinkleff, L. Spani Molella, G. Kühn, and K. Danzmann

Institute for Gravitational Physics, University Hannover
and Max Planck Institute for Gravitational Physics
D 30167 Hannover, Germany
E-mail:rolf-hermann.rinkleff@aei.mpg.de

The experiment presented here used a fixed frequency resonant coupling laser and a tunable probe laser to measure the optical properties in a cesium atomic beam in in the cesium D_2 line. Using a third off-resonant laser a heterodyne interferometer performed simultaneous absorption and phase shift measurements of the coupling or the probe laser [1]. In this research several different measurements of absorption and dispersion were performed. The signal features of the transmitted intensities of the probe and coupling laser showed strong differences in the vicinity of the hyperfine transitions excited by the probe and coupling laser. Light induced birefringence, electromagnetically induced absorption (EIA), electromagnetically induced transparency (EIT), and normal absorption were observed.

In the closed transition 6s $^2S_{1/2}$, F=4 — 6p $^2P_{3/2}$, F=5, while the probe laser swept through the resonance, the signal of the probe laser showed EIA. Simultaneously an enhanced transparency of the coupling laser appeared, combined with a further central absorptive peak at zero probe laser detuning, in agreement with theoretical prediction [2]. In the closed transition 6s $^2S_{1/2}$, F=3 — 6p $^2P_{3/2}$, F=2 the signals of the probe and coupling lasers showed EIT. In both hyperfine transitions the intensity dependent refractive index of cesium was measured. Large Kerr nonlinearities at low light intensities were observed up to a value of $n_2 \approx 3 \times 1^{-5}$ cm^2mW^{-1}, which is about 14 orders of magnitude larger than the value for quartz. Higher order nonlinear components contributing to the refractive index were also determined.

In an other investigation, the coupling laser was stabilized on the transition 6s $^2S_{1/2}$, F=4 — 6p $^2P_{3/2}$, F=4 while the probe laser was scanned over the transition 6s $^2S_{1/2}$, F=4 — 6p $^2P_{3/2}$, F=5. The probe laser transmitted intensity showed a normal absorption profile, whereas the transmitted intensity orthogonally polarized with respect to the polarization of the probe laser showed a dispersion like profile [3] which could be explained in terms of light induced birefringence. The dependence of this signal on the laser intensities will be discussed.

Acknowledgment: Supported by the grant no. SFB 407 of the Deutsche Forschungsgemeinschaft.

References

[1] L.Spani Molella, R.-H. Rinkleff, K. Danzmann, Phys. Rev. A 72. 041802(R) (2005).

[2] C. Goren, A.D. Wilson-Gordon, M. Rosenbluh, H. Friedman, Phys. Rev. A 69, 053818 (2004).

[3] L.Spani Molella, R.-H. Rinkleff, K. Danzmann, Spectrochimica Acta (in press)

A DFB diode laser for metastable barium pumping

C.Gabbanini

Istituto per i processi chimico-fisici del C.N.R, Via Moruzzi 1, 56127 Pisa, Italy
E-mail: carlo.gabbanini@ipcf.cnr.it

Barium is the only alkaline-earth element that has not been cooled yet. This is because the strongest $6s^2\ ^1S_0 \rightarrow 6s6p\ ^1P_1$ transition is not closed but has several loss channels to metastable states. Efficient and easy-to-handle sources for repumping are therefore necessary to close the loss channels and allow sufficient optical cycling on the cooling transition. The decay occurs from the $6s6p\ ^1P_1$ state to the $5d6s\ ^1D_2$ and $^3D_{1,2}$ states. The strongest transition is the electric-dipole allowed $6s6p\ ^1P_1 \rightarrow 5d6s\ ^1D_2$ at 1.500 μm, with a theoretical transition probability of 2.62 10^5 s^{-1} [1].
A DFB diode laser (Specdilas D-1504), operating at 1.504 μm at room temperature, has been settled in a vacuum box, in order to be cooled below 0° C, extending its wavelength setting range. The diode tunability has been checked by WM spectroscopy of water vapor in the 1.5 μm region using a 0.5 m cell and a InGaAs detector. By analyzing the spectrum, obtained by scanning the diode temperature from 30° C to -20° C, with the HITRAN database of H_2O, the diode frequency can be tuned by more than 20 cm^{-1} with no mode hops.
Next the diode laser has been applied to investigate the $5d6s\ ^1D_2 \rightarrow 6s6p\ ^1P_1$ absorption in a barium see-through hollow cathode lamp (galvatron). The absorption has been detected both by WM spectroscopy and by phase sensitive detection after modulation of the discharge current. The absorption intensity and line width have been studied as a function of the galvatron current. The absorption has been monitored also in a saturated absorption configuration, but no sub-Doppler line feature has been observed. This should be due to velocity-changing collisions (VCC) with neon atoms in the hollow cathode lamp.
The repumping effect of the IR radiation has been observed in a thermal barium atomic beam, under excitation by a c.w.ring dye laser of the $6s^2\ ^1S_0 \rightarrow 6s6p\ ^1P_1$ transition at 553.5 nm and LIF detection. The simultaneous application of this laser with another repumping source should be sufficient to implement laser cooling of barium.

References

[1] V.A.Dzuba and J.S.M.Ginges, Phys.Rev.A 73, 032503 (2006)

A new apparatus for K-Rb degenerate ultracold mixtures

Jacopo Catani, Luigi De Sarlo, Paolo Maioli, Francesco Minardi, Massimo Inguscio

LENS and Dipartimento di Fisica, Universita' di Firenze, Italy

We implemented a new apparatus designed to produce ultracold Rb-K degenerate mixtures with a fast production cycle. This new kind of apparatus should allow us to investigate a relatively unexplored field of atomic physics, those ultracold mixtures of different bosonic species, rich of intriguing research perspectives, exploiting the possibility to change the interactions tuning an external magnetic field. We utilize ^{87}Rb and ^{39}K (or ^{41}K), provided by two independent bright sources (2-Dimensional Magneto-Optical Traps, 2D-MOT). The sample is then laser-cooled by means of a 3D-MOT, and the last phase of evaporative cooling takes place in a novel kind of in-vacuo purely magnetic trap (milli-trap), whose main feature is to give a very strong confinement of the sample with a small energy dissipation. Up to now we achieved Bose-Einstein condensation of the ^{87}Rb atomic sample. This will allow us to use this component as a refrigerator for the bosonic potassium sample, whose self interaction properties do not allow direct evaporative cooling, hence preventing the direct Bose-Einstein condensation of the sample.

Recent improvements in the accuracy and sensitivity of the LNE-SYRTE atomic gravimeter

J. Le Gouët, J. Kim, D. Holleville, A. Clairon, A. Landragin, F. Pereira Dos Santos

LNE-SYRTE, CNRS UMR 8630
Observatoire de Paris, 61 av. de l'Observatoire, 75014 Paris, France
E-mail:julien.legouet@obspm.fr

We use atom interferometry to perform an absolute measurement of the gravitational acceleration g with ^{87}Rb free falling atoms. In our experiment the atomic wave function is splitted and recombined by three stimulated Raman transitions, produced by two counter-propagating lasers. The interferometer phase shift can be written as $\Delta\Phi = \varphi(0) - 2\varphi(T) + \varphi(2T)$, where φ is the phase difference between the two lasers, and T is the time separation between two consecutive pulses. In the ideal case, the interferometer phase shift is related to g by the relation $\Delta\Phi = k_{eff} g T^2$ (where k_{eff} is the difference between the two wave vectors of the lasers) but the signal to noise ratio is limited by any temporal fluctuations of the laser phase difference. Even though the lasers are phase-locked, many sources of phase noise will affect the signal to noise ratio : generation of the reference frequency (quartz oscillators and frequency chain), intrinsic noise of the phase-locked loop (PLL), limited bandwidth of the PLL... As for the accuracy of the absolute measurement of g, one has to take into account many systematic effects : quadratic Zeeman effect, one and two photon light shifts, alignments of the lasers with the local gravity acceleration, frequency dependent phase shifts, Coriolis effect...

I would have introduced some original investigations on the sensitivity of our interferometer in a short oral communication. In this poster I will develop recent improvements in the accuracy and detail the review of the investigated noises sources.

Ionization in a quantized electromagnetic field

I. A. Gonoskov[1], V. A. Mironov[1] and G. A. Vugalter[2]

[1] *Institute of Applied Physics RAS, Nizhny Novgorod, Russia*
[2] *Nizhny Novgorod State University, Nizhny Novgorod, Russia*
E-mail:gonoskov@ufp.appl.sci-nnov.ru

The interaction of a strong electromagnetic field with atoms is a very actual problem of physics which has motivated a large number of theoretical works. In most cases the electromagnetic field was described in a classical consideration. However, it turns out that such a semi-classical approach which uses the quantum consideration for electrons and the classical consideration for electromagnetic field is inapplicable for a large number of interesting and actual problems. Moreover, sometimes it yields mistaken results and often faces with very cumbersome analytical expressions. Our work is devoted to construction of a full quantum model of the field-atom interaction, which uses a quantum description of the electron as well as of the electromagnetic field. It is shown that many difficulties and questionable assumptions and statements of the semi-classical approach can be avoided in the full quantum consideration. As one of the applications of the full quantum theory, the ionization of an atom in a strong electromagnetic field is studied.

We begin with the stationary Schrödinger equation for a free electron and a single-mode photon field with interactions in the dipole approximation [1]. Applying the modified shift operators [2,3] and some new scale transformations, we have solved the initial equation and obtained rather simple expressions for the complete set of egienfunctions and corresponding eigenvalues of the full quantum Hamiltonian. Using this eigenvalues, we have also derived an expression for interaction energy.

To describe ionization, we use a simple model. We consider the atom with one stationary level in the resonator with a single-mode photon field in the dipole approximation in one-dimensional case. Using our analytically obtained result for the transition matrix element, we have found expressions for the ionization rate in different cases. For example, we have modified the Keldysh formula for the multiphoton ionization rate [4] for the quantum electromagnetic field case with arbitrary parameter values. We have also generalized the well-known result for the one-photon ionization rate. We have shown that the quantum effects of the electromagnetic field in different cases can be important in a wide range of intensities.

The work was partly supported by the Russian Foundation for Basic Research (RFBR grant No 06-02-16739).

References

[1] Dong-Sheng Guo and G. W. F. Drake, J. Phys. A: Math. Gen. 25, 3383 (1992).
[2] P. Filipowicz, J. Phys. A: Math. Gen. 18, 1675 (1985).
[3] Dong-Sheng Guo and T Aberg, J. Phys. A: Math. Gen. 21, 4577 (1988).
[4] L. V. Keldysh, Sov. Phys. -JETP 20, 1307 (1965).

Photoionization of fixed in-space H_2^+ in various geometrical arrangements

R. Della Picca[1], P. D. Fainstein[1], M. L. Martiarena[1] and A. Dubois[2]

[1] *Centro Atómico Bariloche, 8400 Bariloche, Argentina*
[2] *Laboratoire de Chimie Physique-Matière et Rayonnement, Université Pierre et Marie Curie, 75005 Paris, France*
E-mail: pablof@cab.cnea.gov.ar

Angular distributions of electrons emitted in collisions between photons, electrons and ions with atoms and molecules provide detailed information about the collision dynamics. These reactions involve the knowledge of many-particle bound and continuum states. While the former can be obtained accurately with Hartree-Fock or Density Functional methods, much less is known about the continuum. In many cases these states cannot be obtained exactly and approximate method must be employed. One of the most common is to approximate the exact many-particle continuum wavefunction by a product of two-particle continuum wavefunctions. The only way to check the accuracy of this approximation is to compare the results with experimental data or with exact calculations.

To test certain approximations it is best to consider model systems. Recently, exact calculations, within the dipolar and Born-Oppenheimer approximations, of differential cross sections for photoelectrons emitted from fixed in-space H_2^+ have been performed [2-3]. Different geometrical configurations of the internuclear axis and polarization vector were considered. The exact results have been compared with calculations employing the 2C-wavefunction, which approximates the H_2^+-continuum by a product of two two-particle continuum wavefunction centered on each nuclei of the target [1]. Large discrepancies have been found showing that the 2C-approximation fails at low photoelectron energies (below 100 eV). A partial wave expansion of the transition amplitude shows that the 2C-approximation is not able to represent features which are due to the two-center nature of the target. The angular distribution at different photoelectron energies is determined by the weights of partial waves with definite symmetries. Recent calculations but for photoionization by high intensity, high frequency, ultrashort laser pulses [4] show great similarities showing therefore that the nature of the two-center potential produces general features in the photoelectron spectra which can not be accounted for by perturbative approximations.

References

[1] M. Walter, J. Briggs, J. Phys. B **32**, 2487 (1999).
[2] T. N. Rescigno, D. A. Horner, F. L. Yip, C. W. McCurdy, Phys. Rev. A **72**, 052709 (2005).
[3] R. Della Picca, P. D. Fainstein, M. L. Martiarena, A. Dubois, J. Phys. B **39**, 473 (2006).
[4] S. Selstø, J. F. McCann, M. Førre, J. P. Hansen, L. B. Madsen, Phys. Rev. A **73**, 033407 (2006).

Precise *ab initio* relativistic calculation of highly-charged ions

S. Kotochigova[1,3], I.I. Tupitsyn[2] and P. J. Mohr[3]

[1] *Temple University, Physics Department, Philadelphia, USA*
[2] *St. Petersburg University, Physics Department, St. Petersburg, Russia*
[3] *National Institute of Standards and Technology, Gaithersburg, USA*
E-mail:skotoch@temple.edu

We developed an *ab initio* multiconfiguration Dirac-Fock-Sturm method combined with a many-body perturbation theory for the precise calculation of inner-and-outer-shell transitions in highly-charged ions. Extensive non-orthogonal basis sets contain both Dirac-Fock and Sturm atomic wave functions allowing an efficient description of correlation effects and a fast convergence of the configuration interaction procedure. The major quantum-electrodynamics effects are obtained by calculating the one-electron Lamb shifts using an approach developed in [1] and applying an effective nuclear charge. For a given one-electron state, the effective nuclear charge was chosen to reproduce the related Dirac-Fock electron charge density at the Compton wavelength distance from the nucleus. We present results of our calculation for X-ray spectra of Fe VI - Fe XIV detected by the Reflection Grating Spectrometer on a board of satellite-borne X-ray telescope XMM-Newton. We compared our data with the observed absorption spectra and results of other theoretical studies.

References

[1] S. Kotochigova, P. J. Mohr, and B. N. Taylor, Can. J. Phys. 80, 1373 (2002).

Observation and interpretation of Nd^{3+} and Tm^{3+} free ion spectra

J.-F. Wyart[1], A. Meftah[1], W.-Ü L. Tchang-Brillet[2,3] and N. Champion[2]

[1] *Laboratoire Aime Cotton (CNRS UPR3321), Bat. 505, centre universitaire Paris-11, 91405-Orsay, France*
[2] *LERMA, (CNRS UMR8112), Observatoire de Paris-Meudon F-92195 Meudon, France*
[3] *Université Pierre-et-Marie Curie (Paris6)*
E-mail:jean-francois.wyart@lac.u-psud.fr

Triply ionized lanthanides are of highest interest for many reasons. The applications of their compounds to lasers, optics and quantum information processing, phosphor developments in the lighting industry are well-known. So far, interpretations of their free ion spectra had failed except for Pr IV, Tb IV and Yb IV. In the case of Nd IV, spectrograms made at NBS (1980) have been completed by new observations of sliding spark spectra on the 10.7m vacuum ultraviolet spectrograph at the Meudon Observatory. Various conditions of excitation helped to select Nd IV in wavelengths lists containing also Nd III and Nd V. In a first analysis, more than 550 lines have been classified as transitions between 37 levels of $4f^3$ and 85 levels of $4f^25d$. The parametric interpretation of $4f^3$ levels enables checks of effective parameters that represent far configuration interaction [1]. The interpretation of the first excited configurations is in progress and their lowest levels are $4f^25d\ ^4I_{9/2}$: 70819.18 cm^{-1}, $4f^26s\ ^4H_{7/2}$: 110056.55 cm^{-1} and $4f^26p\ ^4I_{9/2}$: 147544.85 cm^{-1}. Perturbations of high odd levels by the core-excited configuration $5p^54f^4$ are obvious.

paragraph
The same methods are now applied to the Tm IV spectrum for which spectral plates are being produced at Meudon. The strongest transitions of the array $4f^{12}$-$4f^{11}5d$ lead to derive the ^3H,^3F,^1G,^1D anf ^1I terms of the ground configuration. Throughout this work, the comparison of observed intensities with transition probabilities calculated by the methods of Cowan [2] was very helpful.

french CNRS-PNPS program is greatly acknowledged.

References

[1] J.-F. Wyart, A. Meftah, A. Bachelier, J. Sinzelle, W.-U L. Tchang-Brillet, N. Champion, N. Spector, J. Sugar, J. Phys. B: At. Mol. Opt. Phys. **39**, L77-L82 (2006)
[2] R. D. Cowan, *The Theory of Atomic Structure and Spectra*, Univ. of Calif. Press, Berkeley (1981) and computer codes

Comparison of models for evolution of x-ray satellite lines

T. Mukoyama[1], M. Uda[2] and L. Kövér[3]

[1]*Kansai Gaidai University, Hirakata, Osaka, 573-1001 Japan*
[2]*Waseda University, Doshita 2-40-5, Nerima-ku, Tokyo, 179-0086 Japan*
[3]*Institute for Nuclear Research of the Hungarian Academy of Scinces (ATOMKI), H-4001 Debrecen, Hungary*
E-mail:mukoayma@kansaigaidai.ac.jp

When inner-shell photoionization takes place, it is well known that other electrons in the same atom have a small, but definite, probability to be excited into unoccupied bound states or ionized to the continuum [1]. Experimentally such multi-vacancy states can be observed as satellite lines in x-ray emission spectra and Auger electron spectra.
When the incident energy of photons is high, the photoelectron can quickly escape away from the atom without any interaction with atomic electrons. Atomic electrons are excited by the sudden change in atomic potential and this process can be described in the sudden approximation. The atomic excitation probability is given in terms of imperfect overlap between the initial- and final-state wave functions.
For low-energy incident photons, the velocity of the photoelectron is low and the change in the atomic potential due to creation of the inner-shell vacancy is so slow that atomic orbitals can relax adiabatically. The electron transition probability should be treated in the time-dependent perturbation theory. Up till now there have been developed three theoretical models for electron transition in the adiabatic approximation.
Thomas [2] assumed that the time dependence of the Hamiltonian due to the presence of the photoelectron is written by the error function. Vatai [3] retained only the monopole term in multipole expansion of the Coulomb interaction between the photoelectron and atomic electrons and adopted the classical straight-line trajectory for the ejected photoelectrons. In the recent model of Roy *et al.* [4] the time-dependent part of the Hamiltonian is assumed to be the exponential function and the final-state electron is in the continuum state.
The Thomas model has been often applied to analyze the experimental results for evolution of x-ray satellite lines, but other models have been scarcely used. Furthermore, no comparison of these three models has been reported so far. In the present work, we modified the model of Roy *et al.* and obtained an additional model. The experimental evolution curves for x-ray satellite lines accompanying photoionization were fitted to these four models and comparison between them is made. The difference in the approximations used for these models is discussed.

References

[1] T. Mukoyama and Y. Ito, Nucl. Instr. and Meth. Phys. Res. B87, 26 (1994).
[2] T. D. Thomas, Phys. Rev. Lett. 52, 417 (1984).
[3] E. Vatai, Phys. Rev. A 38, 3777 (1988).
[4] M. Roy, J. D. Lindsay, S. Louch and S. J. Gurman, J. Synchrotron Rad. 8, 1103 (2001).

High lying doubly excited states and anomalies in photoionization of He below N=4 and N=5 He^+ thresholds

L. Argenti[1] and R. Moccia[2]

[1]*Dipartimento di Chimica Applicata e Scienza dei Materiali (DICASM), Università di Bologna, via Saragozza 8, I-40136 Bologna, Italy*
[2]*IPCF, CNR, via G. Moruzzi 1, 56100 Pisa, Italy*
E-mail:l.argenti@sns.it

A new B-spline based K-matrix method has been implemented to investigate photoionization in atoms with simple valence shells. Thanks to the flexibility of B-splines, a common basis can be used to reproduce all the essential features of continuum wave functions together with the *ab initio* description of a large number of doubly excited (N, n) autoionizing states. A detailed study is presented of doubly excited multiplets below N=4 and N=5 ionization thresholds up to $n = 22 \div 23$. The first intruder state in autoionizing series, $[031]_5^+$ (parabolic quantum numbers $[N_1 N_2 m]_n^A$ [1]), which is known to fall at only 10 meV below N=4 threshold, has been resolved theoretically for the first time [2]. Computed total cross section near the intruder state compares favorably to the accurate measurement (σ= 2 meV) of Püttner *et al* [3]. Below N=5 threshold, multiplet series are prolonged well beyond the two well known $[041]_6^+$ and $[131]_6^+$ intruder states. The present direct approach to complex spectra with highly excited Rydberg states seems to be a valid alternative to multichannel quantum defect theory (MQDT)[4-6] and to complex rotation method [7,8].

References

[1] J. M. Rost *et al*, J. Phys. B: At. Mol. Opt. Phys. **30**, 4663 (1997)
[2] L. Argenti and R. Moccia, J. Phys. B: At. Mol. Opt. Phys. (2006) (*submitted*)
[3] R. Püttner *et al* J. Electron Spectros. **101-103**, 27 (1999)
[4] M. J. Seaton, Proc. Phys. Soc. **88**, 801 (1966)
[5] U. Fano, Phys. Rev. A **2**, 1866 (1970)
[6] M. J. Seaton, Rep. Prog. Phys. **46**, 167 (1983)
[7] B. R. Junker, Adv. At. Mol. Phys. **18**, 207 (1982)
[8] W. P. Reinhardt, Ann. Phys. Chem. **33**, 223 (1982)

Inner-shell resonant photodetachment of C^-: Dramatic role of dynamical relaxation in collective response

G. Kashenock and V. Ivanov

St.Petersburg Polytechnical University, St.Petersburg 195251, Russia
E-mail:galya.abroad@mail.ru

The strong near-threshold resonance in the photodetachment from inner $1s$-shell of the carbon negative ion is investigated within the many-body theory approach, the RPAE&DEM [1-3]. The shape-resonance parameters, energy $\varepsilon_{\rm res} = 0.857$ eV and width $\Gamma = 0.122$ eV, are determined. The complex, mixed ("shape-Feshbach") nature of the resonance is revealed. The calculated cross sections are in fair agreement with the recent experimental data [4]. The collective character of the response to the external electromagnetic field in the strongly correlated C^- target is clearly demonstrated, with the dynamical relaxation of the core being the most pronounced of the collective effects.

We use our method for simultaneous inclusion of the dynamic polarization potential generated in a system "neutral atomic core + electron", dynamic relaxation (screening) (these correlations are treated within the Dyson equation method, DEM) and electronic correlation within the RPAE. One may pick out certain infinite series of Feynman diagrams in the perturbation expansion over electron-electron interaction with the definite physical meaning. We include the related many-particle corrections one-by-one and analyze their particular contributions to calculated observables. Earlier the approach has been applied successfully to calculations of characteristics (cross sections, angular distribution parameters, photoelectron phaseshifts) for the resonant photodetachment from outer shells of few-electron open-shell negative ions, *e.g.* He^-, B^-, C^- [1-3]. Now we expand our method to deal with an even more sensitive probe for many-electron effects - the *inner-shell* resonant photodetachment (a process of a keen interest for both theory and experiment in the recent five years) from the deep $1s$-subshell of C^-.
Within the RPAE&DEM many-electron correlations are considered for the initial ion-state and for the photoelectron moving in the field of the relaxing atomic core in the process

$$C^-(1s^2\ 2s^2\ 2p^3\ \ ^4S) + \hbar\omega \rightarrow C(1s\ 2s^2\ 2p^3\ \ ^5S) + e^-(\varepsilon p)\ \ (^4P).$$

We introduce dynamical polarization and relaxation corrections in the description of photoelectron propagator by solving the Dyson equation for the reducible self-energy part $\tilde{\Sigma}$ of Green's function with the effective screening interaction included.
The whole atomic system is involved in C^- photodetachment process, core electrons and outgoing photoelectron being strongly coupled by correlational interaction. The decisive role in forming of the resonance structure in the vicinity of the $1s$-threshold is proved to belong to the dynamical relaxation of the core. This effect leads to transformation of the discrete photoelectron state, quasi-bound in the open $2p$-shell, into the strong narrow shape resonance in the photodetachment $p-$continuum (with a peak of $\sim$45 Mb in the cross section at $\omega = 281.8$ eV). The resonance maintains the mixed nature, of Fechbach-origin, affected also by the dynamical polarizational correlations. This feature manifests itself lucidly in the photoelectron phaseshift behavior. It is shown that only comprehensive inclusion of dynamical collective effects in its complex interplay yields an adequate description of the process and an agreement with the experimental data for absolute cross sections [4].

References

[1] V. K. Ivanov, G. Yu. Kashenock, G. F. Gribakin,A. A. Gribakina, J.Phys.B 29, 2669 (1996). [2] G. Yu. Kashenock and V. K. Ivanov, J.Phys.B 30, 4235 (1997). [3] G. Yu. Kashenock and V. K. Ivanov, Phys.Lett.A. 245, 110 (1998). [4] T. W. Gorczyca, Rad.Phys.Chem. 70, 407 (2004).

Rydbergseries of Xe doubly excited states between 25.25 eV and 25.50 eV observed after excitation with extremely narrow bandwidth monochromatized synchrotron radiation

W. Kielich[1], S. Klumpp[1] L. Werner[1] and A. Ehresmann[1] I.D. Petrov[2], Ph. V. Demekhin[2] and V. L. Sukhorukov[2]

[1] *Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology, University of Kassel, Germany*

[2] *Rostov State University of Transport Communications, Rostov-on-Don, Russia*

E-mail: ehresmann@physik.uni-kassel.de

Rydbergseries of Xenon doubly excited states $5s^2 5p^4 n\ell n'\ell'$ between exciting-photon energies of 25.25 eV and 25.50 eV were observed using photon-induced fluorescence spectroscopy (PIFS)[1] in the spectral range of the vacuum ultraviolet (VUV) between 92 nm and 100 nm. For these experiments synchrotron radiation from the electron storage ring BESSY II, Berlin, at the undulator beamline U125/2-10mNIM monochromatized by a 10m-normal incidence monochromator equipped with a grating of 1200 l/mm was used. It was possible to identify the recorded resonance structures in the excitation cross section of the fluorescence line $5p^5\ ^2P_{3/2} - 5p^4(^3P_2)5d[1]_{3/2}$ at $\lambda = 95.95\,nm$ [2] as Rydbergseries $5s^2 5p^4 5dn'p$ starting with $n' = 15$ using the method published in [3].

References

[1] Schmoranzer et.al., Nucl. Instr. Meth. Phys. Res. A 467-468, p1526-1528 (2001)

[2] NIST Atomic Spectra Database, Version 3.0.3,
http://physics.nist.gov/PhysRefData/ASD/index.html
and References therein

[3] Ehresmann et.al., J. Phys. B: At. Mol. Opt. Phys 37, L251-L257 (2004)

Multiconfiguration Dirac–Fock wavelengths and transition rates in the X-ray spectra of highly charged Ga-like ions from Yb^{39+} to U^{61+}

P. Quinet[1,2], E. Biémont[1,2], P. Palmeri[1] and E. Träbert[3]

[1] *Astrophysique et Spectroscopie, Université de Mons-Hainaut, B-7000 Mons, Belgium*
[2] *IPNAS, Sart Tilman B15, Université de Liège, B-4000 Liège, Belgium*
[3] *Physics and Advanced Technologies, Lawrence Livermore National Laboratory, Livermore, CA 94550-9234, USA*
E-mail:patrick.palmeri@umh.ac.be

A series of wavelength measurements of resonance transitions in highly charged gallium-like ions have been carried out recently at the Lawrence Livermore National Laboratory Electron Beam Ion Trap (LLNL-EBIT) facility. They concerned W XLIV [1], Os XLVI [2], Au IL [3], Bi LIII, Th LX and U LXII [2]. These new experimental data justify a detailed theoretical analysis of radiative parameters for heavy ions ($Z \geq 70$) along the isoelectronic sequence.

In the present study, a multiconfiguration Dirac–Fock (MCDF) technique has been used for computing the wavelengths and transition probabilities for lines in the X-ray spectra of the gallium-like ions from Yb LX to U LXII. Results are presented for the $4s^24p - 4s^24d$ and $4s^24p - 4s4p^2$ allowed transitions (E1) as well as for the forbidden transitions (M1 and E2) within the ground configuration $4s^24p$. A comparison of the calculated wavelengths with the few experimental results available is presented. These new theoretical results will be useful as a test of experimental observations, and their predictive power will be valuable where experimental data are missing.

References

[1] S.B. Utter, P. Beiersdorfer and E. Träbert, Can. J. Phys. 80, 1503 (2002).
[2] E. Träbert, P. Beiersdorfer, K.B. Fournier and M.H. Chen, Can. J. Phys. 82, 1 (2004).
[3] E. Träbert, P. Beiersdorfer, K.B. Fournier, S.B. Utter and K.L. Wong, Can. J. Phys. 79, 153 (2001).

k

Low-density plasma channels generated by the femtosecond pulses

N. Vujicic, H. Skenderovic, T. Ban, D. Aumiler and G. Pichler

Institute of Physics, Bijenicka 46, Zagreb, Croatia
E-mail:natasav@ifs.hr

Femto second pulses are well known to propagate in the atmosphere over several tens of meters as plasma channels (filaments). The basic principle of this self-guiding is a dynamical equilibrium between self-focusing due to the Kerr effect and defocusing effects due to the laser plasma generation. The plasma channel is induced along the propagation of the fs laser pulses, by multiphoton or tunneling ionization of medium. For theoretical description of fs laser propagation through different media the complete dynamic between self-focusing, diffraction and ionization have to be involved in solving the nonlinear Schrdinger equation *(NLS)*. Since the free charges contribute in diffraction process, it is crucial to determine their concentrations for any further analysis of the fs laser propagation.
In our paper [1] we have characterized the plasma channel formed in the trail of an intense femtosecond laser pulse propagating through the low pressure helium, air and nitrogen gas. Relaxation times of the generated plasma channel up to 60 μs were measured, depending on the gas, concentration and applied voltage between the electrodes. From the solutions of the kinetic model for charged particle concentrations we concluded about the dominant mechanisms presented in our experimental system. By instantaneous laser ionization the initial electron density $n_e(0)$ is created. The $n_e(t)$ decay exponentially in time predominantly due to the electron-attachment of neutrals. In low density plasmas the recombination processes do not play crucial role as in the case when the plasma is generated at atmospheric pressure.
For the theoretical calculations of the measured time-dependent plasma channel a mathematical model proposed in [2] based on the equivalent current circuit is used. By comparing the calculated and measured time-dependent $U_{OSC}(t)$ voltage, the electron-attachment coefficients η and the initial electron densities $n_e(0)$ for a given conditions are obtained. The electron densities in the 10^8-10^9 cm^{-3} range are found. The electron-attachment rate coefficient η and the *DC* plasma channel conductivity are in good agreement with the previously reported values.

References

[1] N. Vujicic, H. Skenderovic, T. Ban, D. Aumiler, G. Pichler, App. Phys. B, **82**, 377 (2006).
[2] H.D. Ladouceur, A.P. Baronavski, D. Lohrmann, P.W. Grounds, P.G. Girardi, Opt. Commun., **189**, 107 (2000).

Time-resolved emission and VUV imaging at low temperature colliding plasmas.

J. Pedregosa-Gutierrez, K.D. Kavanagh, H. de Luna, And J.T. Costello

NCPST and Scool of Physical Science, Dublin City Univeristy, Dublin, Ireland.
E-mail:jofre.pedregosa@dcu.ie

We report measurements on the collision of two line plasmas formed by splitting a laser beam and focussing the two resultant beams on a flat calcium target using a cylindrical lens. The study of colliding plasmas is a topic of interest to a number of communities such as those working on fusion energy generation and x-ray lasers and hence, most work to date on them has involved high temperature (0.1-3KeV) plasmas. However, 'technological' laser plasmas such as those used in pulsed laser deposition of materials[1] are usually of a much lower temperature ($< 5eV$). So the motivation for our current study is to explore the dynamics of such plasmas in a counter-propagating colliding plasma geometry[2], with a view to developing the layer formed at the collision interface as a potentially novel materials deposition source.

Line plasmas were formed by focussing 15ns pulses of 20-50mJ at 1064nm on a flat Ca target to produce focal footprints of 8mm×0.1mm. The weakly ionized plasmas were studied using both broad-band and spectrally filtered ICCD imaging[3]. In addition we have used VUV absorption imaging[4,5] to study ground state species. These techniques helped to track the evolution of atomic and singly charged calcium species in the plumes and stagnation layer of the collision interface. Work is ongoing but it appears that collisionality is lower than expected for these 'cold' plasmas.

References

[1] K. W. Mah, J.-P. Mosnier, E. McGlynn, M. O. Henry, D. O'Mahony and J. G. Lunney App. Phys. Let., **80** (2002) 3301
[2] E.Camps, L. Escobar-Alarcón, E. Haro-Poniatowski, M. Fernández-Guasti, App. Surf. Sci., **197-198** (2002) 239-245
[3]D. Doria, K. D. Kavanagh, J. T. Costello and H. Luna, Meas. Sci. Technol., **17** (2006) 670674
[4]J.S. Hirsch and E.T. Kennedy and A. Neogi and J.T. Costello, Rev. Sci. Inst., **74** (2003) 2996
[5]J.S. Hirsch and K.D. Kavanagh and E.T. Kennedy and P. Nicolosi and L. Poletto and J.T. Costello. Laser and Particle Beams, **22** (2004) 207

Stability and fragmentation of multiply charged clusters of fullerenes

Masato Nakamura[1], and P. -A. Hervieux[2]

[1] *College of Science and Technology, Nihon University, Funabshi, Japan*
[2] *Institut de Physique et Chimie des Matériaux de Strasbourg, GONLO, 23 rue du Loess, 67034 Strasbourg, France*
E-mail:mooming@phys.ge.cst.nihon-u.ac.jp

Stability and fragmentation of multiply charged clusters of fullerenes $(C_{60})_n^{z+}$ are theoretically studied. The energy of charged clusters is estimated both by using the results of accurate calculations for $(C_{60})_n$ clusters [1] and by the liquid drop model. In the accurate calculation, geometrical shell effects are taken into account. Energy barriers for various fragmentation channels are calculated using a simple model [2] in which two fragments clusters are in contact at the transition state. For all the cases studied, among various decay channels, the lowest energy barrier corresponds to the emission of singly-charged monomer C_{60}^+. Appearance sizes $n_c(z)$ (the cluster with charge z is unstable for $n < n_c(z)$ are calculated and compared with recent measurements by Manil *et al.* [3]. As shown in Table 1, the experimental measurements are reproduced within a considerable accuracy by both methods. Although the liquid drop model essentially explains the appearance size, geometric shell effects play an important role in particular for highly charged clusters. Furthermore, due to shell effects, a multiply charged cluster is found to be not always stable even if its size is larger than the appearance size. Detailed results are presented in article [4].

z	Present Work	Experiment
2	7 (9)	5
3	13 (15)	10
4	23 (23)	21
5	31 (32)	33
6	35 (42)	–
7	38 (54)	–

Appearance sizes, $n_c(z)$, for $(C_{60})_n^{z+}$ together with experimental data [3]. The numbers in parenthesis correspond to the predictions of the liquid drop model.

References

[1] O. Echt, D. Kreisle, E. Recknagel, J. J. Saenz, R. Casero, and J. M. Soler, Phys. Rev. A **38**, 3236 (1988).
[2] P. J. K. Doye, D. J. Wales, W. Branz, and F. Calvo, Phys. Rev. B **64**, 235409 (2001).
[3] B. Manil, L. Maunoury, B. A. Huber, J. Jensen, H. T. Schmidt, H. Zettergren, H. Cederquist, S. Tomita, and P. Hvelplund, Phys. Rev. Lett. **91**, 215504 (2003).
[4] M. Nakamura and P. -A. Hervieux, submitted to Chem. Phys. Lett. (2006).

Transmittivity measurements by means of squeezed vacuum light

Virginia D'Auria[1], Corrado de Lisio[1,2] Alberto Porzio[2,3] and Salvatore Solimeno[1,3]

[1] *Dipartimento Scienze Fisiche, Università di Napoli "Federico II", Napoli, Italy*
[2] *Coherentia – CNR–INFM, Napoli, Italy*
[3] *C.N.I.S.M. Napoli, Italy*
E-mail:alberto.porzio@na.infn.it

A method for probing the transmittivity T of a sample with squeezed vacuum radiation is discussed. Standard methods rely on direct measurement of the radiation intensity entering and leaving the sample. Sufficient accuracy can be achieved by using beams so intense to contrast the shot–noise and the detector noise. Nevertheless, in some circumstances, using high input intensity is either not useful (in case of very low absorption) or unwise (strongly non-linear materials or samples whose structure may be altered by intense photon fluxes). In the proposed method the probe beam is a squeezed vacuum field (SV) generated by a below threshold Optical Parametric oscillator (OPO) and then, characterized by a balanced homodyne detector. The propagation through non resonant media transforms the state into another SV one with different variances of the field quadratures ΔX_ϕ^2. The change of the variance ΔX_ϕ^2 is used for retrieving the transmittivity T by measuring the field fluctuations in a suitable spectral range. The dependence of the accuracy of the proposed method on the SV state parameters is also examined and the method accuracy is compared with that achievable with standard techniques. The main advantage of this method is a very low number of photons interacting with the sample. The probe beam is amplified by the homodyne local oscillator, and the effects of the detector technical noise can be neglected even in the limit of very feeble beams. The effective dose transferred to the sample is reduced of some order of magnitude with respect to standard techniques based on intensity measurements on coherent beams.
To test the method, it has been applied to neutral density filters of know absorbance using as a probe a SV (@1064 nm) of few pW power. The T values obtained by tomographic reconstructing the state parameters are only few percents less accurate than those relative to a filter characterization based on the absorption of a coherent beam of 1mW. The accuracy is of the order of the quantum limit, confirming that the method does not suffer substantially from technical noise sources.

Conical emission from rubidium vapor pumped by fs laser

Hrvoje Skenderović, Nataša Vujičić, Ticijana Ban, Damir Aumiler, and Goran Pichler

Institute of physics, Bijenička cesta 46, Zagreb, Croatia
E-mail:hrvoje@ifs.hr

An intense, near-resonant laser field can significantly modify the absorption and emission spectra of an atomic system. When a blue-detuned, intense, near-resonance laser beam propagates through the atomic vapor, a diffuse ring of light may be observed around the central laser spot in a far field. This phenomenon has been referred in the literature as conical emission (CE). CE was observed both in resonant and nonresonant media, using pulsed nanosecond [1] and cw [2] lasers. Sarkisyan et. al. reported the observation of potassium atomic vapor CE produced by 2 ps laser pulses [3]. Recently, we reported about first experimental observation of CE based on a Cs_2 molecular resonance using a femtosecond laser [4].

In the present work we report about CE in rubidium vapor induced by $\sim$ 10 nJ, 100-fs laser pulses. The CE was observed when the central laser wavelength was in the 740-840 nm interval which covers Rb D2 and D1 resonance lines. The self-focusing of the laser beam, spatial and spectral characteristics of the observed CE, cone angle dependence on the laser wavelength are described. The temporal characteristics of the laser pulses propagated through the Rb vapor is measured using intensity cross-correlation with SHG crystal. Several physical mechanisms that could lead to the CE are discussed.

References

[1] D. J. Harter and R. Boyd, Phys. Rev. A 29 739 (1984).
[2] J.F. Valley, G. Khitrova, H.M. Gibbs, et. al. Phys. Rev. Lett. 64, 2362 (1990).
[3] D. Sarkisyan, B.D. Paul, S.T. Cundiff, et. al. J. Opt. Soc. Am. B 18, 218 (2001).
[4] D. Aumiler, T. Ban and G. Pichler, Phys. Rev. A 71, 063803 (2005).

Transformation of the laser line shape in multi-photon processes

N. Kolachevsky[1,2], A. Matveev[1,2], J. Alnis[1,3], S. Bergeson[1,4], P. Fendel [1] and T.W. Hänsch[1,5]

[1] *Max-Planck-Institute for Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany*
[2] *P.N. Lebedev Physics Institute, Leninsky prosp. 53, 119991 Moscow, Russian Federation*
[3] *University of Latvia, 19 Rainis Blvd., LV-1586 Riga, Latvia*
[4] *Brigham Young University, N283 ESC, Provo, UT 84602, USA*
[5] *Ludwig-Maximilians-University, Munich, Germany*
E-mail:kolach@fromru.com

Since the first experiments in the late 1970s, the $1S-2S$ spectroscopy in atomic hydrogen and deuterium has provided essential data for fundamental physics. One of the present experimental objectives is to reduce the size of the experimental setup since it will open not only the possibility to create a transportable optical frequency reference, but also will give way for completely new experiments like $1S-2S$ spectroscopy in antihydrogen, tritium and positronium.

Recently, we have demonstrated a compact solid-state laser source for $1S-2S$ spectroscopy in atomic hydrogen [1]. It is based on a frequency-quadrupled master-oscillator power-amplifier diode laser system operating at 972 nm. The frequency of the diode master-oscillator is stabilized to a highly stable optical reference cavity. Since in this case the excitation of the $1S-2S$ transition corresponds to an 8-photon process (two second harmonic generation stages and two-photon absorption), the question of how the spectral line shape of the laser transforms in the frequency doubling and other multi-photon processes becomes critical.

Here we present a detailed experimental analysis of the power spectrum of the diode laser at 972 nm used for hydrogen spectroscopy and its transformation in the frequency doubling process. We compare the power spectrum of the beat notes between the new solid state system and an independent highly stable dye laser-based system at 486 nm and 243 nm.

We experimentally demonstrate that the ratio η of the diode laser power falling in the narrow spectral peak (*carrier*) to the total laser power transforms as $\eta' = \eta^4$ in the optical frequency doubling process, similar to the radio-frequency domain [2]. For our diode laser system we reached $\eta_{972\,\mathrm{nm}} = 0.99$ which corresponds to the $1S-2S$ excitation efficiency in the narrow spectral line of $\eta_{121\,\mathrm{nm}} = \eta^4_{243\,\mathrm{nm}} = \eta^{16}_{486\,\mathrm{nm}} = \eta^{64}_{972\,\mathrm{nm}} \simeq 0.5$ for our new source.
We also study the transformation of the carrier spectral line width in the frequency doubling process. We have demonstrated that in the case of dominating deep low-frequency frequency noise the line width will be doubled, while in the case of dominating shallow hi-frequency noise it will be quadrupled. For highly-stabilized optical reference cavities the main noise source is acoustics which corresponds to the first case.
Significant progress in stabilization of the 972 nm laser has been recently achieved by implementing the new concept of the optical cavities in vertical configuration [3] which resulted in sub-20 Hz spectral line widths and significant reduction of the size of the hydrogen laser system.

References

[1] N. Kolachevsky, J. Alnis, S. D. Bergeson, and T. W. Hänsch, *Phys. Rev.* A **73**, 021801(R) (2006).
[2] H.R. Telle, "Absolute Measurements of Optical Frequencies" in: *Frequency Control of Semiconductor Lasers, p. 137, ed. M. Okai, John Wiley & Sons, (1996).*
[3] M. Notcutt, L.-S. Ma, J. Ye, and J.L. Hall, Opt. Lett. **30***, 1815 (2004).*

Enhanced Four-Wave Mixing in mercury isotopes, prepared by Stark-chirped rapid adiabatic passage

M. Oberst[1], J. Klein, and, T. Halfmann

[1] *Department of Physics,*
University of Kaiserslautern, Germany
E-mail: oberst@physik.uni-kl.de

We demonstrate significant enhancement of four-wave mixing in coherently driven mercury isotopes to generate vacuum-ultraviolet radiation at 125 nm [1]. The enhancement is accomplished by preparation of the mercury atoms in a state of maximum coherence [2], i.e. maximum nonlinear-optical polarization, driven by Stark-chirped rapid adiabatic passage (SCRAP) [3,4]. In this technique a pump laser at 313 nm excites the two-photon transition between the ground state $6s^2\ ^1S_0$ and the target state $7s\ ^1S_0$ in mercury. A strong, off-resonant radiation field at 1064 nm generates dynamic Stark shifts. These Stark shifts serve to induce a rapid adiabatic passage process on the two-photon transition. During the process a coherent superposition of the two states is established, which enhances the nonlinear-optical polarization in the medium to the maximum possible value. The maximum coherence permits efficient four-wave mixing of a pump laser and an additional probe laser at 626 nm. The efficiency is further enhanced, as the SCRAP process allows to stimulate the *complete* set of different mercury isotopes to participate in the frequency conversion process. This enlarges the effective atomic density of the medium. Thus, we observe the generation of vacuum-ultraviolet radiation at 125 nm enhanced by more than one order of magnitude with respect to conventional frequency conversion [1]. Parallel to the frequency conversion process, we monitored the evolution of the population in the medium by laser-induced fluorescence. These data demonstrate efficient coherent population transfer by SCRAP.

References

[1] M. Oberst, J. Klein, and T. Halfmann, Opt. Comm. Special Issue on "Quantum Control of Light & Matter", *in press to be submitted soon.*

[2] M .Jain, H. Xia, G. Y. Yin, A. J. Merriam, and S. E. Harris, *Phys. Rev. Lett.* **77** (1996) 4326

[3] N. V. Vitanov, T. Halfmann, B. W. Shore, and K. Bergmann, *Annu. Rev. Phys. Chem.* **52** (2001) 764.

[4] T. Rickes, L. P. Yatsenko, S. Steuerwald, T. Halfmann, B. W. Shore, N. V. Vitanov, and K. Bergmann, *J. Chem. Phys.* **113** (2000) 534.

[5] http://www.quantumcontrol.de

Some corrections to GRASP92

K.C. Froese Fischer[1], G. Gaigalas[1,2] and Y. Ralchenko[1]

[1] *National Institute of Standards and Technology, Gaithersburg, USA*
[2] *Vilnius pedagogical university, Vilnius, Lithuania*
E-mail:gaigalas@itpa.lt

The GRASP92 package[1] is a suite of programs for atomic structure calculations based on Dirac-Hartree-Fock theory. In this abstract we report corrections that concern three issues. Corrections to a logical error are reported that affect extended optimal level (EOL) calculations important for correlation studies. The removal of a limitation on diagonal energy parameters is recommended for correlation orbitals.

The third correction removes an error in the evaluation of one-electron matrix elements for tensors of rank greater then zero. In order to test the presence of an error, MCHF Breit-Pauli calculations were performed for S II for all levels of $3p^3$ using wave function expansions over the configurations $3s^23p^3$ and $3p^5$. Orbit-orbit effects were omitted in the calculation of the Breit-Pauli Hamiltonian. The resulting radial functions from the MCHF[2] calculation were used to define low order, two component radial functions for Dirac theory. These orbitals were the input for the Dirac-Coulomb configuration interaction calculation using `rci92`. The suspicion of an error was confirmed when the same wave functions were used with the code REOS[3] for calculation of transition rates from $^2D^o_{3/2}$, $^2D^o_{5/2}$, $^2P^o_{1/2}$, $^2P^o_{3/2}$ to the $^4S^o_{3/2}$ ground state in length and velocity form. Though this simple calculation does not give results with good agreement between length and velocity, there is good agreement between MCHF Breit-Pauli, REOS and, in all but one case, with GRASP92 in the length form. For the $^4S_{3/2} - {}^2P_{1/2}$ transition, the length form for GRASP92 is six orders of magnitude larger than for other codes, though velocity forms of GRASP92 and REOS are in perfect agreement. There are similar errors for the $^2D_{3/2} - {}^2P_{1/2}$ and the $^2D_{5/2} - {}^2P_{1/2}$ levels, too.

It is interesting to note that for all transitions there was agreement in the length form of the transition probability (A_{ki}) of 2-3 significant digits between Breit-Pauli and Dirac theory. The Breit-Pauli calculations use a transition operator which, in the velocity form, does not include all the low-order corrections. In many cases, the agreement in the velocity form is within an order of magnitude when length and velocity differ by 3-4 orders of magnitude.

Our investigations show that the biggest disagreement between the correct values of the diagonal matrix elements and the value which the program GRASP92 is computing are when the transition operator with rank $k = 2$ is under the investigation. So this error affects E2 transition probabilities, hyperfine parameters B and quadrupole moments.

References

[1] F.A. Parpia, C. Froese Fischer, and I.P. Grant, Comput. Phys. Commun. 94, 249 (1996).
[2] C. Froese Fischer, Comput. Phys. Commun. 128, 635 (2000).
[3] S. Fritzsche, C. Froese Fscher, and C.Z. Dong, Comput. Phys. Commun. 124, 340 (2000).

Measurement of the SH electron affinity by Photodetachment Microscopy

C. Delsart, W. Chaibi, C. Drag and C. Blondel

Laboratoire Aimé-Cotton, UPR CNRS 3321, bâtiment 505, F 91405 Orsay cedex, France
E-mail: christian.delsart@lac.u-psud.fr

Atomic and molecular electron affinities (^eA) are as important characteristics as ionization energies, but they are more difficult to measure experimentally and to calculate. The difficulty is even bigger for molecules, for they can vibrate and rotate. That results in imbricate and complicated series of photodetachment thresholds for molecular anions. Among these thresholds, it is a challenge to identify the one corresponding to ^eA, i.e. to the energy difference between the lowest rovibrational state of the neutral and the lowest rovibrational state of the anion.
The presently known value of ^eA for the SH molecule, $^eA = 18688(17)$ cm^{-1}, was quoted in the last review on the molecular electron affinities [1]. It appeared interesting to apply our technique of "Photodetachment microscopy" to perform a very precise determination of ^eA. Indeed, we recently applied this method to a new measurement of the electron affinity of the ^{16}OH molecule with a high relative precision ($\simeq 0.5.10^{-7}$) [2].
Photodetachment microscopy relies on the observation of the electron interferogram obtained by laser detachment of a negative ion in a uniform electric field [3]. The quantitative analysis of this interference pattern, essentially by counting the fringes and numerical fitting, is based on the "free-electron approximation" and on the *s*-wave behavior of the detachment final state. It gives a very sensitive way of measuring the initial kinetic energy of the photodetached electron. Such an analysis is expected to be also valid for the SH$^-$ ion.
Laser photodetachment microscopy was applied to a beam of ^{32}SH$^-$ ions ($\simeq$ 0.1 nA), which was produced from a hot cathode discharge source, accelerated at 1.2 keV, selected with a Wien filter and decelerated to 300 eV. The ion beam was focussed in the interaction zone and the electric field value was F $\simeq$ 198 V/m. Photo-excitation was provided by a single mode CW Pyrromethene 556 dye laser ($\simeq$ 200 mW) pumped with an argon-ion laser, and tuned to the 535 nm wavelength with a short and long time stabilization. The laser wavelength was measured by an *Ångstrom* WS-8 lambdameter with a wavenumber accuracy of about $\pm$ 0.001 cm^{-1} [3].
The interferograms of the particular R3(0) and Q3(6) thresholds belonging to different rotational detachment series of the SH$^-$($X\,^1\Sigma^+$;v=0)$\rightarrow$SH($X\,^2\Pi_{3/2,1/2}$;v=0) threshold are recorded at different laser wavelengths on a 2D-detector [3]. In order to eliminate the unknown Doppler shift, the laser is set to intersect the ion beam twice, back and forth, at two distinct places, resulting in a pair of well-separated images. Using this scheme, we analyze quantitatively the interferograms by the fitting methods developed for atomic detachment microscopy [3]. A preliminary value of the ^{32}SH electron affinity is $^eA = 18669.540(20)$ cm^{-1}. An optimized value, the precision of which will be increased by three orders of magnitude in comparison with the value presently available in the literature, will be given at the conference.

References

[1] J. C. Rienstra-Kiracofe, G. S. Tschumper, H. F. Schaefer III, S. Nandi, and G. B. Ellison, Chem. Rev. 102 (2002) 231-282, p. 261; F. Breyer and P. Frey, H. Hotop, Z. Phys. A, 300 (1981) 7-24.
[2] F. Goldfarb, C. Drag, W. Chaibi, S. Kröger, C. Blondel, and C. Delsart, J. Chem. Phys. 122 (2005) 014308(10); C. Delsart, F. Goldfarb, and C. Blondel, Phys. Rev. Lett. 89 (2002) 183002(4).
[3] C. Blondel, W. Chaibi, C. Delsart, C. Drag, F. Goldfarb, and S. Kröger, Eur. Phys. J. D 33 (2005) 335-342.

A facility for efficient production and for Magneto-optical trapping of Francium

L.Corradi[1], A.Dainelli[1], A.Burchianti[2], C.deMauro[2], A.Khanbekyan[2], S.Veronesi[2], V.Biancalana[2], C.Marinelli[2], E.Mariotti[2], L.Moi[2], S.Sanguinetti[3], P.Minguzzi[3], S.N.Atutov[4], L.Tomassetti[4], R.Calabrese[4], and G.Stancari[4]

[1] *Legnaro National Laboratories, I.N.F.N., Italy*
[2] *Dipartimento di Fisica, Università di Siena, Italy*
[3] *Dipartimento di Fisica, Università di Pisa, Italy*
[4] *Dipartimento di Fisica, Università di Ferrara and I.N.F.N. Italy*
E-mail:mariotti@unisi.it

A facility for radioactive atoms is operating at the Legnaro Laboratories of the Italian National Institute for Nuclear Physics (I.N.F.N). The goal is to collect cold samples of different Francium isotopes in a Magneto - Optical Trap (MOT) for studies in atomic, nuclear and particle physics. In fact, high resolution spectroscopy of poorly known atomic levels, cold collision processes and tests of the Standard Model in atomic systems are good example of a very interesting frontier and/or interdisciplinary field of research. Francium is a suitable tool because both a lot of work has to be performed in order to complete the information about level structure and features and one expects enhanced parity violating effects and reduced theoretical uncertainties from isotope comparisons. In the poster, the design and the performance of the Legnaro Fr sources as well as the recent efforts in the optimization of all the other experimental parameters will be discussed

Optical Tweezers: a tool for the investigation of complex systems at mesoscopic scales

L. Miccio[1,2], G. Pesce[1,2], G. Rusciano[1,2], A. Sasso[1,2] and L. Selvaggi[1,2]

[1] *Dipartimento Scienze Fisiche, Università di Napoli "Federico II", Napoli, Italy*
[2] *CNISM, Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia. Napoli, Italy*
E-mail:pesce@na.infn.it

The study of complex fluids founds application in several fields; in particular, the reological properties of biosystems are a crucial aspect for their biological function. Here we present the development of an Optical Tweezers System devoted to the investigation of the microrheological properties of complex fluids. In particular, the response of the investigated materials (hyaluronic acid solution, living cells), as function of the frequency is performed by analyzing the Brownian motion of a trapped bead, used as probe. The viscoelastic moduli G' and G" are obtained from the fluctuation-dissipation theorem and the generalized Stokes-Einstein relation.

References

[1] K.M. Addas, C.F. Schmidt, J.X. Tang, Phys. Rev. E **70**, 021503 (2004)
[2] P.G. De Gennes, *Scaling Concepts in Polymer Physics* Cornell University Press London (1979)
[3] M. Doi and S.F. Edwards, *The Theory of Polymer Dynamics* Clarendon Press: Oxford England, (1988)

Mi

Development of a Raman Tweezing System for analysis of nanoparticles produced in combustion processes

A. C. De Luca [1,2], G. Pesce[1,2], G. Rusciano[1,2] and A. Sasso[1,2]

[1] *Dipartimento Scienze Fisiche, Università di Napoli "Federico II", Napoli, Italy*
[2] *CNISM,Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia. Napoli, Italy*
E-mail:giulia.rusciano@na.infn.it

In this work we present the development of a Raman Tweezing System in order to analyse the interaction of biological tissues with nanoparticles produced in combustion processes. A variant of the Raman spectroscopy, Surface Enhanced Raman Spectroscopy[1], will be employed to enhance the yield of the Raman interaction. In our setup, a Nd-YAG laser beam is focused with high NA to immobilize and to manipulate a single cell, while a Ti:Sa laser, focused inside the cell, acts as Raman probe. The system will be used to detect nanoparticles inside different cellular sites to estimate the penetration capability of these particles through the cell membrane as function of their dimension.

References

[1] K. Kneipp, H. Kneipp, I. Itzkan, R. R. Dasari, and M. S. Feld, Chem. Rev. , **99**, 2957-2975 (1999).

Thursday, June 8th

Coherent interaction between cold atoms and photons

D. Delande[1], B. Grémaud[1], R. Kaiser[2], R. Kuhn[3], G. Labeyrie[2], C. Miniatura[2], C. Müller[3], O. Sigwarth[1,3], Th. Wellens[1,2], and D. Wilkowski[2]

[1]*Laboratoire Kastler Brossel, Université Pierre et Marie Curie, 4 Place Jussieu, F-75005 Paris*
[2]*Institut Non Linéaire de Nice Sophia Antipolis, 1361 route des Lucioles, F-06560 Valbonne*
[3] *Physikalisches Institut, Universität Bayreuth, D-95440 Bayreuth*
E-mail:Dominique.Delande@spectro.jussieu.fr

Thanks to the narrow atomic resonances, atoms may scatter light extremely efficiently. Using cold atoms, it is thus possible to prepare an optically thick atomic gas in which a photon is typically multiply scattered. In a disordered atomic medium, interference terms between various multiple scattering paths are most of the time washed out by the disorder. However, this is not always the case, leading to coherent effects such as coherent backscattering of light, which has been experimentally observed, with some specific features associated with the pecularities of atomic scatterers, and the so-called "weak localization" effect. At large atomic density (but before Bose-Einstein condensation takes place), it could even be that destructive interference effects become dominant, leading to complete localization("strong localization") of light in the cold atomic medium. By exchanging the role of the photons and the atoms, one can study the situation where atomic waves are multiply and coherently scattered by a disordered optical potential, leading again to weak and strong localization. We show that this regime can be reached with present state-of-the-art experiments.

Femtosecond Quantum Control

Tobias Brixner

Physikalisches Institut, Universitätt Würzburg,
Am Hubland, 97074 Würzbur, Germany
E-mail: brixner@physik.uni-wuerzburg.de

Obtaining active control over the dynamics of quantum-mechanical systems is a fascinating perspective in modern physics. The broad spectral intensity distribution and phase function of femtosecond laser pulses can be specifically manipulated to drive quantum systems coherently into desired reaction pathways [1, 2]. One of the most successful schemes employs a pulse shaper in combination with a learning algorithm and direct feedback from the experiment. The first demonstration in femtochemistry was the control of gas-phase molecular photodissociation [3], but in recent years coherent control experiments have been reported for a large variety of objectives and quantum systems, ranging from atoms over small and large molecules to biomolecular complexes and solid-state systems. In high-harmonic generation, spectral-temporal properties can be controlled by femtosecond pulse shaping, and coherent soft X-rays are produced with increased efficiency and high selectivity. The initial motivation for the theoretical development of quantum control strategies in the 1980s was the control of chemical reactions. But despite many experimental successes in the gas phase or with liquid-phase selective photoexcitation, the initial goal of control over bond breakage in liquids had not been realized. First results from a new technique of *accumulative* quantum control will be presented in which macroscopic amounts of chemical photoproducts are generated depending on the applied pulse shape. The technique of polarization shaping opens new perspectives as the polarization state of light can be varied within a single femtosecond laser pulse. This vectorial control over $\vec{E}(t)$ gives a flexible access to the three-dimensional nature of field-matter interaction $V(t) = -\vec{\mu}\cdot\vec{E}$. Polarization shaping can also be applied in coherent control of ultrafast nano-photonics. Simulations show that novel *nano-femto* spectroscopies can be implemented in which pump and probe excitations occur not just at different times but also at different positions with a spatial resolution far below the diffraction limit [4]. First experimental results for the control of nanoscopic photoelectron emission demonstrate the feasibility and potential of this scheme which should enable the direct spatial probing of nanoscale energy transfer processes. Due to the universality of closed-loop learning optimization of ultrashort laser pulses, a broad field of applications opens up in all areas where femtosecond laser technology is used.

References

[1] S. A. Rice, M. Zhao, Optical Control of Molecular Dynamics, Wiley, New York (2000).
[2] T. Brixner, G. Gerber, ChemPhysChem 4, 418 (2003).
[3] A. Assion, T. Baumert, M. Bergt, T. Brixner, B. Kiefer, V. Seyfried, M. Strehle, G. Gerber, Science 282, 919 (1998).
[4] T. Brixner, F. J. Garc?a de Abajo, J. Schneider, W. Pfeiffer, Phys. Rev. Lett. 95, 093901 (2005).

Threshold laws for break-up of a quantum particle into several charged fragments: theory and experiment

V. N. Ostrovsky

V. Fock Institute of Physics, St Petersburg State University, 198504 St Petersburg, Russia

Threshold laws for different processes in atomic physics are long-standing subject of research in theory and experiment [1]. Among them threshold laws for break up of a quantum particle into several charged fragments have a special status (the typical examples of such processes are multiple ionization of an atom by electron impact and multiple photoionization). The statistical considerations are insufficient here since the behavior is governed by dynamic correlation of receding fragments in multiparticle continuum. This was first recognized by Wannier [2] who considered case of three charged fragments (ionization of an atom by electron impact). Wannier showed that fragmentation cross section obeys power law, $\sigma_{\rm fr} \sim E^{\mu}$, where E is excess energy above threshold and the threshold index μ is a non-trivial function of charge Z of the residual ion. The generalization for an arbitrary number of fragments N with different charges and masses was suggested in Ref. [3]. The threshold theory is based on existence of special classical trajectories in a system of charged particles. These trajectories describe *scaling* in time of initial configuration without changing its shape. The shape of *scaling configuration* depends on charges and masses of fragments. There is an interesting analogy [4] between the scaling configurations and famous Thomson's [5] (or surface Coulomb) problem.
Along with mathematically rigorous threshold laws valid for $E \to 0$, the *secondary threshold laws* are sometimes discussed. These laws are operative at some separations from the threshold on the energy scale. They could be observed in realistic experiments where true threshold behavior produces a weak signal that in case of non-ideal energy resolution could be masked by contributions from higher E. The secondary threshold laws imply existence of some physical mechanism for break up reaction. It seems that the first fully reliable identification of a secondary threshold law was obtained for triple photoionization of Li atom where it is related to strong orbital energy asymmetry in initial Li($1s^2 2s$) configuration [6]. The recently suggested resonance mechanism [7] leads to the emergence of secondary threshold laws in processes of multiple ionization of noble gas atoms (with symmetrical p^6 configuration) by electron impact. This provides a possible explanation of the recent experimental results [8] which exhibit strong deviation from predictions of Wannier-type theory for the threshold index μ.

References

[1] H. R. Sadeghpour, J. L. Bohn, Cavagnero MJ, Esry BD, Fabrikant II, Macek JH, Rau ARP, J. Phys. B **33**, R93 (2000).
[2] G. H. Wannier, Phys. Rev. **90**, 817 (1953).
[3] M. Yu. Kuchiev and V. N. Ostrovsky, Phys. Rev. A **58**, 321 (1998).
[4] V. N. Ostrovsky and J. M. Rost, Few Body Systems, 2006 (accepted for publication).
[5] J. J. Thomson, Phil. Mag. **44** (ser. 5), 293 (1897); **7** (ser. 6), 237 (1904).
[6] R. Wehlitz, T. Pattard, M. T. Huang, Sellin IA, Burgdorfer J, Y. Azuma, Phys. Rev. A **61**, 030704 (2000).
[7] G. F. Gribakin, S. Sahoo, V. N. Ostrovsky, Phys. Rev. A **70**, 062717 (2004).
[8] B. Gstir, Denifl S, Hanel G, Rummele M, Fiegele T, Stano M, Feketeova L, Matejcik S, Becker K, Scheier P, Mark TD, Nucl. Inst. & Meth. B **205**, 413 (2003).

Switching off power broadening : Coherently enhanced selectivity in trace detection

A. Peralta Conde, L. Brandt, and, T. Halfmann

Department of Physics, University of Kaiserslautern, Germany
E-mail:halfmann@physik.uni-kl.de

Coherent interactions of light and matter often exhibit, on the first glance, stunning features, which permit improvements and applications in all fields of optical physics. Among applications of coherent interactions are (i) the manipulation of population distributions, e.g. to prepare population inversion in a quantum system; [1] (ii) the control and manipulation of photofragmentation processes [2,3]; (iii) the control and enhancement of nonlinear optical processes, e.g. frequency conversion; [4,5] (iv) quantum information processing and optical data storage; ...and many others more.

As an example for a surprising phenomena in coherent excitation the talk discusses complete suppression of power broadening in strongly, but also coherently driven media [6]. This is of particular interest for applications in laser-based trace detection, which is usually implemented by resonantly enhanced multi-photon ionization (REMPI). REMPI exhibits a well-established tool, providing high efficiencies and selectivities in analytical applications. However, while the efficiency of trace detection increases with the driving laser intensities, power broadening reduces the spectral resolution.

The talk introduces a coherent variant of REMPI, which permits complete suppression of power broadening. The technique is based on coherent population return (CPR), i.e. population is driven by a coherent radiation field from a ground to an excited state and back again. Power broadening does not occur, if the population in the upper state is monitored after the excitation process. Thus, if the ionization and excitation laser are delayed in a REMPI experiment, no power broadening limits the spectral resolution - no matter how strongly the transitions are driven. We demonstrate trace detection by REMPI, assisted by CPR, to monitor isobars of NO-molecules. We show, that irrespective of the driving laser intensity, high selectivity is maintained even if a transition is driven strongly in saturation [6,7].

References

[1] N.V. Vitanov, T. Halfmann, B.W. Shore, and K. Bergmann, Ann. Rev. Phys. Chem. 52, 763 (2001).
[2] T. Peters, L.P. Yatsenko, and T. Halfmann, Phys. Rev. Lett. 95, 103601 (2005). [3] K. Bhmer, T. Halfmann, L.P. Yatsenko, D.Charalambidis, A.Horsmans and K. Bergmann, Phys. Rev. A 66, 013406 (2002)
[4] T. Rickes, J. P. Marangos and T. Halfmann, Opt. Comm. 227, 133 (2003)
[5] M. Oberst, J. Klein, and T. Halfmann, Opt. Comm. Special Issue on "Quantum Control of Light & Matter", *in press*
[6] A. Peralta Conde, L. Brandt, and T. Halfmann, Phys. Rev. Lett., *to be submitted soon*
[7] http://www.quantumcontrol.de

One and Two-Color Photoionization with the DESY (FLASH) EUV FEL

M. Meyer[1], D. Cubaynes[1], P. O'Keeffe[1], H. Luna[2], P. Yeates[2], E. T. Kennedy[2], J. T. Costello[2], P. Orr[3], A. Maquet[4], R. Taeib[4], S. Dusterer[5], E. Plonjes-Palm[5], P. Radcliffe[5], H. Redlin[5], A. Azima[5], and J. Feldhaus[5]

[1] *LIXAM/CNRS, Centre Universitaire Paris-Sud, F-91405-Orsay, Cedex, France*
[2] *National Center for Plasma Science and Technology and School of Physical Sciences, Dublin City University, Dublin, Ireland*
[3] *International Research Centre for Experimental Physics (IRCEP), Queen's University Belfast, BT7 1NN, Northern Ireland, UK*
[4] *Laboratoire de Chimie Physique-Matiere et Rayonnement, UMR 7614, Universite Pierre et Marie Curie, 11 Rue Pierre et Marie Curie, 75231 Paris Cedex 05, France*
[5] *HASYLAB, DESY, Notkestrasse 85, D-22603, Hamburg,Germany*
E-mail: John.Costello@dcu.ie

Free Electron Lasers, operating on the principle of Self Amplified Spontaneous Emission [1], open up completely new vistas in intense laser matter interaction as they have the potential to provide ultrashort pulses of coherent laser radiation with photon energies far above the ionization thresholds of matter ranging from single atoms to bulk solid materials. As a result, non-linear optics and spectroscopy can be extended into the extreme ultraviolet (EUV) and x-ray portions of the electromagnetic spectrum for the first time. In contrast to traditional visible lasers, the predominant interaction of EUV FEL radiation is expected to be with inner shell electrons. The spectral characteristics of ultrashort pulses from Phase II of the Extreme-UV (EUV) Free Electron Laser (FEL) at DESY, Hamburg, now known as Free electron Laser At DESY Hamburg (FLASH), have been measured using both photon and photoelectron spectroscopy [2]. FLASH pulses are generated stochastically by Self Amplified Spontaneous Emission (SASE). Each pulse has a duration of 20-50 fs and is composed of an intense and spectrally complex fundamental centered at a photon energy of $\sim$38 eV with a bandwidth of 0.5% accompanied by higher harmonics each carrying an intensity of typically $< 1\%$ of that of the fundamental. The harmonic to fundamental intensity ratios are in remarkable agreement with a simple statistical model of SASE FEL radiation. In addition, two-photon ionization of atomic helium has been measured by combining femtosecond extreme-ultraviolet (XUV) pulses from the Free Electron Laser at DESY with intense light pulses from a synchronized Nd-YLF laser [3]. Sidebands appear in the photoelectron spectra when the two laser pulses overlap in both space and time. Their intensity exhibits a characteristic dependence on the relative time delay between the ionizing and the dressing pulses. However they appear to be surprisingly weak, especially when compared to all measurements to date where phase coherent high harmonics of an optical laser constitute the XUV source. The result demonstrates that the intrinsic sideband intensity in intense two colour photoionization experiments is in fact quite weak and that interference between multiple overlapping sidebands is the main determinant of sideband intensity in the HoH experiments.

References

[1] J. Andruszkow et al., Phys. Rev. Lett. 85, 3825 (2000)
[2] S. Dusterer et al., Optics Letters (accepted for publication 2006)
[3] M. Meyer et al., Submitted for publication 2006

Electronic and optical feedback control of a single trapped ion

Daniel Rotter[1], Pavel Bushev[1], Francois Dubin[1], Manas Mukherjee[1], Carlos Russo[1], Christoph Becher[1], Jürgen Eschner[2], Rainer Blatt[1]

[1]*Institut für Experimentalphysik, Universität Innsbruck, Austria*
[2]*ICFO - Institut de Ciencies Fotoniques, 08860 Castelldefels (Barcelona), Spain*
E-mail: juergen.eschner@icfo.es

We study the dynamics of a single trapped ion under (i) optical feedback from a distant mirror, and (ii) electronic feedback acting on the ion's vibration in the trap. The experiments are carried out with a single barium ion, trapped in a miniature Paul trap and continuously laser-excited and -cooled. Its resonance fluorescence is registered with photon counting detectors. A mirror at variable, large distance reflects part of the fluorescence back onto the ion [1].

We have shown earlier that optical feedback from a single distant mirror leads to modified spontaneous emission [1], level shifts [2,4], and mechanical action [3]. Here we report on the effect of the mirror on the photon-photon correlation function $g^{(2)}(\tau)$. This correlation function, which without mirror shows typical anti-bunching at $\tau = 0$, is notable changed: depending on the ion-mirror distance, the anti-bunching minimum may shift to finite τ, and a peculiar kink at the feedback time (which we vary between 1.5 and 6 ns) signals the retarded back-action of the light returning from the mirror.

The interference between light from the ion and light returning from the mirror is also used to establish electronic feedback control of the ion's motion. The ion's vibration in the trap generates sidebands at the trap frequency in the fluctuation spectrum of the resonance fluorescence. We use these sidebands for tracking the ion's trajectory, for cooling it by phase-shifted feedback (cold damping) [5], and for phase-locking the vibration to an external reference oscillator.

References

[1] J. Eschner et al., Nature **413**, 495 (2001).
[2] M. A. Wilson et al., Phys. Rev. Lett. **91**, 213602 (2003).
[3] P. Bushev et al., Phys. Rev. Lett. **92**, 223602 (2004).
[4] U. Dorner and P. Zoller, Phys. Rev. A **66**, 023816 (2002).
[5] P. Bushev et al., Phys. Rev. Lett. **96**, 043003 (2006).

Acknowledgements We acknowledge theoretical support by V. Steixner, P. Rabl, and P. Zoller from the Institut für Theoretische Physik, Uni Innsbruck. We acknowledge travel support from the Spanish Ministry of Education and Science (MEC) and the ÖAAD through the 'Accion Integrada' Program.

New Measurements of Neutral, Singly and Doubly Ionized Iron Group Spectra by Fourier Transform and Grating Spectroscopy

R. Blackwell-Whitehead[1], D. Smillie[1,3], J.C. Pickering[1], D. Blackie[1], A.P. Thorne[1], G. Nave[2], P.L. Smith[3]

[1] *Blackett Laboratory, Imperial College, London, United Kingdom*
[2] *National Institute of Standards and Technology, Gaithersburg, USA*
[3] *Harvard-Smithsonian Center for Astrophysics, USA*
E-mail: r.blackwell@imperial.ac.uk

We report new laboratory measurements using the unique high resolution vacuum-UV Imperial College (IC) Fourier transform spectrometer (FTS) to measure spectra of astrophysically important atoms and ions. The IC VUV FTS combines high spectral resolution (resolving power 2 million at 200nm) with a broad spectral range from the visible to 135nm, (typical wavelength accuracy is 1 part in 10^7). Accurate high resolution laboratory spectra are required to fully interpret new astrophysical spectra obtained by the latest generation of ground based and satellite borne spectrographs such as VLT/CRIRES and FUSE. Astronomers urgently require accurate data for wavelengths, energy levels, line broadening effects and oscillator strengths. The new atomic data are applied in analysis of astrophysical spectra, elemental abundance studies and diagnostics of astrophysical plasmas.

Our current measurement program includes many neutral, singly and doubly ionized iron group elements (e.g. Cr I & III, V I & II, Fe I, II & III, Co I, II & III, Ti I):

We have observed doubly ionized spectra of 3d transition group elements using our FTS with a Penning discharge lamp. Spectra of these ions are important in analysis of B–type (hot) star spectra where they dominate, however existing laboratory measurements are in many cases incomplete or inaccurate. We report new UV–VUV measurements of Co III, Cr III and Fe III with the IC VUV FTS, and also with the normal incidence vacuum (grating) spectrograph at the National Institute of Standards and Technology (NIST USA) below our FTS shortwave length cutoff, 135nm. We report intensity calibrated grating spectroscopy measurements for Fe III that complement our FT spectra. Work towards accurate transition wavelengths, energy levels and branching ratios (which, combined with lifetimes, produce oscillator strengths) for these and other doubly ionized iron group elements is presented.

We report new measurements of neutral and singly ionised 3d transition group element spectra. Accurate laboratory data for wavelengths, f-values and line broadening effects for the neutral 3d transition group element spectra are required for the accurate analysis of Low Mass Star (LMS) spectra. LMSs are cool and have peak spectral opacity in the IR. Current LMS spectrum analyses are based on calculated atomic data because of the lack of experimental atomic data in the IR. Uncertainties in the calculated oscillator strengths for some lines (in particular Ti I, Mn I and Cr I) are still large enough to affect seriously the interpretation of the observed line strengths [1]. We report on continuing progress. Our large scale analyses of Cr I, V I and V II are close to completion. We also report new hyperfine structure measurements for V I & II and Mn II.

This work is supported in part by NASA Grant NAG5–12668, NASA inter-agency agreement W–10,255, PPARC, the Royal Society of the UK and by the Leverhulme Trust.

References

[1] Y. Lyubchik, H.R. Jones, Y.V. Pavlenko, S. Viti, J.C. Pickering, R.J. Blackwell-Whitehead, Astron. Astro., 416, 655 (2004)

The formation of reactive atomic fragments via dissociative recombination, disscociative electron attachment and Coulomb explosions

T. M. Orlando

School of Chemistry and Biochemistry and School of Physics,
Georgia Institute of Technology
Atlanta, GA 30332-0400
E-mail:Thomas.Orlando@chemistry.gatech.edu

The inelastic scattering of low energy electrons with atoms, molecules and condensed molecular solids leads to the formation of reactive neutral and ionic fragments via direct excitation and indirect processes which includes dissociaitve recombination, dissociative electron attachment and Coulomb explosions. Most of the recent work in this area has been carried out for gas-phase collision partners using crossed beams, ion-storage rings or cold traps. Another approach which preserves much of the atomic physics is to carry out scattering measurements on condensed solids which have weak coupling. We have pursued this approach using low-energy electron scattering with rare-gas surfaces containing sub-monolayer coverages of water or nanoscale water films deposited on graphite surfaces. The atomic fragment yields and energy distributions are determined using quantum-resolved laser resonance enhanced multiphoton ionization. Specifically, we have examined the production of H (^{2}S) and O (^{3}P, ^{1}D) from electron recombination with H_2O^+ or hydronium ions [1]. We have also examined the formation of H^- (D^-) + OH and O^- + H_2 ($^1\sum_g^+$) via low-energy dissociatve electron attachment [2, 3]. The channels involve the formation and decay of 1 hole-2 electron core-excited Feshbach resonances. The lifetimes of these resonances are dependent upon the overall symmetry of the scattering wave and coupling with neighbors. We have also examined the coupling in this correlated system by measuring the production and removal of H^+, H_2^+ and $H^+(H_2O)_{n=1-8}$ from nanoscale films of amorphous solid water. These channels likely involve localized two-hole one-electron and/or two-hole final states containing $4a_1$, $3a_1$ and/or $2a_1$ character. The correlated two-hole or two-hole, one-electron configurations are localized either on a single site or within a complex. The single site process normally involves interatomic Auger decay and direct ejection of an energetic proton. If the holes are localized within a complex, intermolecular Auger processes may occur leading to intermolecular Coulomb repulsion and cluster ion ejection [4, 5].

References

1.) G. A. Kimmel and T. M. Orlando, Phys. Rev. Lett. 75, 2606 (1995).
2.) G. A. Kimmel and T. M. Orlando, Phys. Rev. Lett. 77, 3983 (1996).
3.) W. C. Simpson, et. al, J. Chem. Phys. 107, 8668, (1997).
4.) J. Herring, A. Alexandrov, and T. M. Orlando, Phys. Rev. Lett. 92, 187602-1 (2004).
5.) J. Herring-Captain, G. A. Grieves, M. T. Sieger, A. Alexandrov, H. Chen and T. M. Orlando, Phys. Rev. B. 72, 035431 (2005).

Electromagnetically Induced Resonances in Sub-Micron Thin Rb-Vapor Layer

Y. Pashayan-Leroy[1,2], D. Sarkisyan[1], A. Sargsyan[1], A. Papoyan[1] and C. Leroy[2]

[1] *Institute for Physical Research, NAS of Armenia, Ashtarak-2, 378410, Armenia*
[2] *Laboratoire de Physique de l'Université de Bourgogne, CNRS-UMR 5027, Dijon, France*
E-mail: david@ipr.sci.am

In experimental works [1-3] it has been demonstrated that the laser spectroscopy of sub-micron thin atomic vapor layers confined in the so-called Extremely Thin Cells (ETC), whose longitudinal dimension is of the order and less compared with the resonant light wavelength, provided a novel method for sub-Doppler spectroscopy. Here we report peculiarities of Electromagnetically Induced Transparency (EIT) phenomenon for the case of ETC with smoothly varying thickness of Rb vapor layer in the range of 780 - 1600 nm, using two single-frequency diode laser radiations with $\lambda \sim$ 780 nm and spectral width $\sim$ 5 MHz. Our Λ-type system is formed on atomic D_2 line of the ^{85}Rb (as well as the ^{87}Rb). The ground state hyperfine levels F_g=2 and F_g=3 of the ^{85}Rb (F_g=1 and F_g=2 of the ^{87}Rb) serve as two lower states, and the excited state $5P_{3/2}$ serves as a common upper level. The linewidth of the EIT resonance in the case of a small laser intensity is $\gamma_{EIT} \simeq 2\Gamma_{21} + \Omega^2/\gamma_N$, where γ_{21} is the relaxation rate between the ground hyperfine levels, with Ω being the Rabi frequency. Also, the EIT resonance contrast strongly depends on γ_{21}. As the size of the vapor cell is reduced, the lifetime of the ground-state coherence becomes shorter because of collisions of atoms with the cell windows: $\gamma_{21} = (2\pi t)^{-1}$, where $t = L/u$ (u is the thermal velocity). Hence, in the case of $L \sim 1$ μm ($2\Gamma_{21} > 100$ MHz), one could expect that the electromagnetically induced transparency effect will vanish (note, that neither additional buffer gas nor paraffin coating have been used). Nevertheless, even in the case of a pure vapor the narrow EIT resonance can be observed [4]. The explanation is that the contribution of atoms with slow normal velocity is enhanced due to their longer interaction time with the laser field. Thus, atoms flying nearly parallel to the windows yield a stronger contribution to the EIT resonance. Due to this atomic velocity-selectivity, the observed linewidth of the EIT resonance is more than by an order narrower than the inverse of the window-to-window flight time of the atoms. It is revealed that the transmission spectrum of the probe laser contains the EIT resonance (of $\sim$ 9 MHz linewidth), along with several times broader velocity-selective optical pumping (VSOP) peak (or dip in absorption spectrum). It is demonstrated that in the case of nonzero detuning of the coupling laser, the EIT resonance and VSOP peak are shifted with respect to each other on the frequency scale, which makes it possible to observe a competition between the two effects (this is not possible to realize in an ordinary cell). Note, that the coherent Dicke-type narrowing effect [2,3] essentially influences the EIT effect, that's why the transmission spectra of the probe laser for the cases $L = \lambda$ and $L = 2\lambda$ are different from that for $L = 3/2\lambda$. In an external magnetic field (of 10-15 G) for the vapor thickness of $L = 2\lambda$, three and five well resolved EIT resonances (of $\sim$ 9 MHz linewidth) have been observed on the ^{87}Rb and the ^{85}Rb, respectively. A theoretical model describing electromagnetically induced transparency effect in extremely thin cell has been developed, and the comparison with the experiment will be presented.
The authors D.S. and A.S. thank ANSEF (Grant 05-PS-opt-0813-233) and D.S., A.S. and A.P. thank SCOPES (Grant IB7320-110684/1).

References

[1] D. Sarkisyan, D. Bloch, A. Papoyan, M. Ducloy, Opt. Commun. 200, 201 (2001).
[2] G. Dutier, A. Yarovitski, S. Saltiel et al., Europhys. Lett. 63(1), 35 (2003).
[3] D. Sarkisyan, T. Varzhapetyan, A. Sarkisyan et al., Phys. Rev. A 69, 065802 (2004).
[4] A. Sargsyan, D. Sarkisyan, A. Papoyan, Phys. Rev. A 73, 033803 (2006).

Internal state detection using Stimulated Raman Adiabatic Passage in cold, trapped Calcium ions

Jens L. Sørensen[1], Ditte Møller[1], Theis F. Q. Iversen[1], Jakob B. Thomsen[2], Michael Drewsen[1]

[1] *Department of Physics and Astronomy, Univeristy of Aarhus, DK-8000 Denmark*
[2] *Optics and Plasma Research Department, Risø National Laboratory*
Frederiksborgvej 399, Build. 128, P.O. 49, DK-4000 Roskilde, Denmark
E-mail:jls@phys.au.dk

When performing quantum information processing on trapped ions it is imperative to have an efficient scheme for detecting the quantum bit (qubit) state. Hence a lot of effort is currently being made in order to find suitable quantum systems with qubit states that can be detected with a high confidence. We present a qubit system made up by the two Zeeman sublevels of the $4S_{1/2}$ ground state of the $^{40}Ca^{+}$ ion. We wish to read out the qubit state by first shelving the population of one Zeeman sublevel in the $3D_{5/2}$ metastable state and subsequently measure the population of the remaining sublevel by observing the fluorescence of the strong $4S_{1/2} \rightarrow 4P_{1/2}$ transition. Our theory predicts that this task can be efficiently carried out by means of two consequtive STImulated Raman Adiabatic Passage (STIRAP) processes [1], consisting of a total of four laser pulses in pairwise counter intuitive time order. Since the STIRAP process relies on the atom following adiabatically the light intensities in a dark state, no population is present in the short lived $4P$ states and hence the atom makes no spontaneous decays. As a result the shelving process can be carried out nearly deterministically as is required for our qubit readout.

We present the results from our latest study of the last step STIRAP, transferring the population of the $3D_{3/2}$ state to the $3D_{5/2}$ state of the Calcium ion. To our knowledge this is the first attempt to apply STIRAP to trapped ions, and initial experiments show a population transfer efficiency in excess of 90 % limited by available laser power and residual resonant stray light after the population transfer. Optimising our parameters we expect to achieve transfer efficiencies above 95 %.

We point out that the STIRAP technique is useful not only in quantum information processing but also in the broader area of atomic and molecular physics, when certain quantum states need to be prepared with high efficiency.

References

[1] K. Bergmann, H. Theuer and B. W. Shore, Rev. Mod. Phys. **70**, 1003, (1998)

CPT resonance in presence of magnetic fields

J. Belfi, G. Bevilacqua, V. Biancalana, Y. Dancheva and L. Moi.

Dipartimento di Fisica, Via Roma 56, 53100 Siena, Italy

Coherent Population Trapping (CPT) is a light-atom coherence effect producing a resonant vanishing of the light absorption by a given atomic system [1]. This process can be observed in three-level atomic systems where two uncoupled levels (e.g. two levels forming an hyperfine doublet or two Zeeman sub-levels of a given hyperfine ground level) are coupled to a common third level by two quasi-resonant light fields (Λ- system). If the phase difference between the two light fields is constant and the two-photon resonance condition is fulfilled, such a system stops absorbing light and the atoms remain trapped in a so-called "dark state". This happens inside a very narrow frequency bandwidth: the width of the CPT resonance is theoretically limited only by the lifetime of the two uncoupled levels. The presence of an external magnetic field (MF) modifies the CPT resonance parameters when Zeeman levels are used to create Λ-system. The shift of the resonance frequency, due to linear Zeeman effect, makes possible to perform absolute MF measurements with high precision and high sensitivity.

We are going to present our results regarding an experimental study of the CPT resonance occurring at the D_2 line hyperfine Zeeman structure in Cs.

The study of the CPT resonance behavior in DC (and even slow varying) MFs is addressed to an applied kind of research. In this case CPT is created when the two lower states of the Λ-system are Zeeman sub-levels belonging to the same hyperfine level (F=4 or F=3). A compact, all optical, probe is realized for the measurement of earth-field range magnetic-field. The laser source is a current modulated or amplitude modulated (in the 1 kHz - 1 MHz range) Pig Tail diode laser. The best sensitivity without shielding and gradient compensation systems is about 500 $\frac{pT}{\sqrt{Hz}}$. A data acquisition system, comprehensive of a PC-controlled laser optical frequency tuning system, makes possible an efficient monitoring of the earth magnetic field. Good agreement is found comparing our results with other kind of earth MF measurements (flux-gate vectorial magnetometer, Geophysical Institute of L'aquila). A gradiometric probe, allowing for a good spatial resolution, for biological MFs measurement (with particular interest in magneto-cardiometry [2]) is under construction. The goal is to get a sensitivity level better than 100 pT over a bandwidth of 100 Hz (heart field parameters). First results and principal problems will be presented.

The CPT behavior in AC MFs is interesting for what concerns the optical properties modification of the atomic system composed by a set of "oscillating levels". We employ a current modulated (at about 4.6 GHz) VCSEL to create CPT when the two lower Zeeman states of the three-level structure belong to different (F=4 and F=3) hyperfine levels. In this case a bias DC MF is applied so that an isolated Λ-system is studied. We can observe then the behavior of a single three level system composed of oscillating levels. A set of side-CPT resonances, separated by the MF modulation frequency appears. The number, the amplitude and the shape of the side-resonances depend on the MF parameters (frequency, amplitude) and also on the time scale of observation in a non-trivial way. In order to understand the basics of this parametric resonance formation, a model based on optical Bloch equations is built up. In this context we are going to present the analogy of this system with an equivalent system consisting in a static atomic level scheme coupled to a pair of laser modes, modulated with different modulation indexes [3].

References

[1] G. Alzetta et al. Nuovo Cimento B 36, 5 (1976)
[2] G. Bison et al. Optics Express 11 (2003)
[3] G. Bevilacqua et al. Phys. Rev. Lett. 95, 123601 (2005)

Quantum control of interactions in a cold Rydberg gas

M. Viteau, T. Vogt, A. Chotia, J. Zhao, D. Comparat and P. Pillet

Laboratoire Aimé Cotton
Campus Universitaire Bat. 505, 91005, Orsay, France
E-mail: Matthieu.Viteau@lac.u-psud.fr

Atoms with a high principal quantum number (Rydberg atoms) have wonderful properties, such as a giant dipole moment. Rydberg atoms interact through induce dipoles (Van der Waals interaction) or permanent dipoles create in electric field. Dipole-dipole interactions are promising for quantum gates[1,2], even in mesoscopic ensembles like cold atoms. An idea, to perform a quantum gate, is to use the dipole blockade effect : when exciting one atom in a Rydberg state, the dipole-dipole interactions shift the levels of the closed atoms, and which cannot be excited anymore using the same frequency. In this talk we will present the first realisation of blockade with permanent dipole. We are also able to control this interaction with a constant electric field [3].

Ultra cold cesium atoms are excited in Rydberg states, with a continous excitation scheme. Performing high resolution spectroscopy we are able to observe the interaction shift and the broadning of the levels. In the same time, we measure the free ions, formed by collision between Rydberg atoms, to verify that the diminution of our signal is not due to ions, and test the origin of these ions. Finally we demonstrate and control (with external electric field) the dipole blockade.

References

[1] D. Jaksch *et al.*, *Phys. Rev. Let.* **85** 2208 (2000)
[2] M. D. Lukin *et al.*, *Phys. Rev. Let.* **87** 037901 (2001)
[3] T. Vogt *et al.*, arXiv:physics/0603038 (2006)

Friday, June 9th

Test of fundamental symmetries with atomic systems

E. Hinds

Physics Department, Imperial College of Science, Technology and Medicine
Blackett Laboratory, Prince Consort Road, London, UK
E-mail:ed.hinds@imperial.ac.uk

Abstract to be announced

Precise mass measurements

T. Fritioff

Stockholm University, AlbaNova University Center, Physics Department,
SE - 106 91 Stockholm, Sweden
E-mail:fritioff@physto.se

With modern Penning trap mass spectrometers the mass of an atom or rather the ion can be determined to a relative uncertainty of about 10^{-11}. The precise mass values that is obtained have a wide spread implication in different fields, from the use in modern metrology to solving questions in fundamental physics.
The masses of the lightest atoms are by definition natural constants for which an improved mass accuracy is always demanded. Of particular current interest is the mass difference between Tritium and Helium-3 that determines the beta-decay Q-value and hence the end-point of the tritium beta-decay. This energy can be used in the search for a finite rest mass of the electron antineutrino. It is not known whether the neutrino is a Majorana particle or not, a question that could be solved by finding a neutrinoless double beta decay in for example ^{76}Ge or ^{136}Xe. The position in the energy spectra of such a decay is precisely given by the Q-value of these decays. Penning traps have been used for a long time to make precise tests of QED. Previously by g-factor measurements of the free electron and today also through measurements of the bound electron g-factor in H- and Li-like highly charged ions. In these measurements the mass of the ion has to be precisely known.
The talk will present the different Penning trap techniques used today to make these measurements, exemplified by mass measurements used in a wide aspect of physics.

The Structure and Dynamics of Negative Ions

David J. Pegg

University of Tennessee, Knoxville, Tennessee, 37996, USA
E-mail: djpegg@utk.edu

The goal of negative ion physics is to gain a better understanding of the role played by electron correlation in the structure and dynamics of multi-electron systems. Negative ions are well suited for such studies since they exhibit an enhanced sensitivity to correlation due to the efficient screening of the nucleus by the atomic electrons. The structure of a negative ion is qualitatively different from that of an atom or positive ion. The difference can be traced to the nature of the force binding the outermost electron, which in the case of a negative ion arises from the induced dipole associated with the polarization of the atomic core. This short-range potential typically supports only a single bound state. Experimental studies involve the detachment of one or more electrons in a controlled manner. Correlation plays a major role in determining the threshold behavior and resonance structure of the detachment cross section. Resonances are associated with doubly excited or core excited states of the negative ion. The talk will focus on the use of accelerator-based methods to investigate the interaction between atomic and molecular negative ions and photons, electrons, heavy particles and external electric fields.

Positron interactions with atoms and molecules

G. F. Gribakin
Department of Applied Mathematics and Theoretical Physics, Queen's University, Belfast, UK
E-mail: g.gribakin@qub.ac.uk

In this talk I want to review a considerable progress achieved over the past decade in understanding the interaction of low energy positrons with atoms and molecules.

Positron interaction with atoms and molecules is a field rich in interesting physical phenomena. One example is given by hugely enhanced rates of positron annihilation in many atomic and molecular gases. These annihilation rates are expressed in terms of an effective number of electrons per target atom or molecule, that contribute to annihilation, $Z_{\rm eff}$. Experimental data shows values or $Z_{\rm eff}$ that range from about 6 for Ne to 400 for Xe, and from 140 for methane, CH_4, to 9×10^3 for CCl_4, 1.2×10^5 for hexane, C_6H_{14}, and 1.8×10^6 for dodecane, $C_{12}H_{26}$.

Naively one may expect that the problem of positron interaction with a many-electron system is simpler than its electron counterpart, e.g. due to the absence of exchange interaction. In reality the positron problem is characterised by a greater role of correlation effects. In addition to the usual $-\alpha e^2/2r^4$-type polarisation potential (α being the dipole polarisability of the target), a short-range contribution due to virtual positronium (Ps) formation results in strong positron-target attraction. In particular, this attraction overcomes positron repulsion from the nucleus and leads to positron binding with many neutral atoms [1].

The development of a many-body theory approach to positron-atom scattering and annihilation has allowed a near complete understanding of the correlation effects described above, and the role of short-range enhancement of the positron annihilation vertex [2]. Thus we now know that correlation effects increase $Z_{\rm eff}$ for Xe by a factor of 10^3, and yield $Z_{\rm eff}$ values in agreement with experimental data. This approach also allows one to calculate accurately the shape of the 511-keV annihilation gamma line [3] and determine the fraction of positron annihilation on inner-shell electrons.

To explain much greater $Z_{\rm eff}$ observed for polyatomic species one needs to combine the notion of positron bound states with the possibility of energy transfer between the light positron-electron and heavy vibrational degrees of freedom. This gives rise to positron-molecule vibrational Feshbach resonances (VFR). Positron capture into such resonances results in dramatic enhancement of the annihilation rates [4,5] due to large densities of molecular vibrational spectra in polyatomics. However, the details of this mechanism are not fully understood. Thus, experimental evidence suggests that positron capture is almost always mediated by vibrational *doorway* states [6] linked to molecular fundamentals. Overall, this problem is difficult to treat theoretically, since one must provide an accurate description of the positron-electron correlations (to describe positron binding) and account for the coupling to the molecular vibration motion, including unharmonic effects and vibrational energy redistribution. So far the zero-range model for a diatomic [7] remains the only dynamical calculation that demonstrates the role of VFR.

References

[1] V. A. Dzuba, V. V. Flambaum, G. F. Gribakin and W. A. King, Phys. Rev. A **52**, 4541 (1995); J. Mitroy, M. W. J. Bromley and G. G. Ryzhikh, J. Phys. B **35**, R81 (2002).
[2] G. F. Gribakin and J. Ludlow, Phys. Rev. A **70**, 032720 (2004).
[3] L. J. M. Dunlop and G. F. Gribakin, J. Phys. B **39**, 1647 (2006).
[4] G. F. Gribakin, Phys. Rev. A **61**, 022720 (2000).
[5] G. F. Gribakin, In *New Directions in Antimatter Chemistry and Physics*, Eds. C. M. Surko and F. A. Gianturco, Ch. 22 (Kluwer Academic Publishers, Dordrecht, 2001).
[6] G. F. Gribakin and P. M. W. Gill, Nucl. Instrum. and Methods B **221**, 30 (2004).
[7] G. F. Gribakin and C. M. R. Lee, Nucl. Instrum. and Methods B, Article in Press (2006).

Atoms on He nanodroplets, and their spin interactions, probed by magnetic dichroism

Johann Nagl, Gerald Auböck, Olivier Allard, Carlo Callegari, Wolfgang E. Ernst

Institute of Experimental Physics, TU Graz, Petersgasse 16, 8010 Graz, Austria/EU
E-mail: carlo.callegari@tugraz.at

With the goal of creating and probing an ensemble of superfluid helium droplets doped with spin-polarized chromophores, we measured laser induced fluorescence (LIF) and beam depletion spectra of the D lines of potassium and rubidium atoms on the surface of superfluid helium droplets, with and without a moderately strong external magnetic field ($\approx 3\,\mathrm{kG}$).
It has been observed so far that an alkali atom (M) dissociates from the droplet upon electronic excitation, either directly or through formation of an excimer, M*He. In both cases this means that optical pumping techniques normally used for gas phase atoms are not directly applicable towards our goal. We are investigating two different approaches to either circumvent or exploit this fact.
In the first approach, we seek transitions that do not result in dissociation of the atom from the droplet. A necessary condition is the presence of a barrier to formation of the excimer, which has been postulated for Rb [1,2]. Indeed, upon comparison of LIF and beam depletion spectra, and of their saturation behavior, we believe we have found, for this system, excitations resulting in fluorescence without depletion.
In the second approach we seek to selectively "bleach" one of the two electron-spin substates of ground state atoms (potassium, so far). With no magnetic field we demonstrate saturation of the D lines with a few hundred mW of laser power. With magnetic field, under saturation, we observe a greater LIF signal for linear polarization of the exciting laser, but no difference between left and right circular polarization. We take this as evidence that the two spin sublevels are equipopulated before excitation, hence no spin relaxation occurs on the timescale of the experiment (tens of μs).
Further measurements on dimers (K_2, KRb, Rb_2), show that their electronic transitions can also be saturated. The spectra acquired so far do exhibit magnetic circular dichroism, suggesting in this case a faster spin relaxation induced by the droplet.
We are in the process of improving the measurement accuracy, thus putting more stringent limits on the relaxation time, and of testing our conclusions with one-color two-laser experiments.

References

[1] J. Reho, J. Higgins, K. K. Lehmann, G. Scoles, J. Chem. Phys. 113, 9694 (2000).
[2] F. R. Brühl, R. A. Trasca, W. E. Ernst, J. Chem. Phys. 115, 10220 (2001).

From dense to dilute bosons: helium droplets vs. trapped BEC

F. Dalfovo

CNR INFM-BEC Center and Dipartimento di Fisica, Università di Trento, Italy
E-mail:dalfovo@science.unitn.it

The physics of Helium nanodroplets is reviewed with emphasis on theoretical aspects and recent results. Some relevant concepts such as the meaning of superfluidity in finite systems, the behavior of elementary excitations and collective modes, as well as rotational properties and quantized vorticity are briefly overviewed. Analogies and differences between Helium nanodroplets and Bose-Einstein condensates of trapped ultracold atoms are discussed, pointing out their common background and peculiar features.

Ellipticity effects in HHG from aligned molecules

C. Altucci[1], R. Velotta[1], R. Torres[2], E. Heesel[2], N. Kajumba[2], J.P. Marangos[2], C. Vozzi [3], F. Calegari[3], E. Benedetti[3], G. Sansone[3], S. Stagira[3], and M. Nisoli[3]

[1]*Dipartimento Scienze Fisiche, Università di Napoli "Federico II", CNISM, Napoli, Italy*
[2]*Blackett Laboratory, Imperial College, London, United Kingdom*
[3]*National Laboraroty for Ultrafast and Ultraintense Optical Science - CNR - INFM, Dipartimento di Fisica Politecnico, Milano, Italy*
E-mail:rvelotta@unina.it

Two-centre interference in the recombination step of molecular high harmonic generation (HHG) has been probed in CO_2 and O_2. We report the order dependence of characteristic enhancements or suppressions of high harmonic production in aligned samples of both molecules. In CO_2 a robust destructive interference was seen consistent with the known separation of the oxygen atoms that are active in HHG. In O_2 a harmonic enhancement was found indicating constructive interference. A good agreement was found with a simple two-centre interference model based on the following equation for the harmonic intensity

$$I(n,\theta) = I_0(n,\theta)\left[1-\cos\left(\frac{2\pi R cos\theta}{\lambda_B(n)}\right)\right]. \tag{3.1}$$

In Eq.(3.1) n is the harmonic order, λ_B is the electron de Broglie wavelength of the re-scattering electron and θ the angle between the molecular axis and the re-colliding electron momentum. We show that the effective momentum of the returning electron wave can be determined from the spectral position of these interferences. The ellipticity dependent studies in CO_2 clearly show how the destructive interference can be "switched off" by increasing the degree of ellipticity and thus shifting the effective resonance condition. In particular, by increasing the ellipticity, we have observed a shift of the position at which the minimum in HHG is observed. If all the aligned molecules uniformly contributed to HHG signal, the shift should move towards the opposite direction. In fact, the presence of an elliptically polarised field leads to a tilting in the electron momentum which in turn breaks the cylindrical symmetry introducing a dependence on the azimuthal angle ϕ . The observed shift can be explained by assuming that molecules for which the tilting leads to a reduction of θ, give larger contribution to HHG. In a simple classical approach we have considered an uniform contribution from half the molecules obtaining a result in agreement with the experimental findings. These results therefore show how the two centre interference can be controlled through the control of laser ellipticity pointing to a broader class of applications in the steering of strong field molecular processes through ellipticity and alignment angle control.

References

[1] C. Vozzi, F. Calegari, E. Benedetti, J.-P. Caumes, G. Sansone, S. Stagira, M. Nisoli, R. Torres, E. Heesel, N. Kajumba, J.P. Marangos, C. Altucci, and R, Velotta, Phys. Rev. Lett. **95**, 153902 (2005).
[2] C. Altucci *et al.*, in preparation.

Dual pulse laser ablation studied by cavity ring-down spectroscopy

N. Čutić, N. Krstulović, and S. Milošević

Institute of Physics, Zagreb, Croatia
E-mail: niksak@ifs.hr

Dual pulse laser ablation is recently attracting attention related to applications such as laser induced breakdown spectroscopy or production of nanoparticles. Depending on the time delay between laser pulses large increase of light emission or particle production rate was observed. However, details of dual laser ablation processes and plume dynamics are still not completely understood. Dual pulse laser ablation might be interesting technique to apply for efficient production of cold molecules. We have performed study of the plume content by using direct absorption method having this application in mind.

Laser ablation was performed within the vacuum chamber which could be evacuated by means of a roots pump system yielding final pressures of about 10^{-3} Torr. For ablation we have used two Nd-YAG lasers (Brilliant 350 mJ at 1064 nm and Brio 100 mJ at 1064 nm). Laser pulses were triggered and synchronized by means of a digital delay generator. For CRDS we have used an excimer (LPX 105E Lambda Physik) pumped dye laser (LPD 3002E Lambda Physik) working with a Rhodamine B dye. The laser pulse duration was about 15 ns and bandwidth about 6 GHz. Targets were mounted on an X-Y translation stage to allow precise positioning (100 mm) and were also rotated to avoid drilling. Details of CRDS arrangement were described in more details previously [1]. Lasers, digital delay generator and oscilloscope were controlled by a PC computer using a homemade LabVIEW program which also allows analyses of CRDS ringdown signal in various time windows [2].

In the present work we have studied dual laser ablation in the parallel laser beam configuration. As a test case targets of manganese or titanium were used and atomic spectra measured in the wavelength range around 630 nm. Results show clear increase (tenfold) of atomic absorptions for the case of dual laser ablation compared to single laser absorptions. We have explored CRDS potential (simultaneous determination of particles densities and velocities [3]), for study of dynamics of the plume depending on the time delay between laser pulses and the buffer gas environment. Preliminary results showed high potential of the dual laser ablation for the efficient production of molecules and particles.

References

[1] N. Krstulović, I. Labazan, S. Milošević, Eur. Phys. D 37 209-215 (2006).
[2] I. Labazan and S. Milošević, J. Phys. D: Appl. Phys. 37 2975-2980 (2004).
[3] I. Labazan and S. Milošević, Phys. Rev. A 68 032901 (2003).

A novel type of tuneable atomic beam splitter : van der Waals - Zeeman transitions of metastable neon atoms

J. Grucker, J.-C. Karam, M. Boustimi, F. Perales, V. Bocvarski*, J. Baudon, G. Vassilev, J. Robert and M. Ducloy

Laboratoire de Physique des Lasers, UMR 7538 CNRS, Université de Paris Nord, 99 Avenue J.-B. Clément, 93430 Villetaneuse, France
(*) Institute of Physics-Belgrade, 11000-Zemun, Belgrade, Serbia-Montenegro
E-mail: grucker@galilee.univ-paris13.fr

Owing to the recent discovery of ultra narrow metastable rare gas atoms beam [1], surface-induced transitions between Zeeman sub-levels of metastable neon atoms traversing a micro-slit Copper grating are investigated. The quadrupolar part of the surface van der Waals interaction suddenly perturbs the evolution of the Zeeman sub-levels in a magnetic field **B** (a few hundred Gauss) [2], giving rise to van der Waals – Zeeman transitions. Exo-energetic inelastic transitions are identified by the related deflections γ. As the atom kinetic energy (65 meV) is large compared to Zeeman energies (μeV), these γ angles are small (mrad). However, the combination of our ultra narrow Ne^* ($^3P_2$) beam with a position – sensitive detector allows us to resolve these deflections. In a diagram (γ, $B^{1/2}$) the locations of the inelastic peaks are fitted by straight lines of slopes proportional to $|\Delta m|^{-1/2}$ where Δm is the magnetic number change [3]. It is important to notice that vdW – Zeeman transitions are able to split the atom into a superposition of different Zeeman sublevels. Because the transverse coherence of the atomic beam (R_{cohe} ≈1266 nm [1]) is not large enough to cover the complete width of one grating slit (due to the grating inclination, the effective slit width is $w_e = 5.8$ μm), it is worth noticing that the splitting is coherent only for a same sign of deflection angle γ as the sign of the deflection depends on the border of the slit next to which the transition happened. However providing that $R_{cohe} \geq w_e$ (this can be achieved by slowing down the atoms for instance or using a nano grating), one can realize a beam splitter with equal energy loss on both sides. As there is no position information in this situation, the coherence of the two split beams will be complete. As the values of deflections γ depend on B magnitude, these transitions can be used as a tuneable atomic beam splitter.

References

[1] J.-C. Karam et al., J.Phys.B : At.Mol.Opt.Phys., **38**, 2691 (2005)
[2] N. Papageorgiou et al, Ann. Phys. (Paris), **20**, 611 (1995)
[3] J.-C. Karam et al, Europhys. Lett., **74**, 36 (2006)

Superintense laser field action on surface with forming the femto-second plasma and new laser spectroscopy of nuclear isomers

A.V. Glushkov

Odessa University, P.O.Box 24A, Odessa-9, 65009, Ukraine
E-mail: glushkov@paco.net

It is known that using super short light pulses changes principally a character of interaction of a laser radiation with substance [1]. For laser intensities more than 10^{15} Wt/cm^2 electrons get energy of 100-1000eV and it is realized a process of forming the femto-second laser plasma.(FLP). We consider possibilities of governing by processes, which are taken a place in the FLP in nano-structured porous materials (NSPM; Si). NSPM consist of the separated clusters set with the fractal structure. The key mechanism of the hot electrons generation in plasma is provided by oscillation of electron on the border 'plasma-vacuum or resonant absorption of laser radiation. One may wait for the sharp increasing the hot electrons generation and X-ray radiation. For large laser intensity it is observed a new type of the hydrodynamic ablation with the explosion character. Experimental estimates show that a velocity of the plasma flying of the strongly porous samples Si ($I \sim 3 \cdot 10^{16}$ W/cm^2) is $\sim 10^8$ cm s^{-1}, that is $\sim$ to energy 2 ± 1 MeV. We carried out the modelling of FLP forming in the porous materials on the basis of the energy balance equations [2]. Special attention is devoted to the modelling the system: NSPM with clusters, on surface of which there is a great number of bonds with H and OH groups. In a case of D-and OD group's one can wait for realization of the cluster explosion process and reaction D+D$\rightarrow \alpha$+n (3,8MeV). One can wait for appearance of the powerful flow of neutrons in plasma under intensity of heating pulse $\sim 10^{16}$ Wt/cm^2. In the high density plasma there is possible an excitation of the low lying isomers (level energy less 20 keV) by means of the channels: photo excitation by own X-ray plasma radiation, the electron impact excitation, electron conversion etc. We calculated properties of stable and long lived nuclei low lying isomers characteristics (energy, decay channels etc.), using methods [3]. In conclusion an observation of effect of the excitation for isomer nuclear level in laser plasma is discussed.

References

[1] Superstrong Fields in Plasmas. Eds.: M. Lontano *et al.*, AIP Conf. Proc., 426 (1998); V.M. Gordienko, A.B. Saveliev, UFN 169, 78 (1999); A.V. Andreev *et al.*, JETP Lett. 66, 312 (1997).
[2] A.V. Glushkov *et al.*, Int. J. Quant. Chem. 101, 531 (2005); Progr. Theor. Phys. (2005); J. Phys. CS (2005).
[3] E.P. Ivanova, L.N. Ivanov, A.V. Glushkov, A.E. Kramida, Phys. Scripta. 32, 512 (1985); E.P. Ivanova, A.V. Glushkov, J. Quant. Spectr. Rad. Transfer 36, 127 (1986); A.V. Glushkov, L.N. Ivanov, Phys. Lett. A 170, 33 (1992); J. Phys. B 26, L379 (1993); A.V. Glushkov, S.V. Malinovskaya, In: New Projects and New Lines of Research in Nuclear Physics. Eds.: G. Fazio and F. Hanappe, World Sci., Singapore, 146 (2003); Nucl. Phys. A. 734, e21 (2004); A.V. Glushkov *et al.*, Int. J. Quant. Chem. 99, 889 (2004); 99, 936 (2004); Preprints of Institute for Spectroscopy of Russian Acad. Sci., NAS 1, 2, 3, Troitsk, 1994.

Quantum Dynamics of Ultracold Electronically Excited Atoms in a Magnetic Trap

I. Lesanovsky[1] and P. Schmelcher[2]

[1] *Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany*
[2] *Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany and Theoretische Chemie, Institut für Physikalische Chemie, Universität Heidelberg, INF 229, 69120 Heidelberg, Germany*
E-mail:peter@tc.pci.uni-heidelberg.de

We investigate the quantum dynamics of ultracold electronically excited atoms exposed in a magnetic quadrupole trap. First a general Hamiltonian which describes the quantum dynamics of an atom in an arbitrary linear magnetic field configuration is derived. This makes our approach applicable to a wide range of atoms and field configurations. The coupled center of mass and electronic motion is solved by incorporating an adiabatic separation of the dynamics. We provide the adiabatic energy surfaces and discuss under which conditions trapped center of mass states can be achieved for highly excited atoms. Energies and wavefunctions of the corresponding quantum dynamical hybrid states are studied thereby entering a new regime where both the external and internal motion are coupled and quantized leading to e.g. ring states. By analyzing the properties of the resulting combined motion we demonstrate that the extension of the electronic wavefunction can exceed that of the center of mass motion. Such atoms cannot be considered as being point-like. A discussion of the electromagnetic transitions is also provided.

References

[1] I. Lesanovsky and P. Schmelcher, Physical Review Letters 95, 053001 (2005)
[2] I. Lesanovsky and P. Schmelcher, Physical Review A 72, 053410 (2005)

Dipole-dipole interaction in a chromium Bose-Einstein condensate

M. Fattori[1], A. Griesmaier[1], T. Koch[1], J. Stuhler[1], T. Pfau[1], S. Giovanazzi[1], P. Pedri[2] and L. Santos[3]

[1] *5. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany*
[2] *LPTMS, Bâtiment 100, Université Paris-Sud, 91405 ORSAY cedex, France*
[3] *Institut für Theoretische Physik III, Universität Stuttgart, 70569 Stuttgart, Germany*
E-mail: m.fattori@physik.uni-stuttgart.de

During the last decade, the most interesting results obtained in the field of ultra-cold atomic gases have seen the van der Waals inter-particle interaction playing a crucial role. For most purposes such interaction can be considered short range and isotropic.
Very recently the physics of dipolar gases has attracted new interest, resulting as one of the most promising research directions in the physics of ultra-cold atoms. In fact thanks to the long-range and the anisotropic character of dipole-dipole interactions many exciting phenomena have been predicted to occur in dipolar quantum gases [1].
To investigate them, we have realized a chromium Bose-Einstein condensate (BEC) of up to 100,000 condensed atoms within a crossed optical dipole trap. In fact chromium atoms possess very large magnetic moments of 6 Bohr magnetons. As a consequence, the magnetic dipole-dipole interaction (MDDI) is much stronger than in previously realized BECs, e.g., by a factor of 36 compared to alkali atoms. Hence, MDDI starts to be comparable to the contact interaction.
In agreement with the theory of dipolar quantum gases, the anisotropic nature of the MDDI can be proved releasing the condensate from a cigar shaped trap and observing, in time of flight measurements, the change of the aspect-ratio for different in-trap orientations of the atomic dipoles. To our knowledge this is the first observation of mechanical effect of MDDI in a gaseous system [2].
Since one can exploit Feshbach resonances [3] to adjust contact like atom-atom interaction and use rotating magnetic fields to tune the dipole-dipole interaction [4], interaction regimes ranging from only contact to purely dipolar can be realized.

References

[1] K. Gòral, L. Santos, M. Baranov, L. Dobrek, and M. Lewnstein, Phys. Scripta T 102, 74 (2002).
[2] J. Stuhler, A. Griesmaier, T. Koch, M. Fattori , T. Pfau, S. Giovanazzi, P. Pedri and L. Santos , Phys. Rev. Lett. 95, 150406 (2005).
[3] J. Werner, A. Griesmaier, S. Hensler, J. Stuhler, T. Pfau, A. Simoni and E. Tiesinga, Phys. Rev. Lett. 94, 183201 (2005).
[4] S. Giovanazzi, A. Görlitz and T. Pfau, Phys. Rev. Lett. 89, 130401 (2002).

Evaporative cooling of a magnetically guided atomic beam

T. Lahaye, G. Reinaudi, Z. Wang, A. Couvert, J. Dalibard and D. Guéry-Odelin

Laboratoire Kastler Brossel, Département de Physique de l'École Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France.

More than ten years after the achievement of BEC in dilute gases and the first experiments leading to the extraction of *pulsed* atom lasers from such condensates, the creation of a continuous-wave atom laser is still a challenge. A possible scheme towards this goal, consisting in applying evaporative cooling on a magnetically guided atomic beam, was studied theoretically in [1]. The prerequisite for reaching quantum degeneracy with such a technique is the achievement of the collisional regime for the atomic beam: typically, an atom must undergo around $N \sim 200$ elastic collisions during its propagation along the guide. Our group achieved recently the collisional regime for a beam [2], with $N \sim 8$.

I will report on our recent progress in the manipulation and evaporative cooling of a magnetically guided, high flux beam of ^{87}Rb atoms. Typically 7×10^9 atoms per second propagate in a 4.5 m long magnetic guide, providing a transverse gradient of 800 G/cm, with a temperature $T \sim 550$ μK, at an initial velocity of 90 cm/s. The atoms are subsequently slowed down to 60 cm/s using an upward slope. The relatively high collision rate (5 s^{-1}, yielding $N \sim 20$) allows us to start forced evaporative cooling of the beam by means of radio-frequency knifes, leading to a reduction of the beam temperature by a factor of 4, and a ten-fold increase of the on-axis phase-space density [3]. We have also developed a more local evaporation technique relying on the elimination of energetic particles on a material surface [4]. I will discuss the limitations of our current experimental setup and describe preliminary work aimed at overcoming them.

References:

[1] E. Mandonnet, A. Minguzzi, R. Dum, I. Carusotto, Y. Castin and J. Dalibard, Eur. Phys. J. D **10**, 9 (2000).
[2] T. Lahaye, J. M. Vogels, K. J. Günter, Z. Wang, J. Dalibard and D. Guéry-Odelin,, Phys. Rev. Lett. **93**, 093003 (2004).
[3] T. Lahaye, Z. Wang, G. Reinaudi, S. P. Rath, J. Dalibard and D. Guéry-Odelin, Phys. Rev. A **72**, 033411 (2005).
[4] G. Reinaudi, T. Lahaye, A. Couvert, Z. Wang, and D. Guéry-Odelin, to appear in Phys. Rev. A.

Towards a quantum degenerate ^{133}Cs-^{87}Rb mixture

M. L. Harris, P. Tierney and S. L. Cornish

Department of Physics, Durham University, Rochester Building, South Road, Durham DH1 3LE, UK.
E-mail: margaret.harris@durham.ac.uk

We report progress on a new experiment designed to produce a quantum degenerate mixture of ^{133}Cs and ^{87}Rb. Such mixtures constitute an extremely rich 'playground,' with possible future applications in ultracold heteronuclear molecule formation [1], quantum information processing [2], and sympathetic cooling [3]. Atomic interactions (both inter- and intra-species) determine the fundamental properties of the mixture, e.g. stability and miscibility. A mixture of Cs and ^{87}Rb is particularly attractive, as the rich Feshbach structure of Cs leads to wide tuneability of the Cs-Cs scattering length, whilst the scattering length of ^{87}Rb is essentially independent of magnetic field. Knowledge of interspecies collisions, however, is currently limited to the upper hyperfine ground states [4]. Hence, the first phase of our experiment will characterise interspecies collisions for the Cs $|F = 3, m_F = -3\rangle$ and Rb $|1,\text{-}1\rangle$ states. A search for an interspecies Feshbach resonance will allow us to place tight constraints on the value of the interspecies scattering length a_{12}, while a comparison between measured rethermalisation rates and collisional Monte Carlo simulations [5] will allow us to measure a_{12} directly. Once the scattering length is known, additional Monte Carlo studies will simulate sympathetic cooling of Cs by direct evaporation of ^{87}Rb, a method which could offer an alternative route to quantum degeneracy in Cs.

In our experiment, the mixture is prepared using a double magneto-optical trap (MOT) apparatus in which a two-species pyramid MOT acts as a source of cold atoms for a second 'science' MOT. A system of six diode lasers (three for each species) is used to derive the laser frequencies required for both MOTs, as well as for optical pumping and imaging the ultracold mixture. Measurements of light-assisted inelastic Cs-Rb collisions in the MOTs are presented, as are studies of optimum loading parameters for the dual-MOT system. In the next stage, Cs and Rb atoms in the target states will be transferred to a 'baseball' type Ioffe-Pritchard magnetic trap for further studies.

References

[1] A. J. Kerman et al., Phys. Rev. Lett. 92, 033004 (2004); B. Damski et al., Phys. Rev. Lett. 90, 110401 (2003); E. A. Donley et al., Nature 417, 529 (2002).
[2] D. DeMille, Phys. Rev. Lett. 88, 067901 (2002).
[3] C. Myatt et al., Phys. Rev. Lett. 78, 586 (1997); A. Mosk et al., App. Phys. B 73, 791 (2001); G. Delannoy et al., Phys. Rev. A 63, 051602 (2001).
[4] M. Anderlini et al., Phys. Rev. A 71, 061401 (2005).
[5] Z.-Y. Ma, A. M. Thomas, C. J. Foot and S. L. Cornish, J. Phys. B: At. Mol. Opt. Phys. 36, 3533 (2003).

Relativistic multi-configuration hyperfine structure calculations for the ground state of Vanadium

O. Scharf[1] and G. Gaigalas[1,2]

[1] *Vilnius University Research Institute of Theoretical Physics and Astronomy, A. Goštauto 12, LT-01108 Vilnius, Lithuania.*
[2] *Department of Physics, Vilnius Pedagogical University, Studentu 39, LT-08106 Vilnius, Lithuania.*
E-mail: oliver@itpa.lt

We report about the pure *ab initio* calculations of the ground state hyperfine structure of Vanadium. The calculations are based on the GRASPVU package [1,2]. Due to the complex structure with 13 valence electrons, a new method is used.

The developed method allows one to detect the convergence, the influence of defined correlation groups and thus to make well defined approximations for the configuration state function space. The method gives one the possibility to study hyperfine structure splitting of complex atoms and ions and using modern computing facilities to achieve fairly accurate results.

The hyperfine structure of the low lying levels of Vanadium are known from experiment. Semiempirical calculations for the hyperfine structure exist resembling the experimental results within 5%. The hyperfine structure constants for the ground state of Vanadium have recently been obtained in the multi-configuration Hartree-Fock approach by our group. The calculated values agree within 3% with the experimental results. A strong influence of the core correlation was observed [3].

Further investigation using the multi-configuration Dirac-Fock approximation are presented. The method applied to Vanadium allows one to limit the configuration state function space from nearly 600 000 configuration state functions to 30 000 most important ones. The dependency of the A factor on the correlation groups is similar in both, the multi-configuration Hartree-Fock and Dirac-Fock approximation. The $3s$ and $4s$ orbitals are polarized but the net effect on the hyperfine structure compensates. As in the multi-configuration Hartree-Fock approximation, the Dirac-Fock approximation leads to good agreement (within 5%) with the experimental results. The same strong influence of the core correlation is observed.

References

[1] F. A. Parpia, C. Froese-Fischer, I. P. Grant, Comp. Phys. Com. 94, 249 (1996).
[1] C. Froese-Fischer, G. Gaigalas, Y. Ralchenko, Book of Abstracts of XXXVIII EGAS Conference, 7-10, June, 2006, Ischia, Italy.
[3] O. Scharf, G. Gaigalas, Centr. Europ. J. Phys. 4(1), 42 (2006).

High precision calculation of relativistic and nuclear recoil effects in the lithium atom.

M. Puchalski and K. Pachucki

Institute of Theoretical Physics, Warsaw University
Hoza 69, 00-681 Warsaw, Poland.
E-mail:mpuchals@fuw.edu.pl

Variational calculations in Hylleraas coordinates, which include explicit powers of inter-electronic distances, are well established as providing the most precise wave functions for two- and three-electron atomic systems. Effective method for evaluating three-electron integrals in Hylleraas coordinates will be presented. Our approach bases on analytical evaluation of all integrals with the help of recursions relations[1-3]. Several results for the lithium, including $2S - 3S$ transition, the isotope shift and the hyperfine interaction will be presented, with the accuracy, which is few orders of magnitude higher than obtained previously[4].

References

[1] M. Puchalski, K. Pachucki, Phys. Rev. A **73**, 022503 (2006)
[2] K. Pachucki, M. Puchalski, Phys. Rev. A **71**, 032514 (2005)
[3] K.Pachucki, M. Puchalski, Phys. Rev. A. **70**, 032502 (2004)
[4] Z.-C. Yan, M. Tambasco, and G.W.F. Drake, Phys. Rev. A **57**, 1652 (1998)

Search for new electronic levels in praseodymium, europium and lanthanum

B. Furmann, A. Krzykowski, D. Stefańska and J. Dembczyński

Chair of Quantum Engineering and Metrology,
Faculty of Technical Physics, Poznań University of Technology,
Poznań, Poland
E-mail: furman@phys.put.poznan.pl

The results of application of a nonstandard procedure of search for new electronic levels are presented. It is based on the measurements of the hyperfine structure for the unclassified spectral lines with laser induced fluorescence (LIF) and the comparison of the results with the available values of the hfs constants for the known or the theoretically predicted levels. This procedure has proved to be very efficient for praseodymium. More than 50 new levels, belonging to the odd configurations, with energy values between 25000 cm^{-1} and 35000 cm^{-1} in praseodymium atom, as well as more than 40 new levels with energy values between 9000 cm^{-1} and 35000 cm^{-1} in praseodymium ion have been found [1,2]. Each of the new levels have been verified through the measurement of several spectral lines involving them. It seems interesting, that despite the large number of the new levels found independently by the group of Prof. Guthoehrlein from Hamburg [3], only little of the levels found in our investigations happened to coincide with the ones found by them. In the case of the atom the measurement only in one spectral region has been sufficient for an unequivocal determination of the energy of the level. For the ion measurements have been performed in the wavelength ranges 565-608 nm and 412-465 nm. In the case of europium an initial measurement of the hfs constants for the known electronic levels proved indispensable for efficient identification of the new levels. The hfs constants for 54 known were determined (the results were presented at the previous EGAS conference [4]).
A complementary use of the information extracted from the isotope shifts and the Zeeman spectra has yielded a final identification of the new levels. A similar initial measurements have been carried out for lanthanum atom (the hfs A constants for more than 50 odd levels and 15 even levels have been determined for the first time).

This work was supported by Poznań University of Technology under project BW-63-028/06

References

[1] B. Furmann, D. Stefańska, E. Stachowska, J. Ruczkowski, J Dembczyński, European Physical Journal D17, 275, (2001)
[2] B. Furmann, D. Stefańska, J. Dembczyński, E. Stachowska, Physica Scripta 72, 300, (2005)
[3] G.H. Guthoehrlein - Private Communication
[4] B. Furmann, D Stefańska, J. Dembczyński, EGAS 37 Dublin Poster P1-62

Transition Probabilities of Important Ar Ions Multiplets

K. Katsonis[1], M. Cornille[2], R.E.H. Clark[3], J. Abdallah Jr.[4], Ch. Berenguer[1], A. Ndiayé[1]

[1] *CNRS and LPGP, UMR 8578, Université Paris-sud, 91405 Orsay cedex, France*
[2] *LUTH, UMR 8102 CNRS, Observatoire de Paris, 92195 Meudon cedex, France*
[3] *Nuclear Data Section, IAEA Vienna, Austria*
[4] *LANL Los Alamos, USA*
E-mail: konstantinos.katsonis@pgp.u-psud.fr

Results of our evaluation of Ar ions transition probabilities (A_{ij}) will be described and commented on during the Conference. Part of this work is related to a coordination research project of the IAEA, in support of controlled fusion applications. We are addressing A_{ij} of singly or higher ionized species of Ar, in order to extend our Collisional - Radiative (C-R) code to describe Argon plasmas with up to six times ionized species [1]. Thus, successive Argon spectra preceding Ar VII (in which all of the external $3p^6$ electrons have been stripped) can be taken into account, depending on the plasma temperature of interest. We have compared *in extenso* results coming (a) from CbA, our Coulomb Approximation code based in the approximation introduced in [2], (b) the code contained within the SUPERSTRUCTURE package developed at University College [3] and (c) the Los Alamos National Laboratory (LANL) codes [4] available through the Internet [5].
Data obtained from other theoretical calculations or measured experimentally, including data contained in well known databases whenever available, have also been considered. The existing data are known to be very scarce, while a huge number of transitions must be taken into account in reconstituting the spectrum belonging to each multiplet. Therefore, *ab initio* calculations for transitions involving levels of which the corresponding energies have not been measured are mandatory. The available evaluated energy levels (and transition probabilities, whenever they exist) from the NIST site [6], although of very good quality, are not sufficient for our task; therefore, we are doing benchmark calculations in order to supplement the available database with new data reliable enough for our model.
Recent calculations include: (a) The $4p \leftarrow 4d$ multiplet of Ar III, which constitutes the second in order of importance from the non-resonant multiplets of the third Argon spectrum. In general, our low ionized Ar calculations suggest that the relativistic effects are not very pronounced. Subsequently, the $3d \leftarrow 4p$ multiplets of Ar III have been studied. (b) The resonant transitions of the $3p \leftarrow 4s$ multiplet belonging to the Ar II spectrum. (c) The $4s \leftarrow 4p$ and $3d \leftarrow 4p$ multiplets of the Ar IV spectrum. Here, the $3d \leftarrow 4p$ multiplet has been chosen instead of the more obvious choice of the $4p \leftarrow 4d$ one, because for the latter no energy levels are given in the NIST database for the moment. This work aims to establish the validity of our Ar calculations for slightly higher ionization stages.

References

[1] K. Katsonis, D. Zhang, Ch. Berenguer, R.E.H. Clark, M. Cornille "A Collisional – Radiative Model for Ar I to VI Spectra Diagnostics", this Conference.
[2] D.R. Bates, A. Damgaard, *Phil. Trans. Roy. Soc. (London)* A242, 101 (1949).
[3] W. Eissner, M. Jones, H. Nussbaumer, *Compt. Phys.Commun.* 8, 270 (1974).
[4] J. Abdallah Jr, R.E.H. Clark, R.D. Cowan *"CATS: The Cowan Atomic Structure Code"* Report LA-11436-M (1988).
[5] http://aphysics2.lanl.gov/tempweb/
[6] http://physics.nist.gov/cgi-bin/AtData/main_asd

Xe I and Xe II Transition Probabilities and Excitation Cross Sections

K. Katsonis[1], M. Cornille[2], G. Maynard[1], R.E.H. Clark[3], J. Abdallah Jr.[4], Ch. Berenguer[1], A. Ndiayé[1]

[1]*CNRS and LPGP, UMR 8578, Université Paris-sud, 91405 Orsay cedex, France*
[2]*LUTH, UMR 8102 CNRS, Observatoire de Paris, 92195 Meudon cedex, France*
[3]*Nuclear Data Section, IAEA Vienna, Austria*
[4]*LANL Los Alamos, USA*
E-mail: konstantinos.katsonis@pgp.u-psud.fr

Because of the importance of Xe plasmas for contemporary industrial applications, especially for electric propulsion and the divertor region of Tokamak plasmas, we are systematically addressing their Collisional-Radiative(C-R) modeling, seeking the most extensive comparison of our theoretical results with values measured by us in various experimental devices and/or available in the literature. The theoretical methods which we are using, are the same with those of the Ar case [1]. An extended review has been recently made available [2] giving most of the necessary energy levels for the Coulomb approximation calculations. In the present contribution, we restrict ourselves to the simplified case where the local electron temperature (T_e) of the plasma is considered as being sufficiently low (a few eV) in order to have a negligible influence of the Xe^{q+} ions with q>2 on the line intensities calculated by the C-R model for the Xe I and Xe II spectra, even if the presence of the twice ionised species becomes significant at temperatures which are lower than those of the Ar plasmas. For our theoretical Xe I and II spectra, comparison with the experimental ones, mainly for the $6s \leftarrow 6p$, $7p$ and $6p \leftarrow 5d$, $6d$ multiplets has shown satisfactory agreement. In correctly formulating our model, detailed evaluation was made of the transition probabilities corresponding to most multiplet components in order to achieve completeness; special care was devoted to transition probabilities belonging to the experimentally observed leading transitions. Results of this evaluation will be shown in the Conference.

Together with the spontaneous emission, electron collision excitation (and de-excitation) plays a very significant role in the formation of the plasma spectra. Therefore, special attention has been given to the correct evaluation of the relevant cross sections, for which only scarce data are available. Importance of the excitation by electron impact is increasing whenever the lower level of the transition is significantly populated. This is the case with the ground and metastable levels. Once the excitation cross section is evaluated, the inverse process, collisional de-excitation, can be easily evaluated through micro-reversibility. For Xe I some cross sections are available for the ground level and for the $6s$, $6p$ excited levels, the Xe II data being even more scarce. We have made extensive use of the LANL codes [3] in order to obtain a consistent set of excitation cross sections to be used with our C-R model. Part of the results obtained will be presented and commented on during the Conference.

Three of us (KK, ChB, AN) gratefully acknowledge support from the Groupement de Recherche CNRS/CNES/ SNECMA 2232 *"Propulsion à Plasma pour Systèmes Spatiaux"*.

References

[1] K. Katsonis, M. Cornille, R.E.H. Clark, J. Abdallah Jr., Ch. Berenguer, A. Ndiayé, *"Transition Probabilities of Important Ar Ions Multiplets"*, this Conference.
[2] E.B. Saloman, *J. Phys. Chem. Ref. Data* 33, 765 (2004).
[3] http://aphysics2.lanl.gov/tempweb/

A Collisional–Radiative Model for Ar I to VI Spectra Diagnostics

K. Katsonis[1], D. Zhang[2], Ch. Berenguer[1], R.E.H. Clark[3], M. Cornille[4]

[1] *CNRS and LPGP, UMR 8578, Université Paris-sud, 91405 Orsay cedex, France*
[2] *Max-Plank-Institut fuer Plasmaphysik, EURATOM Ass., Wendelsteinstr. 1 17491 Greifswald, Germany*
[3] *Nuclear Data Section, IAEA Vienna, Austria*
[4] *LUTH, UMR 8102 CNRS, Observatoire de Paris, 92195 Meudon cedex, France*
E-mail: konstantinos.katsonis@pgp.u-psud.fr

Non-intrusive emission spectroscopy plasma diagnostics allows for evaluation of the local temperature and density; it also provides information on the constituents and the most important processes encountered in the plasma. For a satisfactory application of such diagnostics, a full Collisional-Radiative (C-R) model is needed, taking into account all the present species, both neutral and ionized, together with their excited states (including their structure and transition probabilities) and also the rates of the contributing processes. As a sequel of our emission spectroscopy studies we report here on work in progress on emission spectroscopy diagnostics of the WEGA Stellarator plasma, when fed with Argon. This device, operated at IPP Greifswald, is mainly used for basic research in plasma physics, including educational training and for testing of new diagnostic equipment [1]. Emission spectroscopy diagnostics will be subsequently extended to He discharges, which are also studied in the same device. The present task takes advantage of a general study aiming for the characterization and optimization of the WEGA plasmas [2] and of bolometric results obtained recently [3].
According to measurements made at IPP, an electron temperature T_e of about 10 eV prevails in WEGA for Ar discharges, with an electron density n_e of about 10^{12} cm^{-3}. Our calculations, based on a simple coronal model, are applied to the full Ar I to Ar V spectra, plus partial radiation from Ar^{5+}. Of course, all of these spectra are not expected to be simultaneously present in an homogeneous plasma with a single T_e, but in the case of the separatrix- and/or limiter-plasmas of WEGA a "mixture of temperatures" may explain the detection of signatures of all of the ionized Ar species as well as of the neutral, possibly altering the total radiated energy. Accordingly, more than one Maxwellian distribution prevails for some or for all of the present species. Typical Ar I-III spectral lines have now been identified in various WEGA discharges. The main features of the relevant spectra will be shown and commented on during the Conference. They will also be compared to our theoretical spectra, in order to investigate the real presence and percentage of each ionized species and judge about the form of T_e in connection with possible departures from the unique Maxwellian distribution.

References

[1] M. Otte *et al.* p. 1.211, in 31 EPS Conference on Plasma Phys. and Controlled Fusion, St Petersburg, 7-11 July (2003).
[2] K. Horvath *"Characterisation and Optimisation of WEGA Plasmas"*, PhD Thesis, Greifswald University (2005).
[3] D. Zhang, M. Otte, L. Giannone *"Bolometer Results in the Long-Microwave-Heated WEGA Stellarator"* p. 187, in PLASMA 2005, M J Sadowski *et al.* Edts. Opole, Poland 2005, AIP Conf. Proc. 812, NY (2006).

Spin-orbit interaction induced decay of doubly excited states in Helium

E. Lindroth

Atomic Physics, Fysikum, Stockholm University, S-106 91 Stockholm, Sweden
E-mail:lindroth@physto.se

The doubly excited states of the non-relativistic helium atom have during the last decades served as the primary model systems to test methods to handle resonance states. These states couple to the continuum of He^+ and an outgoing electron and are thus autoionizing. A correct and efficient treatment of this coupling have here been a key issue. A number of methods to calculate doubly excited, autoionizing, states have been developed and today non-relativistic calculations can be done with more or less machine accuracy for at least part of the spectrum. In contrast very few relativistic methods exist for calculations on autoionizing states and hardly any have been applied to helium
Among the doubly excited states lying above the first ionization threshold there are in most ions a number that of symmetry reasons cannot autoionize in LS-coupling[1]. In many cases these states can still autoionize through spin-orbit coupling and even for rather light ions this non-relativistically forbidden decay mode can be important compared to alternative paths as radiative decay. This can be understood from the fact that when autoionization is non-relativistically allowed it often dominates over radiative decay with orders of magnitude and thus even a tiny admixture of a component that can autoionize may suffice to make this path important. The spin-orbit induced admixture of different LS-terms can in addition vary substantially even between different fine structure components belonging to the same term since the presence of nearby states of the same total angular momentum, J, strongly affects the admixture.
We start from the Dirac Hamiltonian and use complex rotation to handle the coupling to the continuum. Most of the doubly excited states in helium are, especially relativistically, dominated by a set of configurations, e.g. by $2p_{1/2}^2$, $2p_{3/2}^2$ and $2p_{1/2}2p_{3/2}$, that are very close in energy. To handle this situation we use a perturbation expansion from an *extended model space*. The idea is that strongly coupling configurations, forming the model space, are included through direct diagonalization of the Hamiltonian, while other configurations are included by perturbation theory.
The spin-orbit interaction induced decay through admixture of different LS-terms scales as $\sim \alpha^4 Z^8/\Delta E^2$, where ΔE is the energy difference to the state being mixed in. When mixing can occur with states belonging to the same configuration $\Delta E \sim Z$ and the induced decay rate scale as $\sim \alpha^4 Z^6$ in other cases the scaling is expected to be $\sim \alpha^4 Z^4$. The leading contribution is due to spin-orbit mixing in the field of the nucleus, but also the electronic field contribute although with a weaker Z-scaling. The contributions from the Breit interaction to the energy is very small for a light system as helium, but the spin-spin and spin-orbit interactions included in this way is of the same formal order as the spin-orbit interaction from the Coulomb part of the electronic interaction and affects the forbidden decay rates in leading order. The Breit interaction is in fact of relatively large importance for the decay rate of the most longlived states, and dominates for some states.

References

[1] M. Tokman et al., Phys. Rev. A. 66, 012703, (2002)

Calculation on Dielectronic Recombination - Spectroscopy of highly charged ions

E. Lindroth

Atomic Physics, Fysikum, Stockholm University, S-106 91 Stockholm, Sweden
E-mail:lindroth@physto.se

Multiply excited, autoionizing, states are frequently encountered as resonances in atomic processes as ionization or electron-ion recombination. The presence of resonances can change the probability for a process by orders of magnitude and there is thus an obvious interest to be able to describe them and make quantitative predictions of their effects. In addition there are many interesting spectroscopic aspects related to resonances.
The probability for the process of electron-ion recombination is in fact often governed by the resonant process of dielectronic recombination and the contribution varies drastically from one charge state to the other since it strongly depends on the density of doubly excited states. The change in electronic configurations when one electron is added or removed can be enough to change the recombination rate coefficients by orders of magnitude. Predictions of the recombination rate requires thus precise spectroscopical knowledge. Of the same reasons, measurements of recombination resonances can in fact be used to access highly accurate information on atomic energy levels, especially for highly charged ions. One among the presently most accurate determinations of an energy splitting in a few electron highly charged ion is obtained from the cross section for recombination with free electrons near the ionization threshold of an highly charged lead ion (Pb^{53+})[1], and several Li-like ions have their most precise determination in this way [2,3]. The spectroscopic principle is that during the formation of a resonance the valence electron is excited by the capture of a free electron into a Rydberg state. The binding energy of the latter can be estimated to excellent accuracy and the excitation energy can then be accessed. The determination of the excitation energy is in many cases sensitive to many-body quantum electrodynamical effects as well as to the hyperfine structure[4].
Results will be shown for the effect from hyperfine interaction on the dielectronic recombination of Li-like scandium, recently measured at the TSR storage ring in Heidelberg and for the astrophysically interesting ion Si^{3+}, measured at the CRYRING storage ring in Stockholm.

References

[1] E. Lindroth *et al.*, Phys. Rev. Lett. **86**, 5027 (2001)
[2] S. Kieslich *et al.*, Phys. Rev. A. **70**, 042714 (2004)
[3] S. Madzunkov *et al.*, Phys. Rev. A. 65, 032505, (2002)
[4] R. Schuch *et al.*, Phys. Rev. Lett. **95**, 183003 (2005)

On the calculation of scattering cross sections on the basis of Feynman path integral with high accuracy Gaussian approximation

A. A. Mityureva, V. V. Smirnov

Faculty of Physics, Saint Petersburg State University 198504, St. Petersburg, Russia
E-mail: smir@paloma.spbu.ru

This work proceeds our studies on the application of path integration to the scattering problems of atomic physics [1-6]. The studies are based on various evaluation procedures for exact continual path integral representation of scatting amplitudes (or directly of scattering cross sections in density matrix formalism).
Evaluation process may be subdivided on two parts. First one is a finite dimensional approximation of continual path integral by projection on discrete paths. This leads to high dimensional integral which is evaluated by some way at the second stage. We had tested several procedures for the second stage of a finite dimensional path integrals evaluation [2, 4-6], and have concluded that approximation by Gaussian integrals may be effectively extended on electron-atomic collisions [5, 6].
Previous works [5, 6] uses a few terms Gaussian expansion of the integrand in a finite dimensional path integral. So we have inaccuracy on both stages of path integral evaluation process. In this work for the simple potential scattering model we make a high accuracy Gaussian expansion. This reveals practically only discretization errors of the first stage - finite dimensional projection, which depends on the single parameter - the number of discrete path points.
Test calculations of the differential cross sections are performed for the scattering of wave packet by a three-dimensional spherically symmetric Gaussian potential. They are in good agreement with high accuracy calculations using the phase functions method.

References

[1] V. V. Smirnov. Theor. and Math. Phys. 90, n.1, 155 (1992).
[2] V. V.Smirnov and A. A.Mityureva. J. Phys. B, 29, n.13, 2865 (1996).
[3] V. V. Smirnov. J. Phys. A, 32, n.7, 1285 (1999).
[4] A. A. Mityureva, A. N. Semenov, and V. V. Smirnov. Vestnik St. Petersb. Univ., Ser. 4 (Phys.), i.4 (n.28), 13 (2002).
[5] A. A. Mityureva, V. V. Smirnov. Opt. & spectr., 99, n.1, 8 (2005).
[6] A. A. Mityureva, V. V. Smirnov. Opt. & spectr., 101, n.2, (2006) (in print)

Extended analysis of the even configurations of Ta II

Ewa Stachowska[1], Jerzy Dembczyński[1] and Laurentius Windholz[2]

[1] *Chair of Quantum Engineering and Metrology, Poznań University of Technology, Poznań, Poland*
[2] *Institute of Experimental Physics, Graz University of Technology, Graz, Austria*
E-mail:ewa.stachowska@put.poznan.pl

This work extends the analysis of the complex atomic structure of the tantalum ion. This was stimulated by new experimental data obtained by the last author. Semi-empirical calculations of the fine- and hyperfine structure of the system of the following 25 configurations have been performed :

$\underline{5d^4}$ + $5d^3n'g$ (n′=5-6) + $\underline{5d^36s}$ + $5d^36d$ + $\underline{5d^26s^2}$ + $5d^26sn'g$ (n′=5-6) + $5d^26sn''d$ (n″=6-10) + $5d^26sn'''s$ (n‴=7-10) + $5d^25f6p$ + $5d^26p^2$ + $5d6s^2n''d$ (n″=6-7) + $5d6s6p^2$ + 5d5f6s6p + 5d5f6s7p + 5d6s6d7s.

Until now only levels of the configurations $(5d+6s)^4$, underlined above, were known. Our extended analysis using this new data allowed us to establish the position of higher excited configurations, of which until now no levels were known.

This work was partially supported by PUT (project BW 63-028/06).

New Energy Levels of Ta II

L.Windholz, and U. Zaheer

Inst. f. Exp. Physics, Graz University of Technology, Petersgasse 16, A-8010 Graz, Austria
E-mail:windholz@tugraz.at

Even given in the famous tables of Ch. Moore [1] and further analyzed in the paper of C.C. Kiess [2] in 1961 and later by F.-J. Wyard [3], F.-J. Wyard and J. Blaise [4], the level structure of the first ion of ^{181}Ta is by far not completely known.
In our group in Graz we have investigated the hyperfine structure and fine structure of the ^{181}Ta atom since 1990 ([5] and references therein) by laser excitation of unclassified spectral lines. Combination of laser spectroscopy and high resolution Fourier transform spectra (provided to us by J.C. Pickering and R. Engleman) made it possible to enlarge the number of known Ta I levels by a factor of 2 (now ca. 600 Ta I levels are known). These investigations were extended to Ta II. Hyperfine constants of most of the known Ta II levels were published by Zilio and Pickering [6] and Eriksson [7]. For other levels we made our own determination. Using these results, Ta II classifications could be verified by comparing predicted and observed hyperfine patterns.
But still there are hundreds of strong spectral lines in the Fourier spectra which are not classified, most of them in the ultraviolet region showing well-pronounced hyperfine patterns. Most of these lines belong to the spectrum of the first ion, Ta II.
In 2002 it was possible to find two high-lying even Ta II levels with energies of ca. 72000 cm^{-1} [8]. In this paper the strategies to find new levels are given detailed. The introduction of these levels explained not only the wave numbers of several unclassified lines, moreover, the hyperfine patterns of all these lines were modeled correctly, too.
In the mean time we cold found some further high lying levels, given below. These are the highest known levels of Ta II.

J	Parity	Wavenumber (cm-1)	A (MHz)	B (MHz)	Published
1	e	72225.2	430(2)	-728(80)	[8]
2	e	72786.79	1344(15)	-1090(350)	[8]
2	e	75294.45	-30(10)	-1500(400)	-
3	e	75048.39	740(20	-1200(300)	-
3	e	76923.95	2436(10)	-450(100)	-
4	e	77196.89	410(50)	-1100(500)	-
5	e	78966.63	335(30)	-50(200)	-

References

[1] Ch. Moore; "Atomic Energy Levels", Vol. III; Natl. Bur. Stand. (U.S.) Circ. No. 467, Washington, D.C. (U.S. GPO 1958)
[2] C.C. Kiess; J.Research National Bureau of Standards 66A, 111 (1962)
[3] J.-F. Wyart; Physica Scripta 18, 87 (1978)
[4] J.-F. Wyart and J. Blaise; Physica Scripta 42, 209 (1990)
[5] N. Jaritz, L.Windholz, D. Messnarz, H. Jäger, R. Engleman Jr.; Physica Scripta 71, 611 (2005)
[6] V.O. Zilio and J.C. Pickering; Mon. Not. R. Astron. Soc. 334, 48 (2002)
[7] M. Eriksson, U. Litzén, G.M.Wahlgrén, D.S. Leckrone; Physica Scripta 65, 480 (2002)
[8] L. Windholz, G.H. Guthöhrlein; Physica Scripta T105, 55-60 (2003)

Radiative lifetimes of metastable states of negative ions

Pontus Andersson[1], Karin Fritioff[1], Joakim Sandström[1], Gerard Collins[1], Dag Hanstorp[1], Anna Ellmann[2], Peter Schef[2], Peter Lundin[2], Sven Mannervik[2], Peder Royen[2], K. Charlotte Froese Fischer[3], Fabian Österdahl[4], Danijela Rostohar[5], David J. Pegg[6], N. D. Gibson[7], Håkan Danared[8] and Anders Källberg[8]

[1] *Department of Physics, Göteborg University, SE-412 96, Göteborg, Sweden*
[2] *Department of Physics, Stockholm University, AlbaNova, SE-106 91 Stockholm, Sweden*
[3] *Department of Computer Science, Vanderbilt University, Nashville, Tennessee 37235, USA*
[4] *Department of Physics, Royal Institute of Technology, AlbaNova, SE-106 91 Stockholm, Sweden*
[5] *IPNAS (Bât. B 15),Université de Liége, Sart Tilman B-4000 Liége 1 , Belgium*
[6] *Department of Physics, University of Tennessee, Knoxville, Tennessee 37996, USA*
[7] *Department of Physics and Astronomy, Denison University, Granville, Ohio 43023, USA*
[8] *Manne Siegbahn Laboratory, Frescativägen 24, SE-104 05 Stockholm, Sweden*
E-mail:pontus.andersson@physics.gu.se

We present a new technique for measuring the radiative lifetimes of metastable states of negative ions that involves the use of a heavy ion storage ring. The method has been applied to investigate the radiative decay of the $np^3\ ^2P_{1/2}$ levels of Te^- (n=5) and Se^- (n=4) and the $3p^3\ ^2D$ state of Si^- for which the J=3/2 and 5/2 levels were unresolved. All of these states are metastable and decay primarily by emission of E2 and M1 radiation. MCDHF calculations[1] of rates for the transitions in Te^- and Se^- yielded lifetimes of 0.45 s. and 4.7 s, respectively. The measured values agree well with these predicted values. In the case of the ^2D state of Si^-, however, our measurement was only able to set a lower limit on the lifetime. The upper limit of the lifetime that can be measured with our apparatus is set by how long the ions can be stored in the ring, a limit determined by the rate of collisional detachment. Our lower limit of 1 min. for the lifetime of the ^2D state is consistent with both of the calculated lifetimes of 162 s for the $^2D_{3/2}$ level and 27.3 h for the $^2D_{5/2}$ level reported by O'Malley and Beck[2] and 14.5 h and 12.5 h respectively, from our Breit-Pauli calculations.

References

[1]F. A. Parpia, C. F. Fischer, and I. P. Grant, Computer Physics Communications 94, 249 (1996).
[2]S. M. O'Malley and D. R. Beck, J. Phys. B 36, 4301 (2003).

Experimental and calculated lifetimes of the NaCs G(3)$^1\Pi$ state

I. Klincare[1], J. Zaharova[1], M. Tamanis[1], R. Ferber[1], A.V. Stolyarov[2], E.A. Pazyuk[2], A. Zaitsevskii[2]

[1] *Department of Physics and Institute of Atomic Physics and Spectroscopy, University of Latvia, Riga, Latvia*
[2] *Department of Chemistry, Moscow State University, Moscow, Russia*
E-mail: klincare@latnet.lv

The G(3)$^1\Pi$ state of the NaCs molecule has been recently well defined by the Fourier spectroscopy analysis of the G$^1\Pi$ – X$^1\Sigma^+$ transitions [1]. This allowed us to measure lifetimes for particular rovibronic levels of the G(3)$^1\Pi$ state. We present here both experimental τ_{exp} and calculated τ_{rad} dependencies on the vibrational and rotational quantum numbers (v, J).

The pure radiative lifetimes τ_{rad} were evaluated using *ab initio* G(3)$^1\Pi$ – X$^1\Sigma^+$; A$^1\Sigma^+$; B$^1\Pi$; D$^1\Pi$ transition dipole moment functions calculated in the interval $R \in$[3.0; 9.5] Å by means of many-body multipartitioning perturbation theory. The calculation shows a dominating role of the transitions to the ground X$^1\Sigma^+$ state. The τ_{rad} calculated for the $v \in$[0; 40] levels monotonically decrease from 42 to 16 ns as v-values increase. The theory also predicts a systematic decrease of τ_{rad} values by (10 - 15)% as J' increase from $J' = 0$ to 100.

The experiment was performed in an alkali resistant glass cell containing a mixture of natural Na and Cs metals. The Ar^+ laser lines 514.5, 496.5, 488.0 and 476.5 nm were used to excite selectively (v, J) levels in the v-range from 3 to 25. The G – X fluorescence spectra were detected in a photon counting regime using a double monochromator with 0.5 nm/mm resolution. The assignment of the G – X transitions was based on Fourier spectroscopy data [1].

The effective lifetimes τ_{eff} of the particular (v, J) G$^1\Pi$ levels were determined directly from the fluorescence decay after pulsed excitation employing time-amplitude conversion and one-photon statistical analysis technique, see [2] for details. The spontaneous lifetime values τ_{exp}^{sp} were obtained by varying temperature within 178° and 246 °C range and extrapolating τ_{eff}^{-1} to zero pressure. We have obtained τ_{exp}^{sp} values for (3; 45); (8; 25); (17; 47); (25; 67) levels. A good agreement between the calculated and measured lifetimes is obtained for the (25; 67) level while a systematic overestimation by about 20 % of theoretical τ_{rad} values for the lowest levels was observed. This discrepancy probably comes from a very week homogenious predissociation of the lowest G-state levels caused by avoided crossing with the D$^1\Pi$ state.

The work has been supported by the NATO SfP 978029 - Optical Field Mapping grant and by the Latvian Council of Science (grant No 04.1308), as well as the Russian Foundation for Basic Researches (grants 06-03-32330 and 06-03-32346). J.Z. acknowledges the support from the European Social Fund.

References

[1] O. Docenko, M. Tamanis, J. Zaharova, R. Ferber, A. Pashov, H. Knockel and E. Tiemann, J. Chem. Phys., accepted.

[2] I. Klincare, M. Tamanis, R. Ferber, E.A. Pazyuk, A. Zaitsevskii, A.V. Stolyarov, Eur. Phys. J. D, submitted.

Excitation of the $(2p^5 3s^2)^2P_J$ states in sodium by energy-selected electrons

V.A. Borovik[1], L.L. Shimon[1] and A.A. Borovik[2]

[1] *Uzhgorod National University, 88000, Uzhgorod, Ukraine*
[2] *Institute of Electron Physics, Uzhgorod, 88017, Ukraine*
E-mail:sasha@aborovik.uzhgorod.ua

It is well known that the electron impact excitation of the lowest $np^5(n+1)s^2$ autoionizing configurations in alkali atoms possesses the pronounced resonance character [1,2]. For obtaining the reliable information on the number, intensity and the energy position of resonances, it is necessary to use the energy-selected electron beams for excitation of target atoms. However, the low excitation cross-sections of the autoionizing states and the limited running time of metal vapour sources both limited to present day the use of such beams in experimental studies.

The electron impact excitation of the $(2p^5 3s^2)^2P$ state (E_{exc}=30.77 eV) in sodium was first investigated at an energy resolution of 0.7 eV [3]. Two broad resonance features observed at approximately 31.7 eV and 33.2-33.3 eV were assigned on the base of 26-state R-matrix calculation as the ^3P_o states of negative sodium ion. The evident compound character of both features denoted the need of further experimental studies at a better energy resolution. Such a study was later performed at a resolution of 0.4 eV [4]. In these data both resonances were completely resolved and their energies were accurately determined at 31.1 eV and 33.6 eV. A step-like rise of the cross-section at 31.8 eV evidently pointed out the presence of the strong cascade processes.

In the present work we have carried out a further improvement of the experimental resolution using an incident-electron beam with an energy width of less then 0.25 eV. As a result, in contrast to all previous works, we have investigated the excitation of the $(2p^5 3s^2)^2P_{3/2,1/2}$ states in sodium *individually*. The experimental details, including some improvements in designing the electron monochromator and the atomic beam source, were extensively described earlier [2]. Due to the low output signal and the limited running time of the sodium vapour source, the measurements for both states were performed only in a narrow incident-electron energy region around the near-threshold feature at 31.1 eV [4].

The measured excitation cross-sections exhibit strong near-threshold resonances located at 30.87 eV ($^2P_{3/2}$ state) and at 31.17 eV ($^2P_{1/2}$ state). In the region of the latter resonance the excitation cross-section of the $^2P_{1/2}$ state equals to that for the $^2P_{3/2}$ state. At higher impact energies (up to 31.5 eV) a smooth decrease of the cross-section is observed for the $^2P_{3/2}$ state but a scatter in the data is present in excitation function of the $^2P_{1/2}$ state. The latter may point out the presence of an additional resonance at 31.3-31.4 eV. The sum of both cross sections exhibits all above structures and fits well the shape of the resonance feature at 31.1 eV [4]. The detailed analysis of excitation processes for the $(2p^5 3s^2)^2P_{3/2,1/2}$ states, including the theoretical calculations will be presented at the conference.

This work was supported, in part, by INTAS under grant 03-51-4706.

References

[1] V. Pejcev and K. J. Ross, J. Phys. B 10, L291 (1977).
[2] A. A. Borovik, A. N. Grum-Grzhimailo, K. Bartschat and O. Zatsarinny, J. Phys. B 38, 1081 (2005).
[3] B. Feuerstein, A. N Grum-Grzhimailo and W. Mehlhorn, J. Phys. B 31, 593 (1998).
[4] A. Borovik and V. Krasilinec, Abstracts of 32-nd EGAS Conference (Vilnius), p.247, (2000).

Investigations of the hyperfine structure of metastable levels in chromium atom

A. Jarosz, A. Buczek, B. Furmann, P. Głowacki, M. Elantkowska, J. Ruczkowski, E. Stachowska, D. Stefańska, L. Piatkowski and J. Dembczyński

Chair of Quantum Engineering and Metrology,
Faculty of Technical Physics, Poznań University of Technology,
Poznań, Poland
E-mail: Andrzej.Jarosz@put.poznan.pl

A series of precise measurements of the hyperfine structure of some metastable levels in chromium atom has been performed with the methods of laser induced fluorescence (LIF) on an atomic beam and laser-rf double resonance on an atomic beam (ABMR-LIRF). An atomic beam apparatus designed for generation of an atomic beam from refractory elements with additional discharge for population of metastable levels is applied. Both investigation methods involve the optical excitation from the level under study. For chromium atom most transitions lie in the blue-violet spectral region. As a source of laser radiation a tunable dye laser is used.
A series of metastable levels of chromium atom have been investigated with LIF method [1]. The measurements with the ABMR-LIRF method concerning the lowest-lying metastable level $3d^5 4s\ ^5S_2$ [2] have been completed. The semi-empirical analysis [3] of the fine and the hyperfine structure of chromium atom, based both on own results and the available literature data [4-7], has been carried out, yielding some predictions concerning the unknown splittings of the hitherto not investigated metastable levels. The measurements concerning those levels are planned.

This work was supported by Poznań University of Technology under project BW-63-028/06

References

[1] A. Jarosz, Ph.D.Thesis, Poznań 2000 (unpublished)
[2] A. Buczek, Ph.D.Thesis, Poznań 2002 (unpublished)
[3] J. Dembczyński, W. Ertmer, U. Johann and P. Unkel, Z. Phys. A 321, 1(1985)
[4] W.J. Childs, L.S. Goodman, D. von Ehrenstein, Phys. Rev., 132, 2128 (1963)
[5] H. Bucka, B. Budick, R.J. Goshen, S. Marcus, Phys. Rev. 144, 96 (1966)
[6] U. Becker, U. Teppner and U. Wuesthof, J. Phys. B 11, 2435 (1978)
[7] W. Ertmer, U. Johann, and R. Mosmann, Z. Phys. A 309, 1 (1982)

Promoter and Interference Effects for Resonant Photoexcitation and Autoionization of Ar between 32.5 eV and 33.0 eV

S. Kammer[1], K.-H. Schartner [1], S. Mickat[1], A. Ehresmann[2], L. Werner[2], S. Klumpp[2], H. Schmoranzer[3], I.D. Petrov[4], Ph.V. Demekhin[4], and V.L. Sukhorukov[4]

[1] *I.Physikalisches Institut, Justus-Liebig-Universität , Giessen, Germany*
[2] *Intstitute of Physics, University of Kassel, Kassel, Germany*
[3] *Fachbereich Physik, Technische Universität Kaiserslautern, Kaiserslautern, Germany*
[4] *Rostov State Transport University, Rostov-on-Don, Russia*
E-mail: Schartner@exp1.physik.uni-giessen.de

The photoabsorption of Ar is studied experimentally, using the method of photon induced fluorescence spectroscopy (PIFS), and theoretically for energies between 32.5 eV and 33.0 eV. Resonant excitation and autoionization of doubly excited $3p^4(^3P)4s^2P_{3/2,1/2}$ np Rydberg states are observed as dominant mechanism to populate doublet and quartet satellites of the $3p^4$4s,3d configurations. High n numbers of the 3/2 series are populated preferentially with an interesting minimum at n = 20. The theoretical analysis explains this feature by a complex interference between perturber states and strong interactions between members of the 1/2 and 3/2 Rydberg series. Moreover, for the strong autoionization channels good agreement between measured and calculated absolute cross sections is obtained.

Electric field induced hyperfine level crossing signals in 7, 9, $10^2D_{5/2}$ Cs at two-step laser excitation

M. Auzinsh, K. Blushs, R. Ferber, F. Gahbauer, A. Jarmola and M. Tamanis

Department of Physics and Institute of Atomic Physics and Spectroscopy, University of Latvia, 19 Rainis Blvd., LV-1586 Riga, Latvia
E-mail: jarmola@latnet.lv

We present measurements of level crossing signals in an electric field of m_F Zeeman sublevels of hyperfine F levels at two step laser excitation of the $n\mathrm{D}_{5/2}$ states of cesium with $n = 7$, 9, and 10. From these signals we were able to measure atomic constants, such as the hyperfine constant A and the tensor polarizability α_2, by fitting experimental signals with the results of simulations. Coherent excitation of magnetic sublevels influences the spatial distribution of linearly polarized laser induced fluorescence (LIF) radiation. When magnetic sublevels with $\Delta\mathrm{m} = \pm 2$ cross as a result of the quadratic Stark effect resonances in the LIF signals of definite polarization can be observed as a function of electric field. For lower values of the total angular momentum J, e.g., J = 3/2, these resonances are well separated and correspond directly to the level crossing positions, from which, in turn, atomic parameters can be determined [1]. However, for J = 5/2, there are many more magnetic sublevel crossings, and they are so closely spaced that resonance peaks cannot be resolved. Moreover, the shape of the level crossing signals is a function of which magnetic sublevels are excited and thus depends on the laser detuning. Nevertheless, with a detailed theoretical description of the level crossing signals information about atomic parameters can again be extracted. We have developed such a model [2] and tested it for the case of J = 3/2 [1], and now apply the model to determine atomic parameters for the J = 5/2 case by comparing simulated with measured signals.
The experiment is performed with cesium vapor in a sealed glass cell. Transparent Stark electrodes separated by a 2.5 mm gap create electric fields up to 2000 V/cm. We populated the $n\mathrm{D}_{5/2}$ states of cesium atoms using two step laser excitation ($6\mathrm{S}_{1/2} \rightarrow 6P_{3/2} \rightarrow nD_{5/2}$) using two counterpropagating laser beams and observed the LIF at the $n\mathrm{D}_{5/2} \rightarrow 6P_{3/2}$ transition. In the first step we use a diode laser. For the second step a diode laser is used if $n = 7$ and a dye laser if $n = 9$ or 10. The first laser is polarized parallel to the electric field, which is along the z-axis. The second laser is polarized in the x-direction. The LIF passes through a linear polarizer and is focused into a monochromator. LIF intensities I_x and I_y are measured as a function of electric field and compared with simulations. By fitting experimentally measured signals with a model and using atomic constants such as hyperfine constants and polarizabilities as the adjustment parameters, it is possible to determine atomic constants more precisely than they have been reported in the literature thus far.

We acknowledge support from NATO Grant SfP-978029 "Optical Field Mapping" and Latvian State Research Programme funding grant Nr. 1-23/50 "Perspective inorganic materials for photonics and energetics". K.B., F.G., and A.J. thank the European Social Fund for support.

References

[1] M. Auzinsh, K. Blushs, R. Ferber, F. Gahbauer, A. Jarmola, and M. Tamanis, Opt. Comm. (to be published), (arXiv:physics/0511035).
[2] Kaspars Blushs, Marcis Auzinsh, Phys. Rev. A 69 (2004) 063806, (arXiv:physics/0312124).

Lifetime measurements of metastable states in singly charged ions

P. Lundin[1], P. Schef[1], J.Gurell[1], S. Mannervik[1], E. Biémont[2,3], D. Rostohar[3], P. Royen[1], L-O-Norlin[4]

[1] *Physics Department, Stockholm University, Stockholm, Sweden*
[2] *Astrophysique et Spectroscopie, Universitet de Mons-Hainaut, Mons, Belgium*
[3] *IPNAS (Bât. B 15), Université de Liége, Sart Tilman, Belgium* [4] *Physics Department, Royal Institute of Technology, Stockholm, Sweden*
E-mail:peter.lundin@physto.se

A Laser Probing Technique (LPT) [1,2] has been used for studies of metastable states in singly charged ions in the storage ring CRYRING at the Manne Siegbahn Laboratory [3] in Stockholm, Sweden. Probing certain states in atomic spectra is made possible through the use of a cw tunable ring dye laser. Laser light is applied at different delay times in order to determine the population decay of a particular metastable level. The pressure inside the storage ring may be varied slightly which allows the collisional depopulation rate to be determined in order to extract the pure radiative lifetime. Since this method was introduced lifetimes ranging from a few ms to tens of seconds have been measured.

Recently the lifetime of the $5d\,^2D_{3/2}$ state in Ba II was measured. The lifetime of this state, $\tau = 91 \pm 27$ s (preliminary), is currently the longest lifetime ever measured at CRYRING and it is in good agreement with the previous measurement done by Yu et al. [4] as well as with two different theoretical calculations performed by Guet et al. [5] and Glorieux et al. [6].
The lifetimes of the states $^6I_{13/2}$ and $^6K_{11/2}$ in Nd II have also recently been measured. The lifetimes for these levels were experimentally determined to be $\tau = 4.6 \pm 0.9s$ and $\tau = 23 \pm 4s$ respectively. The experimental results are complemented by extensive calculations of different levels in Nd II.

References

[1] J. Lidberg et al, Nucl. Instr. and Meth B152, 157 (1999)
[2] S. Mannervik, Physica Scripta T100, 81 (2002)
[3] Manne Siegbahn Laboratory homepage at http://www.msi.se
[4] N. Yu, W. Nagourney, H. Dehmelt, Phys. Rev. Lett. 78, 4898 (1997)
[5] C. Guet, W.R. Johnson, Phys. Rev. A 44, 1531 (1991)
[6] I. Glorieux, M. Godefroid, N. Veack, 20th EGAS, 47 (1998)

The Stark effect and doubly excited states of helium

K.C. Prince[1,2], V. Feyer[3,5], M. Coreno[3,4], R. Richter[1], M. de Simone[2,4], A. Kivimäki[2], A. Mihelič[6] and M. Žitnik[6]

[1] *Sincrotrone Trieste, in Area Science Park, I-34012 Basovizza (Trieste), Italy*
[2] *INFM-TASC, Gasphase Beamline@ ELETTRA, in Area Science Park, I-34012 Basovizza (Trieste), Italy*
[3] *CNR-IMIP, Montelibretti (Rome), I-00016 Italy*
[4] *INSTM, Trieste, Italy*
[5] *Permanent address: Institute of Electron Physics, 88017 Uzhgorod, Ukraine*
[6] *J. Stefan Institute, 1000 Ljubljana, Slovenia*
E-mail:feyer@tasc.infm.it

The information obtained in spectroscopy depends critically on the technique used to obtain that information. The doubly excited states of helium, which occur in the range 60-80 eV, were investigated for many years primarily by ion yield. More recently it has been shown that a new understanding can be obtained by observing these states by means of fluorescence yield spectroscopy. We have investigated the states below N=2 by wavelength resolved visible/UV spectroscopy [1], using an apparatus described in [2], and by total VUV yield spectroscopy. More recently we have turned our attention to the Stark effect on these states [3], which has received considerable attention (see references in [3]).

Using total VUV spectroscopy, two new series of states are observed at moderate fields (< 10kV/cm), and assigned to the previously unobserved even ^1P_e series, and a group of ^1D_e series. The ^1S_e states are observed indirectly via their mixing with nearby ^1P_o states. The observations at moderate field contradict theoretical predictions that field strengths about an order of magnitude greater are necessary to observe the Stark effect on He doubly excited states at low quantum numbers.

We also observe changes in the relative intensities of two of the dipole allowed series. This is explained by the fact that the mixing of even and odd states by the field also mixes the autoionizing/fluorescence character of even states with the odd states. Mixing with strongly autoionizing states confers this character on the odd state, causing the intensity to decrease in the fluorescence yield spectrum.

References

[1] M. Coreno, K.C. Prince, R. Richter, M. de Simone, K. Bučar, and M. Žitnik, Phys. Rev. A 72, (2005) 052512.

[2] M. Coreno, M. de Simone, M. Danailov, R. Richter, A. Kivimäki, M. Žitnik, and K.C. Prince, J. Electron Spectroscopy and Related Phenomena 144-147, (2005) 39-42.

[3] K.C. Prince, M. Coreno, R. Richter, M. de Simone, V. Feyer, A. Kivimäki, A. Mihelič and M. Žitnik, Phys. Rev. Lett. 96, 093001 (2006).

Evolution of Ag $L\alpha$ Satellites

S. Sakakura[1], Y. Ito[1],T. Tochio[2], M. Vlaicu[3], H. Yoshikawa[3], H. Oohashi[3], E. Ikenaga[4], K. Kobayashi[4] and F. Koike[5]

[1]*Laboratory of Atomic and Molecular Physics, ICR, Kyoto University, Uji, Kyoto 611-0011, Japan*
[2]*Keihanna Interaction Plaza inc., Seika-cho, Soraku-gun, Kyoto 619-0237, Japan*
[3] *National Institute for Materials Science, SPring-8, 1-1-1 Kouto, Sayo-gun, Hyogo 679-5148, Japan*
[4]*Japan Synchrotron Radiation Research Institute (JASRI), 1-1-1 Kouto, Sayo-gun, Hyogo 679-5148, Japan*
[5]*Kitasato University School of Medicine, 1-15-1 Kitasato, Sagamihara, Kanagawa 228-8555, Japan*
E-mail:caligula@scl.kyoto-u.ac.jp

The Ag $L\alpha$ X-ray emission spectra around L_1, L_2 and L_3 absorption edges were measured using a high-resolution double-crystal vacuum spectrometer at the BL15XU undulator beamline SPring-8. We analysed the observed spectra using Lorentzian model. The relative intensities of satellite structures, which are originated from the double-hole states of L_3M_4 and L_3M_5, were estimated.
But the mechanism of the double-hole states of L_3M_4 and L_3M_5 has not clarified. They can be created by either or both the $L_3M_{4,5}$ shake process or/and L_1-$L_3M_{4,5}$ Coster-Kronig transition. The shake process is the ionization (shake-off) or excitation (shake-up) of outer-shell electrons during ionization of inner-shell electrons by photons or charged particles, and can occur during excitation. Coster-Kronig transition is nonradiatve transition and relaxation process that is independent of excitation energy.
According to the work of Chen *et al.*[1], L_1-L_3M_4 Coster-Kronig transition was forbidden for $50 \leq Z \leq 77$, L_1-L_3M_5 Coster-Kronig transition was forbidden for $50 \leq Z \leq 74$, and L_1-$L_3L_{4,5}$ Coster-Kronig transition is possible in the case of Ag($Z = 47$). In this work, we observed the intensities of the $L\alpha$ satellites were drastically increased at the L_1 absorption edge. So, the Ag $L\alpha$ satellites are caused mainly by L_1-$L_3M_{4,5}$ Coster-Kronig transition.
This experiment was performed under the approval of the proposal No. C03A15XU-2004N and Kyoto Prefecture Collaboration of Regional Entities for the Advancement of Technological Excellence, JST

References

[1] M. H. Chen *et al.*,At. Data Nucl. Data Table. 19, 97

$KL - L^2$ satellites spectra in Mg $\sim$ Cl elements

K. Yokoi[1], S. Sakakura[1], Y. Zou[1], Y. Ito[1], H. Oohashi[2], T. Tochio[3], H. Fujimura[4], T. Shoji[4], F. Koike[5]

[1]*Laboratory of Atomic & Molecular Physics, ICR, Kyoto University, Uji, Kyoto 611-0011, Japan*
[2]*National Institute for Materials Science, SPring-8 1-1-1 Kouto, Sayo-gun, Hyogo 679-5148, Japan*
[3]*Keihanna Interaction Plaza Inc., Seika-cho, Soraku-gun, Kyoto 619-0237, Japan*
[4] *X-ray Research Laboratory, RIGAKU Co., 14-8 Akaoji, Takatsuki, Osaka 569-1146, Japan*
[5] *Kitasato University School of Medicine, 1-15-1 Kitasato, Sagamihara, Kanagawa 228-8555 Japan*
E-mail:yosi@elec.kuicr.kyoto-u.ac.jp

Most of studies on the contributions from the effects of shake process in atom to x-ray absorption spectra have recently been carried out, in order to elucidate the electron correlation. The x-ray absorption spectra in $3d$ transition metals were examined in the energy region of $K + L$ double electron excitation. However, no significant features attributed to multi-electron excitations are found in the spectra, so that $K + L$ edges for $3d$ elements were not confirmed. The result could be explained by theoretical predictions due to lower shake-up probabilities for $K + L$ transitions.
With the advent of the third generation synchrotron radiation, we can do experiments on the threshold behavior of satellites including the excitation dynamics in atoms. First detailed photoexcitation measurements were performed by Deslattes *et al.* on Ar, by Deutsch *et al.* on Cu, by Sternemann *et al.* on Ge, by Raboud *et al.* measuring the KL x-ray emission on Ar, and more recently, by Shigeoka *et al.* and Diamant *et al.* observing KL x-ray emission of Fe or Fe and Co induced by monoenergetic photons to investigate the $K + L$ double excitation from threshold to saturation. Shigeoka *et al.* suggested the contribution of $2s$ spectator hole to the $K\alpha_{3,4}$ satellites around the threshold. Although there is an excellent report on the KL double electron transitions in Na to Cl elements by Dousse's group, we have no reports on the experiments of the evolution in the $K\alpha_{3,4}$ satellites. $KL - L^2$ spectra in Mg $\sim$ Cl elements were investigated using a high resolution double-crystal spectrometer together with the comparison of the shake probability in order to confirm the intensity ratio, the energy values, and the width in the satellites. Moreover, the origin of the $K\alpha_{3,4}$ satellites, especially, for Mg, Al, and Si could not be explained clearly by the contribution of the $1s2s \rightarrow 2s2p$ and $1s2p \rightarrow (2p)^2$ spectator holes using GRASP^2 code.

Measurement and Modeling on Self-Reversal of the Ca^+ $4s(^2S_{1/2}) \rightarrow 4p(^2P_{1/2,3/2})$ Doublet in Expanding Laser Plasma Plumes

K.D. Kavanagh, H. Luna and J.T. Costello

School of Physical Sciences, Dublin City Universtiy, Dublin, Ireland
E-mail:jtc@physics.dcu.ie

Table-top laser-produced plasmas have a number of applications as light sources for extreme-UV lithography [1] and pulsed laser deposition [2]. Optical spectroscopy of such plasmas is a key diagnostic providing information of parameters such as ionization balance, electron temperature and electron density. The latter is highly sensitive to the spectral line profile. Laser-produced plasmas possess steep density gradients and hence any technique used to extract such information must of necessity be space-resolved. We have recently developed a novel system to do this [3].

One further complication, especially associated with laser plasmas which comprise hot dense emitting cores surrounded by cooler plume material is opacity. This can be so significant as to result in line self-reversal, which again has a strong spatial dependence. To tackle this problem we have taken the case of the 4s-4p resonance doublet in Ca^+ which possesses a high oscillator strength and hence can be expected to exhibit strong self-absorption in appropriate plasma conditions.

We will present the results of time and space resolved spectroscopic measurements on the doublet along with a model fit to the spectra based on the work of Sakka *et al* [4], which permits the extraction of useful plasma data from the distorted line profiles.

References

[1] J. White, P. Hayden, P. Dunne, A. Cummings, N. Murphy, P. Sheridan and G. OSullivan, J. Appl. Phys. 98, 113301, (2005).
[2] M.W. Stapleton, A.P. McKiernan, and J.-P. Mosnier, J. Appl. Phys. 97, 064904, (2005).
[3] D. Doria, K.D. Kavanagh, J.T. Costello and H. Luna, Meas. Sci. Technol. 17, (2006)
[4] T. Sakka, T. Nakajima and Y.H. Ogata, J. Appl. Phys. 92, (2002).

Mean charge values of heavy ions in dilute hydrogen

Yu. Ts. Oganessian[1], V. K. Utyonkov[1], Yu. V. Lobanov[1], F. Sh. Abdullin[1], A. N. Polyakov[1], R. N. Sagaidak[1], I. V. Shirokovsky[1], Yu. S. Tsyganov[1], A. N. Mezentsev[1], K. Subotic[1], K. J. Moody[2], J. F. Wild[2], N. J. Stoyer[2], M. A. Stoyer[2], R. W. Lougheed[2], D. A. Shaughnessy[2] and J. M. Kenneally[2]

[1] *Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, 141980 Dubna, Russian Federation*
[2] *University of California, Lawrence Livermore National Laboratory, Livermore, California 94551, USA*
E-mail: abdullin@sungns.jinr.ru

We measured the mean electronic charge $< q >$ of heavy ions with atomic numbers Z=89 through 118 traversing dilute hydrogen gas with velocities ranging from 1 to 2.6 times the Bohr velocity [1,2]. We observe a strong linear dependence of the average charge on the velocity of the ions, and only a weak dependence on their atomic number Z. A more detailed examination of the experimental results shows that the $< q >$ values reflect the influence of the 5f electron shell on the properties of these elements.

Our new data on mean charge values of latest synthesized superheavy elements with Z=115 [3] confirm previous findings.

References

[1] Yu.Ts. Oganessian et al., Phys. Rev. C 64, 064309 (2003).
[2] Yu.Ts. Oganessian et al., JINR Communication D7-2002-287 (2002); Lawrence Livermore National Laboratory Report, UCRL-ID-151619 (2003).
[3]Yu.Ts. Oganessian et al., Phys. Rev. C 69, 021601(R) (2004).

The NaRb $A^1\Sigma$ - $b^3\Pi$ complex revisited by Fourier transform spectroscopy

O. Docenko[1], M. Tamanis[1], R. Ferber[1], E.A. Pazyuk[2], A. Zaitsevskii[2], A.V. Stolyarov[2], A. Pashov[3], H. Knöckel[4] and E. Tiemann[4]

[1]*Dept. of Physics and Institute of Atomic Physics and Spectroscopy, University of Latvia, Riga, Latvia*
[2]*Department of Chemistry, Moscow State University, Moscow, Russia*
[3]*Department of Physics, Sofia University, Sofia, Bulgaria*
[4]*Institut für Quantenoptik, Universität Hannover, Hannover, Germany*
E-mail: tamanis@latnet.lv

We present a comprehensive study of the $A^1\Sigma^+ \sim b^3\Pi$ complex of the NaRb molecule performed by the Fourier transform spectroscopy. The strongly spin-orbit (SO) coupled $A^1\Sigma^+$ and $b^3\Pi$ states correlating with Na(3s) + Rb(5p) asymptote [1] exhibit oscillating irregularities in rovibronic structure [2]. The prospects of producing cold mixed-alkali molecules via photo-association reaction through this complex [3], or it's applicability for conversion of cold molecules into their ground state [4], cause particular interest to the $A \sim b$ complex problem. The goal of the present work is to obtain accurate rovibronic termvalue data in a wide range of vibrational-rotational quantum numbers, and reduce them directly to deperturbed potential energy curves and the r-dependent SO matrix elements for the $A^1\Sigma^+$ and $b^3\Pi$ states.

NaRb molecules were produced in a heat pipe oven. Laser induced fluorescence spectra were measured by the Fourier transform spectrometer (Bruker IFS 120HR). In the first excitation scheme, fixed Ar^+ laser lines excited the $D^1\Pi$ and $C^1\Sigma^+$ states and the relevant $D, C \rightarrow A \sim b$ rovibronic transitions were observed along with the $D, C \rightarrow X$ fluorescences. In the second scheme a tunable Ti - sapphire laser was used to excite directly the $A \sim b$ levels while the $A \sim b \rightarrow X$ transitions were observed. Overall 2180 termvalues corresponding to $v \in [0, 49]$, $J \in [4, 163]$ rovibrational numbers of the $A \sim b$ complex were assigned for both $Na^{85}Rb$ and $Na^{87}Rb$ isotopomers. The experimental termvalues belonging to mutually perturbed A and b states were deperturbed simultaneously in the framework of inverted close-coupled approach ICCA [2]. The derived adiabatic potentials for the interacting A and $b^3\Pi_0$ states together with electronic SO parameters A^b_{SO}, ξ^{Ab}_{SO} as functions of the internuclear distance allowed us to restore most of the observed level positions with the standard deviation of 0.01 cm^{-1}, and to explain unusual relative intensity distribution in the $D, C \rightarrow A \sim b$ rovibronic transitions.

The work is supported by DFG through SFB 407. O.D., M.T. and R.F. acknowledge the support by the NATO SfP 978029 - Optical Field Mapping grant and by the Latvian Council of Science (grant No 04.1308). Moscow team acknowledges the support by the Russian Foundation for Basic Researches (grants 06-03-32330 and 06-03-32346). A.P. acknowledges the support from the Alexander von Humboldt Foundation. J.Z. is grateful to the European Social Fund for support.

References

[1] M. Korek, A.R. Allouche, M. Kobeissi, A. Chaalan, M. Dagher, K. Fakherddin, M. Aubert-Frecon, Chem. Phys. 256, 1 (2000).
[2] M. Tamanis, R. Ferber, A.V. Zaitsevskii, E.A. Pazyuk, A.V. Stolyarov, Hongmin Chen, He Wang, W.C. Stwalley, J. Chem. Phys. 117, 7980 (2002).
[3] S. Azizi, M. Aymar, and O. Dulieu, Eur. Phys. Journ. D 31, 195 (2004).
[4] W.C. Stwalley, Eur. Phys. Journ. D 31, 221 (2004).

High Resolution Spectroscopy of H_3^+, $H_2D^+$and $D_2H^+$with CRDS and LIR

P. Hlavenka[1], R. Plašil[1], I. Korolov[1], G. Bánó[2], D. Gerlich[3] and J. Glosík[1]

[1] *Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
[2] *Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, Budapest, Hungary*
[3] *Institut für Physik, Technische Universität, Chemnitz, Germany*
e-mail: petr.hlavenka@mff.cuni.cz, juraj.glosik@mff.cuni.cz

The ions H_3^+ and its deuterated isotopologues (H_2D^+, D_2H^+ and D_3^+) play important roles in the kinetics of dense interstellar medium, planetary atmospheres and also in laboratory produced plasmas. The main challenge for understanding these ions and their interaction at low temperatures are state specific experiments. This requires manipulation and a simple but efficient in situ characterization of their low-lying rotational states.

We report studies of Near-IR transitions from the lowest rotational energy levels of H_3^+, H_2D^+ and D_2H^+. A high sensitivity diode laser based *cavity ringdown spectrometer* (CRDS), with sensitivity up to 5×10^{-9} cm^{-1} was used to measure the very weak absorption lines. The ions of the interest were produced by a microwave discharge in He buffer gas with $Ar/H_2/D_2$ admixture. For H_3^+, 7 lines in P and R branches of $v_2 = 3 \leftarrow 0$ were observed in region 6800 - 7250 cm^{-1} and used for recombination rate coefficient measurement at 100 and 300 K [1]. The search for absorption transitions of $D_2H^+$and H_2D^+ ions in the Near-IR region was guided by the ab initio model of the J. Tennyson's group at UCL. Three D_2H^+absorption transitions ($v_1 + 2v_3 \leftarrow 0$) $2_{02} \rightarrow 3_{13}$, $1_{01} \rightarrow 2_{12}$ and $0_{00} \rightarrow 1_{11}$ were identified at frequencies 6534.377(1) 6535.950(1) and 6536.319(2) cm^{-1}, for details see [2]. The H_2D^+ transitions ($2v_2 + v_3 \leftarrow 0$) $1_{11} \rightarrow 2_{02}$, $0_{00} \rightarrow 1_{11}$ and $1_{01} \rightarrow 2_{12}$ at frequencies 6491.322(1), 6466.501(1) and 6459.031(2) cm^{-1} were also identified. The build CRDS setup is used for H_2/D_2 plasma diagnostics.

The measured transitions frequencies were used for *laser induced reaction* (LIR) characterization of the low-lying rotational states in low temperature ion trapping experiments. A 22-pole RF low temperature (4 K) ion trap was used in LIR experiments, for details see [3]. Several hundreds of ions are stored in the cryogenic trap. Ions are cooled down by collisions with cold He atoms and some of them can get excited by IR photon from laser beam passing through the trap. In the presence of argon, the internal energy of excited ion is opening an otherwise endothermic proton (deuteron) transfer reaction channel and formed ArH^+ and ArD^+ are detected by a mass spectrometer. By scanning the diode laser the profile of the absorption line is obtained. From the Doppler broadening of D_2H^+ $0_{00} \rightarrow 1_{11}$ absorption line (identified by CRDS) the kinetic temperature of trapped ions $\sim$ 9 K was determined. This is a direct *in situ* diagnostics of ion kinetic temperature and state populations, applicable to ion traps and sources of cold ion in storage rings.

Acknowledgements. This work is a part of the research plan MSM 0021620834 and it was partly supported by GACR (202/03/H162, 205/05/0390, 202/05/P095), GAUK-278/2004 /B-FYZ/MFF.

References

[1] P. Macko, G. Bánó, P. Hlavenka, R. Plašil, V. Poterya, A. Pysanenko, O. Votava, R. Johnsen, J. Glosík, Int. J. of Mass Spectrometry 233, 299 (2004).
[2] P. Hlavenka, R. Plašil, G. Bánó, I. Korolov, D. Gerlich, J. Ramanlal, J. Tennyson and J. Glosík, Int. J. of Mass Spectrometry, in print (2006).
[3] J. Glosík, P. Hlavenka, R. Plašil, F. Windisch, D. Gerlich, A. Wolf, H. Kreckel, Phil. Trans. R. Soc. London A, in print (2006).

Lifetime determination of degenerate molecular levels in cw regime using the Autler-Townes effect

T. Kirova[1], A. Ekers[1], R.Garcia-Fernandez[2], M.Auzinsh[1], K.Blush[1], N.Bezuglov[3], L.P.Yatsenko[4], K.Bergmann[2], O.Dulieu[5], and M.Aymar[5]

[1] *Institute of Atomic Physics and Spectroscopy, University of Latvia, LV-1586 Riga, Latvia*
[2] *Department of Physics, University of Kaiserslautern, D-67663 Kaiserslautern, Germany*
[3] *Fock Institute of Physics, St. Petersburg State University, 198904 St. Petersburg, Russia*
[4] *Institute of Physics, Ukrainian Academy of Sciences, Kiev -39, 03650 Ukraine*
[5] *Laboratoire Aime Cotton, CNRS, Campus d'Orsay, 91405 Orsay Cedex, France*
E-mail: tkirova@temple.edu

Most schemes of laser manipulation of quantum states rely on the use of strong field effects in light-matter interactions, which can be interpreted in terms of the Autler-Townes (AT) effect [1]. The AT effect is observed as splitting of spectral lines in the excitation spectrum due to "dressing" of the molecular energy levels by a strong laser field. The AT effect itself has a potential for development of novel applications, like the recently demonstrated technique for lifetime and branching ratio measurements of highly excited molecular states using cw laser fields [2]. The method is demonstrated on example of the $5^1\Sigma_g^+$(v=10, J=9) state in Na_2.

The experiment was performed in a supersonic molecular beam of Na_2 crossed by two parallel co-propagating laser beams. The probe laser excites the $X^1\Sigma_g^+$(v"=0, J"=7) to $A^1\Sigma_u^+$ (v'=10, J'=8) molecular transition, whereas the strong field couples the excited state $A^1\Sigma_u^+$ (v'=10, J'=8) to the final $5^1\Sigma_g^+$ (v=10, J=9) state. The fluorescence signal from both the excited and final states was detected as a function of the probe field detuning for different detunings of the strong field. The excitation spectra exhibit the typical AT doublet pattern with the separation between the AT components equal to $\sqrt{\Omega_S^2 + \Delta_S^2}$, where Ω_S and Δ_S represent the coupling field Rabi frequency and detuning respectively. Ratio of the two AT peaks intensities is shown to depend on the strong field detuning and lifetimes of the intermediate and upper levels.

Analysis based on the dressed-states approach [3] shows that when the probe field is sufficiently weak and in the case of non-degenerate levels and negligible inhomogeneous broadening, this ratio is a simple function of the lifetime of the final level and can therefore serve as a tool for its direct measurement. Under real experimental conditions molecular levels exhibit magnetic sub-level degeneracy, and profiles of spectral lines are subject to Doppler broadening. Simulations based on the density matrix equations of motion were performed and gave best fit with the experimental data for a value of 40ns for the lifetime of the $5^1\Sigma_g^+$ (v=10, J=9) state in Na_2. This value is in good agreement with the theoretical estimates based on ab initio calculations.

Acknowledgements This work was supported by INTAS Grant 05-1000008-8013; EU TOK project LAMOL; Russian Found. for Basic Research Grants 05-02-16216, 05-03-33252; NATO Grant EAP. RIG.981378.

References

[1] S. H. Autler and C. H. Townes, Phys. Rev. 100, 703 (1955).
[2] R.Garcia-Fernandez et al. PRA 71, 023401 (2005).
[3] C. Cohen-Tannoudji and S. Reynaud, J. Phys. B, 10, 345 (1977)..

Modeling of Autler-Townes effect in diatomic molecules for three and four-level scheme

M. Auzinsh, K. Blushs, A. Ekers, E. Valbahs

University of Latvia, Department of Physics and Mathematics, Rainis Blvd. 19, Riga LV-1586, Latvia
E-mail:edvards@lanet.lv

A common use of lasers in spectroscopy is to determine, by observation of absorption or fluorescence, the electronic structure of atoms. When the excited state of an atom is also coupled to a third state by a second, strong laser field through an allowed electric-dipole transition, then the excitation signal becomes significantly modified; for a sufficiently strong coherent field, it appears as two distinct components, a pattern often termed the Autler-Townes doublet, honoring those who first observed it [1]. Recently Autler-Townes effect has been observed also in diatomic molecules - Li_2 [2] and Na_2 [3]. In case of molecules effect can be complicated by the fact that the angular momentum J of states that are coupled by laser fields is rather large 10 or even larger and these rotation levels are composed of a large number of degenerated magnetic sublevels. Each pair of magnetic sublevels has different transition strength and consequently is characterized by its own specific Rabi frequency. Even more - these pairs of magnetic sublevels that are coupled by the laser field often can not be considered as independent. Due to spontaneous transitions these pairs are connected together. Until now Autler-Townes effect in molecules were describe by a simplified model of many independent three level systems [2,3]. In this report we offer a comprehensive analysis of Autler-Townes effect in molecules in which we solve the complete set of optical Bloch equations for multilevel system in which we take into account mutual connection of all magnetic sublevels involved in the process. We take into account also the real linewidth of the lasers that are involved in the excitation. For that we are exploiting decorrelation analysis base on two models of the fluctuation of laser radiation - random phase jump model and phase diffusion model [4]. Analysis were performed for traditional scheme of two laser excitation used in [3] as well as for four laser excitation used in [2]. We demonstrate that for different types of molecular transitions P, ($\Delta J = J_{upper} - J_{lower} = -1$) Q ($\Delta J = 0$) and R ($\Delta J = +1$) one can expect different structure of Autler-Townes signals in molecules. Thus for P and R type of transitions rather strong laser field is needed in order to resolve Autler-Townes peaks arising from different magnetic sublevels. At the same time for Q type of molecular transitions this structure can be observed for much weaker laser light intensities.

We acknowledge support from the Latvian Government material science project Nr. 1-23/50 Perspective inorganic materials for photonics and energetics. K. B. and E. V. thank the European Social Fund for support. This work was supported by the EU TOK projects LAMOL and NATO Grant EAP.RIG.981387 (A.E.).

References

[1] S. H. Autler and C. H. Townes, Phys. Rev. 100, 703 (1955).
[2] J. Qi, G. Lazarov, X. Wang,1 L. Li, L. M. Narducci,3 A. M. Lyyra, F. C. Spano, Phys. Rev. Lett. 83, 288-291 (1999);
[3] R. Garcia-Fernandez, A. Ekers, J. Klavins, L. P. Yatsenko, N. N. Bezuglov, B. W. Shore, and K. Bergmann , Phys. Rev. A 71, 023401-023417 (2005).
[4] K. Blushs, M. Auzinsh, Phys. Rev. A 69, 063806 (2004).

Measure of polarizabilities using large molecules interferometer

M. Berninger, A. Stefanov, S. Deachapunya, and M. Arndt

Institut fr Experimentalphysik Universitt Wien Asutria
E-mail:Andre.Stefanov@univie.ac.at

We present a new method to measure polarizabilities of large molecules in the gas phase. We use a Talbot-Lau interferometer as a very sensitive deflectometer. This setup has already shown interferences with 1μm period of large molecules with masses up to 1632 amu [1].
In an electric field E, the force applied on a molecule with polarizability α is $F = \alpha E \nabla E$. By designing the shape of electrodes such that the force is constant over the beam section, we are able to measure shifts of interference pattern with a resolution of 20 nm, which is about a factor 100 better than classical deflectometry of molecular beams [2]. This allows us to measure polarizabilities of fullerenes and porphyrins. Our first measurements for C_{60} show a polarizability of 86.2 [A] with an error of 8%.
Further improvement of the system and calibrations could lead to an error of absolute polarizabilities below 4% and even 1% for relative polarizabilities. This method could also be used for separation of molecules in the gas phase as function of their polarizabilities. Finally the systems could be redesigned in order to be much more compact and versatile.

References

[1] L. Hackermller, et al., Phys. Rev. Lett 91, 90408 (2003).
[2] R. Antoine, et al., J. Chem. Phys., 110 (1999)

Production of ground state negative ion beam

A. Lindahl[1], P. Andersson[1], C. Diel[2], D. Hastorp[1] and D. J. Pegg[3]

[1] *Department of Physics, Göteborg University, SE-412 96 Göteborg, Sweeden*
[2] *Institut fuer Physik, Johannes Gutenberg-Universität, Mainz, D-55099 Mainz, Germany*
[3] *Department of physics, University of Tennessee, Knoxville, Tennessee 37996, USA*
E-mail:anton.lindahl@physics.gu.se

Isotopically pure beams consisting of negative ions in their ground state find application in a variety of fields, including mass spectrometry. We will describe our recent efforts to achieve this goal. The method is based on selective photodetachment from a beam of negative ions collinearly superimposed on a laser beam. The selectivity is achieved by exploiting the well-defined thresholds of the photodetachment cross section, which are isotope and isobar specific. To enhance the isotope selectivity we utilize that different masses experience different doppler shift in the collinear geometry.
Negative ions of the element of interest are extracted from a commercial ion source, accelerated and mass selected. This procedure produces a beam of ground and excited state ions that, in general, consists of different isotopes and isobars. A laser beam with photon energy such that it depletes the population of excited ions is applied to the ion beam in a collinear geometry. By deflecting the ion beam, it is possible to get rid of the neutral particles in the produced in the photodetachment. After this, the ion beam consists of a specific isobar and isotope in the ground state. The beam produced can now be used in any specific experiment. In our case, we have probed the ion beam with another laser to measure the depletion. Our overall goal is to try to improve the selectivity in mass spectrometry, and to conduct fundamental studies on atomic and molecular ions in the ground state.
We will describe a demonstration experiment designed to deplete the population of excited states of ions. We chose the P^- ion for this work. This ion has a single electronic ground state, the $3s^2 3p^4\ ^3P$ state, with three fine structure levels. The aim of the experiment was to deplete the $J = 0{,}1$ levels in the first stage of photodetachment, leaving the beam ions in the $J = 2$ level only. The threshold energies for the $J = 0, 1, 2$ levels have been measured to be 5760, 5840 and $6020 cm^{-1}$, respectively. All three levels were depleted to better than 99% by the use of photons of energy $13900 cm^{-1}$. By tuning the laser to $6000 cm^{-1}$, the $J = 0{,}1$ levels were depleted to 40%, leaving the beam ions in the $J = 2$ level unaffected. Work is in progress to improve the amount of depletion.

Photoassociation spectroscopy of $^{87}Rb_2$ long range molecular states analysed by the Lu-Fano mehtod coupled to the Le Roy-Bernstein formula.

H. Jelassi, B. Viaris de Lesegno and L. Pruvost

Laboratoire Aimé Cotton, univ Paris Sud, bat 505, 91405 Orsay, France
E-mail:laurence.pruvost@lac.u-psud.fr

Experimental results of the photoassociation (PA) of ^{87}Rb cold atoms, obtained in the asymptotic range below the $5S_{1/2}$+$5P_{1/2}$ dissociation limit, are presented and analysed in the context of the Lu-Fano approach coupled to the LeRoy-Bernstein formula. The PA spectra are obtained by trap loss spectroscopy[1]. They exhibit vibrational progressions corresponding to the 0_g^-, 0_u^+ and 1_g molecular states.

In the near-dissociation region, the molecular interaction is fully described by an atomic model including the dipole-dipole interaction. It gives the asymptotic behavior of the molecular potential curves, namely a $1/R^3$ or $1/R^6$ internuclear distance dependence. Eigen energies of such potentials are then given by the Le Roy-Bernstein formula[2]. The measured energy positions of the resonances are analyzed by using this formula. The Lu-Fano approach is then applied to the data in order to extract from this analysis the deviations to the formula and therefore to the asymptotic molecular potential. To that purpose, a quantum defect is defined for the molecular states, as for Rydberg atomic states, and, its energy variation is analyzed.

For the 0_g^- molecular states we observe a linear variation of the quantum defect, which is the signature of the short range behavior of the molecular potential. We show that an improved LeRoy-Bernstein model can to be applied. This approach lets us to determine the phaseshift of the wavefunction at the dissociation limit and the slope of the linear variation[3].

For 0_u^+ states, we also observe the linear variation with some additive sharp variations which indicate a coupling with a neighboring molecular series. The coupling is due to the spin-orbit interaction in the molecule. A two series model allows us to evaluate the coupling, identify two levels of the $(5S_{1/2}+5P_{3/2})0_u^+$ series and predict the energy and the width of its first predissociated level. An experimental signal agrees with the prediction[4].

For 1_g states, the hyperfine interaction induces a structure in the resonances. As soon as the molecular binding energy is larger than the atomic hyperfine interaction, a perturbative approach can be used, leading to 7 equidistant molecular curves. In this case, hyperfine energy shifts can be substrated and the Lu-Fano graph can be computed and used as before.

References

[1] Spectroscopy of Na_2 by photoassociation of laser-cooled Na, P. D. Lett, K. Helmerson, W. D. Phillips, L. P. Ratliff, S. L. Rolston, W. E. Wagshul, Phys. Rev. Lett. **71**, 2200, 1993.

[2] Dissociation energy and long-range potential of diatomic molecules from vibrationnal spacings of higher levels, R. J. Le Roy , R. B. Bernstein, J. Chem. Phys. **52**, 3869, 1970.

[3] Photoassociation spectroscopy of $^{87}Rb_2$ $(5S_{1/2}+5P_{1/2})0_g^-$ long-range molecular states; analysis by Lu-Fano graph and improved LeRoy-Bernstein formula, H. Jelassi, B.Viaris De Lesegno, L. Pruvost, Phys. Rev. A. **73**, 032501, 2006.

[4] Photoassociation spectroscopy of $^{87}Rb_2(5s_{1/2}+5p_{1/2})0_u^+$ long range molecular states: coupling with the $(5s_{1/2}+5p_{3/2})0_u^+$ series analyzed using the Lu-Fano approach, H. Jelassi, B.Viaris De Lesegno, L. Pruvost, submitted to Phys. Rev. A.

Improvements on the refresh rate and dynamical properties of an SLM by sequential readout using an acousto-optic modulator

M. Mestre, B. Viaris de Lesegno and L. Pruvost

Laboratoire Aimé Cotton, univ Paris Sud, bat 505, 91405 Orsay, France
E-mail:laurence.pruvost@lac.u-psud.fr

We have demonstrated the use of an acousto-optic modulator to enhance the refresh rate and dynamical properties of a liquid-crystal spatial light modulator (SLM). The useful area of the SLM surface is split in several zones adressed separately, which are read in a sequence by a steered laser beam. Improvements on the nature of the transition between different holograms are shown. An increase of speed of many orders of magnitude is measured.
The poster will also discuss the advantages of this technique for the manipulation of cold atoms with holographic optical tweezers[1].

References

[1] Improvements on the refresh rate and dynamical properties of an SLM by sequential readout using an acousto-optic modulator , M.Mestre, B. Viaris de Lesegno and L. Pruvost, submitted to Optics Letters.

Ionisation of NH3 by electron impact : structure and dynamical studies

N. Rezkallah[1], S. Houamer[1] and C. Dal Cappello[2]

[1] *Dpt de Physique,Faculté des sciences, université Ferhat Abbas, Sétif,19000, Algérie*
[2] *Laboratoire de Physique Moléculaire et des Collisions, Institut de Physique, Université Paul Verlaine-Metz, 1 Boulevard Arago, 57078 Metz Cedex 3, France*

A theoretical approach is presented to calculate multiply differential cross sections for NH3 molecule in the Born approximation where the projectile is described by a Plane wave. The wave function of the target is described by molecular orbitals consisting on a linear combination of slater type atomic orbitals centered on a common point [1].
To test the accuracy of the wave function used to describe the target, an electron momentum spectroscopy of the process is investigated and our calculations are compared to the experimental results of Bawagan et al. [2] performed at intermediate energy in the non coplanar symmetric geometry . The two outgoing electrons, sharing the same energy (600eV), are both described by plane waves and the exchange effects between them are taken into account.
As the (e,2e) are still very rare for molecular targets like NH3, simple and double differential cross sections are calculated making numerical integrations over scattered solid angle. The differential cross sections are displayed with respect to the ejection angle and compared with experiments [3] . The method can be easily generalized for small molecules.

References:

[1] R. Moccia , J. Chem. Phys. 8, 2176 (1964)
[2] A. O. Bawagan, R. Muller-Fiedler, C. E. Brion, E. R. Davidson and C. Boyle, Chem. Phys. 120, 335 (1988)
[3] M. V. V. S. Rao and S. K. Srivastava, J. Phys. B. 25, 2175 (1992)

Triply differential cross section for double photoionization of helium. Comparison between theory and experiment.

L.Argenti and R.Colle

Dipartimento di Chimica Applicata e Scienza dei Materiali, Università di Bologna, Bologna, Italy
E-mail:colle@sns.it

We present a new method, based on the use of two-particle Green functions and projected electron-electron potential, for the calculation of triply differential cross sections (TDCS) for double photoionization of atoms and molecules. The main advantages of the method are the tunable accuracy of the results and its efficient applicability to molecules.
We apply the method to the calculation of TDCS for double photoionization of helium at energies and geometries covered in recent experiments[1]. Comparison with experiments and other calculations is very promising.

References

[1] L. Avaldi, A. Huetz, J. Phys. B: At.Mol.Opt.Phys. 38, S861 (2005).

Absolute angle-differential cross sections for electron-impact excitation of neon atoms from threshold to 19.5 eV

M. Allan*, K. Franz*,†, O. Zatsarinny‡, K. Bartschat‡ and H. Hotop†

* *Département de Chimie, Université de Fribourg, CH-1700 Fribourg, Switzerland*
† *Fachbereich Physik, Technische Universität Kaiserslautern, D-67653 Kaiserslautern, Germany*
‡ *Department of Physics and Astronomy, Drake University, Des Moines, IA 50311, USA*
E-mail:hotop@physik.uni-kl.de

Cross sections for inelastic electron scattering from rare-gas atoms are of great importance for gaseous discharge physics [1], but - except for He - the theoretical description of these processes has remained a substantial challenge. Recently, however, significant progress has been made, by means of a semi-relativistic B-spline R-matrix (close-coupling) method with non-orthogonal orbitals [2]. For thorough tests of theoretical approaches, it is highly desirable to compare the computed results with detailed experimental information, such as angle-differential excitation cross sections, obtained in absolute units at impact energies near threshold, where the excitation process is dominated by a prominent anion resonance structure [2-6]. A particular point of interest is the final-state-specific coupling of the anion resonances. Apart from numerous work on He (see, e.g., [3,5]) and some results for Ar [3] and Kr [3,4], such data are currently missing in the literature. Using a high-resolution electron beam machine [5], we have studied the excitation of neon atoms to all four levels of the Ne($2p^5$ 3s) configuration in the near-threshold energy range (E = 16.6 - 19.5 eV); first results were reported in [7]. Here we present absolute excitation cross sections at the four angles 45°, 90°, 135°, and 180°. Much of the prominent anion resonance structure, especially around 18.5 eV [2,3,6,7], has been resolved. The experimental results are compared with angle differential cross sections calculated by the B-Spline R-matrix approach described in [2]. Excellent overall agreement between the measured and the calculated energy dependence, particularly regarding the shapes and relative heights of the resonance features is observed. The measured absolute values of the cross sections and the angular distribution, studied over the full angular range at $E = 18$ eV are consistent with theory. In the future the energy range will be extended to join with previous data, measured at a few discrete impact energies above 20 eV (e.g. [8]).

This work has been supported by the European Science Foundation through EIPAM, by the Swiss National Science Foundation, by the Deutsche Forschungsgemeinschaft, and by the US National Science Foundation.

References

[1] L. G. Christophorou and J. K. Olthoff, Adv. At. Mol. Opt. Phys. **44** (2001) 59
[2] O. Zatsarinny and K. Bartschat, J. Phys. B **37** (2004) 2173
[3] S. J. Buckman and C. W. Clark, Rev. Mod. Phys. **66** (1994) 539
[4] J. M. Phillips, J. Phys. B **15** (1982) 4259
[5] M. Allan, J. Phys. B **25** (1992) 1559
[6] J. Bömmels, K. Franz, T. H. Hoffmann, A. Gopalan, O. Zatsarinny, K. Bartschat, M.-W. Ruf and H. Hotop, Phys. Rev. A **71** (2005) 012704
[7] M.Allan, K. Franz, H. Hotop, O. Zatsarinny, and K. Bartschat, J. Phys. B **39** (2006) L139
[8] M. A. Khakoo *et al.*, Phys. Rev. A **65** (2002) 062711

Elastic electron scattering by water molecules

Jorge Luiz da Silva Lino

Universidade Braz Cubas-UBC, Campus I,
08773-380, Mogi das Cruzes, São Paulo, Brazil

An electron collision with water molecule is a fundamental process in various fields such as radiation physics and available chemistry, atmospheric physics and astrophysics. A water molecule can be used as a representative target in the theory of electron collision with polyatomic molecules, which are characterized by a multicentre nature and a long-range force due to a dipole or other multipole moment. In the present paper, elastic electron scattering by H_2O is studied using the Schwinger variational principle with plane waves as a trial basis set (SVP-PW) [1]. Recently, we have shown that the SVP-PW for scattering theory is an effective approach to electron - molecule collisions [2,3]. The main limitation of the Schwinger variational principle resides on what makes it a general method: the expansion of the scattering function is done in a L^2 basis (Cartesian Gaussian functions) and this is very effect only for short-range potentials (the Schwinger's method require a good description of the scattering wavefunction only in the region where the potential is non-zero and as most nolinear molecules have dipole moments the long range of such potentials can make it difficult to adequately represent the trial function in an L^2 basis only). Our implementation of plane waves as a trial basis set can be desirable to adequatly represent, for example, the long range regions. Differential cross sections are obtained for e^- - H_2O from 10 to 50 eV. In these studies the exchange potential is evaluated by Born-Ockur model and our results are found to be in reasonable agreement with experimental data and theoretical studies.

References

[1]-J. L. S. Lino, M. A. P. Lima, Braz. J. Phys. **30**(2), (2000) 432.
[2]-J. L. S. Lino, Rev. Mex. Fis., **49**, (2003) 6.
[3]-J. L. S. Lino, Rev. Mex. Fis. **51**, (2005) 270.

Absolute fragment state selective cross sections for N_2 photodissociation in an exciting photon energy range between 23 eV and 27 eV

L. Werner[1], S. Klumpp[1], A. Ehresmann[1], Ph. V. Demekhin[2], V. L. Sukhorukov[2], K.-H. Schartner[3] and H. Schmoranzer[4]

[1]*Institute of Physics and CINSaT, University of Kassel, Germany*
[2]*Rostov State University of Transport Communications, Rostov-on-Don, Russia*
[3]*I. Institute of Physics, Justus-Liebig University, Germany*
[4]*Department of Physics, TU Kaiserslautern, Germany*
E-mail:ehresmann@physik.uni-kassel.de

The interaction between monochromized synchrotron radiation and molecules in combination with high resolution fluorescence spectroscopy offers a possibility to measure partly on an absolute basis state selective cross sections for photodissociation processes into neutral fragments when excited particles are formed as shown in [1].
Fragment state selective N_2 photodissociation cross sections were obtained by using monochromized synchrotron radiation in an exciting photon energy range between 23 eV and 27 eV with the narrow bandwidth of about 2 meV from the storage ring BESSY II, Berlin Germany, by measuring dispersed fluorescence from excited NI fragments via photon-induced fluorescence spectroscopy PIFS [2]. The dispersed fluorescence radiation was detected by a position-sensitive microchannel plate detector.
The exciting-photon energy range was chosen such that it lies just beneath the threshold for dissociative ionisation into the fragments $\mathrm{NII}(^3\mathrm{P}) + \mathrm{NI}(^4\mathrm{S})$ and $\mathrm{NII}(^3\mathrm{P}) + \mathrm{NI}(^2\mathrm{D})$. In this exciting-photon energy regions intensities from NI fragment fluorescence transitions $2\mathrm{p}^2(^3\mathrm{P})n\mathrm{d}$ and $2\mathrm{p}^2(^3\mathrm{P})n\mathrm{s}$ in the VUV-region were measured as a function of the exciting photon energy. The contribution will describe a method to put the obtained relative emission cross sections to an absolute scale by comparison to the XeII $5\mathrm{s}^1 5\mathrm{p}^6\ ^2\mathrm{S}_{1/2} \rightarrow 5\mathrm{s}^2 5\mathrm{p}^5\ ^2\mathrm{P}_{1/2}$ emission cross section [4] and presents absolute emission cross sections.

References

[1] H. Liebel, A. Ehresmann, H. Schmoranzer, Ph. V. Demekhin, B.M. Lagutin, V. L. Sukhorukov, J. Phys. B: At. Mol. Opt. Phys. 35, 895 (2002).
[2] H. Schmoranzer, H. Liebel, F. Vollweiler, R. Müller-Albrecht, A. Ehresmann, K.-H. Schartner, B. Zimmermann B, Nucl. Instrum. Methods in Phys. Res. A 467-468,1526 (2001).
[3] A. R. Striganov, N. S. Sventitskii, Tables of spectral lines of neutral and ionized atoms, Plenum Data Corporation, New York (1968).
[4] H. Schmoranzer, S. Lauer, F. Vollweiler, G. Reichardt, K.-H. Schartner, G. Mentzel, O. Wilhelmi, V. L. Sukhorukov, B. M. Lagutin, I. D. Petrov, Ph. V. Demekhin, Phys. Rev. Lett. 79, 4546 (1997).

Electron energy and angular distributions following the projectile ionization in relativistic ion–atom collisions

S. Fritzsche[1] and A. Surzhykov[2]

[1] *Institut für Physik, Universität Kassel, D–34132 Kassel, Germany*
[2] *Max–Planck–Institut für Kernphysik, D–69029 Heidelberg, Germany*
E-mail: fritzsch@physik.uni-kassel.de

The projectile ionization of heavy, hydrogen–like ions is studied within the framework of first–order perturbation theory and Dirac's relativistic equation [1, 2]. Emphasis is placed, in particular, on the angular and energy distributions of the emitted electrons as observed in both, the projectile and the laboratory frames. Detailed computations are carried out to investigate the effects from the excited states of the projectiles upon the energy–differential ionization cross sections. For relativistic U^{91+} ions, for instance, a small partial population of the excited $2s_{1/2}$ state results in a much narrower energy spectrum of the emitted electrons than obtained for the case of a pure K–shell ionization. This behaviour of the differential cross sections might help understand a recent observation by Vane an co–workers [3] on the ionization of heavy, hydrogen–like projectiles in ultra–relativistic ion–atom collisions.

Apart of the effects from an excitation of the projectile ions, we also discuss the convergence of the double–differential cross sections by increasing the number of partial waves in the expansion of continuum electron wavefunction. Our calculations clearly indicate that a proper size of the partial–wave expansions is critical in order to ensure an accurate evaluation of the electron energy and angular distributions, both within the laboratory and projectile frame.

References

[1] A. Surzhykov and S. Fritzsche, J. Phys. B 38, 2711 (2005).
[2] S. Fritzsche, A. Surzhykov and Th. Stöhlker, Nucl. Instr. Meth. B 205, 469 (2003).
[3] C. Vane *et al.*, Proc. 21st Int. Conf. of the Physics of Electronic and Atomic Collisions (Sendai, Japan), 709 (2000).

Correction to Doppler profile in supersonic molecular beams

K.Miculis[1], R.Garcia-Fernandez[2], E.Saks[1], I.Sydoryk[1], A.Matveev[3], N.Bezuglov[3], A.Ekers[1].

[1] *Institute of Atomic Physics and Spectroscopy, University of Latvia, LV-1586 Riga, Latvia*
[2] *Department of Physics, University of Kaiserslautern, D-67663 Kaiserslautern, Germany*
[3] *Fock Institute of Physics, St Petersburg State University, 198904 St Petersburg, Russia*
E-mail: michulis@latnet.lv

In supersonic beams, the velocity component $v = v_{||}$ of the molecules along the molecular beam axis has a relatively narrow distribution $F(v)$ around the central flow velocity v_f [1]

$$F(v) = \exp\left(-(v - v_f)^2/(\Delta v)^2\right)/(\sqrt{\pi}(\Delta v)^2). \tag{3.2}$$

The Doppler profile $P(\Delta\nu)$ for laser excitation perpendicular to the beam axis is usually described by the Gaussian function $P \sim \exp(-\Delta\nu^2/\Delta\nu_D^2)$ [2], where the width $\Delta\nu_D = v_r/\lambda$ is associated with the residual velocity component $v_\perp$ perpendicular to the beam axis, which occurs due to finite divergence angle φ of the beam: $v_\perp = \varphi v_f$ [1].
Here, we show that the Doppler profile $P_\perp(\Delta\nu)$ observed perpendicular to the beam axis and formed by nonzero scatter of transverse velocities $v_\perp$ leads to a profile different form that described by the Gaussian function. This profile depends on the distribution $F_\perp(v_\perp)$ of the velocities $v_\perp$, which can be evaluated from the distribution $F(v)$ (1). The function $F_\perp(v_\perp)$ is shown to depend on the distance of molecules from the beam axis, while we assume $v_\perp \equiv 0$ for molecules on axis. The resulting absorption profile as a function of laser detuning $\Delta\nu$ can be described by the following function:

$$P_\perp(\Delta\nu) = \frac{2}{4\pi^{3/2}\Delta\nu_D^3\Lambda}\int_{|\Delta\nu|}^{\infty} d\tau\sqrt{\tau^2 - \Delta\nu^2}\exp\left(-\frac{(\tau - \Delta\nu_D)^2}{\Delta\nu_D^2\Lambda^2}\right); \quad \Lambda = v_f/\Delta v\,. \tag{3.3}$$

Given that the parameter Λ is sufficiently small ($\Lambda \ll 1$), the integral in the above equation can be simplified using the saddle-point technique [2]. Simple expressions for $P_\perp(\Delta\nu)$ can be obtained in two cases: (i) close to resonance the profile is described by the equation

$$P_\perp(\Delta\nu) = \frac{2}{\pi\Delta\nu_D}\sqrt{1 - \frac{\Delta\nu^2}{\Delta\nu_D^2}}; \qquad \Delta\nu_D\ - |\Delta\nu| > \Lambda\Delta\nu_D\,, \tag{3.4}$$

(ii) far from resonance the profile is described by the Gaussian wings:

$$P_\perp(\Delta\nu) = \frac{\Lambda^2\sqrt{|\Delta\nu|}}{2\pi(|\Delta\nu| - \Delta\nu_D)^{3/2}}\exp\left(-\frac{(|\Delta\nu| - \Delta\nu_D)^2}{\Delta\nu_D^2\Lambda^2}\right); \quad |\Delta\nu| - \Delta\nu_D > \Lambda\Delta\nu_D\,. \tag{3.5}$$

The relevance of the profile $P_\perp(\Delta\nu)$ gievn by Eq. (2) with $\Lambda = 0.194$ is demonstrated on example of Autler-Townes doublets in the excitation spectrum of Na_2 molecules [3].
This work was supported by INTAS Gr.05-1000008-8013; EU TOK project LAMOL; Russian Found. for Basic Research Gr.05-03-33252; NATO Gr.EAP.RIG.981378, European Social Fund.

References

[1] *Atomic and Molecular Beam Methods* (ed. G.Scoles, New York, Oxford, 1998).
[2] B.W.Shore, *The Theory of Coherent Atomic Excitation* (Wiley, New York, 1990).
[3] R.Garcia-Fernandez et al. PRA 71, 023401 (2005).

Dynamical linewidths in the Autler-Townes spectra

K.Miculis[1], N.Bezuglov[2], R.Garcia-Fernandez[3], E.Saks[1], and A.Ekers[1]

[1] *Institute of Atomic Physics and Spectroscopy, University of Latvia, LV-1586 Riga, Latvia*
[2] *Fock Institute of Physics, St. Petersburg State University, 198904 St. Petersburg, Russia*
[3] *Department of Physics, University of Kaiserslautern, D-67663 Kaiserslautern, Germany*
E-mail: michulis@latnet.lv

In a recent study [1] we proposed a novel technique for the determination of lifetimes and branching ratios of excited molecular levels based on the measurement of peak ratios of Autler-Townes doublets in the laser excitation spectra. Spectral lineshapes are subject to line broadening, which can affect the measured peak ratios and must be properly taken into account. It is usually assumed that natural broadening and transit time broadening combine to give a Lorentz absorption profile. Under non-stationary conditions, e.g., when molecules in a beam cross a Gaussian laser beam profile of FWHM L at a flow velocity v_f, it can be written as [1,2]:

$$P(\Delta) = \pi\widetilde{\Gamma}/\left(\Delta^2 + \widetilde{\Gamma}^2\right); \quad \widetilde{\Gamma} = \Gamma_{sp} + 1/\tau_{tran}, \tag{3.6}$$

where Δ is the detuning of probe laser field off from resonance and $\tau_{tran} = L/v_f$ is the transit time. Thus, in the weak excitation limit the absorption lineshape is given by the Lorentz profile (1) with HWHM $\Delta\nu = \widetilde{\Gamma}/2$.

In order to verify the validity of Eq. (1), we have solved a model problem for an open two-level system for a molecule moving through a cw laser beam with the constant velocity v_f. The time dependence of Rabi frequency was chosen as $\Omega(t) = \Omega_0 \exp(-2t^2/\tau_{tran}^2)$, corresponding to a Gaussian laser intensity profile $I(z) = I_0 \exp(-4z^2/L^2)$ along the molecular beam axis z.

Analytical solutions for the $\rho_{ij}(t)$ elements of the density matrix equation were obtained for the weak excitation limit, when $\rho_{22} < \rho_{11}$. They show that the absorption lineshape $R(\Delta)$ (i.e., the probability for the molecules to be excited as a function of Laser detuning Δ) is described by the Voight profile:

$$R(\Delta) = \frac{1}{4}\Omega_0^2 \overline{\tau}_{tran}^3 \Gamma_{sp} \int_{-\infty}^{\infty} \frac{dk\, \exp(-k^2)}{\overline{\tau}_{tran}^2 \Gamma_{sp}^2/4 + \left(\overline{\tau}_{tran}\Delta - k\right)^2}; \quad \overline{\tau}_{tran} = \tau_{tran}/2. \tag{3.7}$$

Thus, if the transit time is short or the excited level is long-lived (e.g Rydberg states), i.e. $\tau_{tran} \ll 1/\Gamma_{sp}$, then the absorption profile $R(\Delta)$ strongly deviates from the Lorentzian. The HWHM of the profile (2) can be well approximated (within 10% of accuracy) by the expression

$$\Delta\nu_R = \sqrt{\Gamma_{sp}^2/4 + 4.8 \cdot \ln(2)/\tau_{tran}^2}. \tag{3.8}$$

The value of $\Delta\nu_R$ exceeds the natural linewidth (1) by a factor of four. Both the numeric calculations and the experimental data [1] justify the validity of the Eqs. (2) and (3).

This work was supported by INTAS Gr. 05-1000008-8013; EU TOK project LAMOL; ESF; Russian Found. for Basic Research Grants 05-02-16216, 05-03-33252; NATO Gr. EAP.RIG.981378.

References

[1] R.Garcia-Fernandez et al. PRA 71, 023401 (2005).
[2] B.W.Shore, *The Theory of Coherent Atomic Excitation* (Wiley, New York, 1990).

Projectile electron losses in the collisions with neutral targets

V.I. Matveev[1], E.S. Gusarevich[1], D.U. Matrasulov[2], Kh.Yu. Rakhimov[2], Th. Stöhlker[3], and G. Baur[4]

[1] *Physics Department, Pomor State University, 163002 Arkhangelsk, Russia*
[2] *Heat Physics Department of the Uzbek Academy of Sciences, 700135 Tashkent, Uzbekistan*
[3] *Gesellschaft für Schwerionenforschung mbH, 64291 Darmstadt, Germany*
[4] *Institut für Kernphysik, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany*
E-mail: gusarevich.eugeny@pomorsu.ru

An approach based on the sudden-perturbation approximation (SPA) is presented for the treatment of multiple electron losses of high and intermediate energy projectiles in their collisions with neutral targets. Using this approach, we calculate multiple electron loss cross sections of U^{10+} and U^{28+} projectiles in their collisions with N_2 and Ar targets. In this paper we will assume that the projectile electrons remain non-relativistic before and after collision and each electron is described by the hydrogen-like wavefunction, while target electrons are described via Dirac-Hartree-Fock-Slater one-electron orbitals [1]. Using the SPA consider the averaged one-electron loss probability

$$p(b) = \frac{1}{n_0}\sum_{n=1}^{n_0}\frac{1}{M_n}\sum_{l,m}\int d^3\mathbf{k}\left|\int d^3\mathbf{r}\,\psi_{\mathbf{k}}^{*}(\mathbf{r})\exp\left\{\frac{2iZ_a}{v}\sum_{i=1}^{3}A_iK_0(\alpha_i|\mathbf{b}-\mathbf{s}|)\right\}\psi_{nlm}(\mathbf{r})\right|^2,$$

where summing is performed over the all possible values of the orbital momentum, l, and its projection, m, for a given nth shell, M_n is the number of such values, n is the principal quantum number, n_0 is the number of shells, $\mathbf{k}$ is the momentum of the electron in the continuum, $\mathbf{s}$ is the projection of $\mathbf{r}$ onto the impact parameter, $\mathbf{b}$, plane, v is the velocity of the projectile, Z_a is the target atomic number, A_i and α_i are the constants [1] which can be extracted from proper tables and $K_0(x)$ is the Macdonald's function. Then for the (N_p-N)-loss probability, we have

$$W^{(N_p-N)+}(b) = \frac{N_p!}{(N_p-N)!N!}p(b)^{N_p-N}(1-p(b))^N = \frac{N_p!}{(N_p-N)!}\sum_{m=0}^{N}\frac{(-1)^m}{(N-m)!m!}p(b)^{N_p-N+m},$$

where N_p and N are the initial and final number of projectile electrons. To obtain the corresponding cross section, we should integrate $W^{(N_p-N)+}$ over the whole impact parameter plane. For $N_p \gg 1$, $N_p - N \gg 1$ this integral can be estimated using the Laplace method assuming that the function $p(b)$ has one maximum located inside or on the (left) boundary of the integration interval, $b = 0$. Let $p(b)^M = \exp\{-Mf(b)\}$, then for $M \gg 1$:

$$\int_{b_0}^{b_1}\exp\{-Mf(b)\}g(b)\,db \sim \frac{G}{\mu}\Gamma\left(\frac{\lambda}{\mu}\right)\exp\{-Mf(b_0)\}\left[\frac{1}{FM}\right]^{\frac{\lambda}{\mu}},$$

where $\Gamma(x)$ is the Gamma-function. G, μ, λ, F are the numbers determined from the behaviour of the functions $f(b)$ and $g(b)$ near the maximum of $p(b)$, b_0: $f(b) - f(b_0) \sim F(b-b_0)^{\mu}$, $g(b) \sim G(b-b_0)^{\lambda-1}$. Then for the total cross section of (N_p-N)-electron loss, we have [2]

$$\sigma^{(N_p-N)+} = \frac{N_p!\sigma^{N_p+}}{(N_p-N)!}\sum_{m=0}^{N}\left(\frac{Z_{N_p}^{*}}{Z_{N_p-N+m}^{*}}\right)^2\frac{(-1)^m}{(N-m)!m!}\left(\frac{N_p}{N_p-N+m}\right)^{\frac{\lambda}{\mu}}p(b_0)^{m-N},$$

where $Z_{N_p-N+m}^{*}$ is the effective charge for (N_p-N+m)-electron loss. This equation allow us to calculate projectile electron loss of any multiplicity, using some two known cross sections. $(N_p-N) \gg 1)$

References

[1] F. Salvat, J.D. Martinez, R. Mayol et al, Phys. Rev. A 36, 467 (1987)
[2] V.I. Matveev, E.S. Gusarevich et al, J. Phys. B: At. Mol. Opt. Phys. 39, 1447 (2006)

Integral cross sections for the electron impact excitation of transitions $1s \rightarrow 2s, 2p, 3s, 3p, 3d$ in hydrogen atom

A. A. Mityureva, V. V. Smirnov

Faculty of Physics, Saint Petersburg State University, 198504, St. Petersburg, Russia
E-mail: mitall@paloma.spbu.ru

Integral cross sections for the electron impact excitation of transitions $1s \rightarrow 2s, 2p, 3s, 3p, 3d$ in hydrogen atom are presented. Cross sections are obtained by means of regression technique using all available data for these processes as the regression sample. This approach was introduced and described in our works [1-4]. The characteristic feature of our approach is using all available data represented in refereed journals with equal weights. We have found and took into account 35 works both theoretical and experimental where absolute integral cross sections for transitions $1s \rightarrow 2s, 2p, 3s, 3p, 3d$ in hydrogen atom are represented. We don't consider the works where only differential cross sections are obtained and the works with effective cross sections, where transitions are not resolved.

The regression process uses minimization of the relative sample variance. The regression function with four parameters is used as in [4]

$$Q(E) = p_0 \left(\frac{u}{u+1}\right)^{p_1} (u + p_2)^{-p_3}, \qquad u = \frac{E}{\Delta E} - 1,$$

where ΔE is threshold energy, p_0, p_1, p_2, p_3 - regression parameters. The regression curve is sufficiently flexible to reproduce the general features of cross sections for corresponding processes with an energy spread about $1eV$. Such a parametrized cross section energy dependence may be used for calculation of the processes rate constants in various plasma physical applications.

The scatter of cross sections values in different works reaches several times. At that the relative dispersion is about 25% for transitions $1s \rightarrow 2s, 2p$ and about $30-40\%$ for transitions $1s \rightarrow 3s, 3p, 3d$. It corresponds to the real accuracy, with which considered cross sections are known at present.

The table exhibits regression parameters, relative dispersions D and energies E in cross section values Q maximum.

up level	p_0 a_0^2	p_1	p_2	p_3	D	E_{max} $a.u.$	Q_{max} a_0^2
$2s$	0.572	0.103	0.554	0.67	0.25	0.41	0.59
$2p$	982	0.448	35.4	1.61	0.26	1.43	2.43
$3s$	0.077	0.221	0.141	0.60	0.39	0.48	0.11
$3p$	144	0.203	41.0	1.58	0.32	1.29	0.35
$3d$	0.322	0.196	1.54	1.07	0.31	0.56	0.13

References

[1] A. A. Mityureva, V. V. Smirnov. Optics & Spectroscopy, 74, n.1, 6 (1993).
[2] A. A. Mityureva, V. V. Smirnov. Optics & Spectroscopy, 86, n. 6, 833 (1999).
[3] A. A. Mityureva, V. V. Smirnov, G. A. Ponomarenko. Optics & Spectroscopy, 92, n. 3, 325 (2002).
[4] A. A. Mityureva, V. V. Smirnov. Optics & Spectroscopy, 97, n. 4, 508 (2004).

Ionization with exchange in Ps and atom scattering

Hasi Ray

Department of Physics, Indian Institute of Technology Roorkee,
Roorkee 247667, Uttaranchal, India
E-mail: hasi_ray@yahoo.com and rayh1sph@iitr.ernet.in

In positronium (Ps) and atom scattering, Ps-ionization channels open only at 6.8 eV. Depending on the ionization potential of the target, target-ionization channels open at below or above 6.8 eV. At this energy region the effect of exchange between the target and the projectile electrons are highly important. In our previous studies [1-2] on target-elastic Ps-ionization cross section using a Coulomb-Born-Oppenheimer approximation (CBOA) for Ps-H and Ps-He scattering, we have established the importance of exchange at lower energy region below 70 eV. In the present article we are interested to present the effect of exchange on target-ionization on Ps-H and Ps-He scattering using the similar methodology. In addition we are also interested to present the differential cross sections [3-4] of Ps-ionization for which the experimental data [5] are available.

References

[1] H. Ray, Euro. Phys. Lett. **73**, 21 (2006).

[2] H. Ray, PRAMANA **66**, 415 (2006).

[3] C. Starrett, Mary T. McAlinden and H. R. J. Walters, Phys. Rev. A **72**, 012508 (2005).

[4] L. Sarkadi, Phys. Rev. A **68**, 032706 (2003).

[5] S. Amritage, D. E. Leslie, A. J. Garner and G. Laricchia, Phys. Rev. Lett. **89**, 173402 (2002).

Quantum Control by Ultrafast Dressed State Tailoring

M. Wollenhaupt, T. Bayer A. Klumpp, D. Liese, A. Präkelt, C. Sarpe-Tudoran and T. Baumert

University of Kassel, Institute of Physics, Center for Interdisciplinary Nanostructure Science and Technology (CINSaT),
Heinrich-Plett-Strasse 40,D-34132 Kassel, Germany
E-mail:schulze@physik.uni-kassel.de

We investigate strong field quantum control with shaped intense femtosecond laser pulses. The underlying physical mechanism is selective population of dressed states (SPODS). In experiments on potassium atoms the dynamic of dressed states population is observed. The dressed state population is mapped with time resolved photoelectron spectroscopy as a function of phase parameter. We have demonstrated experimentally the high selectivity of the dressed state population and the tunability of dressed states over $2000\,cm^{-1}$ on potassium atoms [1]. Wave packet simulations on a diatomic model molecule are presented showing the feasibility of SPODS on molecules [2].

References

[1] M. Wollenhaupt, D. Liese, A. Präkelt, C. Sarpe-Tudoran, T. Baumert,
Appl. Phys. B 82, 183-188 (2006) and ref. there in.
[2] M. Wollenhaupt, D. Liese, A. Präkelt, C. Sarpe-Tudoran, T. Baumert,
Chem. Phys. Lett. 419, 184-190 (2006) and ref. there in.

Quantum Dynamics of a Kicked Harmonic Oscillator

L. Huntley and C. Stubbins

Department of Physics, Franklin & Marshall College, Lancaster, Pennsylvania, USA
E-mail: laura.huntley@fandm.edu

A classical system of two masses connected by a spring and subjected to a time-dependent pulse is used to model a kicked quantum harmonic oscillator in free space. This model is of interest because it is related to the Mössbauer effect where the kick is due to the emission of a gamma ray. Furthermore, the model results in coherent states and can be solved analytically.
If x_1 and x_2 are the positions of the masses, m_1 and m_2, the potential energy of the system is written as the sum of energy due to the potential of the spring and the energy bestowed by the force, $F(t)$, acting on m_2

$$V = \frac{1}{2}\mu\omega^2(x_2 - x_1)^2 - F(t)x_2. \tag{3.9}$$

In center of mass coordinates, this potential is used to motivate the form of the Schrödinger equation for the quantum system. The wave function is found using two extended Galilean transformations [1] and the separation of variables technique [2].
The force applied to the system is specified as a Gaussian pulse, and the expectation value for the energy of a system initially in the ground state is calculated. Before the pulse is applied, the system has energy equal to that of an unperturbed harmonic oscillator plus that of the entire system as a free particle. The energy increases as the force acts on the system and is constant once the pulse has died off.
The probability that the system is in an unperturbed harmonic oscillator state is calculated to have the form

$$|C_m|^2 \propto e^{-|z|^2}\frac{z^{2m}}{m!}, \tag{3.10}$$

indicating that our model produces coherent states [3]. We further show that any force acting on the system in a stationary state will produce coherent states once the force has gone to zero, except in the case where the force is turned off at the moment when the oscillator is at its equilibrium position with zero velocity. In this case, the wave function is the original stationary state.
Finally, we examine the case of a delta-function pulse acting on a particle in a general potential, $V(x)$. We find a form for the wave function and investigate the system's behavior if it was initially in a stationary state.

References

[1] D. Greenberger, Phys. Rev. Lett. 87, 10 (2001).
[2] E. Kerner, Can. J. Phys. 36, 371 (1958).
[3] D. Heinzen, D. Wineland, Phys. Rev. A 42, 2977 (1990).

Information Theory and Quantum Similarity of Atoms

A. Borgoo[1], M.R. Godefroid[2], F. De Proft[1] and P. Geerlings[1]

[1]*Department of General Chemistry (ALGC), Vrije Universiteit Brussel (Free University of Brussels), Pleinlaan 2, 1050 Brussels, Belgium*
[2]*Service de Chimie quantique et Photophysique - CP 160/09, Université Libre de Bruxelles, Av. F.D. Roosevelt 50, 1050 Brussels, Belgium*
E-mail: aborgoo@vub.ac.be

In our work we investigate Quantum Similarity [1] for atoms from electron densities and shape functions. We constructed and evaluated an information theory based quantum similarity index (QSI), which reveals the periodicity of Mendeleev's table. This is, to the best of our knowledge, the first periodicity revealing QSI. The QSI quantifies the similarity of two electron densities by measuring the information distance between an atom and the noble gas of the previous row [2]. Showing that the constructed QSI simplifies to a QSI of the shape function of the atoms strengthens the fundamental role of the shape function as carrier of information [3,4].
In an application we employ Carbó's QSI to investigate the importance relativistic effects throughout the periodic table. We show that the comparison of electron density functions obtained in a Hartree-Fock model with electron density functions in a Dirac Fock model reveal the expected evolution of the importance of relativistic effects.

References

[1] R. Carbó, J. Arnau and L. Leyda, Int. J. Quant. Chem., 17, 1185 (1980).
[2] A. Borgoo, M. Godefroid, K. D. Sen, F. De Proft and P. Geerlings, Chem. Phys. Let., 399, 363 (2004).
[3] P. W. A. Ayers, Proc. Natl. Acad. Sci., 97, 1995 (2000).
[4] F. De Proft, P. W. Ayers, K. D. Sen and P. Geerlings, J. Chem. Phys. 120, 9969 (2004)

Steering quantum evolution by quantum mirrors

P.A. Ivanov[1], E.S. Kyoseva[1], and N.V. Vitanov[1,2]

[1]*Department of Physics, Sofia University, James Bourchier 5 blvd, 1164 Sofia, Bulgaria*
[2]*Institute of Solid State Physics, Bulgarian Academy of Sciences, Tsarigradsko chaussée 72, 1784 Sofia, Bulgaria*
E-mail:vitanov@phys.uni-sofia.bg

We propose a simple physical implementation, in a single interaction step, of the Householder reflection in a quantum system of N degenerate ground or metastable states (forming a qunit [1]) coupled simultaneously to an ancillary excited state. We show that any U(N) transformation of this qunit can be constructed from at most only $N-1$ Householder reflections and a phase gate, and we prescribe the recipe for constructing these reflections [2]. We present examples for qubits, qutrits and multidimensional quantum Fourier transforms. We also show that the unitary transformation between any two pure states (generally coherent superposition states) can be realized by only two Householder mirrors.

References

[1] M.A. Nielsen and I.L. Chuang, *Quantum Computation and Quantum Information* (Cambridge University Press, Cambridge, 2000).
[2] P.A. Ivanov, E.S. Kyoseva, and N.V. Vitanov, Phys. Rev. Lett., submitted.
[3] P.A. Ivanov and N.V. Vitanov, in preparation.

Injection of a cold atom cloud into a laser dipole guide with a pulsed magnetic lens

E. Maréchal, B. Laburthe-Tolra, L. Vernac, J.-C. Keller, and O. Gorceix
Laboratoire de Physique des Lasers, UMR 7538 CNRS, Université de Paris Nord, 99 Avenue J.-B. Clément, 93430 Villetaneuse, France
E-mail:marechal@galilee.univ-paris13.fr

We have used a far detuned Yb fiber laser (λ=1075 nm) to guide a cesium cold atom cloud over a distance of about 1 m. The laser, with a waist of 1.3 mm creates a dipole force which confines the atoms along the vertical laser beam. At the maximum available power of 35 W, the potential depth is 3.5 μK [1]. Since the laser detuning is very large, the heating rate by spontaneous emission is negligible. We have injected the guide with a magnetic lens to increase and optimize the coupling into this atomic fiber.

A cold cloud of Cs is first collected in a standard vapor cell MOT. After a molasses stage, we obtain 10^7 atoms at a temperature of 5 μK with a rms radius of 0.85 mm. The MOT beams are then switched off and the cloud falls along the vertical direction. The atoms are detected by imaging on a CCD camera the fluorescence induced by an horizontal resonant light beam located 88 cm below the MOT center (425 ms of free fall).

We first studied the direct loading and guiding of the atoms similarly to [2]. In the presence of the dipole guide, the guided atoms appear on the fluorescence image as a small Gaussian peak superimposed on the broader Gaussian peak of the non guided atoms. The guiding fraction is inferred from these images. We have observed a guiding of the atom cloud along the 88 cm of the fall. The guided fraction increases linearly up to 5 % for power less than 20 W, and saturates for larger power. We interpret this effect as due to thermal effects which alter the beam quality when the power increases.

To optimize the loading of the dipole guide, we have used a pulsed magnetic lens [3]. The lens can change the radial size and the radial temperature of the cold atom cloud. As shown in [4] the guided fraction depends only on these two parameters compared to the waist and to the depth of the dipole guide respectively. The use of the lens allows to optimize the coupling in the dipole guide. The magnetic lens is made of a simple 5 cm diameter and 50 turns vertical axis coil located 9.5 cm below the trap center.

The sequence is the following. After the loading, the atom cloud is polarized by optical pumping in the (F=4, m_F=4) magnetic sublevel. Due to this polarization phase, the cloud temperature is increased from 5 to 8.5 μK. The cloud expands during 130 ms of free fall and reach the magnetic lens center. The current is then pulsed during 10 ms with a given intensity ranging from 0 to 6 Amps, corresponding to increasing lens focal length. The dipole guide is switched on 'directly' or after a given delay. The atoms are then detected by fluorescence imaging and the guided fraction is measured.

The results show clearly that the magnetic lens allows one to finely tune the guided fraction. A gain by a factor of two to three can be obtained. Classical Monte Carlo simulations reproduce the relative behavior but the experimental absolute guided fraction is less important. We interpret this discrepancy as a consequence of thermal effects which can increase the effective waist of the laser beam and distort the dipolar potential.

References

[1] R. Grimm, M. Weidemüller, Yu.B. Ovchinnikov, Adv. At. Mol. Opt. Phys. 42, 95 (2000)
[2] L. Pruvost, D. Marecescaux, O. Houde, H. T. Duong, Opt. Commun. 166 (1999) 199
[3] T. Miossec, R. Barbé, J.-C. Keller, O. Gorceix, Opt. Commun. 209 (2002) 349
[4] B.Wolschrijn, R. Cornelussen, R. Spreeuw, H. van den Heuvell , New J. of Phys. 4 (2002) 69

Inertial forces measurement with cold atom interferometry

A. Gauguet, B. Canuel, D. Holleville, N. Dimarcq, A. Clairon and A. Landragin

LNE-SYRTE, CNRS UMR 3630, Observatoire de Paris,
61 avenue de l'Observatoire de Paris,75014 Paris , France
E-mail:alexandre.gauguet@obspm.fr

We have realized a device based on cold atom interferometry to achieve precision inertial measurement. In contrast with previous analog atomic setups [1][2], we emphasize on the long term stability and the compactness of the device by the use of laser cooled atoms, as previously shown in the field of atomic clock. The expected improvement in stability will enable to consider applications in inertial navigation, geophysics or tests of general relativity as the equivalence principle or the Lense-Thirring effect [3]. The expected sensitivity resulting of our geometry is 30 nrad.s^{-1}.Hz$^{-1/2}$ for rotation and 4. 10^{-8} m.s^{-2}.Hz$^{-1/2}$ for acceleration measurements.

Cesium atoms are loaded from a vapor in two independent magneto-optical traps during 125 ms. The two cesium clouds are launched along parabolic trajectories using moving molasses at 2.4 $m.s^{-1}$, with an angle of 8^o with respect to the vertical direction. At the top of their trajectory, the atoms interact with three Raman lasers pulses equivalent to beam splitters ($\pi/2$ pulses) and mirrors (π pulses), realizing an interferometer. After this interaction sequence the transition probability depends on the inertial forces through the phase difference accumulated between the two arms of the interferometer. Raman transitions enable detection of the internal states of the atoms by fluorescence imaging. The use of two atomic sources allows to discriminate the inertial phase shifts due to acceleration and rotation.

First measurements obtained with this setup lead to a sensitivity of 4.6 10^{-6} m.s^{-2} for acceleration and 2.6 10^{-6} rad.s^{-1} for rotation, for one second averaging time [4]. The sensitivity was limited by the low number of detected atoms and the weak contrast of atomic fringes. This value of contrast could be explained by the temperature of the two atomic sources ($\sim 3\ \mu K$). To reach better performances, the entire cooling system was re-designed in order to increase the number of launched atoms, to optimize the atomic temperatures and to improve the control of the atomic trajectories. With these modifications we are now able to launch 10^6 atoms in the pure quantum state with a velocity dispersion of about 2 V_{recoil} ($\sim 1\ \mu K$). In consequence, this improved the contrast by a factor two. Besides, it is now possible to control independently the two atomic sources in order to better overlap the two atomic trajectories. With these modifications the sensor is now being characterized and optimized to reach the optimum sensitivity which will be presented.

References

[1] F. Riehle, et al, Phys. Rev. Lett. 67, 177 (1997).
[2] T.L. Gustavson, et al, Class. Quantum. Grav. 17, 1 (2000)
[3] ESA Assessment Study Report ESA SCI 10 (2000)
[4] B. Canuel, submitted for publication, arXiv: physics/0604061

The Penning trap mass spectrometer SMILETRAP. Precision mass measurements for fundamental physics

T. Fritioff[1], I. Bergström[2], Sz. Nagy[3], R. Schuch[1], A. Solders[1], and M. Suhonen[1]

[1]*Stockholm University, AlbaNova University Center, Fysikum, SE - 106 91 Stockholm, Sweden*
[2]*Manne Siegbahn Laboratory, Stockholm University, Frescativägen 28, SE-10405, Stockholm, Sweden*
[3]*Johannes Gutenberg-Universität Mainz, Staudingerweg, 7, D - 55128 Mainz, Germany*
E-mail:fritioff@physto.se

The Penning trap mass spectrometer SMILETRAP[1] is designed for precision mass measurements using the merits of highly-charged ions. The highly charged ions are produced in an Electron Beam Ion Source from singly charged isotope separated ions. The ion mass is determined from cyclotron frequency measurements by using the time-of-flight method where the ions are destructively detected. By selecting cold rather than cooled ions, stabilizing the magnetic field by pressure and temperature regulation of the liquid He and trap structure respectively we can achieve a mass precision of better than 1 part in a billion in routine measurements. The mass measurements so far performed are either related to fundamental constants or to masses the accuracy of which is needed for some current questions in fundamental physics.

have measured the mass of Hydrogen and Lithium-like Calcium ions, $^{40}Ca^{17,19+}$, for use in the evaluation of g-factor measurements of these ions the objective being a test of QED.

for calibration purposes in nuclear-charge radii and atomic mass measurements of the neutron halos ^{9}Li and ^{11}Li. This measurement uncovered a discrepancy as large as 14σ (1.1 μu) deviation relative to the value given in the Atomic-Mass Evaluation AME2003.

difference between ^{3}H and ^{3}He a new Q-value of the tritium β-decay was derived resulting in 18.589 8(12) keV, being the most accurate value at present. The Q-value of the tritium β-decay is related to the possible rest mass of the electron antineutrino.

References

[1] I. Bergström, C. Carlberg, T. Fritioff, G. Douysset, J. Schönfelder, and R. Schuch, NIM A, 487, 618 (2002).

BETINA - A Beryllium Trap for the Investigation of Nuclear Charge Radii

Ch. Geppert[1], H.-J. Kluge[1], N. Miski-Oglu[2], R. Sanchez[2], F. Schmidt-Kaler[3], D. Tiedemann[2], M. Zakova[2], C. Zimmermann[4], W. Nörtershäuser[1,2]

[1] *GSI Darmstadt, Germany*
[2] *Institute of Nuclear Chemistry, Johannes Gutenberg - Universität Mainz, Germany*
[3] *Departement Quantum Information Processing (QIP), University of Ulm, Germany*
[4] *Institute of Physics, Eberhard-Karls University Tübingen, Germany*
E-mail:D.Tiedemann@uni-mainz.de

Nuclear charge radii of beryllium isotopes are of great interest in nuclear physics. Particularly the radii of the exotic halo nuclei ^{11}Be and ^{14}Be will provide important information about the interaction of halo nucleons with the nuclear core. Separation of the nuclear volume effect in the isotope shift is the only nuclear-model independent approach for the charge radius determination of short-lived isotopes and has been applied many times on medium and heavy elements. Since the nuclear-mass dependent part of the isotope shift is by far exceeding the volume effect for light elements, a clear separation is only possible if the mass effect can be reliably calculated to an accuracy of 10^{-5} or better. This is currently only possible for systems with up to three electrons [1] and maybe extended to four-electron systems soon [2]. The first charge-radii determinations of light, short-lived isotopes have been performed recently on ^{6}He [3] and the lithium isotopes ^{8,9,11}Li [4,5]. The results provided new benchmarks for nuclear structure theory. We are now preparing high-precision isotope shift measurements on trapped and laser-cooled Be^+ ions to determine the charge radii of ^{7,9,10,11}Be.

Beryllium ions produced at ISOLDE will be buffer-gas cooled and bunched in the ISOLTRAP cooler and buncher radio frequency quadrupole (RFQ) structure. After transfer into a Paul trap the ion temperature will be further reduced by laser cooling. The resonance frequencies of all hyperfine structure components in the $2s_{1/2} \rightarrow 2p_{1/2}$ transition will be determined by fast cycling between cooling and spectroscopy. The experimental setup and the status of the preparations are presented.

References

[1] Z.-C. Yan and G.W.F. Drake, PRA 61, 022504 (2000), PRL 91, 113004 (2003).
[2] K. Pachucki and J. Komasa, PRL 92, 213001 (2004).
[3] L.-B. Wang *et al.*, PRL 93, 142501 (2004).
[4] G. Ewald *et al.*, PRL 93, 113002 (2004).
[5] R. Sanchez *et al.*, PRL 96, 033002 (2006).

Towards coherent control of BEC and single Rydberg atoms on a superconducting atom-chip in a cryogenic environment

T. Nirrengarten[1], A. Qarry[1], C. Roux[1], A. Emmert[1], G. Nogues[1], M. Brune[1], J.M. Raimond[1] and S. Haroche[1,2]

[1] *Laboratoire Kastler-Brossel, École Normale Supérieure, Paris, France*
[2] *Collège de France, Paris, France*
E-mail:thomas.nirrengarten@ens.fr

The research of the Cavity Quantum Electrodynamics group in Laboratoire Kastler Brossel focuses on the manipulation of single quantum systems in a well controlled environment so that the coherent quantum interactions overwhelm the incoherent effects responsible for decoherence and decay. These systems allow for the study of the most fundamental aspects of quantum mechanics as well as the realisation of simple quantum gates.

In previous experiments our group was able to control the internal state of circular Rydberg atoms interacting one-by-one with a microwave field of one or a few photons stored in a superconducting cavity. These Rydberg atoms, highly excited atoms characterized by a high principal quantum number and maximal angular and magnetic quantum numbers, can be considered as excellent two-level systems (and potential qubits).

Our new experiment aims to trap such Rydberg atoms in a combination of static and oscillating electric fields using the high polarizability of these states. To do so, it is first necessary to trap the atoms and cool them down in their fundamental state. This must be done in a cryogenic environment (1-2K) so as to reduce thermal radiation, harmful to the stability of these Rydberg states. We plan to carry out a superconducting "atom-chip" experiment. Atom-chips have already been used successfully at room temperature to produce an atomic gas (generally condensed) at a distance varying from a few μm to a few 100 of μm of the surface of a microchip where the trapping currents flow. Our experiment will provide physical conditions that have never before been achieved in this kind of trap.

The use of superconducting currents will reduce to zero the thermal fluctuations of the currents in the chip, potentially increasing the lifetime of atoms in the trap. Furthermore it will be possible to shortcut the trapping wires, creating a superconducting loop. We will therefore cancel the technical noise due to the external power supplies. Finally we want to avoid the condensate fragmentation due to the fluctuations in the size of the wires (this creating local variations of the magnetic field) by manufacturing conductors with very sharp edges (in collaboration with the Quantronique group of D.Estève in CEA Saclay).

The experiment is still in progress but I will describe in my poster its main features as well as the first results encouraging for a further trapping of a BEC near the chip.

References

[1] P. Hyafil, J. Mozley, A. Perrin, J. Tailleur, G. Nogues, M. Brune, J.M. Raimond, S. Haroche, Phys. Rev. Lett. 93, 103001 (2004).
[2] J. Mozley, P. Hyafil, G. Nogues, M. Brune, J.M. Raimond, S. Haroche, Eur. Phys. J. D 35, 43-57 (2005)
[3] www.cqed.org

Cooling and trapping of Strontium Atoms

T. Chaneliere, D. Wilkowski and R. Kaiser

Institut non linéaire de Nice, UMR 6618 du CNRS, 1361 route de Lucioles, F-06560 Valbonne, France.
E-mail: david.wilkowski@inln.cnrs.fr

Initiated in the mid-seventies, laser cooling, trapping and manipulation of atoms rapidly became a very successful field of research, culminating twenty years later with the observation of Bose-Einstein condensation of alcaline atoms. The first reliable tests of the Doppler theory could only be performed at the end of the eighties. As it turned out, the measured temperatures in the experiments were *well below* the predicted Doppler values. This surprising results indicated that another much more efficient cooling mechanism was at work in the experiments. This mechanism, now known as Sisyphus cooling, was identified soon after. This cooling mechanism is now the basic ingredient for most experiments in the field and thus gave, for many years, the Doppler theory a more academic status. Recent laser technological advances however opened the way to cooling and trapping experiments with earth-alcaline and rare-earth atoms. As these atoms exhibit a zero spin groundstate, Sisyphus cooling is absent.

As a first stage, those atoms are cooled on the dipoled allowed transition connecting the $^1S_0$ ground-state to the $^1P_1$ state (for Sr, $\tau = 5ns$ or $\Gamma = 1/2\pi\tau = 32\,MHz$ with $\lambda = 461\,nm$). The semi-classical Doppler Theory predicts a temperature minimum of $T \propto \Gamma \approx 0.5\,mK$. However, in all experiments, measured temperatures are larger than the Doppler prediction ($T \approx 5mK$ for our Sr experiment). It turns out that Doppler cooling proves very sensitive to heating induced by transverse spatial intensity fluctuations. Taking into account these intensity fluctuations we have showed that theoretical predictions lead now to a perfect agreement with experimental data.

To strongly reduce the temperature, cooling can then be switched to the $^1S_0 \rightarrow ^3P_1$ intercombinaison line. For Strontium, the width of this $869\,nm$ spin forbidden transition is $\Gamma = 7.5\,kHz$ slightly higher than the frequency recoil shift ($\omega_r = 5\,kHz$). Here the semi-classical picture of Doppler cooling does not hold anymore. A full quantum treatment predicts a temperature close to the recoil limit as it was observed in different experiments. In parallel, the recoil frequency shift reduces multiple diffusion in the magneto-optical trap and as a consequence the space density increases. The measured temperature in the MOT are still not in complete agreement with the 1D cooling theory. Indeed the cooling dynamic is very sensible to the magnetic field and to the gravity. As a result, the laser detuning *sees* by atoms remain constant which surprisedly leads to a minimum temperature independent of the real laser detuning.

I will finish my presentation giving some perspectives of this experiment in the field of quantum transport in disordered or quasi-periodical potential.

Sub-Doppler Satellites of Dark-Line Atomic Resonance in the Case of Ordinary Vapour Cell and Extremely Thin Cell

Y. Pashayan-Leroy[1,2], D. Sarkisyan[1], A. Sargsyan[1], C. Leroy[2] and A. Akulshin[3]

[1]*Institute for Physical Research, NAS of Armenia, Ashtarak-2, 378410, Armenia*
[2]*Laboratoire de Physique de l'Université de Bourgogne, CNRS-UMR 5027, Dijon, France*
[3]*Swinburne University of Technology, PO Box 218, Hawthorn VIC 3122, Australia*
E-mail: david@ipr.sci.am

Electromagnetically Induced Transparency (EIT) attracts much attention because of its significance for various applications in metrology, magnetometry and fundamental investigations. However, as a rule, only the narrow spectral region where the EIT resonance is formed is being studied extensively, while the peculiarities of the behaviour of sub-Doppler satellites in the frequency region outside the EIT have not been explored in great depth [1]. Here we present peculiarities of sub-Doppler satellites which are observed in the spectrum of alkali metals in the presence of two lasers, and which accompany the ultra-narrow EIT resonance. We use cells of ordinary length (1 - 50 mm) containing Rb vapor and an extremely thin cell (ETC) filled with pure Rb and with smoothly varying longitudinal thickness L of the atomic vapor layer, in the range $\sim$ 780 - 1600 nm so that L is comparable with λ, where λ is the laser wavelength resonant with D_2 line (780 nm) [2]. Two laser diodes have been used in the geometry for studing the EIT effect. The coupling laser (ω_c) is tuned close to the ^{85}Rb, $5S_{1/2}(F_g{=}3){\rightarrow}5P_{3/2}$ (F_e=2,3) transition, while the probe laser (ω_p) is linearly scanned across the excited states of F_g=2 $\rightarrow$ F_e=1,2,3. For the ordinary cell it is revealed that in the case of exact collinear propagation of the two laser beams the absorption spectrum of the probe laser contains seven velocity selective optical pumping (VSOP) peaks-satellites of increased absorption (including the peak where the Λ system is realized and the EIT effect occurs), while theoretically only five satellites are expected. The two additional VSOP peaks-satellites of increased absorption in some cases could be the dominant ones (by amplitude) in the spectrum. Under the well-defined geometry of the interaction the number of VSOP peaks is reduced to five[1]. The physical origin of the phenomenon will be presented. The frequency separations observed experimentally between the satellites agree with calculations. In the case of ETC the number of VSOP peaks, which are centered on the hyperfine transitions, is reduced to three (including the peak where the Λ system is realized and the EIT effect occurs [3]). The explanation is that the contribution of atoms with slow normal velocity is enhanced due to their longer interaction time with the laser field. Thus, atoms flying nearly parallel to the windows yield a stronger contribution to the VSOP satellite peaks. The VSOP peaks have Lorentzian profile and the linewidth is $\sim$ 30 MHz (depending on the coupling and probe laser intensities). The minimal linewidth of the VSOP peaks is achieved under normal incidence of the laser beams, while for the case when the ETC is tilted there is a strong spectral broadening. A theoretical model describing the VSOP peaks-satellites in ETC has been developed, and the comparison with the experiment will be presented.

The authors D.S. and A.S. thank ANSEF (Grant 05-PS-opt-0813-233) and SCOPES (Grant IB7320-110684/1).

References

[1] A. Sargsyan, D. Sarkisyan, D. Staedter, A. Akulshin, Optics and Spectroscopy, in press.
[2] D. Sarkisyan , D. Bloch, A. Papoyan, M. Ducloy, Optics Commun. 200, 201 (2001).
[3] A. Sargsyan, D. Sarkisyan, A. Papoyan, Phys. Rev. A 73, 033803 (2006).

Precise line intensity and line shape measurements using single-mode frequency-stabilized cavity ring-down spectroscopy

J. T. Hodges[1], D. Lisak[1,2]

[1]*Process Measurements Division, National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, Maryland 20899, USA*
[2]*Instytut Fizyki, Uniwersytet Mikołaja Kopernika, ul. Grudziadzka 5/7, 87-100 Toruń, Poland*
E-mail: dlisak@nist.gov

We applied the cavity ring-down spectroscopy technique for precise line intensity and line shape measurements. Our spectrometer incorporates a frequency-stabilized and tunable comb of resonant frequencies and a continuous-wave external cavity diode probe laser. Detailed descriptions of the spectrometer can be found in refs [1,2]. Using an iodine-stabilized He-Ne laser as a frequency reference we achieved a spectral resolution of 50 kHz.

Rovibrational spectra of the $2\nu_1 + \nu_3$ vibrational band of water vapor were measured with a signal-to-noise ratio of about 1000:1. Detailed investigation of line shape effects [3] and precise control of water concentration in the samples, based on NIST primary humidity standards allowed us to determine line intensities with relative uncertainties of less than 0.5%. This precision is necessary for application to the newest instruments for atmosphere monitoring [4]. Accurate knowledge of line intensities and line shapes is also important in spectroscopic temperature measurements [5] as well as investigation of such a fundamental problems like dependence of line intensity on perturbing gas pressure.

Experimental values of line intensities and the pressure broadening coefficients in nitrogen and in air were compared to values available in HITRAN [6] database.

References

[1] J. T. Hodges, H. P. Layer, W. W. Miller, and G. E. Scace, Rev. Sci. Instrum. **75**, 849 (2004).
[2] J. T. Hodges and R. Ciuryło, Rev. Sci. Instrum. **76**, 023112 (2005).
[3] D. Lisak, J. T. Hodges, R. Ciuryło, Phys. Rev. A **73**, 012507 (2006).
[4] C. E. Miller, L. R. Brown, R. A. Toth, D. C. Benner, and V. M. Devi, C. R. Phys. **6**, 876 (2005).
[5] R. Wehr, E. McKernan, A. Vitcu, R. Ciuryło, and J. R. Drummond, Appl. Opt. **42**, 6595 (2003).
[6] L. S. Rothman *et al.*, J. Quant. Spectrosc. Radiat. Transf. **96**, 139 (2004).

Coherent effects in mismatched V-type rubidium system

S. Vdovic, T. Ban, D. Aumiler and G. Pichler

Institute of Physics, Zagreb, Croatia
E-mail: silvije@ifs.hr

Mismatched V-type systems with coupling field frequency lower than the probe field frequency are ideal candidates for the high-frequency inversionless laser systems [1]. On that account, the study of electromagnetically induced transparency (EIT) in such systems represents the first step in the realization of a high-frequency inversionless lasers [2, 3]. EIT creates the reduction in absorption upon which the LWI is based. Additionally, the V-type configuration provide potentially the best level of transparency in a Doppler-broadened systems, particularly for the cases in which the probe frequency is far in excess of the coupling field frequency [4, 5].

Induced transparency on a blue 420 nm probe light in a Doppler broadened mismatched V-type system using a low power near infrared (780 nm) coupling laser was experimentally observed. Theoretical modeling was carried out utilizing standard density matrix analysis of three-level V scheme with appropriate modifications to take into account the hyperfine splittings of the 5 $^2S_{1/2}$ ground and 5 $^2P_{3/2}$, 6 $^2P_{3/2}$ excited states. Calculated probe absorption line profiles reproduce with great accuracy measured absorption profiles.

Measured transparency on the ^{85}Rb F_g=2 F_e=1,2,3 transitions shows 67% reduction of absorption in the peak of the Doppler broadened line profile. The dependence of the induced EIT window in the ^{85}Rb F_g=2 F_e=1,2,3 absorption line profile on 5 $^2P_{3/2} \rightarrow 6^2P_{3/2}$ unlinked states coherence was analyzed theoretically. In this way it was possible to separate two main mechanisms responsible for the reduction of the absorption in the V-type system: electromagnetically induced transparency and coupling field saturation. We conclude that the observed transparency is predominantly resulting from the coupling field saturation mechanism. There is about 8% of the cancellation of absorption via quantum interference due to coherently prepared rubidium atoms.

References

[1] J.R. Boon, E. Zekou, D. McGloin and M.H. Dunn, Phys. Rev. A 59, 4675 (1999).
[2] O. Kocharovskaya, Phys. Rep. 219, 175 (1992).
[3] W.E. van der Veer, R.J.J. van Diest, A. Doenszelmann and H.B. van Linden van der Heuvell, Phys. Rev. Lett. 70, 3243 (1993).
[4] M.D. Lukin, Rev. Mod. Phys. 75, 457 (2003).
[5] D.J. Fulton, S. Shepherd, R.R. Moseley, B.D. Sinclair and M.H. Dunn, Phys. Rev. A 52, 2302 (1995).

Comparison of sub-Doppler DAVLL and SA laser frequency stabilization schemes

E. Breschi[1], R. Giannini[2], C. Affolderbach[1] , G. Mileti[1], G. Bison [3], A. Weis[3]

[1] *Observatoire Cantonal de Neuchâtel,*
[2]*Institute of microtechnology University of Neuchâtel,*
[3]*FRAP, University of Fribourg, Switzerland*
E-mail: evelina.breschi@ne.ch

Frequency stabilized laser sources are commonly used in atomic physics experiments, such as laser cooling and trapping, and are essential in many applications, such as atomic clocks, magnetometers and interferometers. Active frequency stabilization methods have in common that they require a dispersive signal with a zero-crossing at the locking-point.
Here we present a comparison between two spectroscopic schemes for laser stabilization to the ^{87}Rb D_1 line. The first scheme is based on non-linear (saturated absorption) spectroscopy in thermal vapor cell [1]. The second one, referred to as Dichroic-Atomic-Vapor-Laser-Locking technique (DAVLL) [2, 3], employs a longitudinal magnetic field to split the Zeeman components of an absorption signal. Practically, in the DAVLL setup, the error signal is generated from the difference in the absorption rates of the two circularly polarized (σ^+ and σ^-) light components. One advantage of the DAVLL technique is that no additional laser modulation is needed to obtain the dispersive error signal, which simplifies the electronical components of the setup. As compared to SA, Doppler broadened DAVLL method provides a larger signal and a larger locking range around the atomic transition. SA and DAVLL methods may also be combined [4, 5], resulting a sub-Doppler DAVLL.
The aim of this work is to evaluate the potential and the applicability fields of DAVLL for laser stabilization with respect to the commonly used SA technique. For a systematic comparison of the two schemes, we have performed heterodyne frequency stability measurements of two independently stabilized diode lasers. For the analysis of the stability we distinguish two regimes: the short and the long term time scales.
For the short-term time scales (up to about 100 seconds) the frequency stability is essentially limited by the signal-to-noise ratio. The measured Allan deviation is about $2 \cdot 10^{-12}\ \tau^{-\frac{1}{2}}$ and $3 \cdot 10^{-11}\ \tau^{-\frac{1}{2}}$ for SA and sub-Doppler DAVLL, respectively, for the $F_g = 2 \rightarrow F_e = 2$ transition.
For the long-term time scales (up to about 10^4 seconds) the frequency drifts are related to the sensitivity on the experimental and environmental parameters. The DAVLL setup is less sensitive to the external magnetic field fluctuation with respect to the SA one. Moreover, the absence of the FM modulation eliminates an important source of drift due to the electronics control. The relevant studied parameters are the optical power and the cell temperature. These two parameters don't only influence the amplitude of the signal but also shift the stabilized laser frequency.
In this communication, we will present latest results comparing SA and sub-Doppler DAVLL for short-term and long-term timescales.

References

[1] K. Razdan, D. A. Van Baak, Am. J. Phys., 832 1999.
[2] K. L. Corwin, Z. T. Lu, C. F. Hand, R. J. Epstein, C. E. Wieman, App. Opt. 37, 3295 1998.
[3] V. V. Yashchuk, D. Budker, J. R. Davis, Rev. Scient. Instrum. 71, 341 2000.
[4] T. Petelski, M. Fattori, G. Lamporesi, J. Stuhler, G. M. Tino, Eur. Phys. J. D 22, 279 2003
[5] G. Wasik, W. Gawlik, J. Zachorowski, W. Zawadzki, Appl. Phys. B 75, 613 2002

Considerations towards the possibility of estimation of the coherence relaxation lifetime of the neon $2p^53s$ ($^3P_2$)metastable from the magneto-galvanic resonances

L. Petrov[1], D. Slavov[1], V. Arsov[1], A. Gorbenko[3], V. Steflekova[2], V. Polischuk[3], D. Zhechev[2], G. Todorov[1]

[1]*Institute of Electronics, BAS boul. Tzarigradsko Shosse 72, 1784 Sofia, Bulgaria*
[2]*Institute of Solid State Physics – BAS, 72 Tzarigradsko Chaussee 1784 Sofia, Bulgaria*
[3] *SRI of Physics University of St Petrburg, 198903,Ulyanovskaya 1, St. Peterburg, Russia*
E-mail:lyubomir.p.petrov@gmail.com

In several works it has been shown, that the application of a weak magnetic field on a neon glow discharge leads to a resonant change of the plasma conductivity [1-4].This effect has been called a magneto-galvanic (MG) effect. As indicated by recent studies, its origin can be attributed with a sufficient degree of certainty to the destruction of the $1s_5$ ($2p^53s\ ^3P_2$) self-alignment [5-6]. In order to clarify the origin of the MG resonances we have carried out new experiments in both positive column- and hollow cathode discharges. We have studied the influence of a laser radiation, resonant with the transitions $1s_5$-$2p^53s$, on the MG signals. We have shown, that in both discharges the laser radiation considerably influences the amplitude and the shape of the MG response and in certain cases, depending on the polarization and the power of the laser, that signal might be completely cancelled.

In addition we have studied the magneto-optical (MO) resonances in Faraday and Voigt geometries in a positive column [7-8]. We have carried comparative studies of the MG and MO rezonance widts in dependence on the buffer gas pressure and the discharge current. The influence of the destruction of the self-alignment on the MO signal in those discharges has been discussed. The possible formation mechanisms of the neon $1s_5$ coherence have been shortly examined.

Based on the experimental results, obtained in an improved automated acquisition and data processing system, we discuss the possibility of using the galvanic resonances for estimation of the relaxation constants of the neon $1s_5$ state. The obtained results are compared with those in the literature.

VS, DZ and GT thank the NCSR (grant F-1210/02) for the financial support

References

[1] D. Zhechev, N. Lukomskij, V.Polischuk, M. P. Chaika, Opt. Spektr. 1990, v.69, p..474-475 (in Russian)
[2] N. Lukomskij, V.Polischuk, M. P. Chaika, Opt. Spektr, 1996, v.81, N3, p.369-371 (in Rus.)
[3] M. P. Chaika Opt. Spektr.1995, v78, N1, p.14-19 (in Russian)
[4] G.T.Todorov, P.R. Karavasilev, D.Z. Zhechev Physica Scripta, 1998, vol.57, p.634 – 636.
[5] V.Polischuk, M. P. Chaika, G. Todorov. Opt. Spektr. 2002, v.93, N4 p.533-536 (in Rus.)
[6] D Slavov, L Petrov, VArsov, V Polischuk, N Mihailov and G Todorov online http://dx.doi.org/10.1002/ppap.200500077.
[7] N. Lukomskij., V.Polischuk., M. P. Chaika. Opt. Spektr.1991, v.71, N1, p. 46 -52 (in Rus.)
[8] G. Radionov, E. Saprikin. Autometry , 1985,N6., p. 95-98. (in Russian)

Influence of electromagnetic field on the CPT resonance obtained on two-level degenerated system

E. Alipieva, S. Gateva, and E. Taskova.

[1] *Institute of Electronics, Bulg.Acad.Sc., 72 Tzarigradsko Chaussee, 1784 Sofia, Bulgaria*
E-mail:alipieva@ie.bas.bg

Coherent population trapping (CPT) is an interference effect arising in a three-level atomic system after interaction with two coherent fields which connect the ground levels with a common upper level [1]. In Hanle -configuration the CPT resonance is due to the interference between the Zeeman sublevels of the atoms investigated. The resonance is detected by sweeping magnetic field $\mathbf{B}_0$ around its zero value. The signal is very sensitive to stray magnetic field which moves the energy position of these levels, disturbing in this way the CPT resonance. The influence of dc magnetic field on this resonance was investigated in our previous work [2]. In this work we study the influence of an a.c. magnetic field on the CPT resonance. Our investigations are restricted on the simplest case,named also parametric resonance, when a.c. MF is collinear to the sweeping magnetic field. Recently ,the interest to this resonance is increased since the integration of the modulation and coherent spectroscopy enlarge the application area of the investigations [3].
The parametric resonance was investigated on the D1 ^{87}Rb line (J=2→ J=1 transition) in an uncoated cell. The linearly polarized laser beam trough its σ + and σ- components connects all sublevels of the transition investigated into 3 Λ-systems, creating cpt resonance when the level is degenerated-at zero magnetic field . The ac electromagnetic field (EMF) applied collinearly to the $\mathbf{B}_0$ modulates the frequency difference between the Zeeman sublevels . The Larmor frequency becomes : $\omega = \omega_0 + \omega_1 cos\Omega$t, where Ω is the EMF frequency. Using the matrix density formalism the scattered light intensity is calculated to be proportional to [3]:
$I \sim$CRe$\{e^{2i\psi}\left(\sum_{k=-\infty}^{\infty} B_k e^{ik\Omega t}\right)$
where B_k are Fourier coefficients and ψ is the angle between the laser light polarization vector and direction of observation.The intensity of the scattered from the atoms light is modulated and shows resonance increasing when EMF frequency is multiple to the Zeeman sub-levels difference. The CPT signals were investigated at steady-state case (k=0) and first harmonic frequency (k=1) using linearly polarized and circular polarized excitation. The dependencies on the modulation frequency and amplitude are investigated. The possible application in spectroscopy and EMF measuring are discussed.

References

[1] E. Arimondo, Prog. Opt. XXXV, 257 (1996).
[2] E. B. Alexandrov, M. Auzinsh, D. Budker, D. F. Kimball, S. M. Rochester, and V. V. Yashchuk, Dynamic effects in nonlinear magneto-optics of atoms and molecules; JOSA B 22(1), 7-20 (2005);
[3] Alipieva E., Gateva S., Taskova E., "Potential of the single-frequency resonances for magnetic field measurement", IEEE Trans. Instrum. Meas., 54 (2), pp. 738-741 (2005).
[4]E.Alexandrov,O.Konstantinov, V.Perel, V.Khodovoy, JETP,45, 503-510,1963

Photoemission and photofragmentation of amino acids

O. Plekan[1,2], R. Richter[2], M. Coreno[3,4], V. Feyer[3], M. de Simone[4] and K.C. Prince[2,4]

[1]*Institute of Electron Physics, National Academy of Sciences of Ukraine, Universitetska str. 21, Uzhgorod, Ukraine*
[2]*Sincrotrone Trieste, in Area Science Park - Basovizza, I-34012 Trieste, Italy*
[3]*CNR-IMIP, Montelibretti (Rome), I-00016 Italy*
[4]*CNR Lab. Naz. TASC INFM, in Area Science Park - Basovizza, I-34012 Trieste, Italy*
E-mail:kudelich@rambler.ru, oksana.kudelich@elettra.trieste.it

The physics and chemistry of biological molecules is fundamental for many fields: not only for understanding their behaviour in biological systems, but in biotechnological applications, such as sensors, and in astrochemistry and astrobiology. In order to understand the origin of life in the universe it is necessary to understand the chemistry of these simple molecules in environments subject to ionising radiation.
Theoretical methods are now very advanced and it is possible to calculate the properties of increasingly complex systems, and predict their chemical and physical behaviour. Calculations of molecular properties are typically compared with experimental spectroscopic data to check their validity, and a frequent starting point is the free molecule. For this reason the gas phase photoelectron spectra of bio molecules are of current interest.
The outer and inner valence photoemission spectra of the amino acids glycine, proline and methionine have been measured at the Gas Phase Photoemission Beamline, Elettra, Trieste at 40 and 95 eV photon energies. They are compared to existing data where available and found to be in good agreement. Previous spectra with He I radiation show only the outer orbitals, and here we present new data on the inner valence structure. The valence spectrum shows clear effects which are assigned to the existence of two conformers of proline.
The photofragmentation ion spectra of the same compounds were measured at 5 photon energies with noble gas (He, Ne, Ar, Kr and Xe) resonance radiation close to threshold. As expected, lower photon energies led to "softer" ionisation and reduced fragmentation. However for proline the dominant mass is still $C_4H_8N^+$ at lowest energy, corresponding to loss of a CHO_2 neutral fragment. Similarly for glycine, fragmentation is reduced at lower energy, but the dominant fragment is CH_4N^+ again indicating a loss of a CHO_2 neutral fragment. The binding energies derived from the photoemission spectra indicate which molecular orbitals are ionised by the noble gas resonance radiation, and this in turn has been correlated with the fragmentation patterns. The fragmentation patterns of proline and glycine show similarities because the outer orbitals are similar, with oxygen and nitrogen lone pair character. Methionine behaves very differently because the outer orbital has sulphur lone pair character. Ionization of a sulphur lone pair orbital causes much less molecular fragmentation, while ionization of the nitrogen (HOMO) or oxygen lone pair (second HOMO) leads to scission of the αC (carboxylic) to neighbouring βC bond.

Compact vertically mounted laser stabilisation cavity for hydrogen precision spectroscopy experiment

J. Alnis, A. Matveev, N. Kolachevsky and T.W. Hänsch

Max-Planck-Institute of Quantum Optics, 85748 Garching, Germany
E-mail: Janis.Alnis@mpq.mpg.de

At the vertical-midplane mounted Fabry-Perot cavities can have 40 dB smaller cavity length changes due to vertical vibrations of the supporting structures, allowing to get sub-hertz laser line widths without complex cavity suspension in springs [1]. We have assembled such cavity for the portable hydrogen laser system [2] and compare the performance using optical beat note measurements with the dye-laser system used routinely in the hydrogen 1S-2S precision measurements [3].

The 7 cm long vertical cavity spacer and mirrors are made of Ultra-Low-Expansion glass (ULE). We measure the finesse of 400000 at 972 nm by optical ring-down method. Recording of the cavity resonance peak drift as a function of temperature allows to estimate that ULE sample has thermal expansion coefficient zero-point at +7 degrees Centigrade which is lower then the optimal temperature (that would be above the room temperature). This puts stringent requirement on temperature stabilisation. We use two layers of temperature stabilisation. The inside vacuum chamber is controlled to 1 mK by integrating regulator with a 5 hour time-constant. Each wall of the outside enclosure is controlled separately by 6 fast ON/OFF temperature controllers. The vacuum chamber is made of aluminium with surface treated for UHV compatibility with a strong sodium base and nitric acid. All seals are made with indium. With a 3 l/s ion getter pump the pressure inside is 1 x 10^{-8} mbar.

The vertical cavity and the necessary optics are assembled on a 40x40 cm vibration isolation platform. That is a significant size and weight reduction comparing to 1x2 m platform for the cavity used with dye laser. In order to characterise the diode laser stabilised on a vertically mounted cavity we observe the optical beatnote of a frequency doubled diode laser system with the dye laser system. The beatnote width is less than 20 Hz at 486 nm. Each subsequent frequency doubling reduces the power ratio in the narrow carrier to sidebands (noise) by 4-th power. Starting with 99.5 percent in carrier at 972 nm one ends up with 50 percent of usable power in carrier at the 121 nm two-photon transition. This should be enough for excitation of 1S-2S transition in hydrogen atoms as already demonstrated with the diode laser system in [2].

References

[1] M. Notcutt, L.-S. Ma, J. Ye, and J.L. Hall, Opt. Lett. 30 1815 (2004)
[2] N. Kolachevsky, J. Alnis, S. Bergesson, and T. W. Hänsch, accepted at Phys. Rev. A. Preprint at arXiv.org/Physics/0511162.
[3] M. Fischer, N. Kolachevsky, M. Zimmermann, R. Holzwarth, Th. Udem, T.W. Hänsch, M. Abgrall, J. Grnert, I. Maksimovic, S. Bize, H. Marion, F. Pereira Dos Santos, P. Lemonde, G. Santarelli, P. Laurent, A. Clairon, and C. Salomon, M. Haas, U. D. Jentschura, and C. H. Keitel, Phys. Rev. Lett. 92, 230802 (2004)

Enhanced non-linear Faraday effect in bright coherent states

Z. D. Grujić, M. M. Mijailović, A. J. Krmpot, B. M. Panić, D. V. Pantelić and B. M. Jelenković

Institute of Physics, 11080 Belgrade, Serbia and Montenegro
E-mail:gruja@phy.bg.ac.yu

The non-linear Faraday effect as a Hanle effect of laser light induced birefringence was studied for both bright and dark states in ^{85}Rb. A bright Zeeman coherence leads in a Hanle measurements of laser absorption to an absorption peak, in contrast to a dark resonance which brigs transmission peak. The bright Zeeman superposition was obtained through the closed F_g=3 → F_e=4 transition, in Rb cell at room temperature. The rotation of the plane of polarization of the laser light propagating through a vapor in a longitudinal magnetic field was measured using balanced polarimeter. We have simultaneously detected orthogonally polarized components of the transmitted light from the two channels of the polarization beam splitter, placed behind the cell and rotated by 45 ^{0} with respect to initial polarization [1]. Difference of two signals is proportional to a polarization rotation angle.
There are much less data on polarization rotation for bright than for dark states. Recently much higher Kerr nonlinearity for bright than for a dark state in Rb was found [2]. Large index of refraction corresponds to a large rotation of polarization. In this work we indeed found large polarization rotation angle for the bright state, in excess of several hundred mRad. Maximum of the rotation angle occurs at external magnetic fields between a few μT to a few hundred μT when laser intensity varies between 0.5 and 50 mW/cm^2. The effect of an atom transit time through the laser beam on a ground state coherence decay was demonstrated through polarization rotation slope for B=0 with laser beam waist varying between 1 and 10 mm.
For comparison, similar measurements of polarization rotation were done with the laser locked to the dark state, i.e., F_g=2 → F_e=3 transition. Significantly less rotation and lower rotation rate were obtained than for the bright state. Moreover, the dark state has opposite dependence of rotation on laser intensity than bright state. This results are different from results in a coated cell which show much smaller rotation angle for the bright state [3].

References

[1] A. B. Matsko, I. Novikova, M. S. Zubairy and G. R. Welch, Phys. Rev. A **67**, 043805 (2005).
[2] A. M. Akulshin, A. I. Sidorov, R. J. McLean and P. Hannaford, J. Opt. B: Quant. Semiclass. Opt. **6**, 491 (2004).
[3] D. Budker, D.J. Orlando, and V. Yashchuk, Am. J. Phys. **67**, 591 (1999).

Electromagnetically induced absorption and transparency in Hanle configuration: the case of closed atomic transition

M. M. Mijailović, Z. D. Grujić, A. J. Krmpot, B. M. Panić, D. Arsenović, D. V. Pantelić and B. M. Jelenković

Institute of Physics, 11080 Belgrade, Serbia and Montenegro
E-mail:lekic@phy.bg.ac.yu

We studied experimentally and theoretically propagation of coherent light, resonant with the closed transition in the atomic ^{85}Rb vapor by investigating Hanle effects of electromagnetically induced absorption (EIA). Experimentally we measured transmission of the laser locked at F_g=3 - F_e=4 transition as magnetic field varies between ± 500 mG. Absorption of light in the cell was calculated after using density matrix approach and exact solution of the optical Bloch equations for the atomic system that involves 16 magnetic sublevels of the ground F_g=3 state and of the excited F_e=4 state coupled by linearly polarized laser field in a external variable magnetic field.
Experimental and theoretical results for the EIA width and amplitude agree for experimental laser intensities below 1.5 mW/cm^2, i.e., theoretical Rabi frequencies below $1/2\Gamma$, where Γ is the radiative decay of the excited state. The absorption peak was observed in the experiment even for laser intensity above 100 mW/cm^2, although this and previous calculations [1] predict that at these intensities EIA will disappear and even turn into a transmission peak. This discrepancy occurs because the theory didn't take into account strong increase of amplitude of forward scattering, obtained by measuring transmission of the light polarized perpendicularly to initial polarization. For measuring forward scattering we place polarization beam splitter behind the Rb cell. The forward scattering as a function of an external magnetic field is an absorption peak at all laser intensities.
We made thorough investigation of behavior of the EIA as we varied intensity, beam diameter and elipticity of the input laser light. The laser beam waist affects the measured width of the EIA through the finite interrogation time of an atom by the light, i.e., through different decay rate of the Zeeman coherencies. EIA width varies between 140 mG to 200 mG (35 and 50 kHz, respectively) when laser diameter varies between 15 and 2 mm. Corresponding relaxation decay rates γ_r/Γ are between 0.0003 and 0.01 and also show, in the calculations, similar effects on the width if the EIA. Characteristic of the transmission of the laser light locked to a bright transition is a small change of ellipticity and strong polarization rotation. We have found small effect of a small ellipticity of the input light (compared to linearly polarized input light) on the Hanle EIA shape.

References

[1] F. Renzoni, C. Zimmermann, P. Verkerk, and E. Arimondo, J. Opt. B: Quantum Semiclass. Opt. **3**, S7 (2001).

Resonances in electron and atom scattering by molecules

S.Pozdneev

P.N.Lebedev Physical Institute, Department Quantum Radiophysics,
Laboratory of Photochemical Processes, Leninskiy pr.53, 117924 Moscow, Russia
E-mail: pozdneev@sci.lebedev.ru

The main features of resonance scattering of electrons from molecules are described and resonances are determined on the basis of the theory of collisions in a two-body system [1], as well as resonances emerging as a result of collisions in a few-body system [2,3]. Regularities in the emergence of such resonances and their characteristics are analyzed.
The results of calculations of these resonant processes occurring during collisions of electrons with diatomic molecules, made on the basis of the quantum theory of scattering in a few-body system, are presented. The results of calculation of the cross sections of resonant processes of electron collisions with molecules [4] are compared with the available experimental data and with the results of calculations based on other approximations.
Results of the calculations of the phase shifts, cross sections and Efimov states [2] scattering atom with diatomic molecules based on the three body approximation also are present [4].
A mechanism of appearance and disappearance of the Efimov states of the electron molecular collisions in three-body approximation is present when the force of interaction is changed. It is shown that these states arise from virtual levels which are in turn formed from quasiresonances settled on the real axis. The resonances including virtual levels are calculated by the method based on the solution of the boundary value problem at complex energies based on the Faddeev differential equations [3]. All calculations are performing with the well known potential [1,2,4] in which a strong repulsive component at short distances between atoms is approximated by a hard core. Geometric structure and number of the Efimov states are describe according recent investigation [5]. A special attention is devoted to the substantiation of the method used for calculations resonances and to the investigation of its applicability range.

The calculations of the scattering and bound states of electron molecular were performed on the basis of the most advanced few-body calculation techniques both in boundary condition model (BCM) [2-4] approximation and without BCM approximation.

References

[1] G.J.Schultz, Rev.Mod.Phys., 45,423, (1973); D.A.Micha, Adv.Chem.Phys., 30, 7, (1975).
[2] V.Efimov, Nucl.Phys., A362, 45,(1981); A378, 581, (1982); Phys.Rev., C47, 1876, (1993).
[3]L.D. Faddeev, S.P Merkuriev, Quantum scattering theory for several particles systems, Kluwer, London, (1993).
[4] S.A.Pozdneev, Application of quantum theory of scattiring to the calculations of different processes in nuclear, atomic and molecular physics, Moscow, Janus-K, (2001); J.Russian Laser Research, 22, 175, (2001); JETP, 99,915, (2004).
[5] E.Braaten, H.W.Hammer, M.Kusonoki, Phys.Rev., 67A, 022505, (2003)

Collisions helium atoms with helium molecules

S.Pozdneev

P.N.Lebedev Physical Institute, Department Quantum Radiophysics,
Laboratory of Photochemical Processes, Leninskiy pr.53, 117924 Moscow, Russia
E-mail: pozdneev@sci.lebedev.ru

Results of the calculations of the phase shifts, cross sections and Efimov states [1] scattering atom with diatomic molecules based on the three body approximation are present [2-3]. A mechanism of appearance and disappearance of the Efimov states of the helium trimer $^4He_3$ in three-body approximation is present when the force of interatomic interaction is changed. It is shown that these states arise from virtual levels which are in turn formed from quasiresonances settled on the real axis. The resonances including virtual levels are calculated by the method based on the solution of the boundary value problem at complex energies based on the Faddeev differential equations [4] . All calculations are performing with the well known interatomic potential [2,3] in which a strong repulsive component at short distances between helium atoms is approximated by a hard core. Geometric structure and number of the helium trimer states are describe according recent investigation [5]. A special attention is devoted to the substantiation of the method used for calculations resonances and to the investigation of its applicability range.

The calculations of the scattering and bound states of He_3 were performed on the basis of the most advanced few-body calculation techniques both in boundary condition model (BCM) [2-4] approximation and without BCM approximation. In all considered pair wise potential support only two bound states approximately, but the properties of these states are very different:

- the ground states is strongly bound, whereas the binding energy of the excited state is comparable with binding energy of dimer;

- the sizes of these two states also very different. The characteristic size of the ground state estimated by $< r >$ or $< r^2 >^{1/2}$ is approximately 10 times less than the size of dimer molecule, but the size of the excited state has the same order magnitude of the dimer's one.

References

[1] V.Efimov, Nucl.Phys., A362, 45,(1981); A378, 581, (1982); Phys.Rev., C47, 1876, (1993);
[2] A.K. Motovilov, E.A.Kalganova S.A.Sofianos, J.Phys.B: At.Mol.Phys., v.31, 1279; (1998); J.Chem.Phys., 275, 168, (1997); Phys.Rev., A56, N 3, R1686, (1997). V.Rudnev, S.Yakovlev Chem.Phys.Lett., 22, 97, (2000).
[3] S.A.Pozdneev, Application of quantum theory of scattiring to the calculations of different processes in nuclear, atomic and molecular physics, Moscow, Janus-K, (2001); J.Russian Laser Research, 22, 175, (2001); JETP, 99,915, (2004).
[4]L.D. Faddeev, S.P Merkuriev, Quantum scattering theory for several particles systems, Kluwer, London, (1993).
[5] E.Braaten, H.W.Hammer, M.Kusonoki, Phys.Rev., 67A, 022505, (2003)

Doppler-free absorption spectroscopy of CO_2 at 4.3 micron by means of a continuous-wave quantum cascade laser

A. Castrillo, E. De Tommasi, G. Casa, and L. Gianfrani

Dipartimento di Scienze Ambientali, Seconda Università di Napoli,
Via Vivaldi, 43 I-81100 Caserta, Italy
E-mail: Antonio.Castrillo@na.infn.it

More than ten years ago, the development of a new kind of semiconductor laser in the mid-infrared region, known as quantum cascade laser (QCL) [1], opened new interesting perspectives for basic research in molecular physics, as well as for applications to other scientific domains [2], mainly because all simple molecules exhibit strong fundamental vibrational bands in that spectral window. Nowadays, the QCLs' potential is increasing more and more with the significant advances of the QCLs' fabrication technology, which has allowed to lower the emission wavelength below the limit of 5 μm [3] and bring the operation temperature as close as to room temperature [4], still preserving the continuous wave operation. A further frontier of QCLs is given by the operation in the terahertz frequency range [5].

The present work deals with high resolution molecular spectroscopy by means of a new, continuous wave, liquid-nitrogen cooled, distributed feedback QCL at a wavelength of 4.3 μm, expressly built for us by the company Alpes Lasers. In particular, we report on Lamb-dip spectroscopy for carbon dioxide by means of a free-running QCL. Combining the simple pump-probe scheme with wavelength modulation spectroscopic technique (WMS), we observed the sub-Doppler profile of CO_2 lines belonging to the $\nu_2{}^1+\nu_3-\nu_2{}^1$ hot band. A number of laboratory tests were performed in different experimental conditions in order to quantify the different contributions to the width of the sub-Doppler lines. For this purpose, the WMS spectra were carefully analysed by means of a fitting procedure that was based on the Fourier expansion of a Lorentzian profile, also taking into account residual amplitude modulation effects.

The possible application to frequency metrology is discussed. In particular, we present an experimental approach to measure the absolute frequency of the investigated CO_2 lines, based on frequency conversion of the mid-infrared radiation by means of sum-frequency generation in a periodically-poled lithium niobate crystal [6] and on the use of a near-infrared optical frequency comb generator [7].

References

[1] J. Faist, F. Capasso, D.L. Sivco, C. Sirtori, A.L. Hutchinson, A.Y. Cho, Science 264, 553 (1994).
[2] L. Menzel, A.A. Kosterev, F.K. Tittel, C. Gmachl, F. Capasso, D.L. Sivco, J.N. Baillargeon, A.L. Hutchinson, A.Y. Cho, W. Urban, Appl. Phys. B 72, 859 (2001).
[3] Q. Yang, C. Manz, W. Bronner, K. Khler, J. Wagner, Appl. Phys. Lett. 88, 1127 (2006).
[4] M. Beck, D. Hofstetter, T. Aellen, J. Faist, U. Oesterle, M. Ilegems, E. Gini, H. Melchior, Nature 295, 301 (2002).
[5] M. Rochat, L. Ajili, H. Willenberg, J. Faist, H. Beere, G. Davis, E. Linfield, D. Ritchie, Appl. Phys. Lett. 81, 1381 (2002).
[6] G. Temporão, S. Tanzilli, H. Zbinden, N. Gisin, T. Aellen, M. Giovannini, J. Faist, Optics Letters 31, 1094 (2006).
[7] D.J. Jones, S.A. Diddams, J.K. Ranka, A. Stentz, R.S. Windeler, J.L. Hall, S.T. Cundiff, Science 288, 635 (2000).

Electromagnetically Induced Transparency Resonances in Potassium

G. Alzetta [1], S. Cartaleva [2], S. Gozzini [1], T. Karaulanov [2], A. Lucchesini [1], C. Marinelli [3] and L. Moi[3]

[1] *IPCF-CNR, Area della Ricerca, via Moruzzi 1, 56124 Pisa,Italy*
[2] *Institute of Electronics, BAS, boul. Tzarigradsko shosse 72, 1784 Sofia, Bulgaria*
[3] *INFM UdR Department of Physics, University of Siena, Via Roma 56, 53100 Siena, Italy*
E-mail: dilas@ie.bas.bg

Different approaches have been utilized for Electromagnetically Induced Transparency (EIT) phenomenon observation. Frequently the two ground-state hyperfine (hf) levels of alkali atoms are coherently coupled to a common excited state level by means of two coherent light fields. For the two field preparation, usually diode laser frequency modulation in the GHz region is performed. In some cases it is possible to relax the problem with the laser frequency modulation reducing it to the kHz region. In this approach, coherent coupling of Zeeman sublevels belonging to a single hf level of the ground state is realized. A disadvantage of the second approach is that the hf optical pumping to the ground-state levels non-interacting with the laser field introduces significant loss in the formation of the resonance. To decrease the modulation frequency while still involving the two ground-state hf levels in the resonance preparation, it is promising to use K atoms where the ground-state hf level frequency difference is about 462 MHz.

In this communication we present the results of systematic experimental investigation of the EIT resonances in Hanle configuration and, to our best knowledge, the first observation of EIT resonance, based on the coherent coupling of the two ground-state hf levels to a common excited level in K atoms confined in a thermal cell.

Using mono-mode excitation provided by an extended cavity diode laser system, EIT resonances in absorption have been obtained on the D_1 line of K, in Hanle configuration. In accordance with our expectations for low hf optical pumping rate in K due to the overlapped Doppler profiles of the hf transitions starting from F_g=1 and F_g=2 levels, it has been shown that the resonance contrast is enhanced up to 70%.

EIT resonance based on coherent superposition of the two hf levels of the ground state is evidenced when irradiating K vapour by frequency modulated (around 461,7 MHz) laser light. Unfortunately, the available commercial lasers operating at wavelength matching the D_1 line of K provide output consisting of a great number of modes in a large spectral interval. To provide a frequency modulated in the MHz region output, a solitary multi-mode diode laser is used and one of its modes is tuned in resonance with the D_1 line of K. Even performed by multi-mode laser excitation, the first experiment shows that the contrast of the EIT resonance is very good (up to 40% of the fluorescence). This results is promising for the development of EIT-based systems for precise measurements with relaxed requirements to the laser modulation and with potential for building of more economic practical devices than those utilizing Cs and Rb atoms.

The work was done under collaboration program between the Italian National Research Council and the Bulgarian Academy of Sciences. S.C. and T.K acknowledge also the Bulgarian NCSR for the support (Grant No.F-1404/04).

Investigation of Stark broadening of UV Xe II lines.

R. J. Peláez[1], S. Djurović[2], M. Ćirišan[2], J. A. Aparicio[1] and S. Mar[1].

[1]*Departamento de Física Teórica, Atómica y Óptica, Facultad de Ciencias, Universidad de Valladolid, P. Prado de la Magdalena s/n, 47071, Spain.*
[2]*Departament of Physics, Faculty of Science, University of Novi Sad, Trg Dositeja Obradovića 4, 21000 Novi Sad, Serbia and Montenegro.*
E-mail:ramon@opt.uva.es

In this work, 10 new experimental results of the Stark widths of Xenon II spectral lines in the UV range are shown. These measurements were obtained from Helium(95%)-Xenon(5%) plasma at a pressure of 3 KPa, which was generated by a discharge of 20 μF capacitors at a voltage of 9200 V in cylindrical tube of Pyrex glass, 175 mm in length and 19 mm of internal diameter [1,2]. Under these conditions plasma emission lasts for about 200 μs. The spectra were recorded using a Jobin-Yvon monocromator of Czerny-Turner configuration, with 1500 mm focal length, a grating of 2400 lines/mm and O.M.A. camera with 512 channels of 25 μm pixel width. Under these conditions the linear dispersion varied from 5.8 to 6.2 pm/channel, in first order of diffraction for the spectral range of the lines considered in this work.
Two different techniques were used to calculate the electron density: the spectroscopic, measurement of the Stark width of the He I 388.8 nm line, and the interferometric method, consist in the measurement of the plasma refractivity changes due to the free electrons [3]. The differences between both techniques are lower than 10%, for electron density ranging from 0.2 to $1.6\times10^{23}\mathrm{m}^{-3}$. It was assumed that electron temperature should be similar to the excitation temperature, calculated in this work by a Botzmann-plot of Xe II lines. Using this method temperatures that from 17000 to 29000 K have been obtained.
The original spectrum has been corrected to transmittance and in some cases it has also been necessary to correct it to selfabsorbtion. Also, the spectral lines have been adjusted to Lorentzians functions [4]. For obtaining the Stark width, other broadening mechanisms, like apparatus or Doppler effect, have been considered [5]. The final error of these results has been obtained by considering the quality of the reconstructed profile, the adjustment of the Lorentzian functions and other variables related with the experiment and the processing procedure.

Authors thank S.González for his work in the experimental arrangement, the DGICYT of Spain and Consejería de Educación y Cultura (JCyL) for their financial support under contracts No. FIS2005-03155 and No. VA015A05. S. Djurović, M. Ćirišan, thank to Ministry of Science, Technology and Development, Republic of Serbia for partial support (141024). Dr. J. A. Aparicio wants to express his personal acknowledgement to ONCE for help.

References

[1] J. A. del Val, S. Mar, M. A. Gigosos, I. de la Rosa, C. Pérez and V. R. González, Jpn. J. Appl. Phys. 37, 4177 (1998).
[2] J. A. del Val, J. A. Aparicio, V. R. González and S. Mar, J. Phys. B 34, 2513, (2001).
[3] M. I. de la Rosa, C. Pérez, A. M. de Frutos and S. Mar, Phys. Rev. A 42, 7389, (1990).
[4] M. A. Gigosos, S. Mar, C. Pérez and I. de la Rosa, Phys. Rev. E 49, 1575, (1994).
[5] Aparicio, J. A.; Prez, C.; del Val, J. A.; Gigosos, M. A.; de la Rosa, M. I.; Mar, S. J. Phys. B. 31, 1029(1998).

Multiple Ionization of Atoms in Strong Laser Fields

A. Rudenko[1], Th. Ergler[1], B. Feuerstein[1], K. Zrost[1], V.L.B. de Jesus[2], C.D. Schroeter[1], R. Moshammer[1] and J. Ullrich[1]

[1] *Max-Planck-Institut fuer Kernphysik, Saupfercheckweg 1, 67119 Heidelberg, Germany*
[2] *Centro Federal de Educacao, 8400 Rio de Janeiro, Brasil*
E-mail: j.ullrich@mpi-hd.mpg.de

A main subject of interest in intense laser-atom interactions during the last few years was related to the question how many-electron transitions like double and multiple ionization do occur [1]. In the case of double ionization, for example, each electron might absorb the photons independently (sequential) or one electron absorbs the energy from the laser field alone and then shares it with the second electron via electron-electron correlation (non-sequential ionization). Here, in a first step, one electron is ionized via tunneling or field ionization. Under certain conditions the electron is driven back to its parent ion where, in a second step, it knocks out another electron. Very recently, we were able to perform for the first time differential measurements where we could demonstrate that different ionization mechanisms are active in triple and fourfold ionization of Ne and Ar [2]. This has been achieved by measuring the ion momentum distributions along the laser polarization axis, which is almost perfectly balanced by the electron sum momentum. For any combination of sequential and non-sequential processes, two classes of electrons, which contribute very differently to the ion momentum, can be distinguished: those emitted via tunneling ionization and those emerging from a recollision process. Electrons emitted via tunneling receive a small drift momentum and, thus, contribute only little to the final sum momentum. Instead, electrons emerging from an electron impact ionization event as a result of recollision, gain large drift momenta [3]. The momentum distributions of doubly, triply and fourfold charged ions have been measured for 25 fs laser pulses at various intensities from 1.2 PW/cm^2 up to 20.0 PW/cm^2 (1 PW = 10^{15} W). For example, at 2.0 PW/cm^2 a narrow momentum distribution was found for Ne^{2+} ions with a maximum at zero, indicating that at this intensity double ionization occurs via the sequential mechanism. At the same intensity, however, the distributions for the higher charged states of Ne exhibit a clear double peak structure with almost no ions created with zero momentum. Based on the classical recollision model this is consistent with a mechanism where three or four electrons are set free instantaneously during recollision by an (e,ne) event, a process that is extremely unlikely to happen in field free electron-atom collisions. In contrast, multiply charged Ar ions are produced by combinations of sequential and non-sequential processes. For the case of Ar we also observe a clear difference between the results obtained with 6-7 and 25 fs pulses.

References

[1] A. Becker, R. Doerner and R. Moshammer, J. Phys. B 38 S753 (2005)
[2] A. Rudenko et al., Phys. Rev. Lett. 93 253001 (2004)
[3] B. Feuerstein, R. Moshammer and J. Ullrich, J. Phys. B 33 L823 (2000)

Angular–resolved studies of the x–ray emission from heavy, few–electron ions

A. Surzhykov[1], U. D. Jentschura[1], Th. Stöhlker[2], and S. Fritzsche[3]

[1] *Max–Planck–Institut für Kernphysik, D–69029 Heidelberg, Germany*
[2] *Gesellschaft für Schwerionenforschung (GSI), D–64291 Darmstadt, Germany*
[3] *Institut für Physik, Universität Kassel, D–34132 Kassel, Germany*
E-mail: surz@mpi-hd.mpg.de

Energetic collisions of highly–charged, heavy ions with atoms and electrons have been studied intensively both at the SuperEBIT facility in Livermore [1] and at the GSI ion storage ring in Darmstadt [2]. A special interest has been recently placed on the population of excited ionic states and on the measurement of their subsequent radiative decay. The analysis of the (properties of the) bound–bound transitions in heavy ions now plays a key role for our understanding of electron–electron and electron–photon interactions in the presence of strong electromagnetic fields. In particular, studies of the spectra as well as of the decay rates of highly–charged ions have revealed important information about the relativistic and quantum electrodynamic effects in few–electron systems [3]. Apart from the energies and transition probabilities, however, an alternative and very promising way to learn more about the structure and dynamics of highly–charged ions is given by the measurement of the *angular distributions* of the characteristic photon emission.

In this contribution, we review the recent progress in theoretical investigations of the photon emission from highly charged heavy ions. Special attention will be paid to the angular–resolved x–ray studies which appear to be more sensitive to the retardation and relativistic effects than the analysis of the total cross sections. For instance, we present calculations for the Lyman-α_1 ($2p_{3/2} \to 1s_{1/2}$) and Kα_1 ($1s\,2p_{3/2}\,{}^{1,3}P_{1,2} \to 1s^2\,{}^1S_0$) transitions in the hydrogen–like U^{91+} and helium–like U^{90+} uranium ions following electron capture process and show how their emission patterns may be used as a sensitive tool for studying the multipole mixing and many–electron effects in heavy atomic systems [4, 5]. Beside the one photon bound–bound transitions, we also investigate the angular correlations in the *two–photon* decay of highly–charged, heavy ions [6]. For this decay mode, detailed computations have been carried out, for example, for the $2s_{1/2} \to 1s_{1/2}$ and $3d_{5/2} \to 1s_{1/2}$ transitions in uranium U^{91+} ions and are compared with previous nonrelativistic results.

References

[1] P. Beiersdorfer et al., AIP Conf. Proc. 652, 131 (2003).
[2] Th. Stöhlker et al., Phys. Scr. T110, 384 (2004).
[3] S. Fritzsche et al., J. Phys. B 38, S707 (2005).
[4] A. Surzhykov et al., Phys. Rev. A 73, 032716 (2006).
[5] A. Surzhykov et al., submitted.
[6] A. Surzhykov et al., Phys. Rev. A 71, 022509 (2005).

Configuration interaction effects in low-energy electron collisions with Sn VII

M. A. Lysaght[1], V. M. Burke[2], A. Hibbert[3], C. J. Noble[2], M. P. Scott[3], G. O'Sullivan[1], P. Dunne[1], and P. G. Burke[3]

[1]*School of Physics, University College Dublin, Belfield, Dublin 4, Ireland*
[2]*CSE Department, CLRC Daresbury Laboratory, Warrington, WA4 4AD, UK*
[3]*Department of Applied Mathematics and Theoretical Physics, The Queen's University of Belfast, Belfast BT7 1NN, UK*
E-mail:michaellysaght@physics.org

Laser-produced plasmas (LPPs) containing tin are currently being researched as possible extreme ultraviolet (EUV) sources for next generation nanolithography tools [1-4]. Based on the requirement of establishing collision strengths for population kinetics in radiation transport models of such plasmas, partial wave collision strengths are presented for low-energy electron impact transitions in Sn VII between the $4p^6 4d^8\ {}^3F^e$ ground state and several excited states in the $4p^6 4d^8$, $4p^6 4d^7 5s$ and $4p^6 4d^7 5p$ configurations. The collision strengths are calculated in LS coupling using the parallel R-matrix program PRMAT [5,6] including all terms of the $4p^6 4d^8$, $4p^6 4d^7 5s$ and $4p^6 4d^7 5p$ configurations in the close coupling expansion of the collision wavefunction. The importance of including configuration interaction (CI) functions of the form $4p^4 4d^{10}$, $4p^4 4d^9 5s$ and $4p^4 4d^9 5p$ in the target expansion is explored. Such CI models for both the target and collision wavefunctions are to be extended to include higher lying configurations and their fine structure levels in order to obtain accurate total collision strengths and effective collision strengths for transitions within Sn VII, these being required for current radiation transfer simulations.

References

[1] M. Lysaght, D. Kilbane, N. Murphy, A. Cummings, P. Dunne, and G. OSullivan, Phys. Rev. A 72, 014502 (2005)
[2] G. O'Sullivan, A. Cummings, P. Dunne, P. Hayden, L. McKinney, N. Murphy and J. White, Atomic physics of highly charged ions and the case for Sn as a source material, EUV Sources for Lithography, ed V Bakshi (Bellingham WA: SPIE) at press (2005)
[3] D. Atwood, J. Phys. D: Appl. Phys. 37 (2004)
[4] A. Cummings, G. O'Sullivan, P. Dunne, E. Sokell, N. Murphy, J. White, P. Hayden, P. Sheridan, M. Lysaght and F. O'Reilly 2006 J. Phys. D: Appl. Phys. 39 73-93 (2006)
[5] A. G. Sunderland, C. J. Noble, V. M. Burke, and P. G. Burke, Comput. Phys. Commun. 145, 311-340 (2002).
[6] P. G. Burke, A. Hibbert, and W. D. Robb, J. Phys. B **4**, 153 (1971)

X-ray imaging of collisions between hot dense plasmas

J. Dardis[1], C. L. S. Lewis[2], J. T. Costello[1]

[1]*National Centre for Plasma Science and Technology (NCPST) and School of Physical Sciences, Dublin City University,*
Dublin 9, Ireland
[2]*International Research Centre for Experimental Physics (IRCEP) and School of Physics and Mathematics,*
Queens University Belfast, Belfast BT7 1NN, Northern Ireland
E-mail: john.dardis@gmail.com

We report on the development and construction of a soft X-ray (SXR) imaging and spectroscopy system used to study freely expanding plasmas as well as plasma-plasma and plasma-surface interactions. Colliding plasmas play a key role in areas such as pulsed laser deposition [1], inertial confinement fusion [2], X-ray lasers [3] and laboratory-scale astrophysical simulations [4]. We investigate the collision and interpenetration of laser produced plasmas in the soft X-ray region. Briefly, a pair of point plasmas are formed at the focus of either (i) 250mJ/170ps/1064nm or (ii) 1250mJ/12ns/1064nm pulses. Time integrated pinhole images of the collision of plasmas expanding along the target surface are presented. Low, medium and high Z targets, specifically Magnesium, Copper and Tungsten are used in the imaging experiments. Spectra of the individual source plasmas obtained using a system described in [5] are used to identify dominant ion stages.

The collisionality depends on the ion-ion mean free path (mfp) and the plasma geometrical scale length. At high temperatures the ion-ion mfp is quite large and preliminary results indicate, as one might expect, that there is little or no stagnation. This work will hopefully lead on to the study of plasma-surface interactions.

Work supported by the Irish government's National Development Plan, Science Foundation Ireland Research Frontiers Programme and the Higher Education Authority North-South Co-operation Grants Scheme.

References

[1] E Camps et al., *Appl. Surf. Sci.* 197-198 239 (2002)
[2] T R Dittrich et al., *Phys. Plasmas* 6 2164 (1999)
[3] R W Clark et al., *Phys. Plasmas* 4 3718 (1997)
[4] N C Woolsey et al., *Plas. Phys. Control. Fusion* 46 B397 (2004)
[5] J Dardis et al., in *Opto-Ireland 2005: Optical Sensing and Spectroscopy*, SPIE Proceedings (SPIE - The International Society for Optical Engineering, Bellingham, WA), Volume 5826, pp. 363-370

Multiple shake processes upon inner-shell ionization of atoms

A.G. Kochur and V.A. Popov

Rostov State University of Transport Communication,
Rostov-na-Donu, Russia
E-mail: agk@rgups.ru

Creation of an inner-shell vacancy in an atom may lead to additional excitation/ionization of its outer-shell electrons into the states with the same orbital quantum number l. Such processes of monopole excitation/ionization are called shake processes. They are subdivided into the shake up (SU) and shake off (SO) processes meaning additional excitation to free bound states and ejection into continuum. Combined SU+SO probabilities upon inner shell ionization have been calculated for wide arrays of atoms in sudden approximation [1,2]. Separate calculations on SU and SO probabilities have been performed in [3,4,5].

It is often supposed that the probability of the n_0l_0nl shake processes (nl electron is excited/ionized upon n_0l_0 inner-shell ionization) are mostly *single shake* processes, i. e. only one nl electron is excited/ionized. However, the estimates of the probabilities of *multiple shake* processes [2,5] showed that they may be noticeable. Multiple are those shake processes where more than one electron is additionally excited/ionized.

In this work, within the sudden approximation, we calculate separately the probabilities of single, double, triple and quadruple shake processes in atoms with $3 \leq Z \leq 55$ due to K-, L-, M-, and N-ionization. Calculated relative contributions of multiple shake processes are significant making 10 to 30% of total shake probability depending on initial vacancy n_0l_0 and on the symmetry of the subshell nl being additionally excited/ionized. Most of the multiple shake contribution comes from double shake processes. Triple shakes are small but still noticeable (fractions of per cent), while quadruple shakes are negligible.

The Z-dependencies of probabilities of both single and multiple shakes are non-monotonic: they increase sharply upon the beginning of a new subshell occupation. At the same time, the increase of the multiple shake probabilities is greater due to greater statistical weights of contributing multi-vacancy configurations. As a result, the relative contribution from multiple shake processes is maximal in the beginning of the periodic table rows, and it decreases gradually until the next outer ssubshell is opened.

References

[1] T. Mukoyama and K. Taniguchi, Phys. Rev. A 36, 693 (1987)
[2] A.G. Kochur, A.I. Dudenko, D. Petrini, J. Phys. B.: At. Mol. Opt. Phys. 35, 395 (2002)
[3] T. Mukoyama, Y. Ito, K. Taniguchi, X-ray Spectrom.28, 491 (1999)
[4] A.G. Kochur, V.A. Popov, Rad. Phys. Chem. (2006) accepted for publication
[5] A.G. Kochur, V.A. Popov, Zh. Strukturnoy Khimii (Russia) 100, 714 (2006)

Multiply charged ions formation in a cascade decay of resonantly excited Ar1s $^{-1}$4p^1 state

A.I. Dudenko, A.G. Kochur, I.D. Petrov and V.F. Demekhin

Rostov State University of Transport Communication, Rostov-na-Donu, Russia
E-mail: agk@rgups.ru

The final-ion-charge spectra produced by the cascade decay of the resonantly excited $1s^{-1}4p^1$ state of argon has been calculated in [1] and [2] with accounting for the shake processes during the cascade development. Those calculations were based on the supposition that all the shake channels are exclusively shake off (SO). Such approximation is justified for deeper core electrons, however the main channel of monopole excitation of the $4p$ electron upon initial KLL decay of the $1s^{-1}4p^1$ state is $4p \rightarrow 5p$ shake up (SU). During the decay steps that follow, shake up and shake down transitions dominate for the outermost excited np electron.

In this work, in one-electron approximation, we calculate the Ar^{i+} ion yields produced by the decay of the $Ar1s^{-1}4p^1$ state considering the SU and the SO processes separately. The presence of a weakly bound np electron in the intermediate cascade configurations opens new decay pathways due to the electrostatic interaction within the multiplets, for example, $2p^4(L_iS_i)np^1LS \rightarrow 2p^4(L_fS_f)\epsilon lLS$. The decay rates for such transitions are calculated in the LS coupling approximation.

The ion yield spectra calculated in various approximations are compared with the experiment [3] in the Table. One can see that the most accurate calculation (column c) still underestimates the production of the higher-charged ions. This discrepancy may indicate to the limitations of the one-electron approximation and the step-by-step cascade model.

Ion carge	Ion yield, %			
	Experiment	Theory		
	[3]	a	b	c
0	0.0	0.6	0.6	0.8
1	6.4	8.3	6.0	8.4
2	10.2	9.7	9.4	9.2
3	29.4	46.5	26.5	42.2
4	34.6	26.1	38.9	30.6
5	15.6	8.2	14.6	8.4
6	3.0	0.6	3.9	0.4
7			0.1	

[a] shake processes are ignored; [b] all shakes are attributed to SO;
[c] accurate accounting of SU and SO

References

[1] C. Guenther, E. Hartmann, Nucl. Instrum. Methods B 98, 74 (1995)
[2] A.G. Kochur, Ye.B. Mitkina, J. Phys. B: At. Mol. Opt. Phys. 32, L41 (1999)
[3] J.C. Levin, C. Biederman et al., Phys. Rev. Lett. 65, 988 (1990)

Resonance inelastic scattering of an X-ray photon by a neon-like atomic ion

A.S. Kasprzhitsky, A.N. Nadolinsky, A.N. Hopersky and V.A.Yavna

Rostov State University of Transport Communication, Rostov-on-Don, Russia
E-mail:a.kasprzhitsky@list.ru

In our resent paper [1] we developed the non-relativistic quantum theory and the method of calculation of the values and the three-dimensional shape of doubly differential cross section of resonance inelastic (Landsberg-Mandelstam-Raman-Compton) scattering of a hard X-ray ($h\nu$= 600 eV to 1,5 MeV) by a free atom near its inner-shell thresholds with inclusion of a wide hierarchy of many-particle effects.

The aim of this study is to extend the methods of [1] to the case of resonance inelastic scattering of an X-ray photon by a multiply charged atomic ion.

Within the non-relativistic approximation for the one-electron states wave functions and dipole approximation for the scattering probability amplitudes, the values and the shape of doubly differential cross sections of resonance inelastic scattering of linearly polarized X-ray photon near the 1s-ionization thresholds of the neon atom and the neon-like ions Si^{4+} and $Ar^{8+}$are calculated. Included are the effects of the relaxation of the core within the field of the 1s-vacancy, stabilization of the 1s-vacancy upon going from atom to ion, and the effect of the spin-orbital splitting of the valence $2p^6$-subshell. The results of the calculations are predictions.

Our results may be important in the context of creation of an X-ray laser with a neon-like plasma for active medium [2], particularly, with the use of the $K\alpha_{1,2}(2p\rightarrow 1s)$ emission transition [3].

References

[1] A.N. Hopersky, A.M. Nadolinsky, V.A. Yavna, JETP 101, 597 (2005)
[2] K.A. Janulewicz et al., X-Ray Spectrom. 33, 262 (2004)
[3] H.C. Kapteyn, Appl. Opt. 31, 4931 (1992).

Effect of resonant inelastic contact scattering of an X-ray photon by an atom and an ion

A.N. Hopersky, A.S. Kasprzhitsky , A.N. Nadolinsky and V.A.Yavna

Rostov State University of Transport Communication, Rostov-on-Don, Russia
E-mail:a.kasprzhitsky@list.ru

The existence of the extended resonance structure of total doubly differential cross-section of scattering of the linearly polarized photon by a free atom (ion) due only to the contact type of inelastic scattering [1] outside the regions of the Kα-emission is predicted theoretically. The probability amplitudes for contact inelastic scattering are calculated with an analytical expression derived outside the frame of the dipole and momentum approximation [2] for the transition operator in [3].
Resonance inelastic contact scattering of an X-ray photon is studied for the Ne atom and the neon-like ions Ar^{8+}, Ti^{12+}, and Fe^{16+}. The calculations are performed in the non-relativistic approximation for the wave functions of the scattering states. Included are the many-electron effects of radial relaxation of one-electron orbitals in the Hartree-Fock field of the deep 1s- vacancy and (in the case of the Ne atom) double ionization/excitation of the ground state of the atom.
One may suppose that the development of the X-ray free electron lasers generating the photons of tunable wavelength of 60 to 1 Å ($h\nu$= 0,2 to 12,4 keV) [4] will open the possibility of the detailed experimental studies of extended off-emission-region resonance structures of cross sections of scattering of a photon by a many-electron system.

References

[1] A.N. Hopersky, A.M.Nadolinsky, V.A.Yavna, JETP (2006) submited
[2] R.H. Pratt, Radiat. Phys.Chem. 74, 411 (2005)
[3] A.N. Hopersky, A.M.Nadolinsky, V.A. Yavna, JETP, 101, 597 (2005)
[4] M.A. Kornberg et al., J. Synchrotron Rad. 9, 298 (2002)

QED theory of calculating the electron-collision strengths for multicharged ions and search of the optimal plasma parameters for X-ray lasing

A.V. Glushkov

Odessa University, P.O.Box 24A, Odessa-9, 65009, Ukraine
E-mail: glushkov@paco.net

The X-ray laser problem has stimulated a great interest to development of theoretical methods for modelling the elementary processes in a collisionally pumped plasma. The shocking example is a scheme for accomplishing tabletop X-ray lasing in Li-like ion of Ne at 98 Åin an optically ionized plasma during recombination in the transient regime (Lawrence Livermore Nat. Lab.; Univ. of California). Saturation effects and parametric heating processes by stimulated Raman scattering are analyzed and found to allow energy efficiencies in excess of 10^{-5} for a 100-fsec duration, 0.25-μm laser driver of intensity 10^{17} W/cm^2. Two key theoretical problems must be solved in order to develop a special code and to predict necessary plasma parameters needed for X-ray lasing: i). Highly accurate definition of the rate coefficients for plasma elementary processes that are responsible for the forming emission lines spectra; ii).Developing new exact kinetics calculation schemes for defining the level populations, inversions, line intensities, gain coefficients at definite plasma parameters. The most consistent approach to problem is based on QED. Here the generalized energy approach in gauge invariant scheme [3] is used for consistent QED describing elementary processes in collisionally pumped laser plasma. We develop an optimal scheme for calculation of the electron-collision strength and rate coefficients for the de-excitation (excitation) processes in the Ne-like multi charged ions plasma with estimating optimal plasma parameters for X-ray lasing. We applied our approach to estimate of the electron collisional excitation cross-sections and strengths for Ne-and Ar-like ions.

References

[1] P. Amendt , D.C. Eder, S.C. Wilks, Phys. Rev. Lett. 66, 2589 (1991); E. Golt'z, K. Koshelev, A. Kramida *et al.*, Phys. Lett. A 119, 359 (1987).
[2] A.V. Glushkov, JETP. Lett. 55, 97 (1992); L. Ivanov, E. Ivanova, L. Knight, Phys. Rev. A 48, 4365 (1993); A.V. Glushkov *et al.*, In: New Projects and New Lines of Research in Nuclear Physics. Eds.: G. Fazio and F. Hanappe, World Sci. Publ., Singapore, 2003; Int. Journ. Quant. Chem. 99, 889 (2004); Nucl. Phys. A 734, e21 (2004).
[3] R. Marrs, M. Levine, D. Knapp, J. Henderson, Phys. Rev. Lett. 60, 1715 (1988); H. Zhang, D. Sampson, R. Clark, J. Mann, At. Dat. Nuc. Dat. Tabl. 37, 17 (1987); K.J. Reed, Phys. Rev. A 37, 1791 (1988).

QED theory of discharge of the metastable nuclei during negative muon capture and a search of the possible high power source of monochromatic gamma radiation

A.V. Glushkov, S.V. Malinovskaya and Yu.V. Dubrovskaya

Odessa University, P.O.Box 24A, Odessa-9, 65009, Ukraine
E-mail: glushkov@paco.net

A negative muon captures by a metastable nucleus may accelerate the discharge of the latter by many orders of magnitude (c.f. [1, 2]). For a certain relation between the energy range of the nuclear and muonic levels the discharge may be followed by the ejection of muon, which may then participate in the discharge of the other nuclei. We present a new QED theory for discharge of a nucleus with emission of γ quantum and further muon conversion, which initiates this discharge. Traditional process of the muon capture are in details studied earlier and here is not considered. Within an energy QED approach [2] a decay probability is presented as an imaginary part of the energy shift ImE. The intensities of satellites are linked with ImE of the 'nuclear core + proton + meson' system. Three channels should be taken into account: 1). Radiative purely nuclear 2^j-poled transition (probability P_1); 2). Non-radiative decay, when a proton transits into the ground state and a meson leaves the nuclei (P_2); 3). A transition of proton into the ground state with excitation of meson and emission of the γ-quantum (P_3). Within the QED perturbation theory [1, 2], a full probability is divided into the sum of the partial contributions, connected with decay into definite final states of system. These contributions are equal to the probabilities (P_i). We discuss the optimal conditions of realization of the high power source of the monochromatic γ radiation. For a sample with a sufficiently high density of metastable nuclei and a sufficiently intense muon beam the considered process can result in a sharp increase of γ radioactivity of the sample and may be used as the basis of operation of a high power source of monochromatic γ radiation.

References

[1] V. Gol'dansky, V. Letokhov, JETP 67, 513 (1974); L. Ivanov, V. Letokhov, JETP 70, 19 (1976); A. Glushkov, JETP Lett. 55, 97 (1992).
[2] A. Glushkov, S. Malinovskaya, Int. J. Quant. Chem. 99, 889 (2004); J. Phys: CS (2005); S. Malinovskaya, Int. J. Quant. Chem. 101, 531 (2005); Progr. Theor. Phys. (2005).

Laser-electron nuclear spectroscopy: New effects in spectra of atomic and molecular systems

A.V. Glushkov, S.V. Malinovskaya

Odessa University, P.O.Box 24A, Odessa-9, 65009, Ukraine
E-mail: glushkov@paco.net

A great progress in development of laser technique and accelerators experiments resulted to a new class of problems in atomic and laser physics. Great interest attracts the co-operative dynamical phenomena [1] due the interaction between photons, electron shells and nuclei nucleons. Attractive situation arises under transition to heavy multicharged ions because of changing energy and geometric parameters of electron shell. Character of interaction with a nucleus may strongly change and new channels of laser-electron-nuclear processes are opened. We propose new QED approach to calculation the electron satellites in spectra of the electron-nuclear gamma -transition of the nucleus in atoms. As example, the nuclear transitions in the isotopes Fe, Ne etc. are considered for O-and F-like ions of Fe, Ne. It is shown that the electron-nuclear lines in spectra of emission or absorption can be experimentally observed in plasma of the O-and F-like multicharged ions. Such a situation may be realized in the thermalized plasma. Due to the emission or adsorption of the nuclear γ-quantum in molecular system there is changing the electron vibration-rotation molecular states. As result, general energetic and structural properties of system are changed. We at first develop a new, consistent, quantum- mechanical approach to calculation of the electron-nuclear γ transition spectra (set of vibration satellites in molecule) of nucleus in atom and molecule, based on the energy approach (S-matrix formalism of Gell-Mann and Low) [1]. Decay and excitation probability are linked with imaginary part of the atom (molecule) - field system. Calculation results of the electron-nuclear γ-transition spectra of the nucleus in some atomic and multiatomic systems are given [2]. A spectrum of emission and adsorption of nucleus ^{127}I (203 keV) in molecule of HI is calculated. Estimates are made for vibration-nuclear transition probabilities for number of molecules: diatomics, three-atomic XY2, four-atomic XY3 and five-atomic XY4 ones.

References

[1] V.S. Letokhov, Phys. Lett. A 46, 257 (1974); L.N. Ivanov, V.S. Letokhov, JETP 93, 396 (1987); V.S. Letokhov, V.G. Minogin, JETP 69, 1369 (1975); A.V. Glushkov, L.N. Ivanov, Phys. Lett. A 170, 33 (1992); A.V. Glushkov, S.V. Malinovskaya, In: New Projects and New Lines of Research in Nuclear Physics. Eds.: G. Fazio and F. Hanappe , World Sci. Publ., Singapore, 242 (2003).
[2] A.V. Glushkov, S.V. Malinovskaya, Int. J. Quant. Chem. 99, 889 (2004); Int. J. Quant. Chem. 101, 513 (2005); S.V. Malinovskaya, Int. J. Quant. Chem. 101, 531 (2005).

Electron impact excitation of Ni XI from its ground state

Nupur Verma[1], Alok K.S. Jha[2] and Man Mohan[2]

[1]*Deen Dayal Upadhyaya College, University of Delhi, Delhi, India*
[2]*Department of Physics and Astrophysics, University of Delhi, Delhi, India*
E-mail:verma_nupur123@rediffmail.com

In recent years there has been considerable interest in the study of interaction of electrons and photons with ionized atoms, particularly with iron group elements Ni, Fe, Cr, and Ti, because of their importance in fusion plasmas [1], and in astrophysical plasmas [2]. Nickel is an important impurity element in modern fusion research devices, especially in those where the vessel walls are constructed largly of high-nickel-content alloys (e.g, JET the Joint European Torus). Knowledge of atomic processes involving nickel ions is essential in order to understand and accurately model these plasmas. Emission lines from ions of Nickel have been detected in ultraviolet and extreme ultraviolet solar spectrum and spectra generated in tokamak plasmas [3].

We have used the R-matrix method [4,5] to calculate electron impact collision strengths from the ground state to the first 16 fine-structure levels of argon-like Ni XI. The relativistic effects are incorporated in the Breit Pauli approximation by including one body mass correction, Darwin, and spin-orbit interaction terms in the scattering equations. Configuration interaction wavefunctions [6] are used to represent the lowest 9 LS-coupled target states $3s^23p^6\ {}^1S^e$, $3s^23p^53d\ {}^3P^o$, ${}^3F^o$, ${}^1D^o$, ${}^3D^o$, ${}^1F^o$, ${}^1P^o$, $3s^23p^63d\ {}^3D^e$, ${}^1D^e$ in the R-matrix expansion. Collision strengths are tabulated at selected energies in the range 10 to 70 Ryd. The low energy region is dominated by closed channel (or Feshbach) resonances which perturb the otherwise smoothly varying background collision strength. The effective collision strengths are determined by integrating the collision strength over a Maxwellian distribution of electron energies. Results are presented for the effective collision strengths for a temperature range 10^5-10^7 K, over which the target models should be valid.

We expect our results to be reasonably accurate, since we have accounted for exchange, channel couplings and short range correlation effects in our calculation. Our results are the only collsion strengths and rate coefficients available for this ion. We believe that the data calculated in this work will be useful in solar, astrophysical and laser applications.

References

[1] R.K. Janev, Phys. Scr. T37, 5 (1991).
[2] U. Feldman, W. Curdlt, E. Landi, K. Wilhelm, ApJ. 544, 508 (2000).
[3] U. Kaufman, J. Sugar, W.L. Rowan, J. Opt. Soc. Am. B 6, 1989 (1989).
[4] K.A. Berrington, W.B. Eissner, P.H. Norrington, Comput. Phys. Commun. 92, 290 (1995).
[5] N.S. Scott, P.G. Burke, J. Phys. B. 13, 4299 (1980).
[6] A. Hibbert, Comput. Phys. Commun. 9, 141 (1975).

Optical emission spectroscopy of laboratory plasmas using mini fiber spectrometers

N. Krstulović[1], N. Glavan[2], N. Čutić[1] and S. Milošević[1]

[1] *Institute of Physics, Zagreb, Croatia*
[2] *Technical faculty, University of Rijeka, Rijeka, Croatia*
E-mail: slobodan@ifs.hr

Laboratory plasmas such as radio-frequency inductively coupled discharges or laser induced plasmas have a great potential in various technological and scientific applications [1,2,3]. There is a constant need for improvements of their characterisation in a real time during various processes of material treatments where a rapid change of the plasma content occurs. Optical emission spectroscopy is a traditionally very efficient tool which is becoming even more important with the appearance of a various miniature spectrometers.
In the present study we have explored possibilities (capabilities) of various miniature fiber spectrometers for characterisation of plasma content. We present and discuss several aspects of miniature CCD spectrometers in plasma studies such as a spectral response, spectral resolution, time integration etc.

References

[1] A. Vesel, M. Mozetič, A. Drenik, S. Milošević, N. Krstulović, M. Balat-Pichelin, I. Poberaj, D. Babić, Plasma Chemistry and Plasma Processing in press 2006.
[2] . N. Glavan, N. Krstulović, N. Čutić, S. Milošević, U. Cvelbar, A. Vesel, A. Drenik, M. Mozetič, Vakuumist 25/4 (2005), 29-33.
[3] N. Krstulović, I. Labazan; S. Milošević, U. Cvelbar, A. Vesel, M. Mozetič Materiali in tehnologije. 38 51-54 (2004).

Optical Spectroscopy of lowly ionized Xe Plasmas

Ch. Berenguer[1], K. Katsonis[1], R.E.H. Clark[2], M. Cornille[3], M. Ganciu[1]

[1] *CNRS and LPGP, UMR 8578, Université Paris-sud, 91405 Orsay cedex, France*
[2] *Nuclear Data Section, IAEA Vienna, Austria*
[3] *LUTH, UMR 8102 CNRS, Observatoire de Paris, 92195 Meudon cedex, France*
E-mail: chloe.berenguer@pgp.u-psud.fr

Xe plasmas are often present in the laboratory and in industry (plasma thrusters, plasma reactors, lightning, etc.). Here we are concerned with diagnostics and modeling of the relatively cool plasmas such as those present in applications such as plasma thrusters, or the divertor region of a fusion device. In such cases it is only necessary to consider the lower ionization stages together with the neutral Xe I. According to a simple coronal model [1] accounting of the stages Xe I to V is expected to be sufficient for the description of plasma properties up to about some tens of eV.
We have recently developed a time-independent Collisional – Radiative (C-R) model [2] applicable to relatively cool Xe plasmas. Comparison of the theoretical spectra provided by this model with those obtained experimentally from various Xe plasmas has been used for its validation. Also, our results compare favorably with those coming from the well known LANL codes, which are intended for to address a much larger range of applications [3].
It is well known that the main difficulty in developing C-R models is the collection and evaluation of the necessary atomic data entering in the coefficients of the second member of the relevant Boltzmann equations, leading to the formulation of the statistical equation system. Once these coefficients are validated in the steady state case, extension to the transient, non stationary case can be conceptually reduced to only a matter of the solution of a set of differential equations, with the first member accounting for the temporal and spatial variation of the distribution functions. In fact, the adequate solution of the first member set taking into account the main constraints is so cumbersome that it constitutes a distinct task; "sowing" together the description of the two views constitutes a challenge for adapting the modeling to most realistic cases.
Our C-R model has been used to analyze various Xe spectra. Here, we report on two applications: The first concerns Xe I and Xe II spectra registered in SPT-50 Stationary Plasma Thrusters, made available to us at the Ecole Polytechnique and the ONERA Laboratories, both located in Palaiseau [4]. The second application refers to the spectrum of low temperature Xe plasma contained in a hollow cathode dielectric barrier dicharge, studied at the LPGP Laboratory. In both cases, the spectra of various multiplets belonging to Xe I and II have been analyzed and will be presented and commented on during the Conference.

References

[1] K. Katsonis, A. Siskos, M. Touzeau *"Coronal Type and C-R Modeling of Rare Gases Plasmas"*, International Electric Propulsion Conference IEPC 2003, pap. 285, Toulouse, March (2003).
[2] K. Katsonis, S. Pellerin, K. Dzierzega "*C-R type Modeling and Application in Plasma Diagnostics*" JHTMP 7, 559 (2003).
[3] http://aphysics2.lanl.gov/tempweb/
[4] K. Katsonis, M. Cornille, A. Siskos, M. Tanguy *"Low Temperature Validation of a Xe plasma C-R Model"* 2004, 4^{th} ISPC, 2-9 June, Sardenia, Italy (2004).

Collision of two 355 nm laser-produced plasmas: analysis of time and spatial-resolved image spectra

H. Luna, K. D. Kavanagh, J. Pedregosa-Gutierrez and J. T. Costello

National Center for Plasma Science and Technology and School of Physical Sciences, Dublin City University, Dublin, Ireland
E-mail: hdl@physics.dcu.ie

In this work we present a detailed study on the collision of two laser produced Ca plasmas, formed at the focus of third harmonic of Nd-YAG beams. We use a spectroscopic imaging technique [1] to characterize the plasma formed at the region where the two plasma plumes collide, frequently referred as the *stagnation region*, due to the nature of the collisional regime studied in this work (ion-ion mean free path much smaller than the plasma density scale length).
From the hydrodynamic analysis of the *stagnation region* parameters such as relative brightness, transversal and longitudinal lengths, and life-time were obtained. Finally, absolute electron temperatures and densities were obtained directly from the spectroscopic measurements of visible emission from the *stagnation region*.
This work was supported by the Irish Government's National Development Plan under the Research Frontiers Grants Scheme Science Foundation Ireland. KDK acknowledges support from the 'Embark Scholarship Scheme of the Irish Research Council' for Science Engineering and Technology. HL acknowledges support from the EU FP6 Marie Curie program.

References

[1] D. Doria, K.D. Kavanagh, J.T. Costello and H. Luna, Meas. Sci. Technol. 17 (2006) 670-674

Photoionization microscopy

A. Ollagnier[1], F. Lépine[1], M-A. Lebeault[1], F. Robicheaux[2], M.J.J. Vrakking[3] and C. Bordas[1]

[1] *Laboratoire de Spectrométrie Ionique et moléculaire, UMR CNRS et Université Lyon 1, Bât. A. Kastler, 43 Bd du 11 Novembre 1918, 69622 Villeurbanne Cedex, France*
[2] *Department of Physics, Auburn University, Auburn, Alabama 36849*
[3] *FOM Instituut voor Atoom and Molecuul Fysica (AMOLF), Kruislaan 407, 1098 SJ, Amsterdam, The Netherlands*
E-mail:lepine@lasim.univ-lyon1.fr

In the 80s Kondratovich, Ostrovsky and Demkov ([1] ,[2]) proposed an experiment in which the two dimensional flux of electron produced in a photoionization process in the presence of a static electric field is measured with a position sensitive detector placed at a macroscopic distance, perpendicularly to the electric field. They noticed that this electron current is a direct measurement of the square modulus of the transverse component of the electronic wavefunction. This experiment was named "photoionization microscopy" as it provides an image that is a macroscopic projection of the electronic wave function which properties are determined by the short distance motion of the electron around the nucleus.
The first photoionization microscope has been built recently and first experimental results were obtained on Xe atoms ([3],[4]). Ionization with one and two photons was performed and electrons were detected using a state-of-the-art imaging spectrometer. A typical image shows two main structures explained by the topology of electron trajectories. These results have demonstrated that this asymptotic measurement allows one to distinguish between "indirect" electrons scattered by the ionic core and "direct" electrons with trajectories mainly influenced by the electric field. Even more spectacular is the interference pattern observed for both contributions and the smooth evolution of the number of fringes when the ionization wavelength varies. Moreover, above these general observations, the detail of the measurements showed non trivial features for instance in the angular distribution.
These results can be understood intuitively in terms of interferences between several trajectories followed by the electron in order to reach a given position on the detector. A hydrogenic semiclassical model has been able to describe the main features of the experimental results ([5]). However, a complete quantum description of the photoionization microscopy experiment is needed and requires a more refined theoretical description taking into account the effect of the electric field, ionic core, electronic core and ionization process. A natural approach would be based on the MQDT framework, however a simulation of a complete experiment is extremely computational time demanding. Therefore, we have recently performed calculations based on wavepacket propagation using a split-operator code. This program allows us to calculate the wavepacket at a macroscopic distance from the core and first results show that interference patterns can be well reproduced. This will allow us to study how the interference structure is modified by electron/electron interaction or by the structured continuum.

References

[1] Yu. N. Demkov, V. D. Kondratovich, and V. N. Ostrovsky, Pis'ma Zh. Eksp. Teor. Fiz. 34, 425 (1981).
[2] V. D. Kondratovich and V. N. Ostrovsky, J. Phys. B 17, 1981 (1984), 2011 (1984) , 23, 21 (1990), 3785 (1990).
[3] C. Nicole et al. Phys. Rev. Lett. 88, 133001 (2002).
[4] F. Lépine et al. Phys. Rev. Lett. 93, 233003 (2004).
[5] C. Bordas et al. Phys. Rev. A 68, 012709 (2003).

The use of a new model potential in calculation of the fullerene electron structure

R.Yu. Kilin and V.A. Kilin

Department of Higher Mathematics, Tomsk Polytechnic University, Tomsk, Russia
E-mail:vak@tpu.ru

Traditionally used spherically-symmetric potentials (those of a rectangular well [1], uniformly charged sphere [1], the spherical layer [2], and others, see, i.e., [3]) do not take into account a specific behavior of the exact molecular potential

$$V(\vec{r}) = -\sum_{i=1}^{N} \frac{Z_i e}{|\vec{r} - \vec{R}_i|}$$

in the vicinity of nuclei, $\vec{R}_i(R_i, \theta_i, \phi_i)$, where the inner-shell and subvalent electrons are mostly located. Probably, this is a reason of failing the Hartree-Fock calculations for the entire 360-electron fullerene configuration.

In this work we present the results of Hartree-Fock calculation of the fullerene C_{60} ground state obtained with the new model spherically-symmetric potential,

$$V_d(r) = V(\vec{r})|_{\theta=\theta_0,\, \phi=\phi_0} = -\sum_{i=1}^{N} \frac{Z_i e}{|\vec{r}(r, \theta_0, \phi_0) - \vec{R}_i|},$$

that depends on angular parameters θ_0 and ϕ_0. It can be named as "the potential in a singled out direction. The target distance ρ has been used in calculations as a single parameter instead of θ_0 and ϕ_0. The potential V_d allows the simultaneous using of different values of ρ in calculation of inner-, subvalence- and valence-shell single-electron states. This results in accounting the fullerene molecular properties to a greater extent. Closeness of agreement between the experimental and calculated ionization potentials can serve as a criterion of choosing the proper values of ρ.

Preliminary calculations with the use of $V_d(r)$ in modified computer codes ATOM [4] showed rather good agreement between the experimental ionization potentials and calculated ones for the outermost configuration $s^2p^6d^{10}f^{14}g^{18}h^{10}$, if proper values of ρ are used.

The detailed results for different 360-electron configurations of C_{60}, including those containing the high-momentum electron shells $(n, l)^q = (15, 14)^{58}$, $(16, 15)^{62}$ will be presented at the conference.

References

[1] Gensterblum, G., 1996, Journal of Electron Spectroscopy and Related Phenomena Vol. 81, 89-223.
[2] Ivanov, V.K. Kashenock, G.Yu., Polozkov, R.G. and Solov'yov, A. V., 2001, J. Phys. B: At. Mol. Opt. Phys Vol 34, pp. 669-677.
[3] Yabana, K. and Bertsch, G.F., 1993, Phys. Scr., Vol 48, 633.
[4] M.Ya. Amusia, L.V. Chernysheva, Computation of Atomic Processes. A Handbook for the ATOM Programs (Bristol: IOP), 1996.

Femtosecond pulse train excitation of a Doppler broadened rubidium vapor

T. Ban, D. Aumiler, H. Skenderovic and G. Pichler

Institute of physics, Bijenika 46, Zagreb, Croatia
E-mail:ticijana@ifs.hr

The frequency spectrum of the pulse train consists of a series of fringes separated by the pulse repetition rate. The fringes are regular in frequency space if the pulses in the pulse train have a defined phase relation relative to each other. In the systems where the atomic coherence relaxation time is longer than the pulse repetition period the atoms interact with the spectrum of the pulse train, and not with the spectrum of a single pulse. In that account the short pulse trains can be used for the high resolution spectroscopy [1,2], where the observed linewidths are much less than the Fourier- transform limit of the individual pulse in the train. In our recent papers [3,4] we presented the observation of the velocity selective population transfer between the Rb ground state hyperfine levels induced by fs pulse train excitation. We developed a modified direct frequency comb spectroscopy (DFCS) which uses a fixed frequency comb for the ^{85,87}Rb $5^2S_{1/2} \rightarrow 5^2P_{1/2,3/2}$ excitation (Tsunami mode-locked Ti:sapphire laser with pulse duration of 100 fs and pulse repetition of 80 MHz) and a weak cw scanning probe (TOPTICA DL100, ECDL at 780 nm) for ground levels population monitoring. The Rb($5^2P_{1/2,3/2}$) excited atomic levels have the relaxation times greater than the fs laser repetition period. In the time domain this leads to population and coherence accumulation effects. This corresponds to the interaction of the Rb atoms with the fs frequency comb in the frequency domain. As a result, velocity selective excited state hyperfine level populations are obtained, i.e. the mapping of the frequency comb to the atomic velocity comb. Simultaneously, velocity selective optical pumping of the ground hyperfine levels is achieved. We measured the ^{85,87}Rb ($5^2P_{1/2,3/2}$) hyperfine levels population by monitoring the $5^2S_{1/2} \rightarrow 5^2P_{3/2}$ probe laser absorption. Modulations in the $5^2S_{1/2} \rightarrow 5^2P_{3/2}$ hyperfine absorption line profiles are observed as a direct consequence of the velocity selective optical pumping induced by the frequency comb excitation. The ^{85,87}Rb $5^2S_{1/2} \rightarrow 5^2P_{1/2,3/2}$ fs pulse train excitation of a Doppler broadened rubidium vapor was investigated theoretically in the context of the density-matrix formalism. Simulated $5^2S_{1/2} \rightarrow 5^2P_{3/2}$ absorption profiles were compared with the experiment and the agreement was excellent. The dependence of the observed modulations upon the wavelength and power of the fs laser and external magnetic field was investigated experimentally.

References

[1] A. Marian, M. C. Stowe, J. R. Lawall, D. Felinto and J. Ye, Science 306, 2063 (2004).
[2] A. Marian, M. C. Stowe, D. Felinto and J. Ye, Phys. Rev. Lett. 95, 023001 (2005).
[3] D. Aumiler, T. Ban, H. Skenderovic and G. Pichler, Phys. Rev. Lett. 95, 233001 (2005).
[4] T. Ban, D. Aumiler, H. Skenderovic and G. Pichler, to be published in Phys. Rev. A (2006).

Compression of frequency doubled Nd:glass laser pulses down to 40 fs

I. Procino[1], C. Altucci[1,3], S. Amoruso [1,2], R. Bruzzese [1,2], V. Tosa [4], R. Velotta [1,3], C. Vozzi [5], and X. Wang[2]

[1] *Dipartimento Scienze Fisiche, Università di Napoli "Federico II", Napoli, Italy*
[2] *COHERENTIA-CNR, Napoli, Italy*
[3] *CNISM, Napoli, Italy*
[4] *NIRDIMT, Cluj-Napoca, Romania*
[5] *Dipartimento di Fisica, Politecnico di Milano, ULTRAS-CNR, Milano, Italia*
E-mail:carlo.altucci@na.infn.it

A Nd:glass laser pulse is spectrally broadened in order to obtain a temporal compression. The employed, commercial Nd:glass laser source delivers pulses with energy up to 4.3 mJ at wavelength λ=1055 nm and with pulse duration of 1 ps. The infrared pulse is frequency doubled by a II-type KDP crystal in which also a considerable temporal compression takes place by means of the so-called nonlinear pulse compression [1,2]. The second harmonic pulse (λ=527 nm, 1 mJ, 200 fs) is then focussed at the entrance of a hollow fiber filled with Argon or Krypton. Typical gas pressures falls within the 1-2 bar range. The maximum coupling of the pulse energy with a fiber having the inner diameter of 360 μm is found when using a lens having a focal distance of 25 cm. The fiber is placed in a V-groove and set in a high pressure chamber with quartz windows. Large spectral broadening is obtained because of the self-phase modulation occurring in a Kerr medium. By using the split-step Fourier algorithm [3] the nonlinear Schrödinger equation, describing the ultrashort laser pulse propagation in optical fibers, has been numerically integrated. An excellent agreement with the measured spectra is found in all the experimental conditions. By using a 70-cm long, fused silica hollow fiber an output pulse bandwidth as large as 20 nm is achieved when the pressure chamber is filled with 2 bar of Argon. In such conditions the highest obtained energy coupling to the fundamental beam mode of the fiber is about 40 %, thus leading to about 0.4 mJ output broadened pulses.

Detailed project and design of a double prism compressor [4,5] are, then, presented. The presented compressor compact scheme, based on the use of two SF10 equilateral prisms, will allow one to completely remove the large GVD of the broaden pulses ($\approx$3500 fs^2) and partially compensate also for the third order dispersion. The final predicted pulse duration is of $\approx$40 fs with a pulse energy of about 0.3 mJ concentrated in the hot, central part of the beam. This also leads to a pulse peak power increased by almost a factor of two after compression.
This work is the first attempt where the hollow fiber technique is applied to broaden a laser pulse whose central wavelength is 527 nm, thus opening the way to accessing with relatively high energy laser pulses the few fs duration regime in the centre of the visible range.

References

[1] R. Danielius, A. Dubietis, A. Juozapavicius, A.Piskarskas, G. Tamosauskas, A. Varanavicius, SPIE **5137**, 10 (2003).
[2] Y. Wang, R. Dragila, Phys. Rev. A **41**, 5645 (1990).
[3] G. P. Agrawal, *Nonlinear fiber optics*, 2nd edn. (Academic, San Diego, CA 1995).
[4] R.L. Fork, O.E. Martinez, and J.P. Gordon, Opt. Lett. **41**, 150 (1984).
[5] Ch. Spielmann, M. Lenzner, F. Krausz, and R. Szipöcs, Opt. Comm. **120**, 321 (1995).

Investigating Strong Laser Field Effects in Autoionizing Resonances

C. Banahan[1], J. T. Costello[1], D. Kilbane[1] and P. van Kampen[1].

[1]*National Centre for Plasma Science and Technology (NCPST) and School of Physical Sciences, Dublin City University, Dublin 9, Ireland*
E-mail:caroline.banahan2@mail.dcu.ie

For many years now the study of highly excited or core-excited states has been limited to single photon absorption from the ground state, only allowing a restricted number of states to be accessed [1,2]. Reaching states not accessible from the ground state and studying coupling between highly excited states would provide insight into the fundamental dynamics of atomic systems and allow us to explore new regions in the atomic world. In this work we will study such states using two-photon photoabsorption of ions utilising an XUV plasma source and visible photons from an optical parametic oscillator (OPO) tuneable laser. We tune an OPO laser to the $3p^6 4s^2$ - $3p^6 4s4p$ transition of Ca I to produce a high density of atoms in the 4s4p excited state; we then record the XUV photoabsorption from 4s4p to highly excited states using the DLP technique [3]. This will yield many new first-ever recorded spectral lines in neutral calcium.

Using the DLP technique to isolate the autoionizing 3p-3d giant resonance in Ca II, we aim to study the effects on the ionization dynamics when we couple this state to a higher-lying autionizing resonance by means of the OPO. A drastic modification of the ionization dynamics is currently predicted by sophisticated theoretical methods [4,5] but needs to be verified experimentally. By varying the intensity of the OPO we aim to study the interference effects between the two autoionizing states, namely to study the AC Stark Effect.

Work supported by the Irish Governments National Development Plan under the Basic Research Grants Scheme administered by the Irish Research Council for Science Engineering and Technology.

References

[1] J B West 2001 - *J. Phys. B: At. Mol. Opt. Phys.* **34** R45
[2] B F Sonntag, P Zimmermann. 1992 - *Rep. Prog. Phys.* **55** 911
[3] E T Kennedy 1994 - *Opt. Eng* **33** 3984
[4] N E Karapanagioti *et al* 1995 - *Phys. Rev A* **53** 2587
[5] Y L Shao, D Charalambidis, C Fotakis, Jian Zhang, P. Lambropoulos 1991 - *Phys. Rev. Lett.* **67** 3669.

Femtosecond pulse propagation in a resonant medium

D. Aumiler[1], N. Vujičić[1], Hrvoje Skenderović[1] and G. Pichler[1]

[1]*Institute of Physics, Zagreb, Croatia*
E-mail: aumiler@ifs.hr

The subject of coherent interaction of a short laser pulse and a two-level atomic system has been investigated extensively in literature, both theoretically and experimentally [1]. Many effects in gaseous and solid-state media have demonstrated both the linear absorptive and dispersive nature of the interaction and the nonlinear properties of short-pulse propagation. In particular, effects that are due to coherence, such as self-induced transparency, free-induction decay, optical nutation and photon echo have been observed in experiments in which relaxation times of the medium were longer than the duration of the pulse. Additionally, the reshaping and breakup of low-intensity, or 0π pulses, was reported [2].
In this work we investigate the propagation of an ultrashort (100 fs) laser pulse in the optically thick Rb atomic vapor, in the case when the pulse duration is smaller than the inverse spectral width of the absorption line. The envelope of such a pulse experiences strong reshaping effects and develops an oscillatory temporal structure, as a result of the strong nonlinear behavior of the refractive index over the broad pulse spectrum.
The pulse reshaping is investigated experimentally for different laser detunings and Rb atom concentrations. We imploy a simple theoretical model to interpret the results and demonstrate good agreement with the observations.

References

[1] G. P. Agrawal and R. W. Boyd, *Contemporary Nonlinear Optics* (Academic Press, San Diego, California, 1992).
[2] M. D. Crisp, Phys. Rev. A **1**, 1604 (1970).

Time resolved fluorescence anisotropy of organic nanoparticles formed in combustion processes

A. Bruno[1], P. Minutolo[2], C. de Lisio[1], A. D'Alessio[3]
[1]*Dipartimento di Scienze Fisiche, Università di Napoli "Federico II" and Centro di Ricerca e Sviluppo "Coherentia", CNR-INFM, Complesso di Monte S. Angelo, Via Cintia, I-80126, Napoli, ITALY*
[2]*Istituto di Ricerche sulla Combustione, CNR, P.le Tecchio, 80, 80125, Napoli, ITALY*
[3]*Dipartimento di Ingegneria Chimica, Università di Napoli "Federico II", P.le Tecchio, 80, 80125, Napoli, ITALY*
E-mail: annalisa.bruno@na.infn.it

In the last few years several toxicological and epidemiological studies have undoubtedly associated high concentration of airborne ultrafine particulate matter with increased human morbidity and mortality. Depending on physical and chemical properties, particulate matter with nanometric diameter can deeply penetrate in the pulmonary alveoli, in the circulatory system and also deposit in the brain [1,2]. Consequently, a detailed characterization of nanometric particles is of extreme importance in view of reduction of their effects on human health. Carbonaceous atmospheric aerosols represent approximately 50% of the total particulate matter mass, and a non-negligible fraction is produced in combustion processes as elemental carbon, soot, and organic carbon, whose composition is still essentially unknown. Recent researches have shown that combustion of fuel-rich mixtures promote the creation of organic particles with typical sizes of 2-3 nm before large soot particles formation. These structures are transparent to the visible radiation, and have spectroscopic features similar to aromatic compounds with 2-3 condensed rings. Their coagulation rate is orders of magnitude smaller than the gas-kinetic value, and they also have partial affinity with water that allow to capture them by means of water-sampling. All these features make such particles object of growing concern for their possible adverse health effects and role in the climate radiative balance. Nevertheless, information regarding their concentration, chemical composition, size and adverse health effects is clearly lacking [3-5]. The goal of this work is to study the emission of nanometric particles from combustion systems and at the exhausts of laboratory flames, for which the formation routes of combustion by-products are already known. The particles are collected by means of the water-based sampling technique developed in previous studies. The sampling method is optimised and characterized so that the sampling efficiency is determined both for the sampling in the high temperature environment and at the exhausts. The amount of particulate matter emitted by the practical combustion systems is estimated by determining both light absorption spectra and Total Organic Carbon (TOC) by means of a suitable TOC analyser. The chemical structure of the sampled material is investigated by spectroscopic analysis of light absorption and fluorescence. Time Resolved Fluorescence Polarization Anisotropy (TRFPA) was used as sizing technique [6]. By spectrally resolving the fluorescence light in TRFPA analysis, it is also possible to correlate the particle size to the detection wavelength, which, in turn, is strictly related to the chemical composition.

References

[1] G. Oberdoster et al., Inhalation Toxicology 16, 437-445 (2004).
[2] G. Oberdoster et al., J. Tox. Env. Health 65, 1531-1543 (2002).
[3] A. D'Alessio, A. D'Anna, A. D'Orsi, P. Minutolo, R. Barbella, A. Ciajolo, Proc. Comb. Inst. 24, 973(1992).
[4] A. D'Alessio, A.C. Barone, R. Cau, A. D'Anna, P. Minutolo, Proc. Comb. Inst. 30, 2595 (2005).
[5] H. G. G. Wagner ed., *Soot Formation in Combustion, An International Round Table Discussion*, (Nachrichten der Akademie der Wissenschaften, Gottingen 1989).
[6] A. Bruno, C. de Lisio, P. Minutolo, Opt. Exp. 13, 5393 (2005).

Exactly solvable approximants adjusted to direct and inverse problems for diatomic quantum systems

M. Selg

Institute of Physics of the University of Tartu, Riia 142, 51014 Tartu, Estonia
E-mail:matti@fi.tartu.ee

Nowadays, solution of one-dimensional Schrödinger equation related to a known potential is not any serious problem, except if this elementary act has to be performed many million times in a reasonable time scale. Such a situation is quite common for an accurate spectroscopic calculation concerning transitions between ro-vibrational states of two electronic states in a wide range of nuclear separations. In this case the efficiency of calculations could be essentially improved, if they could be carried out analytically, instead of applying methods of numerical integration. On the other hand, strictly speaking, for any real system the interaction potential is known only approximately. It means that in most cases the solution of the Schrödinger equation only provides an approximate reflection of the reality, not the reality itself. Of course, one's aim (in ideal) is to minimize uncertainties and to build up the "real" potential which would match all experimental data. A possible step-by-step strategy towards this goal is to proceed from an approximate but exactly solvable potential for the system.

The author has developed this kind of reference potential approach in terms of several smoothly joined Morse type components [1]. Besides ordinary Morse potentials these components may be of "reversed" form with a negative dissociation parameter or "pseudo-Morse" potentials having no bound states (if taken separately). Such a multi-component potential is exactly solvable, in the sense that the related energy eigenvalue problem can be solved analytically with any desired accuracy. The optimal number of components is a subject for trial, and their parameters are varied until the best fit with the available experimental data is achieved.

If one manages to construct a sufficiently correct reference potential, a further step might be applying rigorous methods of inverse quantum theory. To this end, one has to accurately ascertain all spectral characteristics of the reference potential, including the full energy dependence (from 0 to ∞) of the phase shift for the scattering states, and the Jost function (the details are described elsewhere [2]). These characteristics can be reused as input parameters for applying methods of the inverse theory. In principle, one can construct an improved potential for the system, and such possibilities will be analyzed on example of diatomic xenon molecule in its ground electronic state. As a particular result, a full agreement with Levinson theorem will be explicitly demonstrated.

References

[1] M. Selg, J. Mol. Spectrosc. **220**, 187 (2003).
[2] M. Selg, Molecular Physics (2006, in press).

Signatures of quantum chaos in doubly excited helium

R. Püttner[1], Y. Jiang[1], D. Delande[2], M. Martins[3], and G. Kaindl[3]

[1] *Freie Universität Berlin, Institut für Experimentalphysik, D-14195 Berlin, Germany*
[2] *Laboratoire Kastler-Brossel, Universite Pierre et Marie Curie, F-75252 Paris Cedex 05, France*
[3] *Universität Hamburg, Institut für Experimentalhysik, D-22761 Hamburg, Germany*
E-mail:puettner@physik.fu-berlin.de

Doubly exited helium approaches the semi-classical limit, i.e. $\hbar \rightarrow 0$, in the region close to the double-ionization threshold. Since the classical counterpart of the helium atom, the classical three-body system, is a non-integrable system, i.e. it can behave chaotic, one expects quantum chaos in the spectrum of the doubly excited resonances in helium close o the double ionization threshold. Studies of these doubly excited states below the single ionization threshold (SIT) I_9 of He^+ showed a transition towards quantum chaos by analyzing the distribution of the nearest-neighbor energy spacings between the resonances [1].
Now we present measurements in the energy region up to the SIT I_{15}, which show excellent agreement with state-of-the-art complex-rotation calculations. Based on these calculations the spectral features were assigned using the classification scheme N, K_n. Here N (n) is the principal quantum number of the inner (outer) electron and K an angular-correlation quantum number. We studied the validity of these approximate quantum numbers by investigating the statistical properties of the nearest-neighbor energy spacings on the basis of the theoretical results. These studies proved that K is a good quantum number for a large fraction of resonances and it dissolves rather slowly while approaching the double ionization threshold. Therefore, the transition region from integrability to full chaos is much larger than expected before. In contrast to the findings on K, it has been found that the physical meaning of the principal quantum numbers N and n is almost fully lost in the energy region of the SIT I_{15}. In addition statistical analyses on the linewidths and Fano-parameters q were performed displaying also interesting precursor signatures of quantum chaos in doubly excited helium. Ericson fluctuations are considered to be a signature of quantum chaos and they are also predicted for helium. However, based on the present assignment of the cross section no indication for the presence of Ericson fluctuations are found; this is attributed validity of K as a good quantum number for a large number of resonance.

References

[1] R. Püttner *et al.*, Phys. Rev. Lett. **86**, 3747 (2001).

Saturday, June 10th

Quantum degenerate atomic gases

Massimo Inguscio

Dipartimento di Fisica and LENS
Polo Scientifico-Università di Firenze, 50019 Sesto Fiorentino, Italy

We shall report on experiments performed at LENS with a BEC of rubidium, a degenerate potassium Fermi gas and mixtures of the two. We shall describe physics with one dimensional and three dimensional optical lattices (crystals of light) and discuss new localization effects induced by disorder. In the mixture the interactions are controlled by magnetic fields (Fano-Feshbach resonances). Perspectives in the direction of stability and formation of molecules will be discussed.

Fermionic atoms in a crystal structure of light

Tilman Esslinger

Department of Physics, ETH Zurich, Zurich, Switzerland

A general introduction to the physics of ultracold atoms in optical lattices will be given. These systems provide a new avenue for designing and studying many-body quantum systems. Exposed to the crystal structure of interfering laser waves the fermionic atoms behave much like electrons in a solid. However, the properties of this synthetic material can be changed at will. The collisional interaction between fermionic atoms in different spin states can be tuned using a Feshbach resonance and the dimensionality is controlled almost like a parameter. In the experiment we have been able to directly image the Fermi surface of the atoms in the optical lattice and to study the transition of the system from a conducting state to a band insulator [1]. Using a Feshbach resonance we have dynamically induced a coupling between the lowest energy bands and formed molecules in the optical lattice [2]. The unique versatility of atoms in optical lattices may allow the study of a whole catalogue of phenomena linked to solid-state physics or even to mimic the physics underlying high-temperature superconductivity.

References

[1] M. Köhl, H. Moritz, T. Stöferle, K. Günter, T. Esslinger, Phys. Rev. Lett. 94, 080403 (2005).
[2] T. Stöferle, H. Moritz, K. Günter, M. Köhl, T. Esslinger Phys. Rev. Lett. 96, 030401 (2006).

A single aluminum ion optical clock using quantum logic

P. O. Schmidt[1], T. Rosenband, D. B. Hume, T. M. Fortier, J. Stalnaker, L. Lorini, J. C. J. Koelemeij[2], W. H. Oskay[3], S. A. Diddams, W. M. Itano, J. C. Bergquist, and D. J. Wineland

National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA
[1]*present address: University of Innsbruck, Austria*
[2]*present address: University of Düsseldorf, Germany*
[3]*present address: Stanford Research Systems Sunnyvale, CA*
E-mail:piet.schmidt@uibk.ac.at

Optical spectroscopy of ions and neutral atoms holds the promise of optical clocks with unprecedented stability and accuracy. In the past, the choice of atomic species with transitions suitable for precision spectroscopy was often restricted to atoms that also had suitable transitions for laser cooling, state preparation and detection. A recent proposal [1] overcomes this limitation by assigning these latter tasks to an auxiliary atomic species using quantum logic methods. In our implementation, a laser-cooled beryllium ion is trapped in a linear Paul trap simultaneously with an aluminum ion [2]. Al^+ has resisted precision spectroscopy in the past since its laser cooling transition is at a wavelength of 167 nm. The Coulomb interaction between the ions allows us to sympathetically cool Al^+ via Be^+. Using quantum logic techniques, we map the internal state of the aluminum ion onto the beryllium ion, where it is then detected with high efficiency. An extension of this technique allows us to deterministically prepare any desired Zeeman substate of the aluminum ion.
Our choice of $^{27}Al^+$ is motivated by its potential as a high-accuracy optical clock: the $^1S_0 \leftrightarrow ^3P_0$ clock transition has a very high Q-factor of $f/\Delta f \simeq 2\times10^{17}$ ($\lambda \simeq 267$ nm) and a small black-body radiation shift [3]. We have used quantum logic based spectroscopy to operate an $^{27}Al^+$ frequency standard by stabilizing a narrow-linewidth (< 6 Hz) interrogation laser to the mean transition frequency of the $m_F = \pm5/2$, $\Delta m_F = 0$ clock transitions. Using a femto-second frequency comb, we have measured the ratio of its frequency to that of the single mercury ion optical frequency standard [4], as well as hydrogen masers maintained by NIST. Largely owing to the higher frequencies in the optical domain, the fractional frequency instability of the Al^+/Hg^+ optical frequency comparison is improved by more than one order of magnitude over the radio-frequency measurement. After an averaging time of approximately 30000 seconds, a fractional frequency uncertainty below 10^{-16} is reached.
The application of quantum logic methods is not limited to optical clocks, but may also be used to perform spectroscopy of atoms and small molecules with complex internal level structure, for which no cycling transition is available.

This work was supported by the National Institute of Standards and Technology (NIST), and the Office of Naval Research (ONR). P. S. acknowledges support from the Alexander von Humboldt Foundation. J. K. acknowledges support from the Netherlands Organization for Scientific Research.

References

[1] D. J. Wineland, J. C. Bergquist, J. J. Bollinger, R. E. Drullinger, W. M. Itano, *Proc. 6th Symposium Frequency Standards and Metrology*, P. Gill, ed. (World Scientific, Singapore, 2002), pp. 361–368.
[2] P. O. Schmidt, T. Rosenband, C. Langer, W. M. Itano, J. C. Bergquist, and D. J. Wineland, Science **309**, 749–752 (2005).
[3] T. Rosenband, W. M. Itano, P. O. Schmidt, D. B. Hume, J. C. J. Koelemeij, J. C. Bergquist, and D. J. Wineland, Proceedings of the EFTF meeting (Braunschweig, 27-30 March 2006).
[4] W. H. Oskay *et.al*, submitted to Phys. Rev. Lett.

Index