SPECTRAL LINE INTENSITIES FOR $\Delta n = 0$ (L-SHELL) TRANSITIONS OF N, O, AND F-LIKE IONS

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Many laboratories are actively investigating radiation spectra emitted from high temperature/high density plasmas produced using gas-puff Z-pinch machines and high power lasers. Spectral-line intensities from these plasmas can be useful temperature and density diagnostics. In a well-diagnosed plasma, information on the emission spectrum can also be used to test the accuracy of theoretical rate coefficients.

Recently time-resolved spectra[1] from an oxygen-like argon plasma produced in a gas-puff z-pinch were measured in the wavelength range 150-200 Å. Over this wavelength range the spectrum contains mostly the $\Delta n = 0$ (L-shell) transitions in ArX-ArXIV and some weak transitions for n = 3 to n = 4 of ArVI-ArVIII. The measured spectra show the predominance of O-like Ar L-shell transitions.

We have developed a model to calculate spectral-line intensities for all the $\Delta n = 0$ (L-shell) transitions in ArXII to ArX as a function of electron temperature and density. Applying these results, we have obtained: (1) spectral-line intensity ratios which can be used to estimate electron temperature and density, (2) synthetic emission spectra to fit experimental measurements.

Our calculation assumes that the plasma has small temperature and density gradients and also neglects the effects of radiation transport. Rather than simulating all the complexity of the plasma, we have developed a simple model which treats only the atomic physics completely. In situations where gradients or radiation transport are important, our model is still very useful to give an upper-bound on experimental data.

Our calculation consists of two steps. First, we apply an ionization balance code[2] to calculate the population of the n = 2 states of N, O, and F-like ions as a function of electron temperature and density. This code lumps the energy levels with the same principle quantum number together to form a single level. The code includes ionization not only from the ground state but also from the excited states. The effect of excited state ionization is to increase the charge-state abundance at lower temperatures. Based on our ionization balance calculation and the predominance of O-like Ar transitions after pinch time, we estimate an electron temperature of 90 eV in these experiments.[1]

The second step is to employ results from the ionization balance calculation to normalize the relative populations given by the detailed atomic spectroscopy code. In the spectroscopy code the relative population for the excited states of an ion is determined by the balance between electron collisional excitation and dexcitation and radiative decay. We assume the effects of ionization and radiative recombination on the excited state populations are negligible since the electron collisional excitation rates are larger than both the ionization and radiative recombination rate by a large factor (approximately 10^2).

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The energy levels and oscillator strengths[3] employed in the calculation were computed using the code SUPERSTRUCTURE.[4] Available measurements[5] of the energy levels were also used. The electron collision strengths[3] for all the $\Delta n = 0$ (L-shell) transitions were computed in a distorted-wave approximation using programs developed by Eissner, Seaton,[6] and Saraph.[7] The calculation employs configuration interaction wavefunctions which are generated using single particle orbitals for modified Thomas-Fermi potentials.

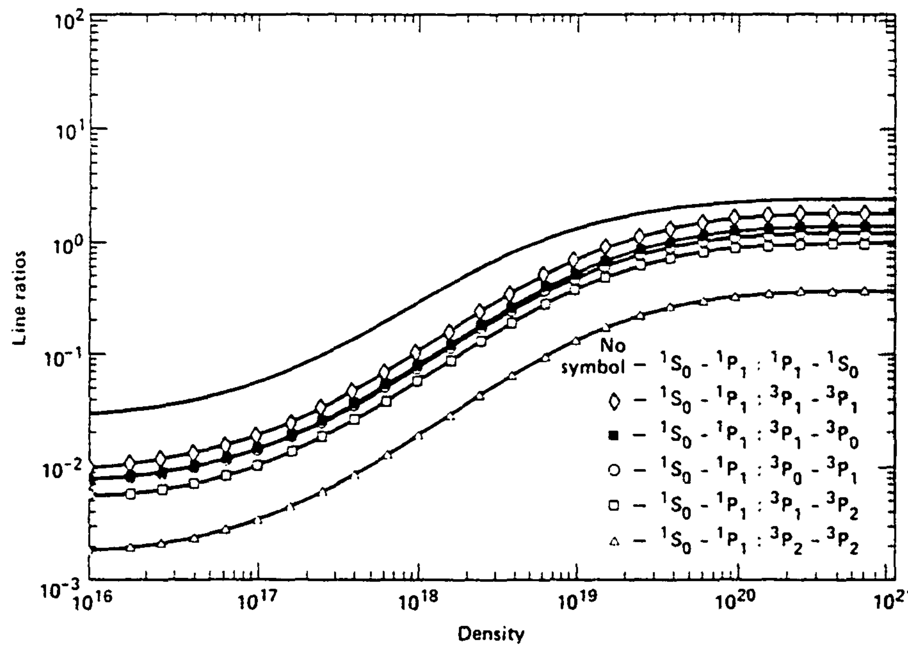

FIG. 1 Density sensitive spectral-line intensity ratios for O-like Ar.

In Fig. 1 we present density sensitive line ratios for $\Delta n = 0$ transitions of O-like Ar. These ratios involve the $^1S_0 - {}^1P_1$ transition from the doubly-excited state to a singly-excited and six transitions from singly-excited states to states in the ground state configuration. These ratios strongly depend on the electron density at 10^{17} cm^{-3} $\leq n_e \leq 10^{19}$ cm^{-3} and approach the LTE limits at $n_e \geq 10^{20}$ cm^{-3}. Since these line intensity ratios all contain a transition which ends up in a state in the ground configuration, their values are significantly affected by the opacity of the plasmas.

In Fig. 2 we give a line-intensity ratio which can be used to estimate the electron temperature of the plasma if its electron density is known. This ratio involves two transitions from a doubly-excited state to a singly-excited state. Since both transitions end up in the excited state, the probability for absorption of the emitted photon is very small. Therefore, this line-intensity ratio should be a good temperature diagnostic once the electron density is determined.

Also plotted in Fig. 2 is a data point for the line-intensity ratio obtained from a recent measurement.[1] Based on the line-intensity ratio for $\Delta n = 0$ transition of O-like Ar (Fig. 1), the electron density of the plasma core was estimated to be 10^{19}cm^{-3}. Using this result for the density, Fig. 2 gives an electron temperature of 90 eV.

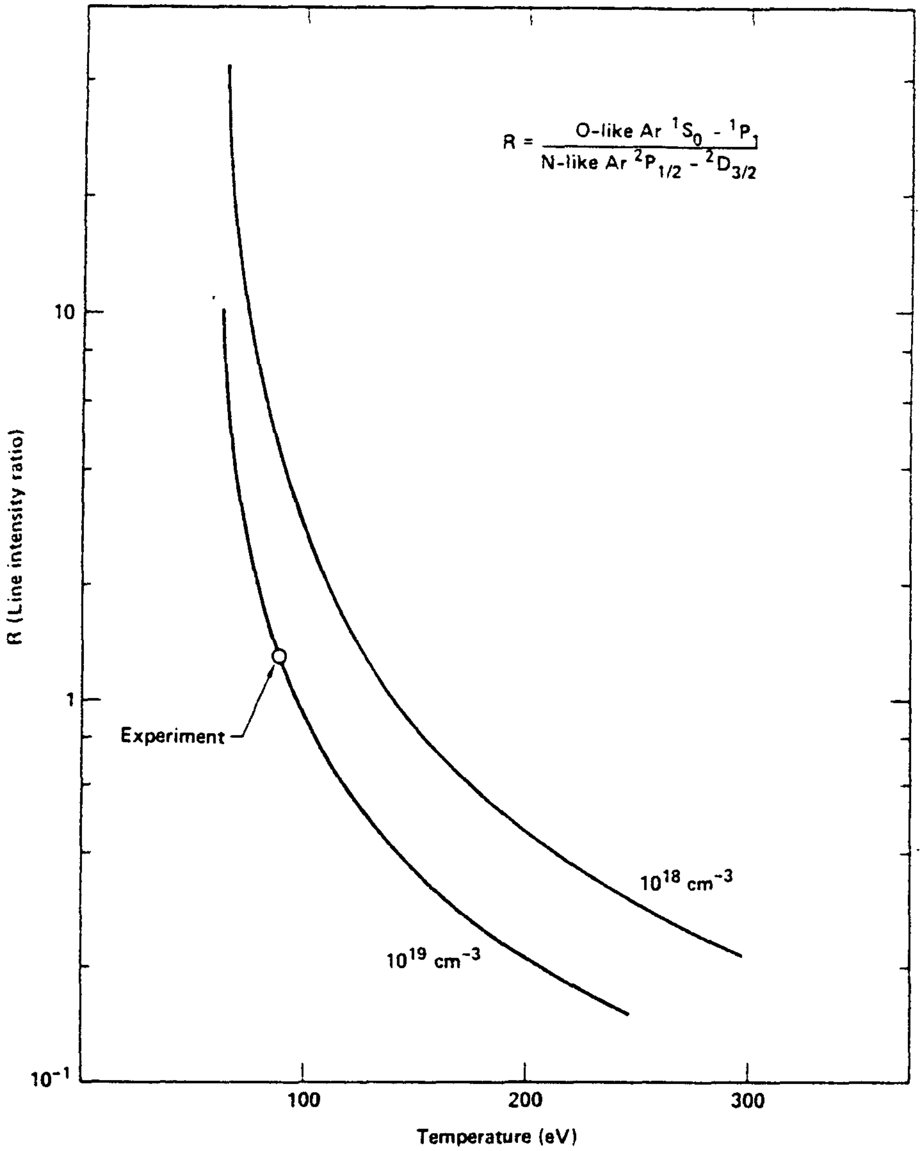

FIG. 2 Temperature sensitive spectral-line intensity ratios. Both transitions start from a doubly-excited state to a singly-excited state.

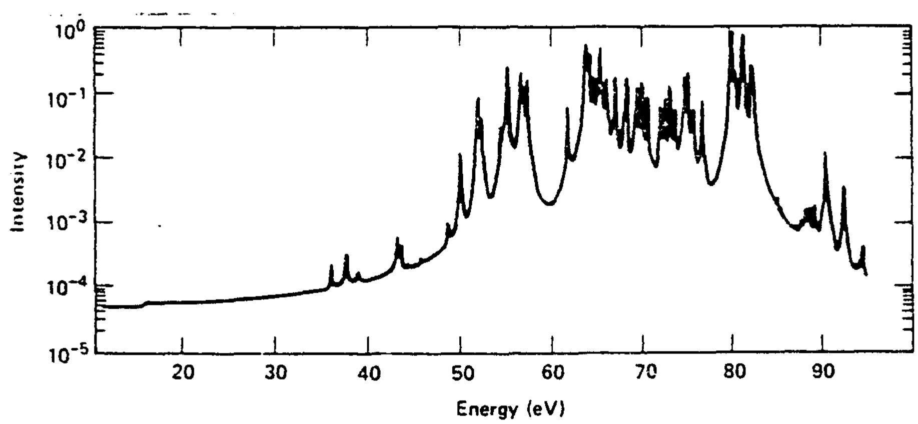

FIG. 3 A synthetic spectrum for the following plasma conditions: (1) electron density = 10^{19} cm^{-3}, (2) ion density = 10^{18} cm^{-3}, (3) temperature = 90 eV, (4) line-width = 0.1 eV, and (5) plasma size = 0.01 cm.

In Fig. 3 we present a typical synthetic spectrum produced using the code SPECTRA[8] for the excited state populations from our calculation.

In summary, we have developed a simple model to calculate spectral-line intensities emitted from a plasma as a function of electron density and temperature. Line-intensity ratios which are useful diagnostics for electron temperature and density are obtained. We have produced synthetic spectra which can be used to fit experimental data to determine plasma temperature and density.

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