ON THE CONFIGURATION MIXING EFFECTS IN THE EXCITATION OF ZnII AND CdII LINES AT ELECTRON-ATOM COLLISIONS

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The excitation of some VUV ZnII and CdII lines arising from both "perturbed" valence-electron levels and "perturbing" subvalence *d*-subshell-electron levels has been investigated at the electron-atom collisions. The excitation functions for the corresponding ZnII (75.5, 77.8, and 76.6 nm) and CdII (78.1, 79.8, and 77.3 nm) lines have been obtained. The similarity observed in their general behaviour, probably, results from strong configuration interaction between their initial states.

It is well known that, in contrast with the alkaline-earth atoms having close-coupled subvalence p^6 subshells, the IIB group atoms (Zn, Cd, and Hg) have the subvalence d^{10} subshells, whose binding energies are much smaller. Moreover, the binding energies for the valence and subvalence subshells of the latter differ by less than a factor of two. Noted structure peculiarity of these atoms results in a strong influence of their subvalence subshells upon the valence subshells.

Recently we have found such influence when investigating the ZnII and CdII spectra excitation in the 50-100 nm region at the electron-atom collisions [1, 2]. All ZnII and CdII spectral lines observed correspond to the Zn^+ and Cd^+ ground-state combinations. Among them the lines arising from the d^9sp configuration levels dominate in intensity. The lines arising from the $d^{10}nl$ (l = p, f) configuration levels are weak. A considerable configuration interaction between the above two ionic level types is well known to cause the *np* and *nf* series perturbation [3, 4]. Below in Figs. 1 and 2 the fragments of the ZnII and CdII spectra show such effect displaying in the principal series line intensities. The spectral lines positions from the $d^{10}np$ levels are indicated in the figures by vertical arrows. From these figures one can see a relative increase of the *np* lines intensities in the vicinity of the d^9sp lines at 77.3 nm (Cd) and 76.6 nm (Zn) contrary to the usual behaviour of the series line intensities. The main interest of the present study was to measure the excitation functions (EFs) of the lines arising from both "perturbed" valence-electron levels and "perturbing" subvalence *d*-subshell-electron levels.

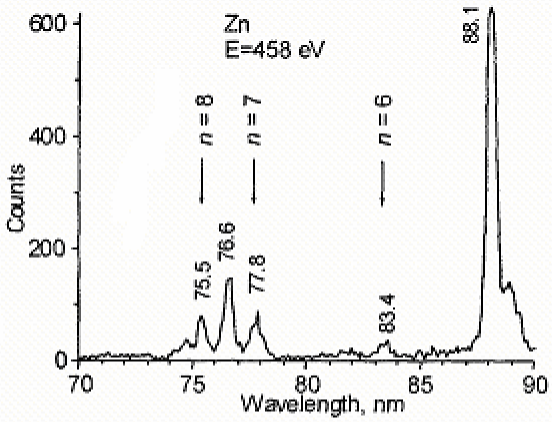

Fig. 1. ZnII spectrum in the vicinity of the n = 6, 7, 8 principal series lines.

Our experimental setup was described in some details earlier in [2]. A ribbon electron beam with a current density of ~10^{-3} A/cm^2 and an electron energy spread of ~1.2 eV was formed by an electron gun with a ribbon oxide cathode and three anodes in the form of planar apertures with rectangular holes 1 × 8 mm in size. The electron energy was varied from the process threshold up to 600 eV. The atomic beam source was of the effusion type, the crucible with the working substance was heated by the quartz incandescent lamps. The beam was formed by an effusion channel with a circular cross section (1 mm in diameter and 3 mm long) made in the crucible wall and a coaxial hole in a cooled aperture. The concentration of atoms in the collision region did not exceed $\sim 10^{12}$ cm^{-3}. A vacuum monochromator constructed according to the Seya-Namioka optical scheme served as a spectral instrument. A replica of a concave toroidal diffraction grating (R_m = 500 mm, R_s = 333 mm, 1200 lines/mm) coated with aluminium and protected by a tungsten layer was placed in the device. An open photoelectron multiplier with microchannel plates of the VEU-7 type operating in the single photon counting mode was used as a radiation detector. The measurement procedure was automated with the help of a personal computer and a CAMAC system.

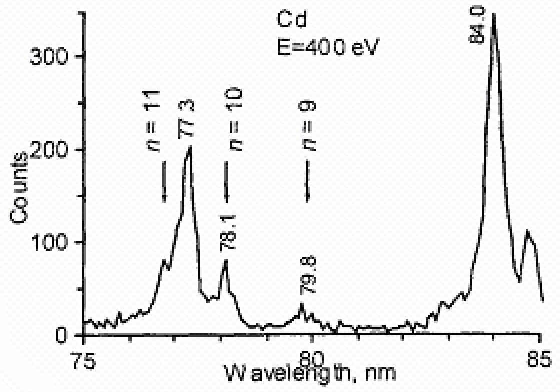

Fig. 2. The CdII spectrum in the vicinity of the n = 9, 10, 11 principal series lines.

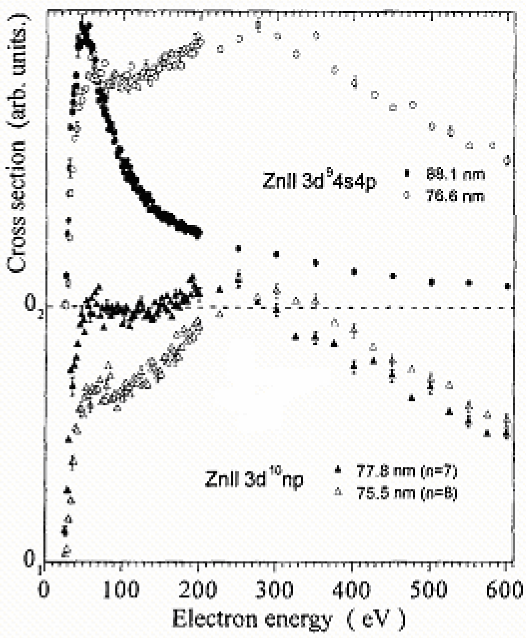

Fig. 3. The EFs of the ZnII spectral lines: 75.5 nm and 77.8 nm – the principal series lines with n = 8 and 7 respectively; 76.6 nm and 88.1 nm – the most intense lines from the $3d^{10}4n4p$ configuration.

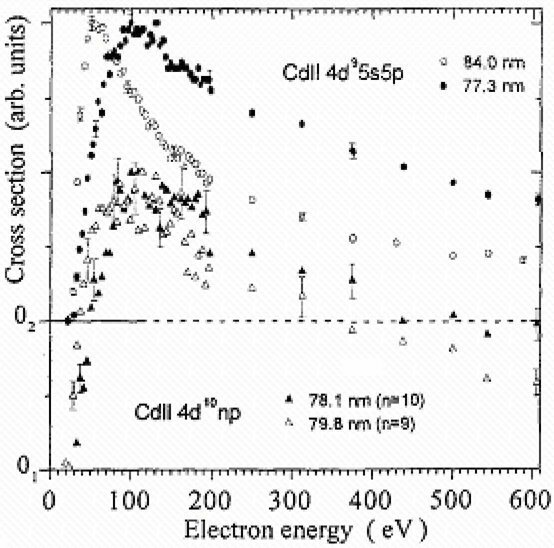

Fig. 4. The EFs of the CdII spectral lines: 78.1 nm and 79.8 nm – the principal series lines with n = 10 and 9 respectively; 77.3 nm and 84.0 nm – the most intense lines from the $4d^{10}5n5p$ configuration.

The EFs results obtained for interesting ZnII and CdII lines are presented in Figs. 3 and 4. These are the ZnII 75.5, 77.8, 76.6 nm lines and the CdII 78.1, 79.8, 77.3 nm lines. For a comparison the EFs of the most intense ZnII 88.1 nm and CdII 84.0 nm lines are shown in these figures.(note that their initial levels cause a very small perturbation in the $d^{10}np$ series [3,4,6]).

Processes resulted in the emission of the lines whose EFs for zinc and cadmium were measured are as follows (see also the spectra in Figs. 1 and 2) :

$$Zn(3d^{10}4s^2) + e \rightarrow \begin{cases} Zn^+[3d^{10}np\ ^2P] + e_{scatt.} + e_{remov.} & (\lambda\lambda\ 83.4,\ 77.8,\ 75.5\ \text{nm}) \\ Zn^+[3d^9(^2D)4s4p(^1P)\ ^2P] + e_{scatt.} + e_{remov.} & (\lambda\ 76.6\ \text{nm}) \quad [3, 6] \\ Zn^+[3d^9(^2D)4s4p(^3P)\ ^2P] + e_{scatt.} + e_{remov.} & (\lambda\ 88.1\ \text{nm})\ , \end{cases}$$

$$\mathrm{Cd}(4d^{10}5s^2) + \mathrm{e} \rightarrow \begin{cases} \mathrm{Cd}^{+}[4d^{10}np\ ^2P] + \mathrm{e}_{\mathrm{scatt.}} + \mathrm{e}_{\mathrm{remov.}} & (\lambda\lambda\ 79.9,\ 78.1,\ 76.9\ \mathrm{nm}) \\ \mathrm{Cd}^{+}[4d^{9}(^2D)5s5p(^1P)\ ^2P] + \mathrm{e}_{\mathrm{scatt.}} + \mathrm{e}_{\mathrm{remov.}} & (\lambda\ 77.3\ \mathrm{nm}) \\ \mathrm{Cd}^{+}[4d^{9}(^2D)5s5p(^3P)\ ^2P] + \mathrm{e}_{\mathrm{scatt.}} + \mathrm{e}_{\mathrm{remov.}} & (\lambda\ 84.0\ \mathrm{nm})\ , \end{cases} \quad [3\text{-}5]$$

where e, $e_{scatt.}$, $e_{remov.}$ are the incident, the scattering, and the removed electrons, respectively.

Figs. 3 and 4 illustrate an unquestionable similarity of the EFs in their general behaviour. The above EFs similarity is, probably, also a displaying of configuration mixing. The similar phenomenon was found earlier when studying the electron-impact excitation of the alkaline-earth atoms [7-10].

There is any more interesting peculiarity in the EFs for the zinc lines arising from the interacting states (see Fig. 3) as concerning the availability of a double-peak structure, i. e. an additional broad feature at the 250-300 eV energy besides the near-threshold feature. Unlike these, both other zinc EFs and all cadmium EFs have one-peak shape. Of course, such difference of their general behaviour should be attributed to a difference in the Zn and Cd atom structures. Nevertheless, the origin of noted difference of the EFs is not clear for us.

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ПРО ЕФЕКТИ ЗМІШУВАННЯ КОНФІГУРАЦІЙ У ЗБУДЖЕННІ ЛІНІЙ ZnII ТА CdII ПРИ ЕЛЕКТРОН-АТОМНИХ ЗІТКНЕННЯХ

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В умовах електрон-атомних зіткнень досліджено збудження деяких ВУФ ліній ZnII та CdII, що виходять як із "збурених" рівнів валентного електрона, так і з "збурюючих" рівнів електрона субвалентної *d*-підоболонки. Одержано функції збудження для відповідних ліній ZnII (75.5, 77.8 та 76.6 нм) і CdII (78.1, 79.8 та 77.3 нм). Подібність, яка спостерігається в їх загальній поведінці, можливо, є результатом сильної конфігураційної взаємодії між початковими станами цих ліній.