Publ. Astron. Obs. Belgrade No. 99 (2020), 47 - 50 *Contributed Paper*

THE $M_{4,5}$NN AUGER SPECTRUM OF KRYPTON IN KINETIC ENERGY REGION 24 – 64 eV

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Abstract. A high resolution electrostatic analyzer in combination with a non-monochromatic electron beam has been used to investigate the Krypton $M_{4,5}$NN Auger spectrum in the kinetic energy region from 24 to 64 eV at 505 eV incident electron energy and at 90° ejection angle. A large number of features produced by Auger and satellite transitions are observed due to the high experimental resolution. The energies and assignments of the observed features are compared with previous experiments and a good agreement is found.

1. INTRODUCTION

The krypton electronic configuration is [Ar]$3d^{10}4s^24p^6$. The energies of the $M_{4,5}$ edges of krypton 3*d* shell are M_5 ($^2D_{5/2}$) = 93.788 eV and M_4 ($^2D_{3/2}$) = 95.038 eV (King et al. 1977) leading to the energy separation between $3d_{5/2,\,3/2}$ of 1.25 eV. The natural width of the 3*d* shell is (88 ± 4) meV. The ionization potentials of the Kr^{2+} ($4p^{-2}\ {}^3P_2$) is 38.358 eV and Kr^{3+} is 74.197 eV (Palaudoux et al. 2010). The binding energies of the 3*s* (M_1), $3p_{1/2}$(M_2) and $3p_{3/2}$(M_3) are 292 eV, 222 eV and 214.6 eV, respectively (Mehlhorn, 1965). The spin-orbit splitting $3p_{3/2}$-$3p_{1/2}$ is 7.6 eV. The widths of the $3p_{1/2}$ and $3p_{3/2}$ are 1.80 eV and 1.48 eV, respectively.

Systematic studies by electron impact with high resolution of krypton $M_{4,5}$NN Auger spectrum have been done by Mehlhorn (1965), Werme et al. (1972), Askela et al. (1984) (and ref's there in). Kr^{2+} ($4p^4nl$) satellite lines have been investigated by Hall et al. (1990), Jauhiainen et al. (1995), Kikas et al. (1996), Yoshii et al. (2007) (and ref's there in) by photoelectron spectroscopy. In this work, we present high resolution Auger spectrum of krypton in the kinetic energy region 24 to 64 eV obtained at 505 eV of incident energy.

2. EXPERIMENT

The apparatus used in the present measurements has been described previously Jureta et al. (2016). Shortly, it consists of a non-monochromatic electron gun (10-2500 eV) and a high-resolution hemispherical analyzer (R_0 = 125 mm) equipped by seven channeltrons to detect ejected electrons. A 20 mm long platinum-iridium non-biased needle with internal diameter of 0.5 mm has been used to produce an atomic beam in the perpendicular direction to the scattering plane. The cylindrical interaction region (50 mm in diameter) is made from the two cylinders of thin μ-metal foils 10 mm apart the collisional plane in order to avoid collection of scattered electrons from metal surfaces. The pass energy of 1 eV was set and then the analyser was operated in the Constant Retarding Ratio (CRR) mode i.e. the ratio (K) of the kinetic energy (E_k) and the analyser pass energy (E_p) during the scan is held constant. ($K \approx E_k/E_p$).

The background and working pressures with krypton gas in the vacuum chamber were $6x10^{-8}$ and $2x10^{-6}$ mbar respectively. With an electron current of about 10^{-6} A, the typical accumulation time for short interval of kinetic energies per spectrum was 30 min with energy step of 20 meV per channel. Each presented spectrum is the result from three measurements accumulated in the same experimental conditions. The transmission was not uniform in lower energy part and all spectra are presented with subtracted background without any further normalization of the data. The calibration of the kinetic energy scale was achieved using the line at 11.72 eV from the Ar [$3s3p^6 3d(^1D)$] excited state (27.48 eV excitation energy) in Ar-Kr mixture at 300 eV. The scale of the incident energies was calibrated using the elastic channel. For higher energies until 2000 eV, the fit made below 200 eV was applied. The FWHM of the elastic peak was roughly 0.80 eV.

3. RESULTS AND DISCUSSION

The krypton $M_{4,5}NN$ Auger spectrum measured at 505 eV incident energy and ejection angle of 90^o is shown in Fig.1. The present spectrum well compares with the one by Werme et al. (1972), although the different approach in calibration procedure leads to a systematic difference in energies of about 0.150-0.170 eV. Both Auger transitions and their satellites contribute to the observed spectrum making a difficulty in their identification. The Auger spectra produced by electrons are complex because they are composed from ejection of one or two electrons from 3*d* shell, but also other transitions can contribute to the spectrum in form of satellites produced either by ionization of the outer valence or inner shells and shake-up and shake-off transitions. The first assignments of the features have been done in comparison of their energies with optical data and shake-up transitions. New data from optical spectroscopy and theoretical calculations helped to complete assignments of large number of measured features. Those are correlation satellites and shake-off transitions. The shake-up and shake-off processes occur when the inner shell is ionized and another electron in simultaneous excitation can either populate other unoccupied orbital (shake-up) or be promoted to the continuum (shake-off). On the other side, the correlation satellites are typical for closely-spaced states with the same total angular momentum and parity (Jauhiainen et al. 1995). They occur in a process of creation of a hole in *s* subshells of the same shell. This hole is filled by a *p* electron from the same shell followed by the simultaneous excitation of another electron to an unoccupied *d* or *s* orbitals.

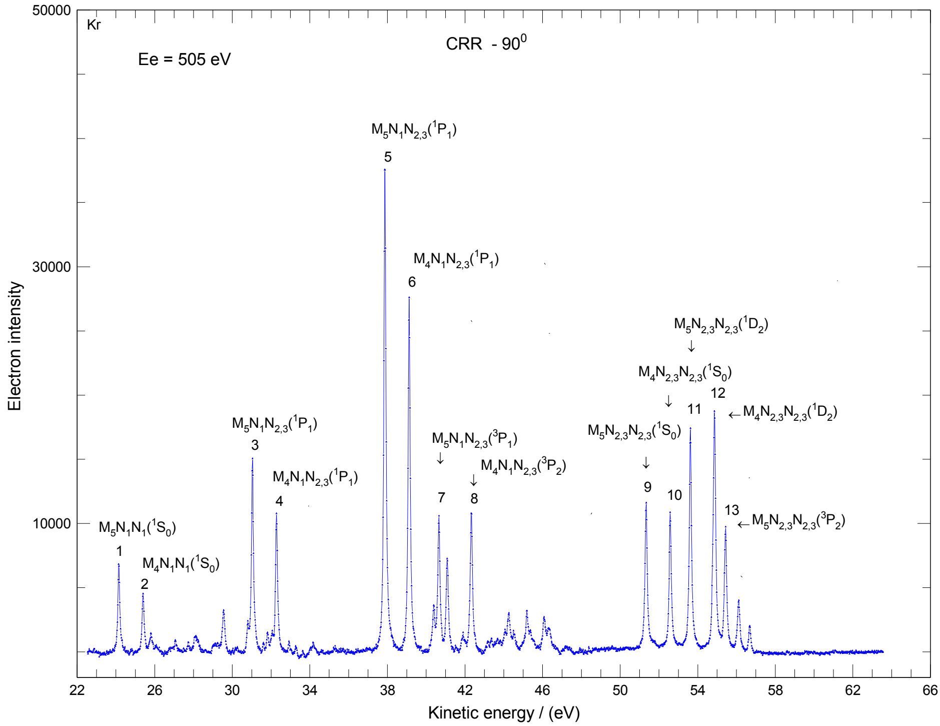

Figure 1: The $M_{4,5}NN$ Auger spectrum of krypton obtained at 505 eV of electron incident energy and 90^0 of ejection angle. Only main lines are assigned. The spectrum is presented with subtracted background with energy step of 0.020 eV. Energies of the peaks (eV) are: (1) 24.14; (2) 25.39; (3) 31.04; (4) 32.28; (5) 37.86; (6) 39.10; (7) 40.64; (8) 42.31; (9) 51.32; (10) 52.57; (11) 53.60; (12) 54.86; (13) 55.43 eV. The FWHM is approximately 110 meV.

Detailed analysis of all spectrum shows that the first kinetic energy region 24 – 34 eV is composed from several pairs of features with energy separation close or equal to the spin orbit splitting of 3*d* shell (1.25 eV). Many features are recognized as satellites produced by either shake-up or shake–off transitions. The first two features (1, 2) are assigned as Auger lines $M_{5,4}N_1N_1(^1S_0)$. The region 34 – 48 eV is composed from 4 pairs of features with energy separation close or equal to the spin orbit splitting of 3*d* shell. The last group of features in kinetic energy region 50 – 58 eV is composed from well-known $M_{5,4}N_{2,3}N_{2,3}$ Auger lines.

Acknowledgements

This work was supported by the Institute of Physics Belgrade, through the grant by the Ministry of Education, Science, and Technological Development of the Republic of Serbia and performed within the bilateral project between Italy and Serbia of particular relevance (Grande Rilevanza) "Nanoscale insights in radiation damage". B.P.M. and L.A. acknowledge the COST Action CA18212 " Molecular Dynamics in the GAS phase (MD-GAS)".

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