Intercombination lines of Al VIII, Al IX, and Al X ions

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Several aluminum lines observed in the Princeton Large Torus tokamak discharges have been identified as intersystem transitions, establishing the energies of the Al VIII $2s2p^3\,^5S$, Al IX $2s2p^2\,^4P$, and Al X $2s2p\ ^3P$ terms. Some observations of isoelectronic transitions in scandium and titanium ions are also reported.

During the course of experiments on the Princeton Large Torus (PLT) tokamak investigating charge-exchange reactions between the heating neutral hydrogen beam and various target ions,[1] aluminum was injected into the discharge to provide a target element not normally present in the plasma. This afforded an opportunity to study some features of aluminum spectra, with a particular result shown in Fig. 1. The essentially deuterium plasma at the location of the emission has an electron density about 2×10^{13} cm^{-3}, and temperature 0.3 keV.

The assignment of the observed lines to the aluminum ionization stages is determined by their observed time behavior relative to each other and the well-known 2^1P-2^1S resonance line of Al X at 332.8 Å which was used to monitor the injection reproducibility. In the scale of Fig. 1, the 332.8-Å line brightness was 5.7×10^{15}, or 20 times the 637.8-Å intercombination line brightness.

In addition to the lines in Fig. 1, a faint aluminum line (about 3×10^{11} photons/cm^{2}sec sr) was observed at 2348 ± 1 Å, with no other observable aluminum line in the range 2349–2378 Å. The time behavior of this line appeared similar to the Al VIII lines, but it could not be ascertained with confidence because of its faintness.

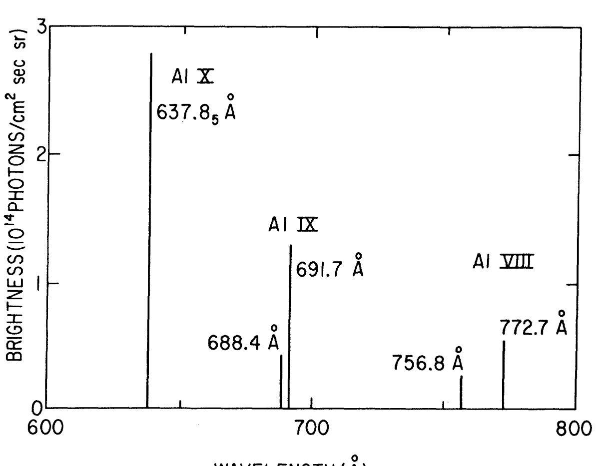

FIG. 1. Wavelengths and brightnesses of observed aluminum ion lines.

The assignment of the observed lines to the particular intercombination transitions, as shown on Fig. 2, follows from the approximately known locations of these transitions,[2,3] and the generally reasonable relative intensity pattern. If the assignments are correct, the related lines are expected to occur at the values in angle brackets in Fig. 2. Unfortunately, the predicted 1151-Å line of Al VIII is probably very weak. In Al IX, the 680-Å line is also expected to be weak, and the 704-Å line coincides with strong O III lines. However, the Al IX 712-Å line and the 2207-Å line of Al VIII ought to be observable. The last would be particularly interesting because the assignment of the 2348-Å line is certainly the most questionable of the set.

We have also made some attempts to observe the isoelectronic transitions in scandium and titanium. The beryllium sequence $^3P_1$-$^1S_0$ intercombination lines are, of course, well established,[4] up to at least Ni XXV and Cu XXVI, and have been observed in the PLT tokamak at 348.6 Å in Sc XVIII and 328.3 Å in Ti XIX. However, in the boron and carbon sequence intercombination lines, results have been meager. In titanium, there is definitely a line at 322.6 Å, which we think is the $^4P_{1/2}$-$^2P_{1/2}$ transition of Ti XVIII. This would put the possibly stronger $^4P_{5/2}$-$^2P_{3/2}$ component practically in coincidence with the 328.3-Å line of Ti XIX. There are two other, fainter lines of titanium, at 361.1 and 359.8 Å. The first of these is probably the $^4P_{3/2}$-$^2P_{3/2}$ transition of Ti XVIII, and the second the $^5S_2$-$^3P_2$ of Ti XVII. The wavelengths assigned to Ti XVIII are about 0.5 Å shorter than Edlén interpolations,[3] but the relative pattern fits reasonably well. The wavelength assigned to Ti XVII would put the other, $^5S_2$-$^3P_1$ component also close to the much stronger 328.3-Å line. These coincidences make titanium an inauspicious element for untangling the intercombination transition. In scandium, there is a line at 352.5 Å, which we think is the $^4P_{1/2}$-$^2P_{1/2}$ transition of Sc XVII. The other strong component, $^4P_{1/2}$-$^2P_{1/2}$, is then expected[3] at 347 Å, where there are fairly strong C III and O IV lines that make the identification difficult. And the $^5S_2$-$^3P_2$ line of Sc XVI is estimated to be in the neighborhood of 386 Å, which is infamous for the strong carbon lines in tokamak plasmas.

We hope these comments may be helpful to anyone else who may attempt to establish these transitions. Perhaps it is best to leave scandium and titanium alone, and go to vanadium and chromium. But a word of warning may be in order. Our present estimate shows that the $^5S_2$-$^3P_1$ line of Cr XIX coincides exactly with the $^4P_{1/2}$-$^2P_{1/2}$ of Cr XX.

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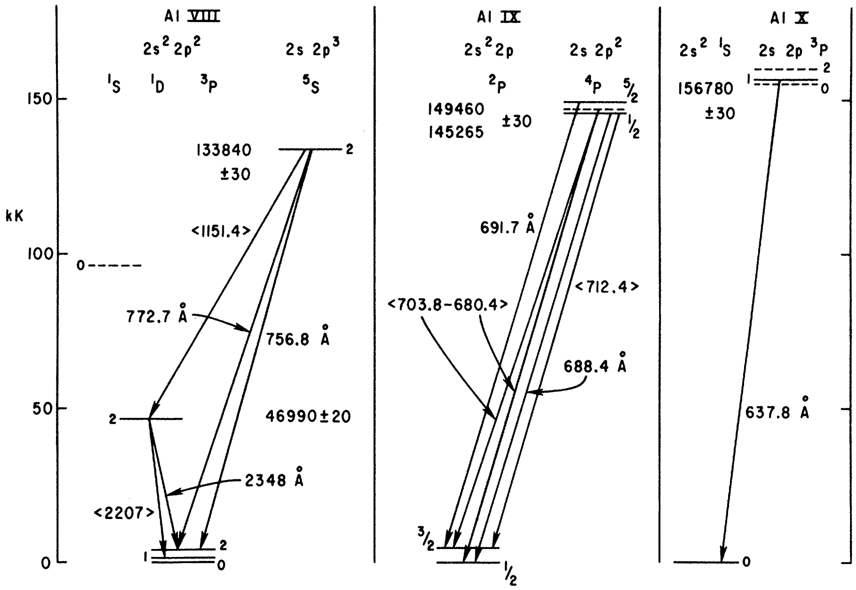

FIG. 2. Transitions assigned to the observed lines, with energy levels and estimated uncertainties in cm^{-1}. Wavelengths of expected lines, in Å, are shown in angle brackets.

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[1] C. H. Skinner, S. Suckewer, S. A. Cohen, G. Shilling, R. Wilson, and B. Stratton (unpublished).

[2] W. C. Martin and R. Zalubas, J. Phys. Chem. Ref. Data 8, 817 (1979).

[3] B. Edlén, Phys. Scr. 28, 483 (1983).

[4] B. Edlén, Phys. Scr. 28, 51 (1983).