Calculations and Measurements of Argon Emission in a Magnetized Linear Plasma Column

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ABSTRACT:

Performing spectroscopic measurements of emission lines in relatively cold laboratory plasmas is challenging because the plasma is often neutral-dominated and is not in thermal equilibrium. However, these types of plasma do offer a unique opportunity for benchmarking the finer details of atomic physics. We report on a new set of atomic data, recently calculated at Auburn University, where we determine rate coefficients for the electron-impact excitation of neutral argon and dielectronic recombination of $Ar^{+}\rightarrow Ar^{5+}$ This data is then used to generate synthetic emission spectra, which are compared to experimental spectra observed in the Auburn Linear EXperiment for Instability Studies (ALEXIS) in an effort to benchmark our atomic calculations. We identify emission lines that are sensitive to variations in temperature and density, and present an outline of our efforts to use this data to develop new optical and temperature diagnostics for the ALEXIS plasma.

MOTIVATION:

The accurate diagnosis of plasma parameters using in-situ probes has been an outstanding issue since the inception of the field. Probes offer the particular advantage of providing localized measurements of plasma parameters, however concerns over the perturbation of the plasma by an inserted probe, the proper interpretation of the probe signal, as well as plasma-induced damage of the probe caused by high thermal and particle fluxes, and the associated introduction of impurities, are just a few of the many reasons why the use of in-situ probes can be problematic.

The majority of non-invasive plasma diagnostic techniques can be characterized as either line-integrated or point measurements. Point measurements have the advantage of providing localized information of important plasma parameters. Optical emission spectroscopy, while providing a line-integrated measurement, often involves far less complex diagnostic development and expense. However, careful analysis is required in order to properly interpret the experimental measurements. This paper focuses on the development of a new generation of spectroscopy-based diagnostic tools.

Modifications have been made to the Auburn Linear Experiment for Instability Studies (ALEXIS) to facilitate its use as a test bed for new atomic data for neutral and low-charge states of argon generated by the Atomic, Molecular, and Optical (AMO) group at Auburn University. This new data can predict photon emissivity coefficients as a function of wavelength for a range of electron densities and temperatures, making it an ideal tool for the creation of theoretical line spectra. ALEXIS is a low-temperature, low-density, neutral dominated argon plasma. Probe based diagnostics are already in place in ALEXIS, capable of measuring both electron temperature and density. The recent addition of two CCD spectrometers have added the capability to collect emission spectra, making it possible to build a database of spectra across a range of densities and temperatures. Preliminary theoretical results suggest temperature and density sensitive emission associated with the line spectra of excited states of neutral argon. Comparison with spectra taken from ALEXIS, combined with probe based density and temperature measurements, offer a possible route to the development of new, non-invasive, temperature and density diagnostics.

The rest of this paper is structured as follows: in Section I we provide technical details about the ALEXIS plasma, Section II discusses the methods used to generate our atomic population model, and presents preliminary results of comparisons with experimental observations within ALEXIS. Section III is a summary of our current results, and suggests possible future work.

SECTION I: The ALEXIS Plasma

ALEXIS is a 1.7 m long, weakly magnetized, linear argon plasma column. The primary plasma source is a 600 Watt RF power supply, operating at 13.56 MHz. Typical RF

Parameter	*Value*
Length	*170 cm*
Diameter	*10 cm*
Plasma-β (max)	*1.0x10^{-4}*
Magnetic Field	*160 – 940 G*
Electron Temperature	*3-7 eV*
Electron Density (max)	*6 x10^{16} m^{-3}*
Neutral Gases	*Argon, Helium, Nitrogen, Neon*
Diagnostic	***Measurement***
Double / Langmuir Probe	*Electron Density and Temperature*
Emissive Probe	*Electric Field, Plasma Potential*
K- Probe	*Wavenumber, Wavelength, Electrostatic Fluctuations*
THORlabs CCS200 Compact Spectrometer	*Emission Spectra (200 – 1000 nm)*
Stellar Net Black Comet UV-VIS	*Emission Spectra (200 – 600 nm)*
Stellar Net SL1- CAL	*Spectrometer Calibration*

Table 1: Parameters and diagnostics of the ALEXIS plasma.

operating power ranges from 30→200 Watts. Currently, installed diagnostics include a double probe for the measurement of electron density and temperature, an emissive probe for floating and plasma potential measurement, and a "k"-probe (a double-tipped Langmuir probe) used to measure wavenumber. Emission spectroscopy is performed with one of two miniature CCD spectrometers. These are detailed in Table 1, along with other relevant plasma parameters. Electron temperature and density measurements are made by applying a tanh curve fit to an I-V trace taken with the double probe.

SECTION II: Atomic Modeling of the ALEXIS plasma.

Our atomic model is based on the term-resolved structure calculation of Ballance and

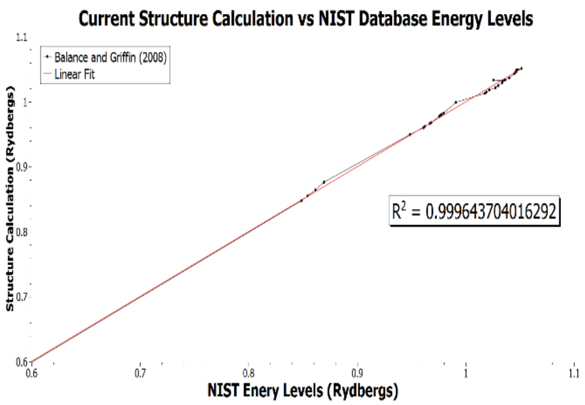

Figure 1: Energy level calculations from the present work compared with NIST. The high correlation coefficient suggests excellent agreement between our energy levels and the accepted standard (NIST).

Griffin [2], which we have extended to include 749 J-resolved levels. The calculated level energies show excellent agreement with the NIST database, as can be seen in Figure 1.

New, fully level-resolved dielectronic recombination (DR) rate coefficients have been calculated using the AUTOSTRUCTURE code package [3,4], in order to investigate the role DR plays in populating excited states of neutral and

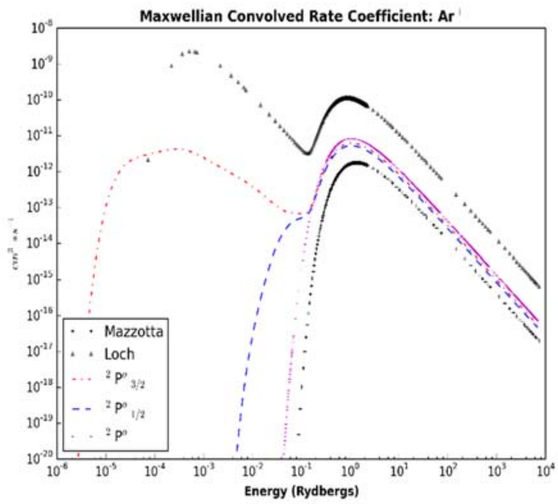

Figure 2: Our DR rate coefficient for Ar+ have significant differences with those in current widespread use.

lightly ionized argon. Significant differences were discovered between these new rates and those presently in widespread use [5,6] (Figure 2).

ALEXIS is neutral dominated, and the main population mechanism for excited states argon in ALEXIS is thought to be collisional. As such, we have employed a newly developed parallel Breit-Pauli R-matrix with Psuedo-States (BPRMPS) calculation to determine electron impaction excitation rate coefficients for neutral argon [2]. From these, we have extracted photon emissivity coefficients in order to generate theoretical

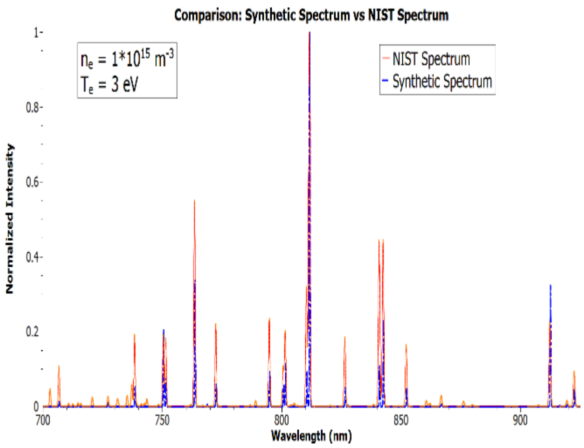

Figure 1: Our theoretical spectra agree well with those from the NIST database.

emission spectra. Preliminary comparisons with the NIST database show good agreement (Figure 3). In addition, our model predicts the presence of temperature and density sensitive spectral lines, which preliminary measurements in ALEXIS have confirmed.

SECTION III: Summary and Future Work

We are using recently calculated atomic data for neutral and low-charge states of argon to model the ALEXIS plasma. We aim to bench mark the atomic data through direct comparison of theoretical spectra with observations in ALEXIS. Based on early results, we believe that diagnostic applications are possible by comparing line ratios of density and temperature sensitive spectral lines.

We intend to continue to refine our atomic model. Our DR rates have yet to be included in the atomic population model, and we plan to further investigate the time dependence of the atomic population in ALEXIS. In addition, the field coils in ALEXIS are undergoing modifications designed to increase the residence time of the electrons within the plasma. Our hope is to increase temperature and density in order to detect spectral lines from ionized states of argon.

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