MEASUREMENT OF THE A-VALUE OF THE $3s^2\ {}^1S_0$ — $3s3p\ {}^3P_1^o$ INTERSYSTEM TRANSITION IN Al II AT 2670 Å: A PROGRESS REPORT

B. Carol Johnson and H.S. Kwong[1]
Harvard-Smithsonian Center for Astrophysics
60 Garden Street
Cambridge, MA 02138

INTRODUCTION

Ratios of intensities of spectral lines produced in the radiative decay of collisionally-excited levels of atomic ions are versatile indicators of electron density in astrophysical plasmas when one of the lines involves a metastable level (see the review by Feldman 1981 and references therein). Radiative transition probabilities (A-values) and electron excitation cross sections are necessary for accurate, quantitative analyses of these plasmas. The work reported here is part of a program of measurements of astrophysically interesting A-values and radiative lifetimes (see the review by Smith et al. 1984); until we began, such anaylyses of astrophysical plasmas depended upon unconfirmed calculated A-values.

Here we report preliminary laboratory study of the intersystem line at 2670 Å in Al II. This line is seen in pre-main sequence stars and symbiotic stars. Brown, de M. Ferraz, and Jordan (1984) observed the Al II] line in T Tauri and included the line in their derivation of the emission measure distribution. They predict line ratios involving Al II] and resonance lines will be density sensitive for $n_e \gtrsim 10^{11}$ cm^{-3}. Recent calculations of the A-value for the $3s^2\ {}^1S_0$ — $3s3p\ {}^3P_1^o$ transition in Al^+ are 2680±50% s^{-1} and 3450 s^{-1} by Cowan, Hobbs, and York (1982) and Laughlin and Victor (1979), respectively.

EXPERIMENTAL METHOD

In our measurements, radiative lifetimes are determined by monitoring the time dependence of the radiative decay from metastable ions stored in a cylindrical, radio frequency (rf) ion trap. In previous work (see, for example, Johnson, Smith, and Knight 1984 or Kwong et al. 1983), metastable ions were created by electron bombardment on source gases. In this measurement, Al^+ ions are produced in a laser plasma, generated by focussing the output of a Q-switched Nd:YAG laser onto a target mounted on the ring electrode of the rf ion trap. Knight (1981) demonstrated that singly charged metal ions produced using this technique were stored in an electrostatic ion trap.

The components of the experiment are indicted in Figure 1 and a timing diagram detailing the sequence of events for each laser pulse is given in Figure 2. The Nd:YAG laser is operated at 10 Hz. The 1.06 μ

---

1. Permanent Address: Department of Physics, University of Nevada, Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154.

laser output is focussed, by a lens external to the vacuum system, onto an Al target after passing through the ion trap. The laser power delivered to the target area of ~ 2×10^{-4} cm^2 in the ~ 10 ns wide pulse is 1.0 to 2.5 MW. The threshold for plasma production is observed at a power density of ~ 3 $GWcm^{-2}$.

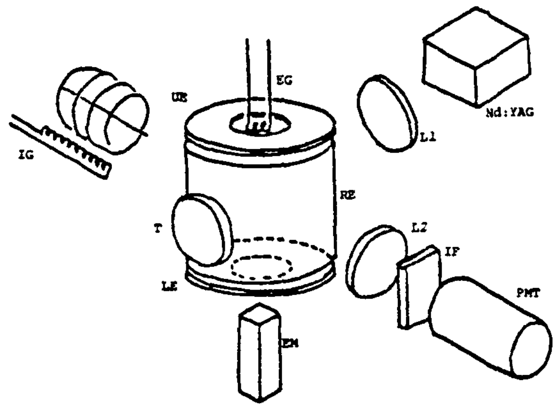

FIGURE 1. Schematic of the experiment. EG = electron gun, Nd:YAG = laser, L1 = lens to focus laser output onto target, T = target, IG = nude ionization gauge, UE = upper electrode, RE = ring electrode, LE = lower electrode, L2 = lens to focus stored ion fluorescence onto PMT, IF = interference filter, PMT = photomultiplier tube, EM = electron multiplier.

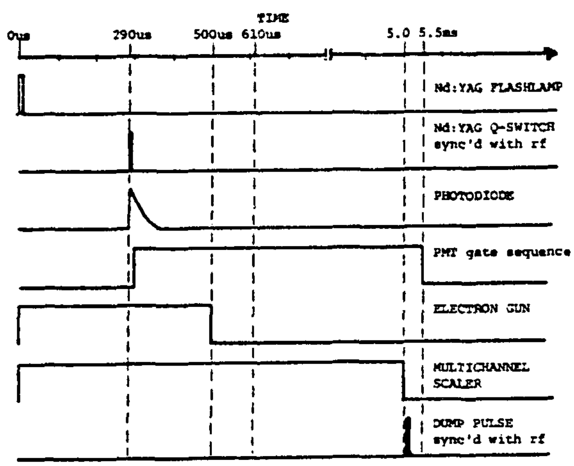

FIGURE 2. Timing sequence for each laser shot. The sequence repeats at 10 Hz. The gain on the PMT becomes constant at the location marked 610 µs.

The plasma is monitored by observing the voltage generated by the collector current of a nude ionization gauge. The temporal behavior of the neutral and ionized component of the plasma is estimated from these data. The plasma-produced stored ions are monitored by "dumping" the ions out of the trap onto an electron multiplier.

https://doi.org/10.1017/S0252921100085614 Published online by Cambridge University Press

Emission from the Al plasma is studied using a 0.3 m scanning monochromator with a RCA 1P28 photomultiplier tube on the exit slit; a prism spectrograph and spectroscopic plates; or a 1P28 photomultiplier tube. For radiative lifetime measurements, (in Al II this corresponds to a measurement of the A-value for the $3s^2\ ^1S_0$ — $3s3p\ ^3P^o_1$ transition, since there is only one decay channel for the $^3P_1$ level), fluorescence from trapped, metastable Al^+ is detected using a solar blind EMR 541Q-05M photomultiplier tube (PMT). A 55 Å FWHM filter centered on 2660 Å with 16 % transmission at 2670 Å limits the bandpass of the system.

Preliminary work indicates emission associated with the laser plasma is strong enough to damage the PMT. Therefore, the PMT is protected by gating the photocathode off during plasma production. Photon counts representing Al II 2670 Å fluorescence are time analyzed using a multichannel scaler with 10 µs resolution.

RESULTS

Temporal studies of the plasma using the ionization gauge indicate that the plasma velocity is approximately 10^6 cms^{-1}; the ions travel faster than the neutrals; and the vacuum system recovers to the base pressure of $1x10^{-8}$ Torr about 10 µs after plasma production. The plasma production efficiency, as determined by the resonance emission lines, the signal observed on the ionization gauge, and the stored ion signal, increases if the laser is focussed to a fresh target area by adjusting the lens external to the vacuum chamber approximately every 1000 laser shots. Spectroscopic studies of the plasma indicate that there is very little continuum from 2000 to 5000 Å. Resonance lines in Al I and Al II have been identified; the strongest emission occurs at 3082 and 3092 Å (the $3p\ ^2P^o$ — $3d\ ^2D$ multiplet in Al I), 3586 Å (the $3d\ ^3D$ — $4f\ ^3F^o$ multiplet in Al II), and 2632 Å (the $3p^2\ ^1D$ — $4f\ ^1F^o$ multiplet in Al II). This latter emission passes through the bandpass filter that is used to isolate the Al II] 2760 Å fluorescence, however it is separated temporally from the intersystem fluorescence by the multichannel scaler.

Ions are trapped following plasma production. The threshold for the stored ion signal is coincident with the threshold for plasma production as determined from the ionization gauge signal. The charge-to-mass ratio of the stored ions inferred from the trap potentials (see Wineland, Itano, and Van Dyck 1983 for a discussion of the stability diagram for rf ion traps) and time-of-flight measurements on the stored ion signal indicates the ions are Al^+ and Al^{++}. Fluorescence within the bandpass of the detection system from stored ions is observed (see Figure 3). The fluorescence is not present if the trap is made to be unstable for storage of Al^+ ions while holding all other conditions fixed. The fluorescence seems to increase if the laser produced plasma is crossed with an electron beam of ~ 200 eV energy, ~ 50 µA current, and 500 µs duration. The data in Figure 3 give a decay rate that is consistent with calculations of the A-value of the intersystem transition in Al^+. However, the data are preliminary and it is premature to quote a measured decay rate.

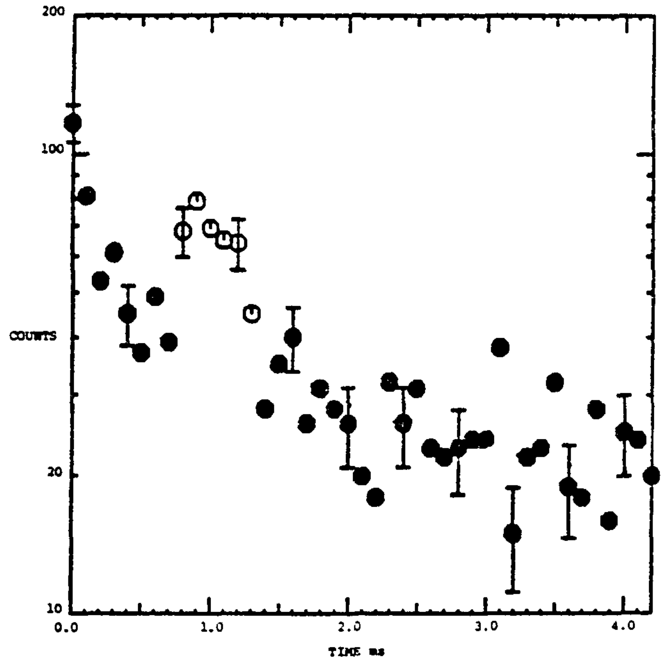

FIGURE 3. Time behavior of fluorescence observed for stored Al^+ ions. The data have been binned in 100 μs channels. Data plotted using open circles are contaminated by noise from the laser.

ACKNOWLEDGEMENTS

The authors thank Peter L. Smith for suggesting this measurement, and W.H. Parkinson for his advice and support. They also thank B.L. Cardon, L.D. Gardner, R.D. Knight, J. Kohl, G.P. Lafyatis, and K. Yoshino for their many useful suggestions concerning laboratory procedures. This work was supported in part by grants from NASA (NGL 22-007-006 and NSG-7304) and NSF (AST-82-17936) to Harvard College and by the Smithsonian Institution.

REFERENCES

Brown, A., de M. Ferraz, M.C., and Jordan, C. 1984, Mon. Not. R. astr. Soc., 207, 831.

Cowan, R.D., Hobbs, L.M., and York, D.G. 1982, Astrophys. J., 257, 373.

Feldman, U. 1981, Physica Scripta, 24, 681.

Johnson, B.C., Smith, P.L., and Knight, R.D. 1984, Astrophys. J., 281, 477.

Knight, R.D. 1981, Appl. Phys. Lett., 38, 221.

Kwong, H.S., Johnson, B.C., Smith, P.L., and Parkinson, W.H. 1983, Phys. Rev. A, 27, 3040.

Laughlin, C. and Victor, G.A. 1979, Astrophys. J., 234, 407.

Smith, P.L., Johnson, B.C., Kwong, H.S., Parkinson, W.H., and Knight, R.D. 1984, Physica Scripta, T8, 88.

Wineland, D.J., Itano, W.M., and Van Dyck, R.S. 1983, in Advances in Atomic and Molecular Physics, eds. D.R. Bates and B. Bederson (New York: Academic Press), 135.

https://doi.org/10.1017/S0252921100085614 Published online by Cambridge University Press