Publ. Astron. Obs. Belgrade No. 84 (2008), 53 - 56 *Contributed Paper*

ELECTRON IMPACT EXCITATION OF YTTERBIUM

B. PREDOJEVIĆ[1,2], D. ŠEVIĆ[1], V. PEJČEV[1,3], D. M. FILIPOVIĆ,[1,4]
and B. P. MARINKOVIĆ[1]

[1]*Institute of Physics, Belgrade, Serbia*
E–mail: bratislav.marinkovic@phy.bg.ac.yu

[2]*Faculty of Natural Sciences, University of Banja Luka, Republic of Serpska, Bosnia and Herzegovina*

[3]*Faculty of Natural Sciences, University of Kragujevac, Radoja Domanovića 12, 34000 Kragujevac, Serbia*

[4]*Faculty of Physics, University of Belgrade, P. O. Box 368, 11001 Belgrade, Serbia*

Abstract. The energy-loss spectra of Ytterbium in energy-loss ranges from 3.30 to 3.75 eV, scattering angles 6^o, 10^o, 20^o at incident electron energies of 20 eV, and from 3.75 to 6.50 eV, scattering angle 0^o at incident electron energies of 40, 60, 80 eV, have been recorded. These spectra are analysed and compared with other available measurements.

1. INTRODUCTION

The Ytterbium is a heavy atom (Z = 70) with a closed-shell, two (6s) valence electron ground state configuration [Kr] $4f^{14}6s^2$ ^1S_o. The electronic structure of Ytterbium makes this atom very interesting for investigations of a number electron atom collision processes. The transitions below the first ionization limit can be divided in two classes. The transitions corresponding to the excitation of the 6s-electrons give the simple spectra and transitions due to excitations of one of the $4f^1$4 electrons give the complex spectra.

An electron energy-loss spectrum of Ytterbium was initially reported by Kazakov and Hristoforov (1983). The spectrum has been recorded at incident electron energy of $E_o = 14$ eV and scattering angle of 90^o. Mandy et al. (1993) have presented energy-loss spectra and a threshold excitation spectrum. Johnson et al. (1998) presented an electron energy-loss spectrum at incident electron energy $E_o = 40$ eV and scattering angle of 10^o recorded with overall energy resolution of 80 meV. In our previous papers (Predojević et al. 2005a, 2005b) we also presented several energy-loss spectra at impact energies of 20 eV and different scattering angles.

In this contribution we present and analyse the parts of energy-loss spectra of Yb which were not enough considerated in previous articles, mainly because of insufficient energy resolution of spectrometers. In this paper, atomic levels of Yb are identified according to the NIST Atomic Spectra Database (2008).

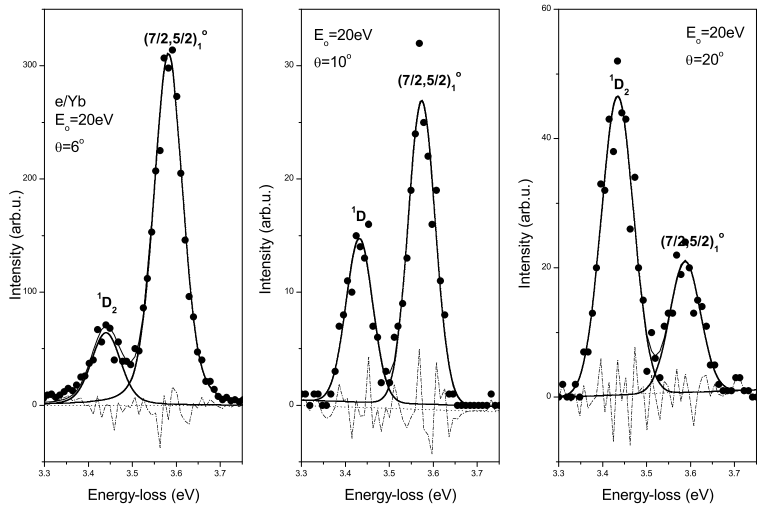

Figure 1: Decomposed energy-loss spectra of Yb at $E_o = 20$ eV ($\theta = 6^o$, 10^o, 20^o): full circles, raw data; line, synthetic spectrum; dashed line, decomposed states; dots, baseline; dash-dot line, difference between raw data and the synthetic spectrum (residuum).

2. THE EXPERIMENT

The apparatus used for the measurements is a conventional cross-beam electron spectrometer described elsewhere (Predojević et al. 2005a, 2005b), operated in energy-loss mode. Overall system energy resolution (as FWHM) was estimated of 65 meV. The energy scale was calibrated against the structure at 4.03 eV attributed to the 4 ^{3}P excitation threshold in Zn (Predojević et al. 2003). The uncertainty of the scale was estimated to be less than 0.01 eV.

Construction of the vapour source as well as the production and the control of the vapour beam have been described in detail in (Predojević et al. 2005a). The measurements are performed at temperature of 870 K for 99,99% purity Ytterbium. This temperature corresponds to a metal-vapour pressure of about 5.2 Pa, at which ytterbium effused through the cylindrical channel (aspect ratio $\gamma = 0.075$) in the cap of crucible.

3. RESULTS

The spectra of Yb recorded at incident electron energy of 20 eV in the energy- loss range from 3.30 to 3.75 eV and scattering angles 6^o, 10^o and 20^o are shown in Fig 1. As one can see the states $4f^{14}5d6s\ ^1D_2$ and $4f^{13}5d6s^2$ $(7/2,\ 1/2)_1$ are resolved with energy resolution of 65 meV.

The states are decomposed and fitted using two Gaussian profiles and synthetic spectra are obtained as sum of these profiles. The values of residuum show that we

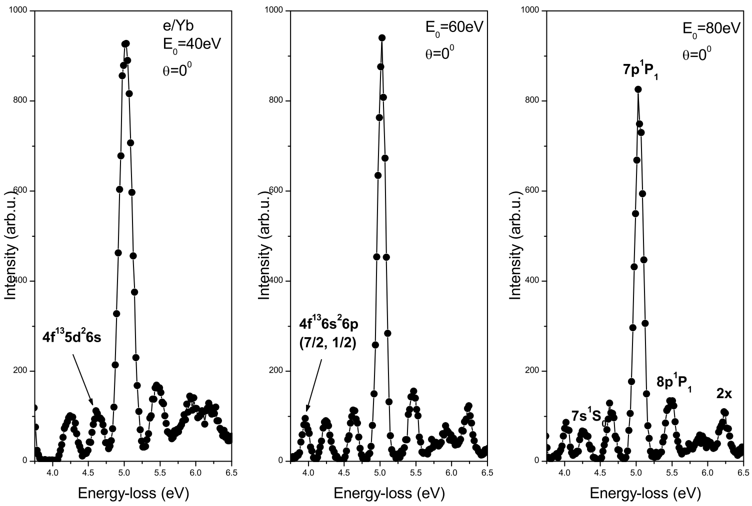

Figure 2: The energy-loss spectra of Yb atom at scattering angle $\theta = 0^o$ and incident electrons energies $E_o = 40$, 60 and 80 eV.

have quite good agreement between the row data and synthetic spectra. Shimon et al. (1981) emphasize that $4f^{14}6s^2\ ^1S_0 \rightarrow 4f^{13}5d6s^2\ (7/2,\ 1/2)_1$ transition have third intensity among 36 optical excitation functions determined in their measurements. These states as an unresolved feature are identified in (Johnson et al. 1998) and marked as $^1D_2$, the same designation was used by Kazakov and Hristoforov (1983) for structure at right side of the resonance line (transition $4f^{14}\ 6s^2\ ^1S_0 \rightarrow 4f^{14}6s6p\ ^1P_1$). It could be observed that in selected energy-loss range intensity ratio $I(^1D_2)/I((7/2,1/2)_1)$ increases with scattering angle. The differential cross sections for electron impact excitation of the $4f^{14}5d6s\ ^1D_2$ and $4f^{13}5d6s^2\ (7/2,\ 1/2)_1$ states at incident electron energies of $E_o = 10$, 20 eV where published in (Predojević et al. 2005b).

The energy-loss spectra at incident electron energies of 40, 60 and 80 eV and scattering angle of 0^o and in energy-loss range from 3.75 to 6.50 eV are presented in Fig 2. At $E_o = 60$ and 80 eV the spectra contain well-resolved feature at 3.980 eV. According with NIST tables this energy belongs to the state with configuration $4f^{13}6s^26p$ (7/2, 1/2); consequently, we have the spectral line from complex part spectra of Yb. At 40^o this state is absent and also has not been identified in previous measurements (Kazakov and Hristoforov 1983).

In all spectra in Fig 2. we find the feature at 4.259 eV.

To this energy, according with NIST tables and previous measurements (Kazakov and Hristoforov 1983), the $4f^{14}6s7s\ ^1S_0$ state is designated. Similarly to the atoms of the IIb group, the (n+1) $^1S_0$ states have significantly stronger intensities compared to the close (n+1) $^3S_0$ states. Also, in all the spectra appears the spectral line at 4.639 eV. This line corresponds to the $4f^{14}6s^2\ ^1S_0 \rightarrow 4f^{13}6s^26p$ transition and did not appear in previous energy-loss measurements. If we accept this classification then this state together with the state at 3.980 eV belongs to the complex spectra of Yb. The state at 5.030 eV is optically allowed transition ($4f^{14}6s^2\ ^1S_0 \rightarrow 4f^{14}6s7p\ ^1P_1$) and this line is strongest in the selected energy- loss range. The differential cross sections for electron impact excitation of the $4f^{14}6s7p\ ^1P_1$ state at incident electron energies of $E_o = 20$, 40 eV where published in our previous paper (Predojević et al. 2005b). The next line at 5.457 eV also belongs to the optically allowed transition ($4f^{14}6s^2\ ^1S_0 \rightarrow 4f^{14}6s8p\ ^1P_1$) and to the simple spectra of Yb. The broad feature in energy-loss range from 5.600 to 6.070 eV consists of many transitions but the energy resolution in our spectrometer was not high enough to resolve these states. In our opinion the feature at 6.20 eV, which exists at all spectra, probably arises due to double scattering of incident electrons after successive excitation of the $4f^{14}6s6p\ ^1P_1$ resonance state at 3.108 eV.

Finally, in energy-loss range from 3.30 to 6.50 eV, we have detected the transitions belonging to both, the simple and complex spectra of Yb. The intensities of lines from these spectra are comparable, as is expected for heavy atoms.

4. CONCLUSION

We presented the preliminary results of decomposed energy-loss spectra of Ytterbium atom. Differential cross sections of higher excited states should be determined experimentaly in near future.

Acknowledgments

This work has been carried out within project 141011 financed by Ministry of Science of Republic of Serbia and bilateral project Serbia Rapublic of Srpska, BH, No. 06/6-020/961-25/05.

References

Johnson, P. V,, Li, Y., Zetner, P. W., Csanak, G., Clark, R. E. and Abdallah, J.: 1998, *J. Phys. B: At. Mol. Opt. Phys.*, **31**, No. 13, 3027.

Kazakov, S. M. and Hristoforov, O. V.: 1983, *Opt. Spektrosk.*, **54**, 750.

Mandy, J. A., Romanyuk, M. I., Papp, F. F. and Shpenik, O. B.: 1993, Proceedengs of the 18th Int. Conf. Physics of Electronic and Atomic Collisions, Eds. Anderson, T., Folkmann, F., and Knudsen, H., Aarhus, Denmark, (Bristol: Hilger) Abstracts p. 167.

NIST: 2008, Atomic Spectra Database of the Physics Laboratory of the National Institute of the Standards and Technology, USA.

Predojević, B., Šević, D., Pejčev V., Marinković, B. P. and Filipović, D. M.: 2003, *J. Phys. B: At. Mol. Opt. Phys.*, **36**, No. 11, 2371.

Predojević, B., Šević, D., Pejčev V., Marinković, B. P. and Filipović, D. M.: 2005a, *J. Phys. B: At. Mol. Opt. Phys.*, **38**, No. 8, 1329.

Predojević, B., Šević, D., Pejčev V., Marinković, B. P. and Filipović, D. M.: 2005b, *J. Phys. B: At. Mol. Opt. Phys.*, **38**, No. 19, 3489.

Shimon, L. L., Golovchak, N. V., Garga, I. I. and Kurta, I. V.: 1981, *Opt. Spektrosk.*, **50**, 1037.