Mixed UTA and detailed line treatment for mid-Z spectral calculations

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Abstract. We developed a method to mix detailed and statistical treatments within the same transition array and for a set of transition arrays entering the spectral or opacity calculations of light and mid-Z elements. By retaining the strongest lines within a given transition array, the method provides a spectral description comparable in accuracy to a detailed treatment approach, where all the lines are explicitly included in the spectral calculation. The remaining weak lines are represented by a UTA-like functional form. Overall, we show that the computational cost approaches the statistical UTA method. The method has been implemented in the Cowan atomic structure code and applied to the calculation of the LTE and non-LTE spectra of two mid-Z elements, xenon and iron. A comparison with recent iron absorption experiments at Sandia National Laboratory will be presented.

ENERGY LEVELS AND OSCILLATOR STRENGTHS FOR TRANSITIONS IN Kr XXXII-XXVIII

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Krypton is an important impurity element in tokamak fusion plasmas, and due to their high temperatures ($> 10^6$ K), many of its ionisation stages are accessible. Therefore, in order to estimate the power loss from the impurities, atomic data (namely energy levels, oscillator strengths or radiative decay rates, collision strengths, etc.) are required for many ions. Since there is paucity of measured parameters, one must depend on theoretical results.

Atomic data so far available in the literature are either confined to a few limited levels/transitions, or lack accuracy. Therefore, we report the above parameters for a comparatively larger number of levels/transitions. Furthermore, we are reporting radiative rates for four types of transitions, namely electric dipole (E1), electric quadrupole (E2), magnetic dipole (M1) and magnetic quadrupole (M2), among the lowest 125, 236, 272, 226 and 113 levels of Kr XXXII, Kr XXXI, Kr XXX, Kr XXIX, and Kr XXVIII, respectively. These levels belong to the $n \leq 3$ configurations. Finally, we also report results of lifetimes for all levels in all five ions, although no measurements are so far available for comparison.

For our calculations, we have adopted the GRASP (*General purpose Relativistic Atomic Structure Package*) code by Dyall et al. [1]. This is a fully relativistic code, and is based on the jj coupling scheme. Further relativistic corrections arising from the Breit interaction and QED effects have also been included. Additionally, we have used the option of *extended average level* (EAL), in which a weighted (proportional to $2j$+1) trace of the Hamiltonian matrix is minimized. This produces a compromise set of orbitals describing closely lying states with moderate accuracy. Furthermore, in order to assess the accuracy of our results, calculations have also been performed from the *Flexible Atomic Code* (FAC) of Gu [2], which is available at the website: `http://kipac-tree.stanford.edu/fac`.

Comparisons are made with the earlier available theoretical and experimental results, and some discrepancies are noted. A complete set of all results will be presented during the conference.

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Total Ionization Cross Sections of Silicon Chlorides by Electron Impact

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Abstract. The knowledge of electron impact ionization cross sections, direct and dissociative, of $SiCl_4$ is important in technological applications. $SiCl_4$ is one of the main volatile products in etching of silicon by chlorine and is also used in plasma feed gas mixtures for selective ion etching and other plasma enhanced chemical vapor deposition processes. We use the binary-encounter-Bethe (BEB) model of Kim and Rudd [1] with molecular orbital parameters derived from approximate Hartree-Fock wave functions to calculate total direct ionization cross sections by electron impact for $SiCl_x$ (x = 1 to 4). We compare these total cross sections with those obtained from the use of valence only molecular orbital parameters from relativistic core potential calculations in the BEB model, with theoretical results of Huo [2] and the only available experimental results for $SiCl_4$ by Basner et al. [3].

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Optimization Of X-ray Laser On The 3p-3s Transition Of Ne-like Ti

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Abstract. Previous experiments performed on the SOKOL-P facility have demonstrated generation of the laser X-radiation (LXR) with the wavelength λ=326 Å on Ne-like Ti ions at sequential irradiation of the targets by two laser pulses of nanosecond and picosecond duration, focused into a narrow line [1]. In these experiments, the effective small signal gain equaled $\approx$30 cm^{-1}. As the design-theoretical analysis shows the limitation of output energy of the X-ray laser at targets of lengths more than 5 mm is determined by effects of saturation and retardations of radiation. In this paper we present results of experiments, where the effect of focusing conditions and pumping laser energy on the laser X-radiation yield was studied. The dependence of the LXR yield on target position relative to the focusing plane of the pumping laser beam was studied. This dependence has a well-defined maximum when the target is positioned at a distance of about 300 μm behind the focusing plane. In this position, the width of the focal line is about 120 μm, and the energy flux density of the pumping laser is $0.5 \cdot 10^{12}$ W/cm^2 in the prepulse of $\approx$ 400 ps duration and about $(1 \div 2) \cdot 10^{14}$ W/cm^2 in the main pulse of 4 ps duration. The main pulse delay is $\approx$ 1.5 ns. The traveling pumping wave mode was realized using the step-like mirror. At the maximum target length (8 mm) the LXR yield is as great as 5-fold, if compared to target irradiation without the step-like mirror. The value of the total laser radiation energy varied from 5.9 to 11.5 J. The energy ratio in the prepulse and the main pulse was kept constant 1:2.4. In this mode, the dependence of LXR yield on the total laser energy was measured. This dependence is demonstrated to have an exponential form.

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Pressure broadening in the far wings of potassium resonance lines

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Abstract. The broadening of atomic lines through collisions with perturbing atoms or molecules is of wide-ranging importance. Spectroscopy of resonance lines of alkali-metal atoms pressure broadened by inert gases at temperatures approaching 1000 K has revealed that far wings of spectral lines possess shapes indicative of the separation-dependent interaction energies between radiators and perturbers. Experimental measurements of the far wings of spectral lines broadened by molecular hydrogen are relatively scarce. If molecular potential energy surfaces and transition dipole moments are available, theoretical methods can be used to calculate pressure broadened line profiles. For helium and for molecular hydrogen, we will present theoretical and experimental absorption coefficients for pressure broadening in the far wings of the potassium $4s$–$4p$ and $4s$–$5p$ resonance lines.
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Keywords:
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Iron Opacity Measurements With Samples Heated By A Dynamic Hohlraum

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Abstract. Laboratory measurements of wavelength-dependent plasma opacities provide benchmark data for opacity models that are a foundation for understanding many phenomena. For example, such data are important for stellar physics, inertial confinement fusion, and z-pinch physics. Measurements of iron opacity at temperatures above 150 eV are in progress using x-rays generated by the dynamic hohlraum radiation source at the Sandia Z facility to heat a tamped sample. The sample consists of layered Mg/Fe with typical thicknesses of 0.3 microns Mg and 0.05-0.10 microns Fe. The sample is tamped by 10 microns CH on both sides to promote uniformity. The x-ray source both heats the sample and provides a broad wavelength backlighter to enable sample absorption measurements. The sample transmission is measured in the 6-16 Angstrom range by comparing absorption spectra obtained with and without the Fe/Mg layer. The electron density and temperature are inferred by analysis of the Mg K-shell transitions. Typical values are Te ~ 155 eV and ne ~ 1e22 cm-3, corresponding to a mass density of 0.05 g/cc. The Fe L-shell absorption features consist of bound-bound transitions in the Ne- F- and O-like charge states, as well as the associated bound-free continuum. Comparisons with Opal, PrismSPECT, and Atomic/MUTA opacity code calculations will be discussed. Radiation-hydrodynamic simulations of the sample conditions are being used to strengthen understanding of the sample conditions and to help in planning a new generation of experiments.

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A radiationally-damped relativistic R-matrix approach to electron-scattering of highly ionised Tungsten species

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Abstract.
The current design plans for the International Thermonuclear Experimental Reactor (ITER) call for tungsten to be employed for certain plasma facing components in the divertor region. Thus, accurate atomic collision data are needed for emission modeling of tungsten. Electron-impact excitation and radiative rates are of particular importance for closed shell species such as Ni-like W and neighboring ion stages that exhibit strong sprectral features.

We report on new fully relativistic *R*-matrix calculations for W^{44-45+}, which include the effects of radiation damping. Radiation damping is found to be small for W^{45+}, but is appreciable for many of the excitations from the ground and metastable levels of W^{44+}. Rates from the present calculations will be combined with those from the calculations for W^{46+} [1] and employed for collisional-radiative modeling for these ions.

Keywords: electron-scattering,Tungsten,plasma modeling,radiation damping
PACS: 34.80

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J. Phys. B: At. Mol. Opt. Phys. 39 No 17 (14 September 2006) 3617-3628

Calculation of the total radiative power loss of a non-LTE Germanium plasma

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A method is proposed for the global calculation of the bound-bound part of the total radiative power loss (RPL), in an optically thin hot plasma. Two types of cases are treated, namely, that within superconfigurations $(n)^N$ and $(n)^{N-1}(n')^1$, and that between those superconfigurations. They are most interesting because, for the small values of n and n', the relevant configurations represent more than 95% of the total population of all the ions. Using the Second-Quantization formalism and an ab-initio atomic-spectroscopy code, it is possible to obtain their contributions to the RPL for all the values of N in terms of some of them.

An application to a Germanium plasma at T_e = 150 eV and $N_e = 10^{20}$ cm^{-3} is presented.

Line Shape And Gain Calculations In Transient X-Ray Lasers: Role of Electron-Ion Collisions

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Abstract. The amplifying medium of a transient x-ray laser pumped by a $\approx$1 ps IR driver is a laser-produced plasma with electron temperatures of many hundreds eV and electron densities in the range 10^{20}-10^{21} per cc. The gain coefficient, and then the output intensity are determined by the two lasing levels population densities and by the profile of the optically thin (lasing) line. These populations need to solve a set of collisional-radiative equations with population transfers depending on collision excitation rates. The knowledge of such rates is essential in population kinetics studies. In order to obtain the collisional excitation rates we have used the codes HULLAC and DW. The main broadening mechanisms concerning lasing lines in the transient pumping scheme are the electron and Doppler broadening. We have used reliable collisional excitation/deexcitation data in a sophisticated line shape code, namely the code PPP developed at Université de Provence. Transient x-ray lasers are often saturated; the interaction of the x-ray laser electric field and the lasing ions should then be correctly accounted for. This yields different populations for the Zeeman levels of the lower lasing J=1 level. We have also investigated the effect of elastic electron-ion collisions transferring populations among the Zeeman sublevels. Hydrodynamic parameters such as electron density and electron and ion temperatures are obtained with the help of the hydrocode EHYBRID.

Electron-impact ionization of the metastable excited states of Li^+

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Abstract.
Studies of electron-impact ionization of the $1s2s\ ^3S$ metastable state of He show a discrepancy between non-perturbative theory and experiment [1]. This disagreement motivates our calculations of electron-impact ionization cross sections for the $1s2s\ ^1S$ and $1s2s\ ^3S$ metastable states of Li^+. Both perturbative distorted-wave and non-perturbative close-coupling methods are used. Term-resolved distorted-wave calculations are found to be approximately 15% above term-resolved *R*-matrix with pseudostates calculations, while configuration-average time-dependent close-coupling calculations are found to be in excellent agreement with the configuration-average *R*-matrix with pseudostates calculations. The non-perturbative *R*-matrix and time-dependent close-coupling calculations provide a benchmark for experimental studies of electron-impact ionization of metastable states along the He isoelectronic sequence.

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Use of Electron-Ion Bremsstrahlung Emission for Shot-to-Shot Absolute Intensity Calibration of the CXRS Diagnostic on the Alcator C-Mod Tokamak

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Abstract. Charge Exchange Recombination Spectroscopy is used as a diagnostic for the local density of the fully stripped boron impurity in the Alcator C-Mod Tokamak. The density is determined from the total absolute intensity of the B^{+4} emission line due to the n=7→6 transition at wavelength of 4944.67Å.[1] In order to perform any absolute intensity measurement, the optical system must be accurately calibrated. For the CXRS optical system, this procedure has typically been limited to just twice a year, before and after the experimental campaign when the C-Mod vacuum vessel is up to air. In order to enhance the accuracy of the absolute line intensity measurement, a new shot-to-shot calibration method is proposed and then applied to actual C-Mod data. The method uses the electron-ion bremsstrahlung emission spectral background which is observed beneath the 7→6 B^{+4} transition line in the emission spectrum that is observed for the for the regular CXRS measurements. The bremsstrahlung emission intensity is predicted using the independently -measured local values of T_e, n_e and Z_{eff} and then compared with the spectral measurements. Thompson Scattering (TS) and the Visible Bremsstrahlung Array (VBA) are standard C-Mod diagnostics and provide the local values of the T_e, n_e and Z_{eff}. The accuracy of the resulting impurity density measurements is affected by the accuracy of the TS and VBA diagnostics, the interpretation of the background emission as pure electron-ion bremsstrahlung, the model used for electron-ion bremsstrahlung, and various other issues such as the appropriateness of the physical model of the charge exchange and other emission processes and accuracy of their corresponding cross sections[2] that are used in the model.

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Reactive Oxygen Species in RF High-Pressure Cold Plasma Jet Used for Biofilm Inactivation

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Abstract.
The removal and disposal of biofilms is an expensive, time-consuming effort required in many industries (medical, piping, and water purification to name a few). Biofilms are bacterial communities that coalesce in an exopolysaccharide matrix, which enables them to adhere to different surfaces and makes them more resistant to conventional sterilization techniques than free, mobile bacteria. Gas discharge plasmas are a novel approach to inactivating biofilms. They contain a mixture of charged particles, chemically reactive species, and UV radiation, all of which are well-established sterilization agents against free microorganisms. Our group has previously shown gas discharge plasmas to be an effective mean for biofilm inactivation. The present work investigates the chemical composition of gas discharge plasmas in order to identify possible biofilm inactivation mechanisms.
Methods: Optical emission spectroscopy was used to determine the chemical content of two types of radio frequency atmospheric pressure gas discharge plasma: nitrogen-based and oxygen-based plasma. The plasmas were generated using an Atomflo 350L plasma reactor (Surfx Technologies) in which discharge occurs in gas flowing through two narrowly-spaced, perforated electrodes (one at ground, one at 27.12 MHz RF). Plasma leaves the reactor through a 2 inch long, narrow slit orifice. A mixture of helium and a secondary gas, nitrogen or oxygen, was used. The spectroscopy data was obtained using an Ocean Optics HR-2000 spectrometer with .5nm resolution.
Results: Three different chemically reactive oxygen species: NO, OH, and O, were identified. These reactive species are known to deteriorate cell walls and outer membranes, leading to cell inactivation. The relative concentrations were found to be dependent on several plasma parameters, such as plasma power, gas flow rate and distance from the plasma source.
Conclusion: There is a presence of chemically reactive oxygen species in both gas discharge plasmas. These results further indicate the potential of gas discharge plasma as an alternative method for biofilm inactivation.

Spectra of Ne II, Ne III, and Ne IV with a Penning Discharge in the Vacuum Ultraviolet

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Abstract. In connection with spectral response and wavelength calibration of the Extreme Ultraviolet Imaging Spectrograph (EIS), we have photographed spectra of neon with a Penning discharge on the 10.7-m grazing-incidence spectrograph at the National Institute of Standards and Technology (NIST). EIS is one of three instruments aboard the Hinode Satellite observatory, which was launched into space in late 2006. Its mission is to acquire high spectral- and spatial-resolution observations of the solar atmosphere at fast cadence. EIS contains a telescope mirror consisting of an off-axis parabola with 1.93-m focal length, a slit assembly, thin Al filters, a normal-incidence toroidal grating of 1.4-m focal length ruled with 4200 l/mm, and two CCD detectors spanning the ranges 170-211Å and 246-291 Å. High-reflectance multilayer coatings are deposited on the reflecting surfaces to provide high efficiency across these wavelength bands [1]. Prior to launch, a Penning discharge lamp was used to test the response of the spectrograph. Neon and magnesium were selected as the carrier gas and electrode material, anticipating that due to their significant solar abundance they might also be present in the EIS spectra. In these tests it was found that the spectra of Ne II, Ne III and Ne IV needed significant improvement in these regions to test EIS satisfactorily.

To address this problem we photographed the spectrum of a Penning discharge with neon gas and magnesium electrodes on the 10.7-m grazing-incidence spectrograph at NIST. Phosphor storage image plates were used as the recording medium [2]. We found that by using flexible steel strips to obtain better conformance of the image plates to the focal surface, wavelength measurements could be carried out to an accuracy of about 0.003 Å. In addition to obtaining new, accurate measurements for the spectra [3], we observed a number of lines of neon not previously reported. Work is continuing to try to improve excitation of the spectrum of Ne IV and revise some of the identifications of Ne III.

The work at NIST was supported in part by the Office of Fusion Energy Sciences of the U. S. Department of Energy and by the U. S. National Aeronautics and Space Administration.

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Ion Temperature and Expansion Velocity Measurements Through Fluorescence Imaging in Ultracold Neutral Plasmas

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Abstract. Fluorescence imaging is performed on Ultracold Neutral Plasmas to distinguish thermal ion velocity from ion velocity due to plasma expansion. Ultracold Neutral Plasmas are created by photoionizing laser-cooled atoms; the resulting ions are a strongly-coupled liquid. In spite of the fact that these plasmas have temperatures as low as one kelvin, they probe universal physics that applies to more energetic systems. However, in ultracold plasmas the relevant time scales are much longer, powerful optical diagnostics are available, and initial density profiles, energies, and ionization states are accurately known and controllable. These strongly coupled systems can be studied with imaging probes. So far, absorption imaging from previous experiments show Doppler broadening due to the radially directed expansion velocity of the plasma, masking random thermal motion of the ions. Doppler broadening of the ion transition spectrum provides information on ion temperature and velocity. Fluorescence imaging of Ultracold Neutral Plasmas eliminates this plasma expansion limitation and produces a spatially-resolved spectrum that is Doppler-broadened due only to thermal motion and shifted due to ion velocity.

A new experimental approach to QED tests in medium-Z systems

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We have built, installed, aligned and operated a *new X-ray spectrometer* to specifications on the *NIST Electron Beam Ion Trap*. This demonstrates major advances over previous spectrometry, especially regarding the stability of the system in response to mechanical and thermal fluctuations, but also in regard to the capacity for accurate absolute calibrations over the full range of its dispersion function.
A series of other developments have also been performed, especially including a novel multiple detector investigation of systematics. Early signs of significant advance with respect to the analysis of systematic and statistical error budgets will be presented.
Opportunities for further and future developments will be discussed.

Asymmetric Explosion of Laser-Irradiated Hydrogen Clusters

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Abstract: In the femtosecond laser heating of small hydrogen clusters, where we expected angle-resolved time-of-flight (TOF) proton spectra consistent with isotropic coulomb explosions, we instead found strong explosion asymmetry with fast protons emitted preferentially in the direction of the laser polarization.

For smaller clusters of lower Z atoms, laser-induced cluster explosions can be understood by the coulomb explosion scenario. Here, all the atoms in the cluster are ionized to a high degree, and the freed electrons leave the cluster, as they are not adequately restrained by remaining positive charge. The cluster then explodes due to repulsive Coulomb forces between the cluster ions, yielding isotropic ion trajectories. For larger clusters of higher Z atoms, the explosion is better described by hydrodynamic expansion. In this case the cluster atoms are ionized by the rising edge of the laser pulse, but the freed electrons cannot leave the cluster owing to the much stronger electrostatic restraining force of the ions. Instead, the electrons are heated by the remaining part of the laser pulse and preferentially drift along the laser polarization direction in the cluster. The hydrodynamic pressure caused by non-uniform electron distribution then drags the ions preferentially along the laser polarization direction. This asymmetric ion emission has been previously observed in argon cluster explosions [1]. In our ion time-of-flight (TOF) measurements we observed asymmetric argon cluster explosions similar to the results of ref. [1]. For much smaller hydrogen clusters, however, we observed asymmetric behavior similar to argon clusters. This contradicts our intuitive picture of the hydrogen cluster explosion dynamics, in which hydrodynamic expansion is unlikely to happen.

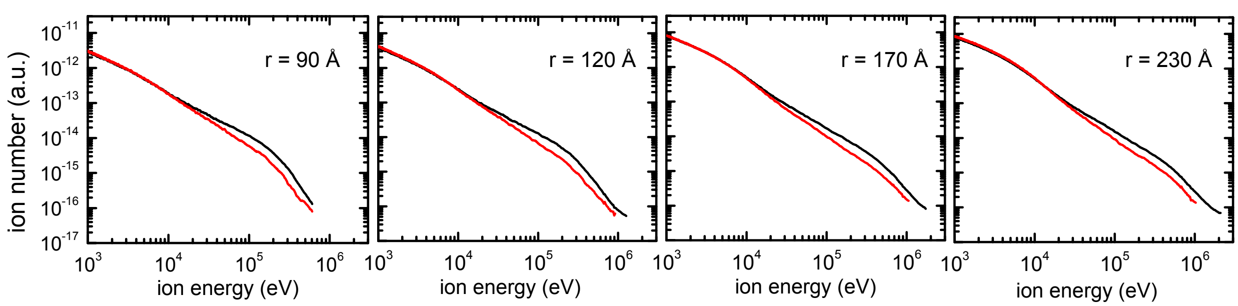

Fig. 1. Argon ion spectra measured for 4 cluster sizes. Black line: laser polarization is parallel to TOF tube axis. Red line: laser polarization is vertical to tube axis.

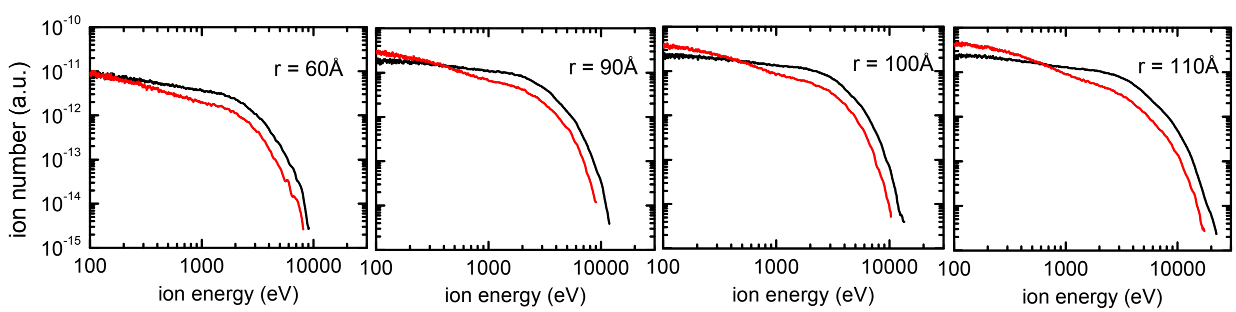

Fig. 2. Proton spectra measured for 4 hydrogen cluster sizes. Black line: laser polarization is parallel to TOF tube axis. Red line: laser polarization is vertical to tube axis.

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FLYCHK At NIST : The Population Kinetics Modeling Capability

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Abstract. Plasma spectroscopy plays an important role in the diagnosis and design of laboratory plasma experiments. With the development of novel plasmas, which access physical regimes in extreme conditions, a general plasma modeling capability is required. This capability is needed to assist in design and analysis of spectroscopic data for a wider range of plasma conditions than previously considered. As a response we have developed FLYCHK [H.-K. Chung, M. H. Chen, W L Morgan, Y. Ralchenko and R. W. Lee, HEDP **1**, 3 (2005)] which is a simple, generalized, non-LTE population kinetics and spectrum generator that provides charge state distributions and synthetic spectra. FLYCHK has been benchmarked against experiments and other kinetics codes and found to provide charge state distributions comparable with both measurements and calculations for most laboratory conditions. At present, an initial version of FLYCHK is implemented at NIST making it widely available to the community with a simple, easy-to-use, fast, and portable interface. Currently, we have 55 users from 14 countries who apply FLYCHK in the area of plasma spectroscopy. We present benchmarked results of FLYCHK, the current status of the code implementation at NIST, and plans for future developments.

PACS: 52.25Jm; 52.25Os;52.40Db;52.70-m

Los Alamos Atomic Data Online

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Abstract. Significant amounts of detailed atomic physics data have been generated using the Los Alamos National Laboratory codes to model and quantify various atomic structure [1], electron impact excitation [2] and ionization processes [3]. These data have been produced for use in collisional-radiative models of plasmas for a variety of applications. Extensive data sets exist for numerous ionization stages of a variety of elements. Efforts are now underway to develop an interactive interface to access these data through the Internet. The interface will allow a user to study a particular element and ionization stage, and permit selection of the data to be viewed. Selections will include atomic structure, electron impact excitation and ionization processes produced by electrons and photons, including autoionization. Fine structure energy levels will be accessible as well as LS terms and configuration-averaged energies. The mixing of basis states for each fine structure level can also be displayed. Radiative transition probabilities from selected levels can be selected in a choice of representations such as gf values, oscillator strength for absorption or emissions, Einstein A coefficients etc. User selection of wavelength or energy can be supported, and cross sections for excitation and ionizations may be displayed in a variety of units. Rate coefficients can also be displayed for collision processes, assuming a Maxwellian electron distribution. A preliminary version of the interface will be available with a limited number of data files. Larger data sets will be added and the interface refined in response to user requests.

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Physics With Multiply Charged Ions In The mVINIS Ion Source

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Abstract. This presentation contains the recent results in production and extraction of multiply charged ions from the mVINIS Ion Source, being of the ECR type. A broad list of obtained ion beam spectra of gases and solid substances [1] gives us a variety of research opportunities in the diagnostics of highly charged ion beams, the plasma diagnostics, spectroscopy in the visible, VUV and X-ray spectral ranges and the low energy interaction of ions with surfaces. The standard diagnostics of highly charged ion beams have been complemented with the high-resolution measurements of the 2D digital beam images (movies). It makes possible the measurements of the position, current, transverse profiles and emittances of a highly charged ion beam (e.g., Xe^{21+}) of the energy of up to 500 keV and the current in the range of 1-300 eμA. The first optical emission spectroscopic study of the ECR plasma in the mVINIS Ion Source was performed. Spectral line shapes and visible spectra of atomic hydrogen and singly ionized inert gases will be presented. In addition, we have used the multiply charged ion beams from solid substances generated with the mVINIS Ion Source (see Fig. 1) to modify materials at the channel for modification of materials (L3A) of the TESLA Accelerator Installation. Some of the results obtained with polymers, carbon materials and fullerenes will be shown.

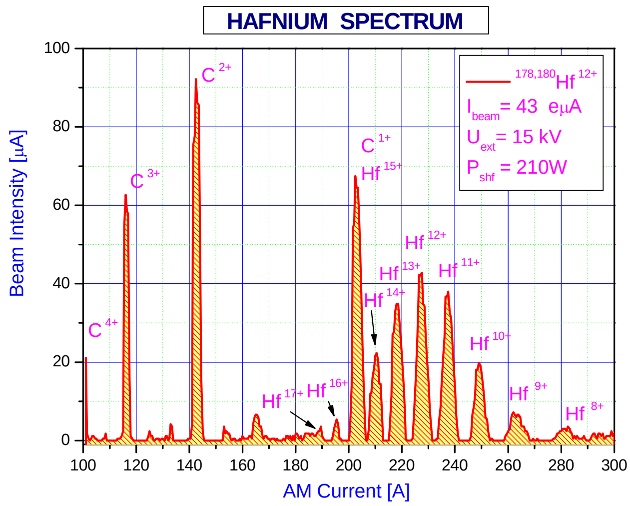

Fig. 1. *A typical spectrum of the hafnium ion beams extracted from the mVINIS, optimized for the Hf^{12+} beam. The beam energy and current are 180 keV and 43 eμA (3 pμA). U_{ext} is the extraction voltage and P_{shf} is the heating microwave power, at the frequency of 14.5 GHz.*

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Fine-structure quantum line broadening data for the 3s - 3p line in Li-like ions

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Abstract. Many atomic codes are now available to built synthetic line spectra of high temperature plasmas. They usually provide energy levels, radiative/autoionisation probability rates, and electron impact collision strengths. Moreinformations could be extracted from them, in particular electron impact line widths which are important for dense plasmas. We present such an extension which was carried on the well-known UCL code package, SUPERSTRUCTURE/ DISWAV/JAJOM. Baranger expression, rewritten by Seaton and formulated in fine-structure, was used. The new code gives the different broadening contributions : excitation, de-excitation and "elastic". As examples, we present the electron line-broadening of the 3s - 3p line in Li-like ions. Comparisons with available theoretical and experimental data are also presented.

Electron-ion collisional data for anisotropic electron distribution : population and alignment

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Abstract. The projectile electron velocity distribution being expanded in terms of Legendre polymonials and the level density matrix elements (ρ_{mn}) being written in tensorial form ($\rho^K{}_q$), one can reduce the different transition matrix elements to a compact expression which can be easily calculated. We present a new version of the well-known UCL code package, DISWAV/JAJOM modified to give electron-ion "collision strengths" for anistropic electron. It is then possible to insert the data directly in a collisional-radiative model (e.g. Fujimoto's Polulation-Alignment Collisional-Radiative model PACR). Transition matrix elements between different $\rho^K{}_q$ are obtained. Such data are important to analyze quantitatively line-polarization of EBIT atomic spectra and radiative transfer (e.g. destruction of alignment by thermal electrons). As example, we shall present data for Be-like oxygen.

Atomic Kinetics Modeling of Photoionized Plasmas

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The availability of high-resolution spectroscopic data recorded by the orbiting telescopes Chandra and XMM-Newton has motivated a renewed effort on the interpretation and modeling of x-ray spectra from astrophysical plasmas and, in particular, photoionized plasmas which are among the brightest sources of x-rays. On the other hand, the possibility of generating photoionized plasmas driven by the Z facility at Sandia National Laboratories creates an opportunity for studying these plasmas in the laboratory as well. We discuss an experimental and modeling effort to investigate the dynamics of photoionized plasmas with an emphasis on atomic kinetics and radiative properties. Unlike collisional plasmas, the atomic kinetics of photoionized plasmas is driven primarily by a flux of photons through photoionization and photoexcitation processes. To this end, we have computed photoionization cross sections with atomic structure and scattering codes, and compare them with absolute cross section measurements. We also present collisional-radiative atomic kinetics and ionization balance calculations for a photoionized neon plasma, and the design of a gas cell experiment driven by the radiation flux from a Z dynamic hohlraum.

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Molecular hydrogen collision rates and the emission spectra of photodissociation regions

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Abstract. We present the results of a long term project whose goal is to simulate fully the spectrum of a molecular cloud exposed to the radiation field of a newly formed hot star. The starlight heats and ionizes the gas which is initially cold and molecular. The resulting overpressure causes the gas to flow away from the molecular cloud towards the star. The chemical, thermal, and ionization states of the gas are set by a host of molecular, atomic, solid state, and dynamical processes. This geometry is central in astrophysics, being found in environments ranging from nearby star-forming regions like the Orion nebula to the most distant and luminous objects we can observe, the starburst galaxies. In this poster we concentrate on the effects of revised molecular hydrogen collisional rates upon the observed spectrum.

PROJECT SUMMARY

This project is described in a series of papers on the dynamics (1), the chemistry (2), the physics of molecular hydrogen (3, 4) and grains (5), and Cloudy, the large scale plasma simulation code that brings all of this together (6). This poster will concentrate on the observational effects of recent calculations of H_2 collision rates.

ACKNOWLEDGMENTS

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Bound electron contribution to the index of refraction of multiply ionized plasmas at soft x-ray wavelengths

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Abstract.
The index of refraction is an essential plasma property that determines the transport of radiation and the laser energy deposition of laser energy in plasmas. It is also a key parameter in the measurement of the electron density by interferometry. For decades the analysis of interferograms of multiply ionized plasmas has relied on the approximation that the index of refraction is due solely to the free electrons. This general assumption makes the index of refraction always less than one. However, recent soft x-ray laser interferometry experiments that we performed for aluminum plasmas at a laser probe wavelength of 14.7 nm demonstrate that bound electrons contribute significantly to the index of refraction at soft x-ray wavelengths. The interferograms show fringes that shift to the left of the reference fringes that, for our experimental conditions, translates into an index of refraction greater than one.

In this conference paper we discuss new soft x-ray laser interferometry experiments of dense plasmas conducted at a different probe wavelength, 46.9 nm, in plasmas created by optical laser irradiation of several different materials (Ag, Al, C, Cu, Mo, Sn). The measurements in carbon, tin and silver showed anomalous fringe shifts, confirming that for plasmas with sufficiently low degree of ionization the contribution of bound electrons to the index of refraction can not be neglected. These results are in agreement with the Average Atom calculations that suggest that for these cases the phenomenon is mostly due to the dominant contribution of bound electrons from doubly ionized atoms. It is important to note that the significance of the bound electron contribution is not strictly limited to plasmas with a low mean ion charge. Nevertheless, most hot plasmas that are many times ionized can be confidently probed using soft X-ray laser interferometry. Also it is possible to either select the probe wavelength to avoid the contribution from bound electrons, or use the combination of hydrodynamic simulations and atomic scattering computations to determine the region of validity of the interferometry measurements. For example, on the case of the carbon plasmas, we used HYDRA code simulations to calculate electron temperature and ionization maps that were then used to identify the regions of the interferograms where the negligible bound electron approximation can be used to measure the electron density of the plasma.

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Photoionization from $4s4p$ levels to $4p^2$ resonances in neutral zinc

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Abstract. In neutral zinc the $4p^2$ configuration lies above the $3d^{10}4s$ ionization limit and consequently its levels become perturbers in the continuum. In non-relativistic theory, $4p^2\ {}^3P$ is a bound state that cannot interact with any $4skl$ continuum channel whereas in relativistic theory, primarily through the spin-orbit operator, the ${}^3P_2$ level acquires a ${}^1D_2$ component that interacts with the $4skd$ ${}^1D_2$ continuum. Thus the $4s4p\ {}^3P^o_{1,2} - 4p^2\ {}^3P_2$ transitions produce observed lines of a diffuse character. In this poster, results will be presented from Breit-Pauli calculations for $4s^2\ {}^1S$, $4s4p\ {}^{1,3}P$, $4s4d\ {}^1D$, $4p^2\ {}^3P$, ${}^1D$ and ${}^1S$ levels. As a first approximation, the interaction with the continuum will be neglected and transition data (transition energies, line strengths, f-values, and A-rates) for all E1 transitions between the levels from these calculations will be reported. The calculations will then be extended to include the interactions with $4skl$ continua and reveal the position and width of the resonances associated with the perturbers. The cross sections for photoionization from $4s4p$ levels confirm the the diffuseness of the observed ${}^3P^o_{1,2} - {}^3P_2$ lines, the distributed nature of the ${}^1D_2$ resonance, and predict the position of the $4p^2\ {}^1S_0$ resonance.

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A Comparative Study of Plasma Equation-of-State Models Used in Los Alamos Opacity Calculations

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Abstract. We present a comparative study for several atomic systems using the various Los Alamos plasma equation-of-state models. In recent years, the Atomic and Optical Theory Group (T-4) has developed a new plasma equation-of-state model, CHEMEOS (Chemical-Picture-Based Model for Equation-of-State Calculations). CHEMEOS is based on the chemical picture of the plasma and uses the free-energy-minimization technique and the occupation-probability formalism. The new model is constructed as a combination of ideal and non-ideal contributions to the total Helmholtz free energy of the plasma. These effects include plasma microfields, strong coupling, and a hard-sphere description of the finite sizes of the atomic species with bound electrons. The equation-of-state results from CHEMEOS will be compared to the current equation-of-state model used in the Los Alamos low Z opacity code, LEDCOP, for the atomic systems of helium and oxygen. Finally, we will present the effects of using a detailed atomic physics equation-of-state model for a high Z plasma, lutetium (Z = 71). The CHEMEOS results for lutetium will be compared to equation-of-state results from average-atom and Thomas-Fermi models.

NIST's Bibliographic Databases on Atomic Spectra

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Abstract. In June 2006, the Atomic Spectroscopy Data Center of the National Institute of Standards and Technology (NIST) released three new Bibliographic Databases containing references to papers with data on atomic properties needed for controlled fusion research, modeling and diagnostics of astrophysical and terrestrial plasmas, and fundamental properties of electronic spectra of atoms and atomic ions.

The NIST Atomic Energy Levels and Spectra Bibliographic Database [1] is the first online version of the NIST bibliographic resources on atomic energy levels and spectra, earlier published on paper as NIST Special Publication 363, last published in 1985. This database includes references to articles on energy levels, transition wavelengths, ionization potentials, isotopic shifts, hyperfine structure, quantum field effects, and Zeeman and Stark splittings in atoms and atomic ions. The main emphasis is given to experimental papers. It also includes papers containing high-precision theoretical calculations of these atomic properties. The database is fairly complete for the period 1967 through 2004. Work is currently in progress to include papers for the period 2005 through 2006. The total number of references is more than 9200.

The NIST Atomic Transition Probability Database, version 8.1 [2], is an update of the previously published version 7.0 of this database published in October 2003. The database is now fairly complete for the period 1964 through 2005. For the new version, about 700 new references have been added, bringing the total number of references to more than 7200.

The NIST Spectral Line Broadening Bibliographic Database, version 2.0 [3], is a major upgrade of the previous online version 1.0. The total number of references is more than 3600, while version 1.0 contained only 800 references. The database is fairly complete for the period 1978 through 2005.

All three databases are now maintained in a unified database management system based on a MySQL server. This system allows us to quickly update the contents of the databases. Any new reference added to the database becomes available to the public on the next day. A robust Data Entry module makes it easy to enter the data and classify the papers by relevant categories.

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New Critical Compilations of Atomic Transition Probabilities for Neutral and Singly Ionized Carbon, Nitrogen and Iron

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Abstract. Because of the continuing interest in the above-cited spectra and because of new literature data of significantly improved quality, we have undertaken new critical assessments and tabulations of the transition probabilities of important lines of these spectra. For Fe I and Fe II, we have carried out a complete re-assessment and update, and we have relied almost exclusively on the literature of the last 15 years, so that this new compilation supersedes our 1988 data volume. Our new tables are about 25% larger for Fe I and almost 50% larger for Fe II, and the estimated accuracies are now for the majority of lines in the 3-10% range for Fe I and in the 10-25% range for Fe II. Our updates for C I, C II and N I, N II address primarily the persistent lower transitions involving principal quantum numbers 2 and 3, as well as a now greatly expanded number of forbidden lines (M1, M2, and E2). For these transitions, sophisticated multiconfiguration Hartree-Fock (MCHF) calculations have been recently carried out, which have yielded data considerably improved from our 1996 NIST compilation and have also yielded many additional forbidden transitions. We plan to enter all this new material into our comprehensive NIST Atomic Spectra Database (ASD).

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A statistical approach for simulating detailed-line spectra

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Abstract. A general statistical model for simulating electric-dipolar lines in complex spectra of LTE or NLTE plasmas is presented. In this model, each transition array is represented by a pair of Gaussian subarrays, whose characteristics (average wavenumbers, strength distributions, and numbers of lines) change in a continuous way from LS (where one subarray vanishes) to jj coupling [1]. The transition amplitude and the two level energies of each line are picked at random in a joint triple distribution, that takes into account the correlation between the line strengths and energies [2]. This insures that the first and the second strength-weighted moments of the line energies are equal to those obtained in the DLA approach. Examples of application to the calculation of Rosseland mean opacities are given (Fe plasma in LTE, for Te= 20 eV and $\rho=10^{-2}$, 10^{-3},10^{-4} g/cc) which show very good agreement with values obtained with the OPAL code [3].

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Inelastic processes in slow collisions of K^+ ions with helium and xenon atoms.

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In the present work the value for absolute cross sections of electron capture, production of free electrons (ionization, stripping) and excitation processes at collisions of K^+ ions with He and Xe atoms were carried out by collision and optical spectroscopy methods, described in details [1,2]. An uncertainty in the determination of an electron capture, ionization and stripping cross sections is about 15% and accuracy of relative measurements for excitation processes was 5% and absolute one did not exceed – 10%.

The data obtained allow us to reveal the mechanism of the inelastic processes. In discussing these results the schematic correlation diagram of the diabatic quasimolecular terms of colliding particle systems was used. This diagram was plotted by following the Barat-Lichten rules [3].

In case of charge exchange processes the most probable mechanism is capture of an electron to the ground state of potassium atom. The process is considered as a result of direct interaction of the corresponding ∑-∑ terms of the quasimolecular systems.

The contribution made by the various processes to the total cross sections of an electron emission in the K^+ - He, Xe collisions is estimated. Have shown, that in the K^+ -He collisions the energy of most of the liberated electrons is smaller than 10-15 eV and smaller than 5-7 eV in the K^+-Xe. It was established, that these electrons for K^+ -Xe colliding pairs come from the doubly excited states of target atom and results from the decay of quasimolecular autoionizing states of colliding particles. In case of K^+ - He the mechanism responsible for the formation of K^{2+} is excitation of autoionizing states of the K^+.

The mechanism for excitation cross section is clarified. Was found that in case of K+ -He collisions the value of the excitation cross section of the potassium ion K^{+*} (4s) state (σ =1.5 10^{-17}cm^2) more than one order of magnitude large than for helium atom state He*(2p) while in the case of K^+- Xe pair the excitation of Xe*(6s) (σ =6.10^{-17}cm^2) occur more effectively.

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New and Improved Atomic Data for Accurate Plasma Modeling

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Abstract. The title of the present conference, "Atomic Processes in Plasmas", is a fitting description for our multidisciplinary, multi-university, collaborative effort. Our team focuses on the tackling of several highly-important atomic phenomena, using state-of-the-art theoretical approaches, coupled with important new experimental measurements, to produce what we assess to be the most reliable atomic data that is essential for meaningful plasma modeling, both for fusion- and astrophysics-related research. Our three main areas of focus are the following. First, we continue to address photoionization of atomic ions - particularly the ubiquitous process of K-shell absorption and ionization. Our absorption data, for example, are used to infer elemental abundances of the interstellar medium (ISM). Our ionization data determine K-shell vacancy production which leads to subsequent Auger or radiative decays affecting ionization balance determinations. Second, we have embarked on a thorough and complete program for determining fluorescence (vs. Auger) emission of K-shell vacancies of all second- and third-row isoelectronic sequences. These branching ratios also affect the subsequent transitions to higher ionization stages. Third, we have undertaken new, methodical calculations for the dielectronic recombination (DR) of all atomic ions for all ionization stages up through zinc for all isoelectronic sequences up through Na-like, and also all iron ions. DR is the dominant electron-ion recombination mechanism in cosmic plasmas. Our calculations represent a significant improvement over previously-recommended, outdated DR data, and a significant portion of our efforts is directed at assessing, through various in-depth investigations, the accuracy of our final recommended data, all made available on our web-accessible database. Representative examples of our latest works in all three main areas of research and their impact on plasma modeling will be presented here.

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Dynamics of converging laser-created plasmas studied with soft x-ray laser interferometry

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Abstract. We present results from a soft x-ray laser interferometry study of dense converging plasmas created by laser irradiation of semi-cylindrical targets with 120 ps duration optical laser pulses at a peak intensity of 1×10^{12} W/cm^2. Interferograms were taken during the various stages of the plasma evolution, yielding electron density maps that describe the plasma evolution. The plasma expands off the target surface and converges in a focal region, creating a concentrated plasma region where the electron density build-up is measured to exceed 1×10^{20} cm^{-3}. The measurements were conducted combining a 46.9 nm wavelength tabletop capillary discharge laser probe with a soft x-ray Mach-Zehnder interferometer based on diffraction gratings. The use of this short wavelength probe beam enables the study of dense plasma conditions that could not be probed with optical lasers. The measurements were compared with simulations from the hydrodynamic code HYDRA, which show that the abrupt density increase near the axis is dominantly caused by the convergence of plasma generated at the bottom of the groove during the laser irradiation pulse.

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A Magnetic-Sublevel Atomic Kinetics Model for Polarized X-ray Satellite Line Emission from Anisotropic Silicon Plasmas

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We developed and applied a NLTE magnetic-sublevel atomic kinetics model aimed at the calculation of polarization characteristics of Li-like satellite line emissions to He-alpha in silicon plasmas. This is achieved by calculating the magnetic sublevel population distribution of the *1s 2l 2l'* states under a variety of plasma density and electron distribution conditions. The purpose of this work is to find X-ray lines whose polarization can convey information about plasma anisotropy, and also identify lines whose lack of polarization can serve as unpolarized references. Furthermore, we describe the most significant population feeding channels leading to alignment creation and hence the line polarization effect. Polarization properties of this Li-like satellite emission are compared with those of the He-like satellites of the Ly-alpha[1]. X-ray line polarization measurements have the potential to serve as anisotropy diagnostics in plasmas driven by high-intensity ultra-short duration pulsed lasers, for example in the context of energetic electron beams relevant for fast ignition.

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Thermal Conductivities from the Purgatorio Code

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Abstract. We present recent calculations of thermal conductivities for various low-Z elements across a wide range of temperatures and densities. The calculations are based on the Purgatorio code, a self-consistent, fully relativistic average atom model. The thermal conductivity is calculated using a modified Ziman formulation approximating multiple orders of the transport equation and electron-ion collision cross sections obtained through a partial wave analysis of the continuum electrons. The contributions of electron-electron collisions to the thermal conductivity and the effects of the structure factor are presented along with comparisons of our results with the predictions of other models.

X-Ray Emission from high-Z plasmas created by a high repetition rate fs laser

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Abstract. For the purpose of developing well-calibrated, short (ps), keV X-ray sources for ultrafast X-ray absorption spectroscopy studies, X-ray spectra have been obtained by focusing a femtosecond, 800 nm, high-repetition rate (1 kHz) laser on various high-Z elements. Sm, Gd, Dy, Er and Yb targets have been used in a "refreshing" mode consistent with the high-repetition rate. The laser duration was varied between 30 fs and 2.5 ps. Two main X-ray diagnostics have been used. A high-resolution (1.3 – 1.6 keV) spectrometer with a spherical mica crystal and a multi-keV (3 – 20 keV) CCD-based broadband spectrometer used in a photon-counting mode. Experimental spectra are compared with calculations performed with a NLTE superconfiguration code.

Electron-Impact Broadening of Isolated Spectral Lines

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Abstract. It is shown that a quantum kinetic theory approach to Stark broadening, extended to non-equilibrium conditions, yields corrections to the standard impact theory that may resolve long-standing discrepancies between theoretical and experimental widths of isolated lines. The corrections depend on the radiator internal state populations and detailed balance property of the perturbing electron gas. Consequently, the emission and absorption line shapes are different except in thermal equilibrium when the profiles satisfy the Kirchhoff-Planck relation. The standard impact theory, however, predicts identical emission and absorption line widths independent of conditions, but only as a result of compensating approximations. This difference presents new opportunities for experimental tests of line broadening theories. Quantitative analysis indicates that such experiments are feasible.

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The NIST TES X-ray Microcalorimeter for High Resolution Spectroscopy

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Abstract. I report on the use of the NIST microcalorimeter detector to perform high-resolution spectroscopy over the energy range 400 eV—8 keV. The microcalorimeter detects slight temperature increases in an absorber from single x-ray photons by using a superconducting transition edge sensor (TES) as a thermometer. The broad energy range of the detector and its high resolution (4.4 eV) allow us to compare the energies of x-ray lines from several elements at the same time. We have made a comparison of K and L lines from 4 elements covering a range of 7 keV. Comparisons at our level of precision test not only the linearity of our detector energy scale, but also the accuracy of the latest x-ray energy tables[1]. We have also conducted quantitative analyses, against standards, of elemental concentrations in several NIST glasses used as standard reference materials. We have determined elemental concentrations in agreement with the accepted concentrations to within 1% of the total, or in the case of the lowest concentration, with an error of 8% in the relative concentration. These analyses included the use of lines which would normally not be resolved by conventional energy-dispersive detectors. By modifying the area and thickness of the absorber, TES microcalorimeter detectors can be optimized for any range of atomic x-ray spectroscopy. Current count rates of a single detector element are limited to a few hundred counts per second. I conclude with a discussion of improvements which will increase the resolution and maximum count rates of these detectors.

*****(collaboration with Nicholas Ritchie and Joel Ullom)

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Kinetic And Spectral Descriptions For Atomic Processes In Plasmas

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Abstract. An investigation has been in progress on the influence of autoionizing resonances on atomic processes in high-temperature plasmas, particularly those encountered in magnetic- and laser-fusion research. In the kinetic-theory description, account is taken of the indirect contributions of autoionizing resonances to the effective rates for excitation, de-excitation, ionization, and recombination. A microscopic many-body kinetic-theory foundation is employed for the systematic reduction to the macroscopic radiation-hydrodynamics description. From the spectral perspective, particular emphasis has been directed at radiative emission processes from autoionizing resonances. These processes can give rise to resolvable dielectronic-recombination satellite features, which have been analyzed to determine plasma temperatures, densities, electric and magnetic field distributions, and charge-state distributions. We also investigate radiative absorption processes, which play important roles in the denser plasmas encountered in laser-matter interactions. Particular emphasis is directed at radiative excitation processes involving autoionizing resonances, which can provide significant contributions to the non-equilibrium ionization structures and to the radiative absorption and emission spectra in the presence of intense electromagnetic fields. A reduced-density-matrix formulation has been under development for the microscopic many-body description of the electromagnetic interactions of atomic systems in the presence of environmental collisional and radiative decoherence and relaxation processes. A central objective is to develop a fundamental quantum-statistical formulation, in which bound-state and autoionization-resonance phenomena can be treated on an equal footing. An ultimate goal is to provide a comprehensive framework for a systematic and self-consistent treatment of non-equilibrium (possibly coherent) atomic-state kinetics and high-resolution (possibly overlapping) spectral-line shapes. This framework would facilitate the fundamental investigation of a broad class of atomic processes in laboratory and astrophysical plasmas covering extensive density and field regimes. This work has been supported by the Department of Energy and by the Office of Naval Research.

Constrained Analysis of Ti Line Absorption From The Compressed Shell Of OMEGA Direct-Drive Implosions

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Abstract. The determination of temperature and density in the plastic shell of inertial confinement fusion implosion experiments is important for diagnosing the conditions of the compressed portion of the shell that confines the core at the collapse of the implosion. To accomplish this, we have developed a Ti-spectral model to analyze K-shell absorption spectra produced by Ti-doped tracer layers embedded in the shell. The Ti is backlit by continuum radiation emitted by the core and plastic behind the tracer layer. Line absorption is observed in Ti ions from F- to Be-like Ti. Detailed modeling and analysis of these absorption line transitions, including the self-emission effect, can yield the Ti ionization state, temperature, density, and areal-density in the tracer layer. The data is analyzed via a weighted least-squares minimization procedure that assumes Poisson statistics for the uncertainties in the data points, and depends on two free parameters. The values of the parameters extracted from the fit can be related to the intensity level of the backlit Bremmstrahlung and the areal density of the compressed shell. They can be further checked for consistency with the estimated conditions in the emitting shell, the size of the core, and the initial areal density of the Ti-doped tracer layer. Results are presented for absorption spectra obtained from experiments where the Ti-doped tracer layer in the shell was located at several distances from the core. This work is supported by a contract from LLE.

He-Like Satellites to H-Like Resonance Lines of Light Elements

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Abstract. Satellite lines appearing near the resonance lines of hydrogen- and helium-like ions were first discovered in 1939 by Edlén and Tyrén who interpreted them as originating from core-excited levels of helium- and lithium-like ions. Since then, these lines became a widely used tool for diagnosing the properties of emitting plasmas. Lately, the satellite lines of light atoms became of interest because they may be used as a diagnostic tool for thermonuclear plasmas. For example, boron is an important constituent of the construction materials in the latest designs of tokamaks, and, as such, it enters the fusion plasma as an admixture. The lines emitted by hydrogen- and helium-like boron have been observed recently in tokamaks. Core-excited levels of helium- and lithium-like ions have been extensively studied, both experimentally and theoretically, for many atoms, especially those with nuclear charge Z greater than 10. The main theoretical technique used in these studies was a $1/Z$-expansion perturbation theory. However, this technique does not work for light atoms. Core-excited helium and lithium were successfully treated using variational non-relativistic methods, since relativistic effects are small in these atoms. However, these effects rapidly grow with increasing Z, so the quality of non-relativistic calculations rapidly deteriorates for $Z > 2$. On the experimental side, observation of satellite lines emerging from core-excited levels is impeded for light elements by their low intensity. An alternate method of observation of core-excited levels is Auger electron spectroscopy. However, with this method it is hard to achieve precision sufficient for unambiguous identification of observed features. The satellite lines of He-like Be, B, C, N, O, and F have been studied mainly in emission of low-inductance vacuum spark and laser-produced plasmas in 1969-1978, while Ne IX was observed in a plasma-focus in 1969. Some attempts were made to observe the He-like satellites with beam-foil spectroscopy (BFS), but the resolution was insufficient. On the other hand, BFS was successfully used to observe transitions between core-excited levels of Li II and Be III in the far ultraviolet. In 1990-1999, the increased resolution of Auger electron spectroscopy resulted in some valuable results for He-like Li, Be, B, and C. However, because of the poor quality of theoretical calculations, the interpretation of features observed by these complementary techniques is often contradictory. In our work on the boron spectra, we made a new use of the Ph.D. thesis of Tyrén [1]. It contains high-quality photographs of grazing-incidence spectra of Be, B, C, N, O, and F between 16 Å and 105 Å, obtained with a low-inductance vacuum spark. By digitally scanning these photographs, we were able to obtain new or improved wavelengths of satellite lines of B IV. Isoelectronic comparison enabled us to obtain improved values for energy levels and resolve some contradictions in existing data not only for B IV, but also in other helium-like spectra. The extraordinary quality of Tyrén's photo plates makes it possible to achieve new insights in these spectra.

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Spectral Data for Tungsten Atoms and Ions, W I through W LXXIV

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Abstract. The spectra of tungsten are highly important for controlled fusion research. Tungsten is one of materials to be utilized for construction of tokamaks. Its erosion and degree of penetration into hot plasma regions can be studied by spectroscopic methods. This requires detailed knowledge of the spectra of tungsten atoms and ions. Many of these spectra were observed and analyzed by a number of research teams since late 1960s. The lowest stages of ionization were studied the most thoroughly. The recently completed critical compilation of energy levels, wavelengths, and transition probabilities of W I and W II [1] contains about 800 energy levels and about 10000 lines, of which more than 700 lines are given with accurately measured transition probability. Ionization energies of tungsten in all stages of ionization were recently determined by Kramida and Reader [2] using original semiempirical methods. The work on critical compilation of spectral data for W III through W LXXIV is currently under way at NIST.

The spectra W III through W VII were analyzed using spark light sources. There are several hundreds of known spectral lines for each of these spectra, except W VI, for which there are only 17 known lines. However, the sliding-spark source cannot produce higher ionization stages of tungsten. Other sources such as laser-produced plasmas, exploding wires, or tokamaks with tungsten injected into the hot plasma region produce ions of substantially higher degree of ionization (21+ to 45+). Thus, there are some gaps in the studied spectra of tungsten ions. Significant progress in the studies of these spectra was achieved recently by using EBIT light source [3,4]. Some experimental data exist now for the following higher ionization stages of tungsten: 13+, 27+ through 50+, 52+, and 64+. For most of these spectra, there are just a few identified lines and energy levels. In the present compilation, we select the best measurement for each observed line and derive the energy levels consistent with the most accurate observed wavelengths. Very often the original classification of the observed lines is ambiguous. We make *ab initio* and semi-empirical calculations of these spectra in order to find the correct spectroscopic notation of the energy levels involved in each transition. For the Na-, Na-, K-, He-, and H-like spectra, despite the lack of experimental measurements, there exist accurate theoretical calculations. We include their results, as these spectra are important for plasma diagnostic applications and for benchmark experiments.

This work is supported in part by the Office of Fusion Energy Sciences of the U. S. Department of Energy.

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Ionization Shifts in Cl K-β Emission from Short Pulse Irradiation of 50 μm Targets

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Abstract. Short pulse laser produced K-alpha x-ray generation for the characterization of hot dense material using x-ray Thomson scattering, is of significant interest for high energy-density experiments such as Inertial Confinement Fusion (ICF) and laboratory astrophysics applications. Recent experiments developing a high temporal resolution narrow bandwidth Cl K-alpha source provided conversion efficiency measurements of K-alpha production to incident laser energy of about 3 x 10^{-5}, more than 1000 photons. The K-alpha x-rays were produced from Terawatt laser irradiation of Cl containing foils at the Callisto laser facility, LLNL, dispersed using highly efficient, Highly Oriented Pyrolitic Graphite (HOPG) crystal spectrometers, and collected using Charge Coupled Devices (CCD) and image plate detectors. For small target foils with a surface area of 50 microns, a shift of about 5 eV in the Cl K-beta line emission for increased laser energy on target was observed. This effect is though to be due to an increased number of ionization states in the solid density material.

Keywords: Ionization shifts, X-ray production, K-shell emission.
PACS: 32.30.Rj

Corrugated Plasma Waveguide: Slow Wave Structure For High Intensity Optical Pulses

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Abstract. We report generation and progress towards applications of a periodically modulated plasma waveguide. These waveguides show exceptional shot-to-shot stability, with adjustable axial modulation periods as short as 70 μm, where the period can be significantly smaller than the waveguide diameter. We have measured guided propagation in these guides at intensities up to ~$5\text{x}10^{17}$ W/cm^2, limited only by our current laser energy. We can generate these modulations with two methods, by either projecting axially modulated Bessel beams onto uniform and extended cryogenic cluster jet flows or using an axially invariant Bessel beam and a tailored cluster flow. These waveguides are 'slow wave' guiding structures capable of supporting intense pulses with sub-light phase velocities, with application to direct laser acceleration of charged particles and phase-matched generation of a wide spectrum of electromagnetic radiation.

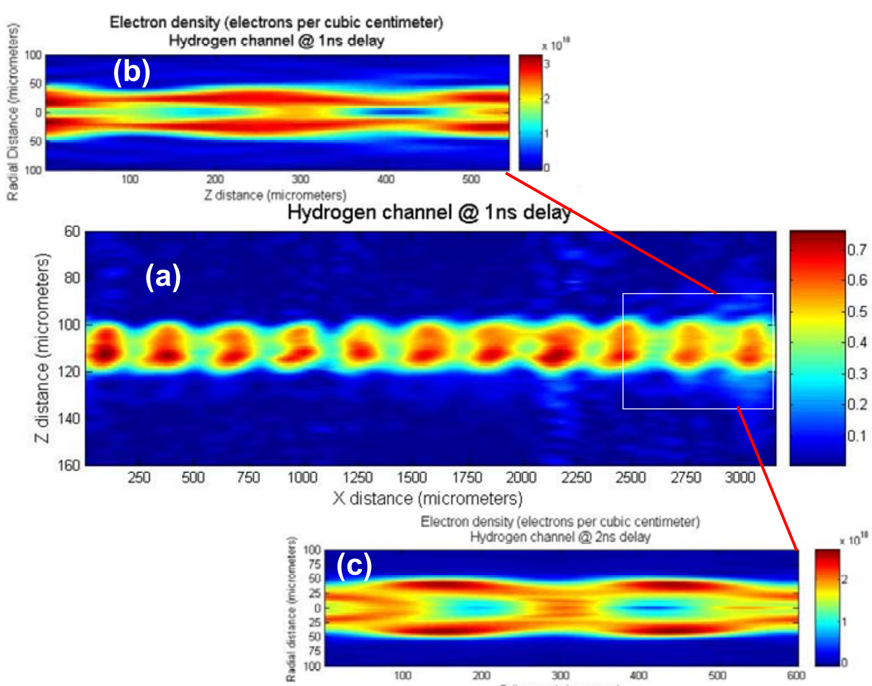

FIGURE 1. (a) Phase image of central section of 1.5 cm long corrugated hydrogen plasma waveguide 1ns after its formation in an elongated hydrogen cluster jet. A 55mJ, 70fs Ti:Sapphire laser pulse was guided down this waveguide ~100 ps before the transverse interferometry probe pulse. Electron density vs. r and z at (b) 1 ns pump-probe delay and (c) 2ns delay extracted from Abel inversion of boxed section of phase image in (a).

Spectral Data Calculations for Multicharged Ions in Hot Plasmas

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Modeling of radiative properties of matter in various problems of high energy density physics calls for realistic description of the emission and absorption spectra of hot plasmas in broad temperature and density ranges. Calculation of these spectra, in turn, implies the knowledge of spectroscopic data of various ions: energies and lifetimes of bound-electron states, wavelengths, probabilities and oscillator strengths of radiative transitions.

The paper presents an overview of activities being run at RFNC VNIITF to generate such spectral data that involve

- development and extension of the online atomic-data information-reference system on the Web — SPECTR-W^3 [1];
- spectroscopic-data calculations for high-Z multielectron ions;
- development of theoretical and numerical models to calculate spectral properties of radiative transitions of high-Z ions in plasmas — spontaneous-emission lineshapes and absorption profiles — allowing for the most important line-broadening mechanisms and effects of electric fields on the population kinetics of ionic states [2,3];
- development of theoretical and numerical models to calculate opacities of the multielectron-ion plasmas utilizing both the detailed and statistically averaged description of the bound-bound and bound-free absorption [4].

Created models and techniques are employed for the laboratory-plasma diagnostics, theoretical studies of resonant properties of x-ray-laser plasmas, modeling of laser-plasma sources of x-ray radiation and calculation of opacities of hot, dense ICF-target plasmas [2–7].

The work has been supported in part by the International Science and Technology Center (ISTC) under the projects #1785-01, 2297-03, and 3504-07.

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Atomic Data for Collisional-Radiative Modelling of Ar and its Ions

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Abstract. We report on new R-matrix with pseudostates excitation calculations for Ar^{+}, comparing the collision strengths and effective collision strengths with a previous non-pseudostate R-matrix calculation. This excitation data is combined with new dielectronic recombination data for Ar^{+} through to Ar^{7+}, based on configuration-average distorted-wave calculations. The new dielectronic recombination data is compared with level-resolved distorted-wave calculations for Ar^{6+} and Ar^{7+}, with good agreement being found for the total rate coefficients for temperatures at which those ions would be formed in collisional plasmas. Our final Ar dataset uses level-resolved distorted-wave recombination data for ion stages greater than Ar^{5+}. Our Ar ionization data consists of R-matrix with pseudostates ionization data for neutral Ar [1] and configuration-average distorted-wave ionization data for all the remaining ion stages. We use this new Ar dataset to evaluate a set of SXB ratios for Ar^{+}, and a set of fractional abundances for all ion stages of Ar, in both cases comparing with literature values.

Keywords: Electron scattering, ionization, dielectronic recombination, argon
PACS: 34.80.Dp, 34.80.Lx, 52.20.Fs

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Interpretation and analisys of spatially-resolved line spectra from Z-driven implosion cores

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Dynamic-hohlraum driven implosion experiments at the Z facility compress plastic shells filled with deuterium gas to keV temperatures and high-densities. A tracer amount of argon is added to the gas fill for diagnostic purposes, and K-shell argon line emission is observed in the photon energy range from 3.1 keV to 4.2 keV, including resonance and satellite line emissions from Li-, He- and H-like argon ions. The line spectra is recorded with gated crystal spectrometers equipped with a slit to provide spatial resolution within the implosion core. Modeling of a set of spatially-resolved line spectra is useful to study the spatial structure of the core at the collapse of the implosion. To this end, we employ a detailed argon spectral model that considers collisional-radiative atomic kinetics, Stark-broadened line shapes, and radiation transport. Several methods for the interpretation and analysis of the data are presented, including a novel application of a niched-Pareto genetic algorithm to drive searches in parameter space for the temperature and density spatial profiles that yield the best simultaneous and self-consistent fits to a set of spatially-resolved argon line spectra. We will discuss the application of these methods to implosion core x-ray spectroscopy, and the spatial structure extracted for Z-driven implosion experiments.

Possible Mechanism of Dispersion in the Shock–Plasma Interaction

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Abstract. Interaction of shock waves with weakly ionized gas generated by discharge has been studied. An additional thermal mechanism of the shock wave dispersion on the boundary between a neutral gas and discharge has been proposed. This mechanism can explain a whole set of thermal features of the shock wave-plasma interaction, including acceleration of the shock wave, broadening or splitting of the deflection signals and its consecutive restoration. Application has been made in the case of a shock wave interacting with laser induced plasma. The experimental observations support well the results of calculation based on the proposed model.

Measuring The Ionization Balance Of Gold In EBIT Which Is Of Importance To ICF

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Predicting the charge state distribution (CSD) of gold is important for inertial confinement fusion (ICF) experiments that utilize radiation from hohlraums to drive the implosions. Present models are not capable of correctly predicting the ionization balance in a non-local thermodynamic equilibrium (NLTE) plasma [1]. Experiments at both high and low densities are needed to help guide the models.

The Au CSD measurements at the Livermore EBIT-II electron beam ion trap were done in ~ 10^{12} cm^{-3} plasmas having electron temperatures of 2.0, 2.5 and 3.0 keV [2]. We experimentally simulated a thermal plasma by sweeping the electron beam in time according to the procedure detailed by Savin [3]. M-band gold spectra were recorded from Ni-like to Kr-like ions [4] in the x-ray range (n=5→3 and n=4→3 transitions) with a crystal spectrometer and the Goddard Space Flight Center (GSFC) micro-calorimeter. The charge balance was inferred by fitting the observed spectra with modeled spectra from the Hebrew University Lawrence Livermore Atomic Code (HULLAC) [5]. Despite the relatively simple atomic physics in the low density EBIT-II plasma, differences existed between the experimentally inferred CSD of these plasmas and the simulations from several available codes (e.g. RIGEL [6]).

Recent Au CSD measurements from experiments at the OMEGA laser facility were made with the Henway and MSPEC crystal spectrometers and are presented and compared with those from EBIT-II.

Our experimental CSD relies upon accurate electron impact cross sections provided by HULLAC. To determine their reliability, we have experimentally determined the cross sections for several of the n=3→4 and n=3→5 excitations in Ni to Kr-like Au and compared them to theory.

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Extraction of Quasi-3D Electron Temperature and Density Distributions of ICF Implosion Cores from Argon K-shell Line Images and the Space-Integrated Spectrum

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Abstract. The determination of temperature and density spatial distributions in inertial confinement fusion (ICF) implosion cores is important to benchmark hydrodynamic simulation codes. We discuss a method to extract electron temperature and density spatial distributions of argon-doped inertial confinement fusion implosion cores based on the fitting Ar Lyα, Heβ, and Lyβ narrow-band image intensity profiles and the associated space-integrated spectrum. We assume that the implosion core consists of multiple core slices with local axial symmetry, and compute the emergent intensity distribution using a detailed atomic and radiation physics model. First, the electron temperature and density distributions are approximated by a search and optimization Pareto Genetic Algorithm (PGA); second, the PGA results are used as an input to a "fine tuner" based on a non-linear least square minimization method. The PGA is good at getting a very good approximation to the best solution starting from a large number of randomly generated (unbiased) solutions, while the fine tuner is good at converging to the best solution from a good initial seed. Therefore, the PGA and the fine tuner complement each other, and their combination represents a robust search and reconstruction method that finds optimal quasi-3D core spatial structure simultaneously and self-consistently. This method is independent of geometry inversions, and can take advantage of not only optically thin, but also optically thick image data. Results are shown for data from argon-doped indirect-drive implosions at OMEGA, considering up to seven core-slices and four fitting objectives: Ar Lyα, Heβ, and Lyβ narrow-band image intensity spatial profiles and the corresponding space-integrated line spectrum.

This work is supported by DOE-NLUF Grant DE-FG52-07NA28062, and LLNL under Contract W-7405-Eng-48.

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A Study of the Importance of R-Matrix Data and Effects of Differing Kinetics Models On Atomic Spectra

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Abstract. The effect due to the accuracy of atomic data on line ratios used for plasma diagnostics has been a subject of discussion for some time. The use of more accurate data sometimes requires the atomic kinetics model to be formulated differently. This is the case with R-Matrix atomic data[1,2] as compared to results obtained from more approximate methods such as the distorted-wave approach. The inclusion of resonances from the coupling of auto-ionizing states to the continuum in R-Matrix cross sections makes it difficult to use these results in the same manner as distorted-wave data due to the issue of double-counting the effect of resonances in the R-Matrix case. Instead R-Matrix data are often employed in a regime where the contribution to high lying levels is treated statistically via branching ratios which, while valid in the low density limit, can lead to erroneous results in the high density limit[3]. This poster reports on ongoing work that explores the effect of different atomic models on the line ratios of He-like systems by comparing the results of GSM[4], a code using statistical methods and R-Matrix data, to the results of the Los Alamos National Laboratory atomic physics codes[5]. An estimate on the range of validity for the GSM results will also be presented.

Keywords: atomic kinetics, atomic spectra, X-ray spectroscopy, He-like ions, R-Matrix theory, distorted-wave theory
PACS: 32.30.-r, 32.30.Rj, 32.70.-n, 95.30.Dr, 95.30.Ky

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Non-extensive Tsallis statistics for NLTE opacities

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Abstract. When thermodynamic equilibrium is assumed, internal energy and entropy are extensive, which means that they are proportional to the size of the system. In non local thermodynamic equilibrium, since the screening is less important, the range of interactions between electrons and ions becomes larger and the plasma is non-Maxwellian. Therefore, it is reasonable to assume that entropy is not extensive anymore, and that Boltzmann-Gibbs standard definition of entropy has to be given up. A few years ago, C. Tsallis [1] has proposed an expression of entropy which relies on a power-law in which the exponent "q" takes into account the deviation from extensivity. We propose to apply Tsallis statistics to plasmas in non local thermodynamic equilibrium (NLTE). In order to calculate the electronic structure, the Density-Functional-Theory-Average-Atom model is generalized within the new statistics. Then, the NLTE opacity can be obtained using a "non-extensive LTE code", in which Fermi-Dirac distribution is replaced by its non-extensive equivalent "q-distribution". The deviation from the Planckian distribution of radiation is also a direct result of the theory. The most difficult point is to find the proper value of the parameter q. For that purpose, two methods are proposed, similar to the ones published in references [2] and [3] initially devoted to the determination of effective temperatures. The present work constitutes the first attempt to relate non-local thermodynamic equilibrium to the breakdown of Boltzmann-Gibbs statistics.

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Electron-Impact Ionization of Homonuclear Diatomic Molecules

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Abstract.
Electron-impact ionization cross sections for several homonuclear diatomic molecules are calculated in a configuration-average distorted-wave method [1]. Core bound orbitals for the molecular ion are calculated using a single configuration self-consistent field method based on a linear combination of Slater type orbitals. The core bound orbitals are then transformed onto a two dimensional (r,θ) numerical lattice from which a Hartree with local exchange potential is constructed. The single particle Schrödinger equation is numerically solved with S-matrix boundary conditions to obtain continuum distorted-wave orbitals. Total cross section results for H_2, Li_2, C_2, and N_2 will be presented and compared with experimental measurements, where available.

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Atomic Transition Probabilities for Cl I - Cl III

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We have compiled new tables of critically evaluated atomic transition probabilities for spectral lines of neutral, singly, and doubly ionized chlorine, Cl I – Cl III, which are of interest for astrophysics as well as for the study of laboratory plasmas. The present data represent an improvement in both quantity and quality over the earlier tabulation [1] published almost four decades ago. We have also tabulated forbidden transitions for these spectra.

In our evaluation procedure, we begin with consideration of all published results. Then we limit our considerations, by means of general assessment criteria, to references with the most accurate results. The final line strength for each line is selected from the best data source, and an accuracy is assigned. In general, we list only transitions with line strengths having estimated uncertainties of ±50% or less.

Only a small amount of experimental data is available for these ions; thus, for most transitions we had to use theoretical values. We have selected results of recent sophisticated multiconfiguration calculations that include spin-orbit effects and other relativistic corrections: MCDF, MCHF, CIV3, MBPT, *etc*. The most reliable experimental values are from emission experiments performed with wall-stabilized arcs. For example, a comparison of experimental line strengths in Cl I, measured by Bridges and Wiese [2] using a high-current wall-stabilized arc, with the MCHF [3] and CIV3 [4] values shows satisfactory agreement. This is a good guide for estimating accuracies when comparisons with experimental data are not possible.

The present compilation was performed as a part of the NIST project on critical evaluation of transition probabilities of light elements from sodium to calcium. We also plan to compile data for the higher ions of chlorine, Cl IV to Cl XVI.

This work is supported in part by the Office of Fusion Energy Sciences of the U. S. Department of Energy.

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Evolution of $L\alpha$, $L\beta_1$ and $L\beta_2$ satellites in the X-Ray emission spectra

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Abstract:

The X-ray satellites $L\alpha_3$, $L\alpha_4$ $L\alpha_5$, $L\beta_1^{I}$, $L\beta_1^{II}$, $L\beta_1^{III}$, $L\beta_1^{IV}$, $L\beta_2^{I}$, $L\beta_2^{(b)}$, $L\beta_2^{II}$ and $L\beta_2^{(c)}$ observed in the L-emission spectra in elements with Z = 40 to 92, have been calculated. The energies of various transitions have been calculated by available Hartree-Fock-Slater using the semi-empirical Auger transition energies in the doubly ionized atoms and and their relative intensities of all the possible transitions have been estimated by considering cross - sections for the Auger transitions simultaneous to a hole creation and then distributing statistically the total cross sections for initial two hole states $2p_{1/2}^{-1}3x^{-1}$ amongst various allowed transitions from these initial states to $3x^{-1}3d^{-1}$ final states by Coster-Kronig (CK) and shake off processes. In both these processes initial single hole creation is the prime phenomenon and electron bombardment has been the primary source of energy. Each transition has been assumed to give rise to a Gaussian line and the overall spectrum has been computed as the sum of these Gaussian curves. The calculated spectra have been compared with the measured satellite energies in L emission spectra. Their intense peaks have been identified as the observed satellite lines. The one to one correspondence between the peaks in calculated spectra and the satellites in measured spectra has been established on the basis of the agreement between the separations in the peak energies and those in the measured satellite energies. Group of transitions under the transition schemes L_3M_x-$M_xM_{4,5}$, L_2M_x-$M_xM_{4,5}$ and L_3M_x-$M_xN_{4,5}$ ($x \equiv$ 1-5), which give rise to these satellites have been identified. It is observed that the satellite $L\beta_2^{(b)}$ in all these spectra can be assigned to superposition of $^3F_4$-$^3G_5$ and $^3F_4$-$^3D_3$ transitions and that this must be the most intense of all these satellites, contributing in order of decreasing intensity. Each of the remaining satellites is found to have different origin in different elements. The possible contributions of suitable transitions to all these lines have also been discussed.

The HeI Isoelectronic Sequence

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Abstract. We present details of our implementation of the HeI isoelectronic sequence in the plasma simulation code Cloudy. While the ideal of an isoelectronic sequence is practical in spectral simulation because atomic data will scale roughly as nuclear charge, the species in the sequence bifurcate neatly into two very different aspects of astronomy. In the case of the neutral helium model atom, we are concerned mostly with optical and infrared radiation. We compare our predictions with observations of the Orion Nebula and obtain excellent agreement. In the case of the helium-like ions, X-ray emission is most important. We consider here the standard X-ray plasma diagnostics in a photoionized plasma and find markedly different behavior from the collisional plasma case.

Keywords: Enter Keywords here.

THE MODEL HELIUM ATOM

The model helium atom is compared with observations of the Orion Nebula (1). We present a novel approach for dealing with the optical depth in λ3889 and demonstrate that the observations must have larger than reported errors. We discuss reddening effects and obtain excellent agreement for a set of about 20 highest quality lines.

THE HELIUM-LIKE IONS

We present semi-analytical and numerical calculations of the standard X-ray plasma diagnostics, *R* and *G*. These were originally developed for the study of collisional plasmas (2, 3). More recently, they have been applied to photoionized plasmas. We demonstrate that the diagnostics tell us very different things about the plasma in these conditions. In particular we consider the effects of continuum pumping and optical depth of the intercombination line.

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Triple differential cross section data of (e, 2e) processes on Na, Mg, K and Ca atoms

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Abstract. 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 and the two outgoing electrons are then detected in coincidence with defined kinematics are known as (e, 2e) experiments. Extensive studies of (e, 2e) processes have been reported on various targets including hydrogen, helium and rare gases [1-2]. Recently, Purohit et al [3-4] 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 alkali targets Na and K and alkaline earth targets Mg and Ca atoms in coplanar symmetric geometry. We have performed the calculation in DWBA formalism using spin averaged static exchange potential. We compare the results of our calculation of TDCS for the above-mentioned targets with the available experimental data [5-6]. We will discuss silent features of the electron impact ionization of alkali and alkaline earth targets. The effects of incident electron energy, distortion, polarization will also be discussed for the alkali and alkaline atoms investigated by us

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Possible Manifestations of Thermally Unstable Shocks in the Supernova Remnant N49

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Abstract.
We present sub-arcsecond imaging in [Ne V] of N49, the brightest optical supernova remnant (SNR) in the Large Magellanic Cloud. Between the "cool" optical and "hot" X-ray regimes, [Ne V] emission indicates intermediate temperatures for collisionally excited plasmas (2–6$\times10^5$K), for which imaging has been extremely limited. We compare the flux in these images to the O VI measured spectroscopically by FUSE in individual apertures and find dereddened line ratios that are reasonably consistent with our predictions for intermediate velocity shocks. The overall luminosity in [Ne V] for the entire remnant is 1.2×10^{36} erg s^{-1}, which, given the measured line ratios, implies an overall O VI luminosity of 1.5×10^{38} erg s^{-1}. These large radiative losses indicate that this material must have been shocked recently relative to the total lifetime of the remnant. We also explore the complex spatial structure. We find [Ne V] tracing the [O III] emission more closely than it does Hα, measure significant shifts ($\sim$0.1 pc) between the peaks of different emission lines, and find two orders of magnitude variations in the flux ratios for different filaments across the remnant. These properties as well as the general filamentary character of the optical emission suggest thermally unstable intermediate velocity shocks.

Keywords: supernova remnants:individual(N49) — ISM: structure — shock waves — ultraviolet: ISM
PACS: 98.58.Mj, 52.35.Tc, 52.70.Kz, 52.35.Py, 95.30.Qd

EUV Spectra from Highly-Charged Ions of Tungsten in the 12-20 nm Region*

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Since tungsten is currently being considered a strong candidate for the plasma-facing material in next-generation tokamaks, accurate knowledge of its emission in the short-wavelength region becomes very important. Continuing the studies of highly-charged ions of tungsten (x-ray spectra and simulations were reported in Ref. [1]) produced on the NIST Electron Beam Ion Trap (EBIT), we recorded EUV spectra in the 12-20 nm region using a grazing incidence spectrometer. Stages of ionization could be distinguished unambiguously by varying the electron beam energy in small steps between 2.1 and 4.3 keV. The spectra were calibrated by separate spectra of highly ionized iron. We also carried out collisional-radiative modeling of the EBIT plasma emission and found good qualitative agreement between theoretical spectra and our observations. Our results complement recent line identifications for W^{40+} -W^{45+} observed in a tokamak [2]. For most lines we agree with their ionization stage assignments. New identifications include allowed and forbidden lines of W^{39+} , W^{44+}, and W^{46+}.

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NIST Numerical Databases for Atomic and Plasma Physics*

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The Physical Reference Data program [1] at the National Institute of Standards and Technology (NIST) supports about 20 numerical and bibliographic databases of importance for atomic and molecular physics. Here we report a number of newly developed or recently updated numerical databases for atomic and plasma physics.

In July 2006 the most comprehensive of our atomic databases, the NIST Atomic Spectra Database (ASD), was upgraded to version 3.1 [2]. The total number of energy levels and spectral lines is about 76,600 and 141,000, respectively. Transition probabilities are available for about 74,000 spectral lines. The recently added data include extensive data for Be II, Ne II, Ne III, Ne VIII, and all ionization stages of Kr. A large number of spectral lines and transition probabilities was added for Al VI-XII and Si I-XIV. A number of corrections for configurations of complex ions were made as well, including level compositions in Ho and Yb ions and term grouping in rare earth elements. Among other modifications in ASD 3.1 is addition of the bibliographic reference for the primary source of data.

In May 2006 we released a new SAHA Plasma Population Kinetics Modeling Database [3] that contains the benchmark results for simulation of plasma population kinetics and emission spectra generated for the 3rd NLTE Workshop. Recently this database was expanded to include the results from the 4th NLTE Workshop. The list of the available physical parameters includes, for example, mean ion charges, central momenta, ionization distributions, and rates of physical processes. A newly developed user interface allows one to easily perform selection and retrieval of data. The results can be visualized by using a graphical interface, which also allows data presentation in different formats.

[1]. URL http://physics.nist.gov/PhysRefData/.
[2]. URL http://physics.nist.gov/PhysRefData/ASD.
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Absolute calibration of a VUV/SXR spectrometer using bolometry

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Abstract. For vacuum ultraviolet (VUV) and soft x-ray (SXR) spectrometers deployed on tokamak experiments, *in-situ* absolute intensity calibrations are troublesome due to a lack of high throughput, portable sources. Conversely, resistive bolometers common on such devices can be absolutely calibrated, in vacuum, to within 5%. A technique is presented to transfer the absolute calibration of a bolometer to a VUV/SXR spectrometer using high-Z impurity emission. Core photon emissivities, calculated from line-integrated bolometry measurements, are used along with plasma cooling rates to determine impurity densities. Impurity transport simulations and emissions modeling are then used to calculate line brightnesses as seen by the spectrometer of interest. Comparing the modeled and measured spectra allows a wavelength resolved calibration coefficient to be determined. Results are shown from Alcator C-Mod using radiation from molybdenum, an intrinsic impurity, to calibrate a 2.2 meter, grazing incidence Rowland circle spectrometer. The use of a puffed, noble gas impurity is discussed to allow the technique to be utilized on a wide range of plasma experiments.

Si Emission Measurements of a Strong Radiating Shock in the Z-pinch Dynamic Hohlraum

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Abstract. The z-pinch dynamic hohlraum is formed when an annular tungsten z-pinch implodes onto a 14mg/cc CH_2 foam and launches a radiating shock that reaches $T_e > 400$eV and heats the hohlraum to $T_r > 200$eV. The conditions of this shock have been inferred through the measurement of time- and space-resolved Si line emission from Si_2O_3 doped at 2.5% by atom over the central 3 - 6mm height of the 12mm tall CH_2 foam. The observed emission spectra are analyzed through collisional-radiative calculations that assume a 2 region model of the Si-doped CH_2 plasma conditions consisting of a hot annular shell surrounding a colder central cylinder. Through these calculations it is determined that non-local photo-pumping processes have an important influence on the observed spectra, particularly from the cooler plasma ahead of the main shock. The use of these calculations for the investigation of the dynamic hohlraum interior conditions are presented and discussed. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.}

Hollow Ion Emission In Dense Plasmas

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Abstract. Line emission from hollow ions and atoms is well known to be observable in beam-foil experiments [1] and heavy ion beam surface interaction [2]. The dominant excitation channel is the charge transfer of electrons from the neutral target to the highly charged projectile ion. In dense plasma physics, hollow ion emission has not yet attracted any attention because their intensity is much below bremsstrahlung and therefore not observable under typical parameter conditions. Recent radiation field kinetic simulations, however, have shown, that intense free-electron laser radiation (as provided by the future facilities XFEL in Germany and LCLS in US) will enable the rise of hollow ion population densities in dense plasmas more than 10-order orders of magnitude higher than in traditional laser produced plasma experiments [3]. This dramatic intensity rise will open up a new field of research in dense plasma spectroscopy and related atomic physics. In the present work, we consider the hollow ion x-ray transitions $2s^n2p^m - 1s2s^n2p^{m-1} + h\nu_{hollow}$. A particular focus will be made on autoionisation which is responsible for the outstanding diagnostic properties of these hollow ion transitions: negligible photo-absorption even in above solid compressed matter and "intrinsic" response times less than ps [4] being in strong contrast to usual resonance lines (which are typically employed for diagnostic purposes) which show large opacity and long time scale (the typical recombination regime of laser heated matter). Detailed calculations are presented for Mg hollow ions.

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Modeling the Intensity of Selected B^{+1} and B^{+4} Emission Lines for Inference of Boron Impurity Density in the Alcator C-Mod Tokamak

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Abstract. Models for the prediction of boron line intensities which are excited by interaction of a boron impurity with a high density, high temperature plasma and with a hydrogen neutral beam are described and then benchmarked against measurements. Boron is always present as an impurity in the Alcator C-Mod Tokamak plasma because it is used for wall conditioning. The lines of interest here are 4940.376, 2s3d $^1D_2$ - 2s4f $^1F_3$, B^{+1}[1] and 4944.67, n=7→6, B^{+4}. Both lines are generated by interaction of boron with the plasma constituents (ambient emission). In addition, the second line is enhanced by charge exchange with a hydrogen neutral beam. Evidently, all lines appear in a narrow spectral band that can be recorded as a function of time on every plasma discharge. The B^{+1} and ambient B^{+4} lines can be used to estimate the density of their parent ions. The portion of the B^{+4} line that is excited by active charge exchange is actually a local measure for the density of B^{+5}. When taken together, the spectra composing this single spectral fragment provide sufficient information to pursue studies of plasma transport or to determine the contribution of boron to the effective charge of a plasma ion, Z_{eff}, which contributes to many types of plasma analysis. The ambient emission is predicted using collisional radiative models (the standard model in the Atomic Data and Analysis Structure (ADAS)[2] as well as locally constructed models) and published atomic data (see Ref.[3] for example). Accurate prediction of the active charge exchange emission is dependent on a detailed empirical description of the hydrogen beam and numerous cross sections. The charge exchange model and its evaluation with scaled cross sections has been reported[4] but improved cross sections are now incorporated.[5] The model predictions will be evaluated with measurements of n_e and T_e from the Thomson scattering diagnostic and the electron cyclotron emission diagnostic and then compared to measured spectral intensities to verify the models. At this time, the method for acquiring the B^{+5} density from the active charge exchange contribution to the B^{+4} intensity includes frequent benchmarking of the cross sections because of potential uncertainties in the n_e and T_e dependencies of the model and subtle changes in the operating point of the hydrogen neutral beam.

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Compilation of Energy Levels and Observed Spectral Lines of Krypton: Kr I – Kr XXXVI

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Abstract. Noble gases are among the most frequently observed spectra in laboratory sources as well as in discharges used for lighting and industrial processes, in plasma diagnostics, and in astrophysical sources. The Atomic Spectroscopy Data Center at the National Institute of Standards and Technology (NIST) is critically evaluating and compiling spectra and energy levels for all ionization stages of the noble gases. Ambiguous line classifications are resolved by means of theoretical calculations of transition probabilities. Optimization of energy levels on the basis of observed lines is carried out where necessary.

Already published are the energy levels and observed spectral lines of xenon covering the available data for all ionization stages Xe I – Xe LIV. A compilation of Ne I data has also been published with a redetermination of the energy levels..

As part of this effort, the energy levels and classified observed spectral lines of the krypton atom have been compiled in all stages of ionization for which experimental data are available. Also included are theoretical energy levels for helium-like and hydrogen-like krypton. Energy level and spectral line tables are provided for 29 ionization stages. Tables are included for Kr I – Kr X and Kr XVIII – Kr XXXVI. They include about 1632 levels and 4509 lines. In addition, energy levels are provided for separated isotopes of neutral ^{84}Kr and ^{86}Kr. We provide a value, experimental, semi-empirical, or theoretical, for the ionization energy of each ion. We also include experimental g-factors for the first two ionization stages. The leading percentages of the configurations and terms in the levels are provided for Kr II – Kr X and Kr XXI – Kr XXV. This compilation takes into account published work through December 2003. There are occasional exceptions in which later work is considered. The krypton compilation is scheduled to appear in the Journal of Physical and Chemical Reference Data early in 2007 and will also be available online at the journal's website.

Work continues on the noble gas compilations. The spectra and energy levels of argon are currently being compiled.

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Infrared Spectrum and Improved Energy Levels of Neutral Krypton

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Abstract. We have studied the infrared spectrum of neutral krypton (Kr I) in its naturally occurring isotopic composition. Kr I was observed in a microwave-excited electrodeless discharge lamp with the National Institute of Standards and Technology 2-m Fourier transform spectrometer (FTS). Our spectra cover the regions 6699 Å to 12 200 Å with a resolution of 0.01 cm^{-1} and 9000 Å to 47 782 Å with a resolution of 0.007 cm^{-1}. The response of the FTS was characterized by using a radiometrically calibrated tungsten strip lamp to obtain relative intensities accurate to 10 % or better over the entire spectral range for lines with good signal-to-noise ratio. Approximately 630 lines were measured and classified, mostly as transitions among previously reported Kr I levels. About 290 of these lines are newly observed in this work. Our line list represents the first comprehensive description of the Kr I spectrum in the extraphotographic infrared region. The high resolution of the spectra allowed us to resolve previously unresolved pair-coupled levels of the $4s^24p^5(^2P_{3/2})4f$ and $4s^24p^5(^2P_{3/2})5g$ configurations. A group of newly observed lines near 26 000 Å was classified as transitions of the $4p^54f$ - $4p^56g$ array, locating all eight of the $4s^24p^5(^2P_{3/2})6g$ levels. A new line at 8299 Å determines the $4s^24p^5(^2P_{3/2})6f[9/2]_5$ level, completing the $4s^24p^5(^2P_{3/2})6f$ configuration. By combining our precise measurements with selected values from previously reported work at shorter wavelengths, we derived improved level values for 64 even and 77 odd parity levels. Most excited levels were determined with uncertainties of less than 0.001 cm^{-1} with respect to each other. The absolute energies of the excited configurations with respect to the ground state were determined with an uncertainty of 0.0002 cm^{-1}.

Study of Atomic Processes in Tin Plasmas for the EUV Sources

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Abstract. We study the extreme-ultra-violet (EUV) source for the next generation microlithography. We perform radiation hydrodynamics simulations of laser produced tin plasmas, to calculate the emission spectrum and conversion efficiency to the λ=13.5nm band. The simulation uses the emissivity and opacity of the plasma, which is calculated from the atomic energy levels and raditaive rates calculated by the HULLAC code. In the plasmas with the T_e=20-50eV, near 10 times ionized tin ions are produced, which emit strong EUV radiation through 4d-4f, 4d-5p, and 4d-5f transition arrays. We obtain the ion abundance, level population by solving rate equations taking multiply- and inner-shell excited states of each charge state into account. The present model of emissivity and opacity also include the fine structure of the transition arrays as well as emission through satellite lines. The wavelengths of resonance lines, for which the calculation is significantly modified due to the effect of configuration interaction (CI), are corrected by the measurements using charge exchange spectroscopy (CXS). The calculated spectra are compared with the experiments over a variety of the pumping laser intensity, pulse duration and wavelength to show the accuracy of the wavelength of the emission lines is important to reproduce the observed spectrum.

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Mid-Z Non-LTE Opacities for Elemental and Multi-Element Plasmas

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Abstract. Recently, Los Alamos National Laboratory's T-4 group has been involved in consolidating its LTE opacity and NLTE plasma modeling capabilities (the ATOMIC project). This synthesis of capabilities has provided the opportunity to explore the radiative properties of plasmas over a broad range of plasma conditions. One area in particular bolstered by this effort has been the study of mid-Z NLTE opacities. Historically, mid- and high-Z NLTE plasma opacity models used to explore a broad range of plasma conditions were computed with models that either included only a small number of atomic states or models that contain a simplifying assumptions that often emphasized reduced execution times over accuracy due to practical constraints. We are attempting to produce a mid-Z NLTE opacity modeling capability in ATOMIC for moderately dense plasmas at the level of detail that has only been traditionally used in LTE opacity tables. We will present in this work the effects of radiation on the frequency dependent opacity function for various mid-Z single and multi-element NLTE plasmas. (LA-UR-07-0095)

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Electron Density Measurements in the Tokamak Recombining Divertor Plasma Region Using Stark Broadening of Deuterium Infrared Paschen Series Emission Lines

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Abstract. While the visible and ultraviolet (UV) Balmer emission lines have been extensively used for tokamak divertor plasma density measurements in the range (0.5 - 5) x 10^{20} m^{-3}, the diagnostic potential of near infrared (NIR) Paschen lines has been largely overlooked. Spatially resolved measurements of deuterium Balmer and Paschen line emission have been performed in the divertor region of the National Spherical Torus Experiment (NSTX). We analyze Stark broadening of the lines corresponding to $2-n$ and $3-m$ transitions with principal quantum numbers n = 7–12 and m = 5–12 using recently published tabulated calculations, namely the Model Microfield Method calculations (C. Stehle and R. Hutcheon, Astron. Astrophys. Suppl. Ser. 140, 93, 1999), the Frequency Fluctuation Model calculations (S. Ferri et al., Proceedings of 14th ICSLS, CP467, Spectral Line Shapes: Vol. 10, 1999), and the calculations based on the VCS theory (M. Lemke, Astron. Astrophys. Suppl. Ser. 122, 285, 1997). Plasma conditions in the recombining inner divertor region in NSTX are such that the natural line broadening, van der Waals broadening due to neutral-neutral collisions, and the broadening due to the Zeeman effect splitting can be neglected. The plasma is optically thin for the ultraviolet (UV), visible and near infrared (NIR) photons. Inner divertor leg densities in the range (0.5–5) x 10^{20} m^{-3} are obtained in 2–6 MW neutral beam heated lower single null H-mode discharges. Line-of-sight densities inferred from the Balmer and Paschen lines are compared to each other, and to independent divertor Langmuir probe measurements. The measured Paschen line profiles show good sensitivity to Stark effects even at densities (2-5) x 10^{19} m^{-3}, low sensitivity to instrumental and Doppler broadenings, and low sensitivity to the Bracket continuum slope. Also, optical signal extraction schemes for the NIR range in harsh nuclear environments can be realized easier than for the UV and visible ranges. These properties make the Paschen series lines an attractive recombining divertor density diagnostic for a burning plasma experiment. This work is supported by U.S. DoE under contracts W-7405-ENG-48 and DE-AC02-76CH03073.

Photoionization cross-sections for Se-ions essential to determining chemical abundances in ionized nebulae : Theory and Experiment

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Abstract. Accurate assessments of elemental abundances in astrophysical nebulae can be made from the direct comparison of the observed spectra with synthetic NLTE spectra, if the atomic data for electron and photon interaction processes are known with sufficient accuracy [1, 2]. Numerical simulations show that derived Se abundances in ionized nebulae can be uncertain by factors of two or more from atomic data alone[3, 4, 5]. Of these uncertainties, photoionization cross section data are the most important, particularly in the near threshold region of the valence shell. The numerical simulations require large numbers of cross sections, which at this time are largely unknown for trans-iron elements.

High resolution measurements have been carried out at the Advanced Light Source in Berkeley, California, using the technique of photo-ion spectroscopy [6, 7] for both singly and doubly ionized Se. We have measured the photo-ion yield for Se+ over the photon energy range 18 eV to 31 eV and Se2+ in range of 30.5 eV to 40 eV, at an nominal energy resolution of 40 meV. Absolute photoionization cross sections have also been determined. Theoretical photoionization cross sections calculations were performed for both of these Se ions using the state-of-the-art fully relativistic Dirac R-matrix code (DARC) [8], re-engineered to run on parallel architectures [9] and utilizing target wave functions determined from the Dirac-Fock atomic structure code GRASP [10, 11]. The theoretical work plays an essential role in determining the metastable state content in the appropriate Se ion beam. Comparison of our cross sections results between theory and experiment are extremely encouraging and a more comprehensive set of results will be presented at the meeting.

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Effects Of Charge Exchange In A Penning Ion Source For Neutron Generators

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Abstract. We investigate numerically the effects of charge exchange in a Penning ion source for neutron generators. We use particle-in-cell modeling with Monte Carlo collision to simulate the electron and ion dynamics, including charge exchange, for parameters typical of DC sources in use today (device size of a few cm, bias voltage of 2kV, extraction voltage of 100kV, deuterium gas pressure of 5mT). We compare results for with and without charge exchange, looking specifically at the effect on transverse velocity spread and neutron generation rate.

Ionization Of Silicon, Germanium, Tin and Lead By Electron Impact

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Abstract. Cross sections for electron impact ionization of neutral atoms are important in modeling of low temperature plasmas and gases. Cross sections for ionization have been calculated for ionization from ground levels and low-lying metastable levels of Si, Ge, Sn and Pb. We use the binary-encounter-Bethe approximation (BEB) for direct ionization and the scaled plane-wave Born approximation for excitations to autoionizing levels. Multiconfiguration Dirac-Fock wavefunctions have been used for the atomic structure. We have also employed a technique to accurately determine the range of excitation energies of the dominant autoionizing levels. It is clear that autoionization is important in these elements and must be included to obtain accurate total ionization cross sections. The calculated ionization cross sections are in good agreement with experimental results.

Revised and Extended Analysis of Mo V

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Abstract. The spectrum of four-times ionized molybdenum (Mo V) has been studied in the wavelength region 250–2848 Å using a sliding spark light source and 10.7-m grazing- and normal-incidence vacuum spectrographs at NIST. The uncertainty of the wavelength measurements is ± 0.005 Å. The ground configuration of Mo V is $4p^64d^2$ and excited configurations are of the type $4p^64dn\ell$. Earlier work on this spectrum was carried out by Cabeza et al. [1]. However, the core-excited configurations $4p^54d^3$ and $4p^54d^25s$ are prominent in the level scheme and exhibit very complex structures. These configurations have not been studied before in the isoelectronic sequence and are being investigated here for the first time. Hartree-Fock calculations were performed to predict the level structure by using the computer code of R. D. Cowan. The two internally-excited configurations alone have 200 energy levels and show strong interactions with the $4p^6$4d5p, 4d6p, 4d7p , 4d4f , 4d5f, 4d6f, 5s5p, 5s4f, 5p5d, and 5p6s configurations. A large number of energy levels from the core-excited configurations have now been found. Several levels of the $4p^54d^25s$ configuration lie above the ionization limit and could not be established. In the even parity system, the new configurations studied are $4p^65s^2$, 5s5d, 5s6s and 4d5g. The earlier reported [1] level 4d5d $^1S_0$ has been revised.

This work is supported in part by the Office of Fusion Energy Sciences of the U.S. Department of Energy.

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Single Shot Time Resolved Measurement of Molecular Alignment in Laser-irradiated Gases

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Abstract: Gases irradiated by high intensity non-ionizing laser fields exhibit a transient nonlinear refractive index response. In monatomic gases the response results solely from the near-instantaneous motion of bound electrons, whereas in polyatomic gases, there is an additional, delayed response due to the relatively slow motion of the nuclei. We use Single-shot Supercontinuum Spectral Interferometry (SSSI) [1] to temporally resolve the refractive index transient and observe the alignment and relaxation of molecular gases irradiated by femtosecond laser pulses. We examine the dependence of the nonlinearity on gas species and pressure, as well as on pump laser energy and pulse duration. This nonlinearity can play a large role in the 'self-channeling'[2] of intense femtosecond laser pulses through the atmosphere.

Our SSSI technique also time-resolves the quantum rotational recurrences that can occur in a molecular gas long after the passage of the pump pulse. The results suggest that strong molecular alignment and its recurrences can take place even in an ionized gas.

Figure 1

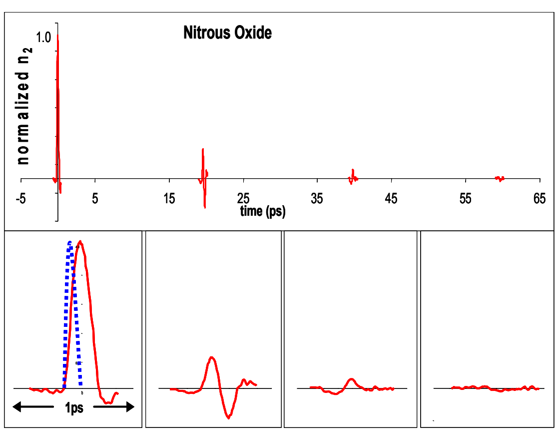

Figure 2

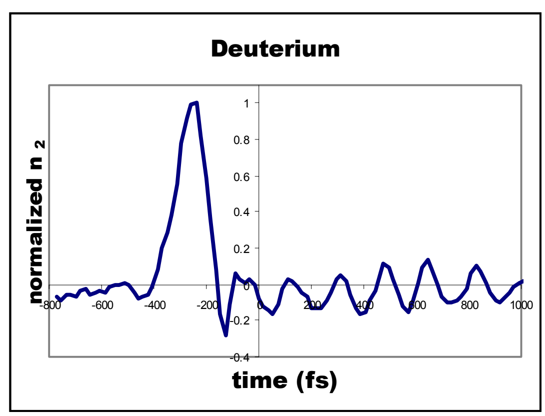

Fig. 1 and 2: Quantum beats (or rotational recurrences) of N_2O and D_2 occur on vastly different time scales, but can both be resolved using SSSI.

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Coupling of Numerical Wall Models with the Edge in Tokamak Plasmas

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Abstract. Fusion plasmas are thermally isolated from material walls by using external magnetic field coils but significant heat flux can reach the plasma walls and interact. Complex interactions between the walls and the edge plasma can affect the core plasma through interactions in the intermediate open-field line region. While resources are being devoted to understanding the coupling between open-field line and closed-field line regions computationally, the complexity of the wall interaction means that only simplified models have been used to date. Computational tools for studying the plasma-wall interactions are needed that are as sophisticated as those for the neutral plasma region. Further, any tool that is developed needs to be able to couple to other codes within the fusion community, such as existing edge plasma simulation codes. We report on our progress developing a detailed model of the sheath/wall system and providing the means to couple this model to existing edge plasma component models. We are extending an existing numerical library of particle-solid interactions to include plasma-material interaction processes of relevance to fusion plasmas at the wall. For modeling the sheath, we are using the VORPAL code which can solve both fluid equations and kinetic equations via Particle-In-Cell (PIC) methods. We are designing these codes with flexible interfaces and dynamic resource allocation so that they can be components of an integrated tokamak simulation framework.

Keywords:

Weak Emission Lines in the Spectra of Hot Stars

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The spectra of stars having a photospheric continuum temperature in the range 10000 to 15000 K (spectral type A0 to B5) have recently revealed the presence of weak emission lines from the second spectra for a number of elements. The emission lines have typical equivalent widths of a few milli-angstroms, are dominated by the elements of the iron group, and are observed in the spectra of sharp-lined stars (presumed to be slow rotators since fast rotation will act to broaden the line beyond the point of detection). Although the phenomenon was first detected in the spectra of the chemically peculiar stars 3 Cen A and 46 Aql (Sigut et al. 2000, ApJ 530, L89) it has since been observed to occur in stars of both normal (solar-like) and peculiar chemical compositions (Wahlgren & Hubrig, 2000, A&A 362, L13). The significance of these observations lies in the supposition that the physical conditions required to create the weak emission lines must exist in the outer atmospheres of all stars in this temperature regime. Stars of spectral type B are not associated with an extended solar-like chromosphere or corona. Up to now the extension of the photosphere to low density for these stars has not been studied due to the lack of diagnostics. The origin of the weak emission lines has been proposed to result from non-LTE conditions in the photosphere (Sigut, 2001, A&A 377, L27) and fluorescent pumping from far-ultraviolet continuum emission (Wahlgren & Hubrig, 2004, A&A 418, 1073), but it remains an open question. The observed characteristics of the weak emission line phenomenon are presented, along with a discussion of the ideas proposed to describe them and future research plans, which include additional observations and new non-LTE calculations.

Spectroscopic Investigation of Laser-Heated Buried Layer Targets*

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Abstract. The spectroscopic investigation of hot, dense matter (T_e approx. 100 - 200 eV, n_e approx. 10^{23} cm^{-3}) produced by ultrashort pulse laser heating of buried layer targets provides experimental access to this interesting regime of high energy density plasma physics. The material of interest is buried underneath a tamping or ablator layer in order to prevent significant expansion during the laser heating [1,2]. The highly dynamic nature of such an extreme state of matter requires ultrafast diagnostics, e.g., x-ray streak cameras with sub-ps temporal resolution [3]. Time-resolved x-ray emission spectroscopy measurements on buried aluminum and germanium layer targets have been performed at the Compact Multipulse Terawatt (COMET) laser, which is part of the recently upgraded Jupiter Laser Facility at the Lawrence Livermore National Laboratory. Systematic studies of the Al K-shell and Ge L-shell emission spectra included the variations in the thickness of the tamping layer, the laser pulse duration, and laser energy. In particular, the 50-nm thin Al and Ge layers are tamped by carbon layers of 0 (untamped), 25, 50, 75, and 100 nm thickness. The intensity of the frequency-doubled (527 nm) COMET laser was varied from 10^{16} W/cm2 to almost 10^{18} W/cm2, and the pulse duration from 500 fs to 5ps. Short-lived (few ps), significantly broadened emission has been observed for the most tamped layer targets and much longer lasting, narrow line emission in the untamped case. Moreover, comparison with the spectral kinetics code SCRAM using LASNEX electron density and temperature predictions show an interesting opportunity for a spectroscopic determination of the fraction of heating by non-thermal electrons.

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Effect of Spectral Line Wings on Rosseland Mean Opacities

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Abstract. Calculations of photon absorption by plasmas have significantly improved over the last two decades. Results from the new opacity codes were essential in order to resolve long-standing astrophysical problems as well as provide good agreement between experimental and theoretical spectra. One reason for improvement is faster computers that allowed better treatments of the myriad spectral lines present in absorption spectra using either line-by-line or statistical methods. Nevertheless, there remain theoretical and numerical challenges. An important issue is the sensitivity of the theoretical photon absorption to spectral line shape models. Variations of Rosseland mean due to model uncertainties will be reviewed, and new numerical methods for computing line wing profiles beyond the common Voigt approximation will be presented.

Emission Spectra of Lanthanide Free Ions. Interpretation of Nd IV and Tm IV

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Abstract. There are many reasons for studying the spark spectra of lanthanides. The modelling of stellar atmospheres in chemically peculiar stars needs a better knowledge of third spectra, whereas the trivalent ions embedded in compounds have a wealth of applications for lasers, for phosphors in the lighting industry and for quantum information optical devices. Finally, the most recent advances in the theory of $4f^N$ configurations need experimental energy levels to test the effective parameters bound with configuration interactions [1]. A major part of free ion IV spectra were missing in the unique critical compilation available [2].

The interpretation of Nd IV used sliding spark spectra taken on the 10 meter normal incidence vuv spectrograph at Meudon observatory, which supplemented spectrograms recorded at NBS (1980). The initial classification [3], i.e. 37 levels of the ground configuration $4f^3$ derived from 550 transitions $4f^3$-$4f^25d$, is now extended to include:

1) the missing upper terms ^2G and ^2F of $4f^3$,

2) the parametric study of all known levels using the codes by Cowan [4]. In the odd parity, 108 levels of $4f^3$+$4f^26p$+$5p^54f^4$ are described by 23 free parameters with a *rms* deviation 91 cm^{-1}. In the even parity, 119 levels of $4f^25d$+$4f^26s$ (70817 - 137456 cm^{-1}) lead to a *rms* deviation 37 cm^{-1}, provided that the core excited configuration $5p^54f^35d$ is added to the basis set.

Concerning thulium, all studied spectrograms were photographed at Meudon in the 700-2300 Å region. More than 750 lines are now classified as Tm IV transitions between 10 levels of the ground configuration $4f^{12}$, 157 levels of $4f^{11}5d$, 33 levels of $4f^{11}6p$ and 9 levels of $4f^{11}6s$. Similar to the case of Nd IV, the $5p^64f^{11}5d$-$5p^54f^{12}5d$ interaction has a significant quenching effect [5] on the calculated $4f^{12}$-$4f^{11}5d$ transition probabilities [6].

In parallel with the IV spectra, a breakthrough in the analysis of Yb V was made and all levels of Nd V $4f^2$, 4f5d, 4f6s and 4f6p (except $4f^2$ $^1S_0$) have been derived from Meudon and NBS experimental data.

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Direct Laser Acceleration of Electrons in the Corrugated Plasma Waveguide

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Abstract. Direct electron acceleration by a radially polarized laser pulse can be quasi-phase matched in a corrugated plasma channel [1]. Modest laser pulses (1 mJ, 100fs) could give large gradients (> 10 MV/cm) over many centimeters.

QUASI-PHASE MATCHING BY A STRUCTURED PLASMA

Direct laser acceleration of electrons by a radially polarized beam has demonstrated an acceleration gradient of 31 MeV/m [2], but this gradient was strongly limited by diffraction, available laser intensity, and the ionization threshold of hydrogen gas.

We propose to eliminate all these limiting factors simultaneously by performing direct electron acceleration with a radially polarized femtosecond laser pulse in a microstructured plasma channel recently produced by our group that allows quasi-phase matching. We present simulations that suggest gradients >1GeV/m over many centimeters are possible using modest, commonly available kilohertz laser systems.

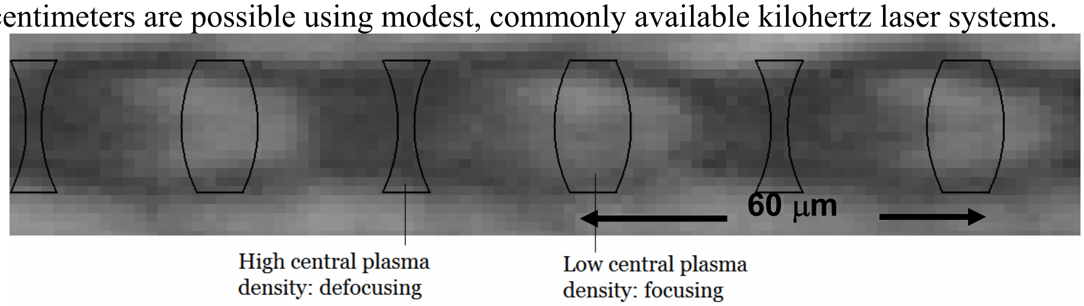

FIGURE 1. High magnification view of an experimental corrugated waveguide produced by our group. The waveguide has alternating peaks and troughs of central electron density, acting as focusing and defocusing micro-lenses. This geometry could potentially eliminate out-of-phase decelerating intensity on axis and further enhance in-phase acceleration intensity.

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