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PRODUCING A STEADY-STATE POPULATION INVERSION\*

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**MASTER**

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## ABSTRACT

An observed steady-state transition at 17.5 nm is identified as the  $2p^5 3s 3p \ ^4S_{3/2} \rightarrow 2p^6 3p \ ^2P_{3/2}$  transition in Na-like aluminum. The upper level is populated by electron inner shell ionization of metastable Mg-like aluminum. From the emission intensity, the rate coefficient for populating the upper level is calculated to be approximately  $5 \times 10^{-10} \text{ cm}^3/\text{sec}$ . Since the upper level is quasi-metastable with a lifetime 22 times longer than the lower level, it may be possible to produce a population inversion if a competing process to populate the lower level can be reduced.

## INTRODUCTION

Quasi-metastable levels of Na-like ions and atoms have previously been proposed as appropriate upper levels in producing population inversions.<sup>1</sup> In this previous study, the inversion between the  $2p^5 3s 3p \ ^4S_{3/2}$  upper level and the  $2p^6 3p \ ^2P_{3/2}$  lower level in Na and  $\text{Mg}^+$  was investigated. In this paper, an investigation of this same transition in  $\text{Al}^{2+}$  is presented. Also included is a technique for populating the upper level, an observation of the transition, and an experimental estimate of the population rate.

## INNER SHELL IONIZATION

The inner shell (2p) ionization rate of  $\text{Al}^+$  for energies well above threshold (100 eV) may exceed the outer shell ionization rate.<sup>2</sup> For  $\text{Al}^+$  in the metastable states ( $2p^6 3s 3p \ ^3P_{0,1,2}$ ), the 2p ionization will populate the  $2p^5 3s 3p$  levels in  $\text{Al}^{2+}$ . Using a multiconfigurational code to calculate the autoionizing and radiative decay rates and assuming a  $2J+1$  weighting factor in populating the upper levels, a radiative emission spectrum can be predicted. Figure 1 shows such a spectrum which includes a 0.05 nm broadening and a 1% increase in the predicted energy levels to slightly decrease the wavelength of the lines, which improves the fit to the data and is well within the uncertainty of the calculation.

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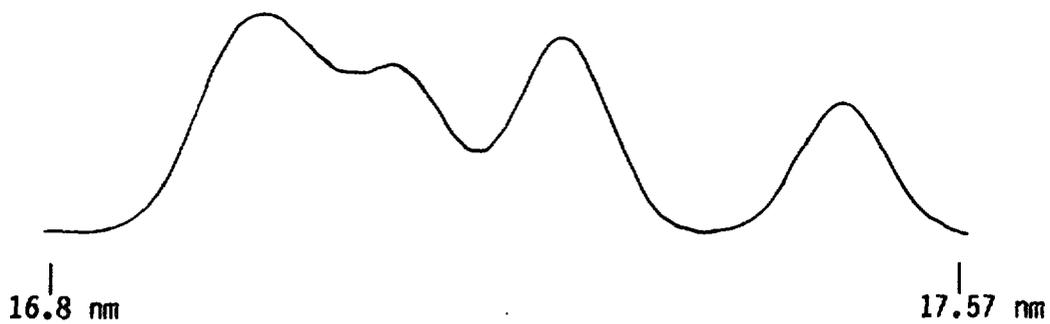


Fig. 1. Predicted spectrum of the  $2p^5 3s 3p - 2p^6 3p$  transitions.

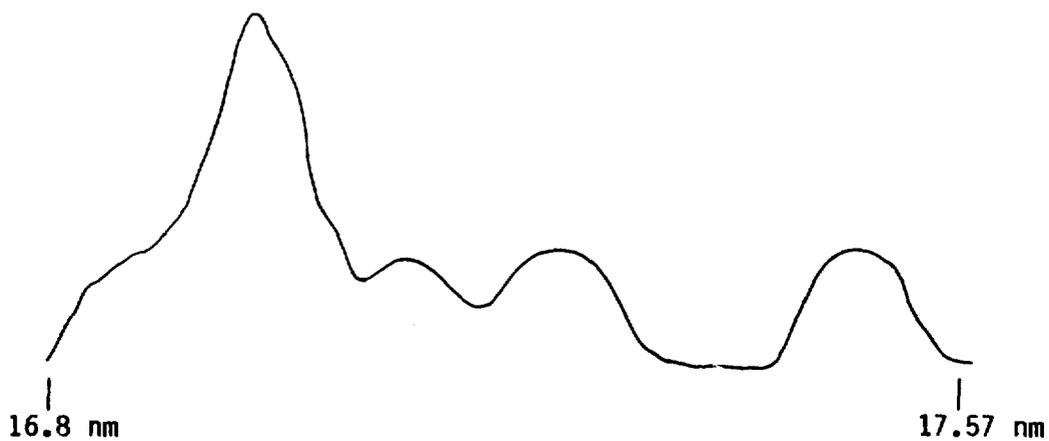


Fig. 2. Observed spectrum between 16.8 and 17.0 nm.

An experimental observation of these transitions is shown in Fig. 2. This was taken with a scanning 2.2 m monochromator observing radiation from the ELMO Bumpy Torus experiment.<sup>3</sup> This device produces a steady-state plasma with aluminum as the dominant impurity and has an electron temperature typically 300 eV. These same transitions have been observed in emissions from Penning discharges.<sup>4,5</sup>

Because the  $2p^5 3s 3p \ ^4S_{3/2}$  level has the lowest energy of the  $2p^5 3s 3p$  levels the  $2p^5 3s 3p \ ^4S_{3/2} \rightarrow 2p^6 3p \ ^2P_{3/2}$  transition will occur at the longest wavelength, in Fig. 2 this is at 17.5 nm. The intensity of this transition may be used to estimate the population rate coefficient by comparison to another intensity with a known excitation rate. Since the 16 nm pair is produced by inner shell ionization of  $Al^{2+}$  in this plasma<sup>3</sup> with a rate coefficient approximately  $5 \times 10^{-9}$   $cm^3/sec$ <sup>6</sup>, the density ratio of  $Al^{2+}$  to metastable  $Al^+$  is typically 3, and the intensity ratio of the 17.5 nm line to the 16 nm pair is approximately 0.03; then the rate coefficient for populating the  $2p^5 3s 3p \ ^4S_{3/2}$  level will be  $5 \times 10^{-10}$   $cm^3/sec$ .

#### THE POPULATION INVERSION

The lifetime of the  $2p^5 3s 3p \ ^4S_{3/2}$  state is 39 nsec which is 22 times longer than the  $2p^6 3p \ ^2P_{3/2}$  state. This large difference will permit a steady-state population inversion to be maintained. The major problem in keeping the inversion comes from the ground state population in  $Al^{2+}$ . Because of the large electron collisional excitation rate from the ground state to the  $2p^6 3p \ ^2P_{3/2}$  level, the ground state density must be kept well below that of the metastable  $Al^{1+}$  density.

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