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DOUBLY-EXCITED LEVELS IN Al III

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We have used the beam–foil technique to search for transitions between the doubly-excited quartet levels in Al III. These levels, due to excitation of an inner-shell 2p electron, lead to radiation in the range of 900 to 1500 Å. Calculations using a multiconfigurational Dirac Fock code have enabled us to propose preliminary identification of a number of transitions in this wavelength region.

1. Introduction

Holmgren et al. [1] were able to identify several highly-excited levels in the doubly-excited term system of neutral sodium. The normal levels of sodium consist of excitations of the single electron outside the closed $2p^6$ inner-shell. Excitation of one of the 2p electrons can yield both doublet and quartet states, all of which lie at least 30 eV above the ionization potential of sodium. A principal interest in these highly excited states is to investigate the possibility of developing a far ultraviolet/X-ray laser, based on possible direct decay to states in the singly-excited system. One long-lived quartet state might be resonantly pumped by a visible laser into a neighboring short-lived state, for example a doublet state of a similar configuration, which then decays through an allowed transition to the doublet low-lying states. Engström et al. [2] have used the beam–foil technique to verify the results of ref. [1], and to measure the mean lives of the upper levels, which were compared with the Hartree–Fock calculations of Charlotte Froese Fischer [3]. The meanlife measurements are sensitive tests of the doublet/quartet mixing in these levels, which is strong in most cases, and important in the search for a possible laser pumping scheme.

An extension of these measurements to higher charged ions in the sodium iso-electronic sequence is straightforward using beam–foil spectroscopy, and should yield identifications of long-lived levels of much higher energy relative to their respective ground-states; and hence, may be useful as upper levels for shorter wavelength X-ray lasers. Measurements along the iso-electronic series will also provide valuable comparison with the theoretical calculations of the strong LS mixing in these states. With these ideas in mind, we have begun a study of the beam–foil spectrum of aluminum to search for these transitions.

2. Experiment

An electron excitation source (a Physicon 910 from Danfysik) with flowing CCl_4 over aluminum filings was mounted at high voltage in the Argonne Physics Divi-

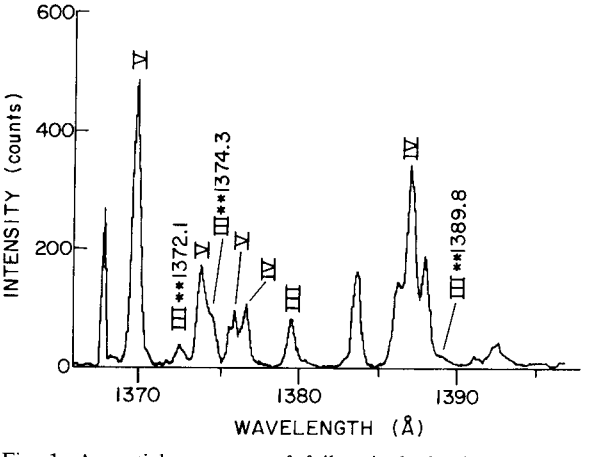

Fig. 1. A partial spectrum of foil-excited aluminum (beam energy 700 keV). Previously known transitions are identified. Possible doubly-excited transitions are marked with a double asterisk and wavelength. Identifications can be found in table 1.

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sion 5 MV Dynamitron. Beam currents of about 1 μA of singly-ionized aluminum, at energies of 700 keV and higher, were mass-analyzed and directed through thin carbon foils (thickness 5 $\mu g cm^{-1}$) Beam–foil spectra were obtained using the usual techniques (e.g. ref. [2]). A 1-m normal incidence vacuum monochromator (McPherson model 225) was equipped with an EMR solar-blind phototube to detect wavelengths above 1050 Å up to about 2000 Å, or with a channeltron to detect radiation between 600 Å and 1200 Å.

A partial spectrum is shown in fig. 1. Fast-beam refocussing of the monochromator [4] enabled us to reduce the linewidths to less than 1 Å, and the spectral line-fitting program gave results which were consistent to within 0.05 Å for most lines. The wavelengths were calibrated using the many known Al IV [5,6] Al V [7] and Al VI [8] within this spectral range.

3. Analysis

The spectroscopy of aluminum in the wavelength region between 800 Å and 1800 Å is essentially complete for ionization stages up to Al V. Hence we are able to classify most of the strong lines seen in the beam–foil spectra. However, quite a number of weak lines remain. By studying their energy dependence with incident beam energy, we expect to be able to estimate the originating charge state of these weak lines. The Al III quartet lines should follow closely the yields of the normal Al IV spectra. However, we were only able to verify that the lines which may be assigned to Al III quartet transitions have disappeared at incident beam energies of 2.0 MeV. This is consistent with the expected charge state distributions for aluminum at that energy.

In table 1, we list the transitions in the Al III quartet system whose theoretical wavelengths show close coincidences with previously unidentified lines in the observed spectra. The identifications must be regarded as only preliminary. Although the unidentified lines do principally appear close to the expected wavelengths, there may be some accidential coincidences. In addition, the fine structures of the quartet terms obtained from our calculations are presumed to be correct in terms of the suggested identifications. However, small changes in these fine structures could well change some of the identifications.

Table 1
Possible identifications in the Al III quartet system

Predicted wavelength (Å)	Transition	Observed wavelength (Å)
991.8	$3p\,^4D_{3/2}-4s\,^4B_{1/2}$	991.2
996.5	$5/2^- \quad 3/2$	994.8
998.9	$1/2^- \quad 1/2$	99.2
		(5 lines)
1002.2	$7/2 \quad 5/2$	1001.3
		1002.5
1004.6	$3/2^- \quad 3/2$	1003.9
1009.9	$5/2^- \quad 5/2$	1008.5
1034.4	$3p\,^4P_{3/2}-4s\,^4P_{1/2}$	1033.3
		1035.3
1038.5	$5/2^- \quad 3/2$	1037.4
1039.5	$1/2^- \quad 1/2$	1039.6
1053.1	$5/2^- \quad 5/2$	1051.2
		1052.5
1053.6	$1/2^- \quad 3/2$	1053.9
1112.6	$3p\,^4S_{3/2}-3d\,^4P_{5/2}$	1109.4
		1113.4
1138.7	$3p\,^4D_{5/2}-3d\,D_{3/2}$	1137.8
1141.4	$5/2^- \quad 5/2$	1143.4
1142.5	$7/2^- \quad 7/2$	1145.4
1149.4	$3/2^- \quad 3/2$	1149.1
1152.1	$3/2^- \quad 5/2$	1151.2
1163.4	$1/2^- \quad 1/2$	1163.6
1176.5	$3p\,^4D_{7/2}-3d\,^4F_{7/2}$	1175.8
1176.5	$5/2^- \quad 5/2$	
1185.8	$7/2^- \quad 9/2$	1192.6
1187.2	$5/2^- \quad 7/2$	1187.4
1188.1	$1/2^- \quad 3/2$	
1188.3	$3/2^- \quad 5/2$	

Table 1 (continued)

Predicted wavelength (Å)	Transition	Observed wavelength (Å)
1206.8	$3p\,^4P_{3/2}-3d\,^4D_{3/2}$	1206.6
1209.2	$5/2^- \quad 7/2$	1210.4
1209.9	$3/2^- \quad 5/2$	
1211.7	$3/2^- \quad 1/2$	
1210.9	$3p\,^4D_{5/2}-3d\,^4P_{3/2}$	
1213.8	$3p\,^4P_{1/2}-3d\,^4D_{3/2}$	1215.6
1218.7	$1/2^- \quad 1/2$	1217.9
		1218.4
1261.9	$3p\,^4P_{5/2}-3d\,^4P_{5/2}$	1261.9
1294.5	$3/2^- \quad 1/2$	1294.5
1296.3	$1/2^- \quad 3/2$	
1321.0	$3p\,^4S_{3/2}-3p^2\,^4P_{1/2}$	1320.5
1329.1	$3/2^- \quad 3/2$	1329.2
1345.1	$3/2^- \quad 5/2$	1343.2
1358.0	$3p\,^4D_{3/2}-3p^2\,^4D_{1/2}$	1358.7
1371.5	$1/2^- \quad 1/2$	1372.1
1375.4	$5/2^- \quad 5/2$	1374.3
1375.5	$3/2^- \quad 3/2$	
1376.1	$7/2^- \quad 7/2$	
1389.4	$1/2^- \quad 3/2$	
1390.8	$5/2^- \quad 7/2$	1389.8
1390.9	$7/2^- \quad 5/2$	
1474.0	$3p\,^4P_{5/2}-3p^2\,^4D_{7/2}$	1473.5
1476.1	$3/2^- \quad 5/2$	1476.6
1548.3	$3p\,^4P_{5/2}-3p^2\,^4P_{3/2}$	1545.0
1558.5	$3/2^- \quad 1/2$	1560.3
		1561.7

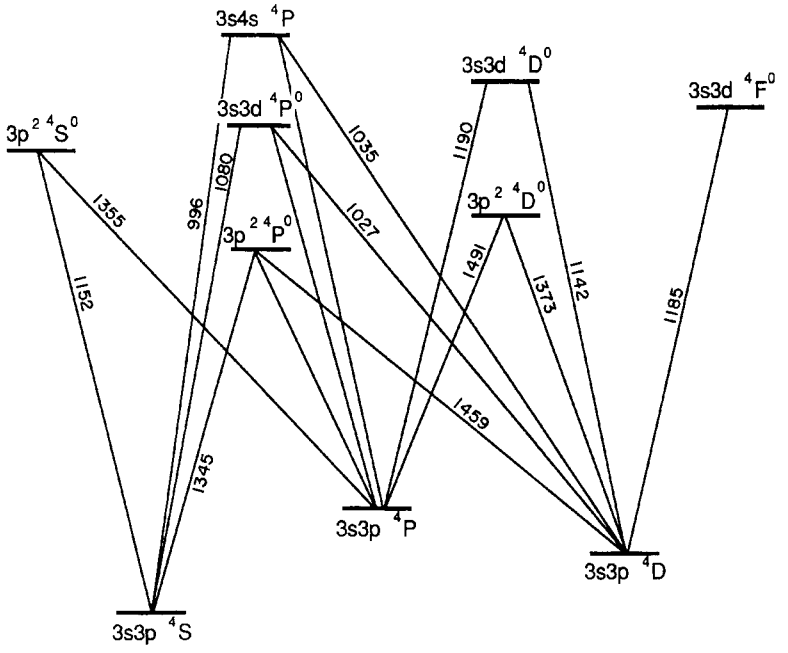

Fig. 2. A Grotrian diagram of the calculated term system of the Al II quartets. The wavelengths are marked in ångströms.

Fig. 2 shows the quartet levels calculated, and the transitions are labelled with calculated wavelengths. The doublet level structure was also calculated. However, we have assumed that these levels decay primarily by autoionization, and have not looked for identifications of possible wavelengths. Most of the quartets also mix (some quite strongly) with the doublet terms, and hence should also autoionize in competition with radiative decay.

To obtain more conclusive identifications, we expect to repeat the experiments with stronger aluminum beams, possibly at lower incident energy, so that decay curves of the Al III quartets can be obtained. The lifetimes are very susceptible to configuration mixing, and such measurements should provide both good support for the suggested identifications, as well as good tests of the multiconfigurational Hartree–Fock calculations.

4. Conclusions

We have made an initial study of the beam–foil spectrum of aluminum at wavelengths between 600 and 1800 Å. We have calculated the expected transition wavelengths in the quartet system of doubly-excited Al III in this wavelength region. We are able to find close coincidences between these calculated wavelengths and unidentified lines in the aluminum spectrum, which indicate that the calculations are accurate to within a few ångströms. Further work is needed to verify the suggested identifications.

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