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The Spectroscopy of High Spin States for Highly Charged Mg-like Ions

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Abstract

Transitions between high spin core-excited states of highly charged Mg-like Ions (Ti, Fe and Ni) have been investigated using beam-foil spectroscopy. The identification of the $2p^53s3p^2\,{}^5D_4$–$2p^53s3p3d\,{}^5F_5$ transition has been aided by calculations and iso-electronic methods.

1. Introduction

An understanding of high spin states in highly charged ions is of current interest due to the possible production of such states in modern ion-microcapillary and other surface interaction experiments, [1]. These states with all spins parallel and many open shells are also of great theoretical interest, because of, e.g. configuration interaction effects. Such states could have relatively long lifetimes and allow the production of metastable hollow atoms. However, little is know about the structure of highly charged ions with many spin-aligned excited electrons. In most cases these states will lie above ionization limits and hence auto-ionize or decay through fast X-ray channels. However, if the maximum *j* values for a given electronic configuration are considered, there often arise levels where the X-ray and auto-ionization channels are suppressed or forbidden. In these cases some metastability can arise and it is such levels which are of interest to the production of metastable hollow atoms. The structure of high spin states is best known for fairly low *Z* Li-like ions where the $1s2s2p\,{}^4P_{5/2}$ level is metastable against X-ray decay and Coulomb auto-ionization. However, there is a Breit induced part to the auto-ionization which is quite strong even for moderately charged ions in the Li I sequence [2]. There is a similar situation in Na-like ions where the $2p^53s3p\,{}^4D_{7/2}$ level is also metastable. In this case the Breit induced auto-ionization is not so dominant as in the Li-like case and the $2p^53s3p\,{}^4D_{7/2}$ level remains long lived even for very highly charged ions [3]. For instance the ${}^4D_{7/2}$ lifetime for Na-like Xe is predicted to be around 2.5 ns [3]. The metastability of the $2p^53s3p\,{}^4D_{7/2}$ level was demonstrated using electron spectroscopy [4] however as yet no lifetime measurement exists. In a previous work the $2p^53s3d\,{}^4F_{9/2}$ [5] level was studied for a number of elements in the Na I sequence using VUV photon spectroscopy. This level is also metastable with regards to X-ray and Auger decay but it has an allowed E1 transition to the metastable $2p^53s3p\,{}^4D_{7/2}$ level. After the identification of the $2p^53s3p\,{}^4D_{7/2} - 2p^53s3d\,{}^4F_{9/2}$ transition a number of other VUV transitions within the core-excited complex were identified for Na-like S and Cl [6]. In the case of Na-like ions there are X-ray [7] and Auger [8] studies of the decay of the core-excited $2p^5nln'l'$ levels as the decay of most core-excited levels is dominated by such decay branches. In the present work a transitions within the core-excited configurations of Mg-like ions will be examined for a number of elements in the Mg I sequence. The ions investigated here are Ti XI, Fe XV and Ni XVII.

Some years ago Gaardsted *et al.* [9] identified a number of core-excited transitions in Mg I. This is so far the only system in the Mg I sequence where such transitions have been identified. Although the gap from Mg I to Ti XI is rather large some useful information could be obtained from [9] concerning the calculations done here, using the Cowan code [10] to assist the spectral line identifications.

The spectra line to be studied here arise from the $2p^53s3p^2({}^3P)\,{}^5D_4 - 2p^53s3p3d({}^4D)\,{}^5F_5$ Transition. Other lines within the core-excited complex may also lead to VUV photon emission, however such transitions along with a study of more elements along the sequence will be subject of a future study.

2. Results and discussion

The spectroscopy data was generated using beam-foil spectroscopy. The Ti, Fe and Ni data were recorded using the RILAC (heavy ion linear accelerator) at the RIKEN laboratory in Japan. Beams were extracted from an ECR ion source and accelerated to the required energies, 0.6 MeV/u for Ti and Fe and 0.8 MeV/u for Ni. The ions were then directed into a beam-foil target chamber, which is described by Ando *et al.* in [11]. Basically the ions are further stripped of electrons and excited by a thin carbon foil, thickness $10\,\mu g/cm^2$. The carbon foil can be translated along the beam direction to allow spectra to be taken at different times after the almost instantaneous foil interaction. The subsequent decay of the excited ions leads to photon emission which is studied here in the VUV region using a 2.2 meter grazing incidence spectrometer observing the beam at an angle close to 90 degrees. The photons are dispersed using a 600 lines/mm grating and detected using a CCD detector system [12]. All spectra were calibrated by using well known in beam reference lines from either Na- or Mg-like transitions [13]. Typical CCD spectra for 0.6 MeV/u Ti and Fe, and 0.8 MeV/u Ni are shown in Fig. 1, note the similarities in the Fe and Ni spectra, this is due to the spectra containing similar charge states whereas the Ti spectrum contains ions belonging to higher iso-electronic sequences. The main con-

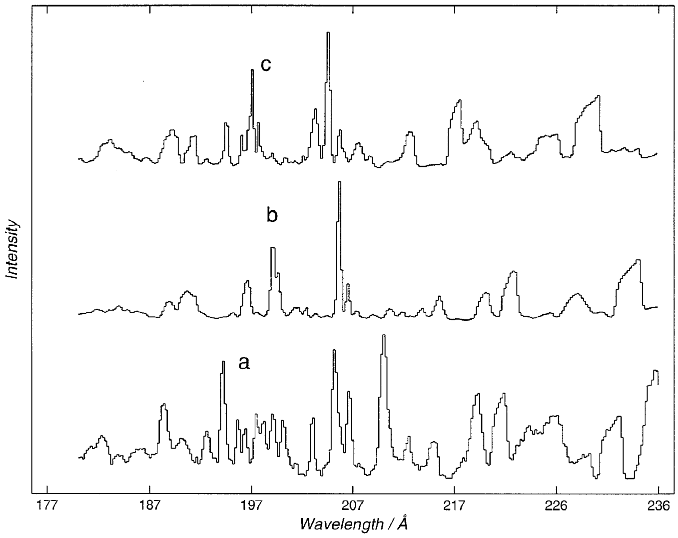

Fig. 1. Spectra recorded in the region of the $2p^53s3p^2\ ^5D_4 - 2p^53s3p3d\ ^5F_5$ transition for Mg-like Ti, Fe and Ni. The Ti and Fe spectra were recorded using a beam of 0.6 MeV/u ions and the Ni spectrum used 0.8 MeV/u. The Fe spectrum has been wavelength shifted by −23 Å and the Ti spectrum by −100 Å for comparison purposes. The intensities are summed and averaged counts along a column of ccd pixels from a 15 minute recording.

Table I. *Experimental and calculated wavelengths for the* $2p^53s3p^2\ ^5D_4 - 2p^53s3p3d\ ^5F_5$ *transition in Mg-like Ti, Fe and Ni. The wavelengths are giver in* Å *and the estimated accuracy of the wavelengths is around 0.1* Å. *The line width for lines close to the center of the CCD chip is around 0.4* Å *for the Fe and Ni spectra and around 0.4* Å *for Ti, see [12]. The calculated wavelengths are from the Cowan computer package [10].*

Ion	Wavelength experiment	Wavelength calculated
Ti	299.7	301.6
Fe	227.2[1]	228.4
Ni	202.1	203.1

[1] Blended by the 3s3p $^3P_1 - 3s3d^3D_2$ Fe XV line.

cern when using a CCD detector for long exposure times comes from random "spikes" in the spectrum caused by cosmic rays. Also, at high beam energies, as used here, stray signal is produced by beam-related-electrons hitting the spectrometer slits etc. However, these events mainly produce higher signals in the pulse height distribution, as the number of electron-hole pairs is a function of the energy of the photon registered by the CCD chip. The final spectra are produced by recording a number of scans under similar conditions, then applying a coincidence check, i.e. lines have to appear in all spectra to be considered as real. In this way the final spectra are almost background free and very weak lines can be observed. It is interesting to note that much of the spectral reduction techniques used here depend on the light source being weak, i.e. only 1 or at most a few photons hit a given pixel during the exposure time. Once a possible candidate line was identified the analysis was checked using the well established methods of iso-electronic comparison, [14] between the measured wavelength and that calculated using the Cowan code. Differences in calculated and measured wavelengths were checked against similar differences for the Na-like core excited transitions reported in [5] as a check on the identifications. It is also interesting to note that the results obtained using the Cowan code depend very much on the spin-state of the transition involved, e.g. calculations for the 3s3p–3s3d transitions are quite good for the $^3P - {}^3D$ transitions but not for the $^1P - {}^1D$ transition. We therefore expect the identifications made here to be reliable, helped by the high spin-states involved, but they will be confirmed in a later work where more ions will be included in the iso-electronic development. The wavelengths for the $2p^53s3p^2\ ^5D_4 - 2p^53s3p3d\ ^5F_5$ transition for the ions studied here are given in Table I. The uncertainties in the experimental wavelengths of around 0.1 Å are based on calibration using close lying 3s3p ^3P–3s3d ^3D Mg-like transitions. Unfortunately the line of interest to this work is blended in Fe XV by another line from Mg-like Fe, namely the 3s3p $^3P_1 - 3s3d^3D_2$. This line crosses through the $2p^53s3p^2\ ^5D_4 - 2p^53s3p3d\ ^5F_5$ line around Fe XV, in Ti XI it is 8.5 Å longer and in Ni XVII 2.2 Å shorter in wavelength.

3. Conclusion

The $2p^53s3p^2\ ^5D_4 - 2p^53s3p3d\ ^5F_5$ transition has been observed in a number of high Z Mg-like ions using techniques of beam-foil spectroscopy. These lines belong to core-excited high spin states of Mg-like ions and may have interest in diagnostics of, e.g. ion-surface experiments, where high spin states may be formed.

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