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EXCITATION OF THE $(2p^53s^2)^2P$ AUTOIONIZING STATE IN SODIUM BY ELECTRON IMPACT

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The excitation functions for the $^2P_{3/2}$ та $^2P_{1/2}$ components of the $(2p^53s^2)^2P_J$ autoionizing doublet state and summary excitation function of this state were obtained for the impact energies from the excitation threshold up to 600 eV. Measurements were performed with an energy resolution of 0,25 eV and 0,4 eV by using the electron spectroscopy method. The strong resonance structure revealed for the first time in the near-threshold excitation of the $^2P_{3/2}$ та $^2P_{1/2}$ components reflects the presence of negative-ion resonances with the suggested configuration $(2p^53s^2)\epsilon l$. The analysis of excitation dynamics over the whole impact energy region from the excitation threshold to 600 eV shows that the resonance excitation cross section reaches a value of 80% of the maximum value of $1,3 \cdot 10^{-18} \text{ cm}^2$. The comparison of data was made with the existing theoretical approaches.

Key words: electron-atom collisions, autoionization, negative ion.

Autoionizing states in atoms and ions play a significant role in determining the parameters of astrophysical plasma and different kinds of laboratory plasma, including laser plasma. In particular, they may influence essentially the charge composition and the population of atomic levels in neutral or charged components of plasma. The use of alkali metals as a basic, or an additional component of plasma environment has initiated during the last 10 years a great interest to the experimental and theoretical studies of autoionization in these atomic systems [1]. However, the experimental studies for alkali atoms are complicated by three principal factors, namely: (i) small excitation cross sections ($< 10^{-18} \text{ cm}^2$), (ii) limited running time of the vapour source and (iii) the chemical activity of high-temperature metal vapors. The last factor takes on special significance in the experimental investigations of electron spectra where the distinctness and stability in time of the energy scale both are key factors in obtaining adequate data on energy position, intensity and excitation dynamics of spectral lines. For the reasons given above, for sodium atoms only two works [2, 3] are known where the electron excitation of the lowest $(2p^53s^2)^2P$ autoionizing state was studied using the electron spectroscopy method.

In the present work the excitation functions for the $^2P_{3/2}$ and $^2P_{1/2}$ components of the $(2p^53s^2)^2P$ autoionizing doublet as well as the excitation function of the $(2p^53s^2)^2P$ state were precisely studied in two regions of the incident electron energy, respectively: (i) up

to 0,9 eV above the excitation thresholds of the components and (ii) from the excitation threshold up to 600 eV. The measurements were performed on the apparatus and by the measuring method both described in details earlier [4]. Briefly, the experimental method consists of the following stages. First, the ejected-electron spectra corresponding to the decay of the $(2p^53s^2)^2P_J$ states were measured for the impact energy values from the excitation threshold to 600 eV. In the near-threshold energy region the increment step of the impact energy was 0,05 eV. The spectra were measured at an observation angle of $54,7^\circ$. In this case the detected ejected-electron intensity does not depend on a possible alignment of the autoionizing states [5]. The spectra were automatically normalized to the intensity of the incident-electron beam by a 'current-to-frequency' converter. By processing these data using the ORIGIN software package, the intensities of lines corresponding to the decay of the $^2P_{3/2}$ and $^2P_{1/2}$ components were determined. The impact energy dependency of these intensities determined the excitation function for each component.

In the near-threshold impact energy region the data were obtained at higher energy resolution by using an incident electron beam with an energy spread (FWHM) 0,25 eV or less and maximum intensity $\leq 0,1$ mA. In this case a 127° electrostatic monochromator [4] was used as a source of incident electrons. A low intensity of measured spectra demanded in this case an essential increase of the dwell time of measurements. This and the limited running time of the vapour source led to narrowing the energy range of measurements. That was the reason for obtaining the data for the $^2P_{3/2}$ and $^2P_{1/2}$ components in the narrow impact energy region up to 0,9 eV above the excitation threshold at 30,77 eV [6].

For performing the measurements over the impact energy region up to 600 eV, an electron gun was used for increasing the intensity of the incident beam to the value of 0,2–0,3 mA. In this case the energy spread of the beam was about 0,4 eV. The combined relative uncertainty, after accounting for fluctuations of the experimental conditions, generally did not exceed 15% in the region 30,8–35 eV and 10% in the region 60–600 eV. Notable exceptions are the first points of both excitation functions where the uncertainty reached 30%. The relative experimental cross sections were put on the absolute scale by normalizing the $(2p^53s^2)^2P$ excitation function to the theoretical cross section [2] at 600 eV.

Fig. 1 presents the excitation function for the $(2p^53s^2)^2P$ state obtained at an energy resolution of 0,4 eV in an impact energy region from the threshold at 30,77 to 600 eV. As it can be seen, in the near-threshold part of the excitation function two strong resonances are clearly observed at the energies of 31,1 eV and 33,6 eV (see arrows). The smaller increment step of the impact energy resolved the shape and the energy position of resonances to be better determined in comparison with previous data [3]. The excitation cross section in maximum of resonances reaches the value of $1,1 \cdot 10^{-18}$ cm². Above 35 eV the behavior of the cross section is typical for dipole transitions from the ground state of atom – a smooth rise of the cross section up to its maximum value of $1,3 \cdot 10^{-18}$ cm² at 150 eV and further smooth decreasing up to 600 eV. Comparing the measured excitation function with that calculated in plane-wave Born approximation [2] shows that the theory describes adequately the experimental behaviors of the cross section only for the impact energies higher than 200 eV.

Fig. 2 presents the excitation functions for the components $^2P_{3/2}$ and $^2P_{1/2}$ obtained at an energy resolution of 0,25 eV. Both functions start with the near-threshold resonances *a*, *b* at 30,87 and 31,17 eV (see arrows). Above the first resonance the

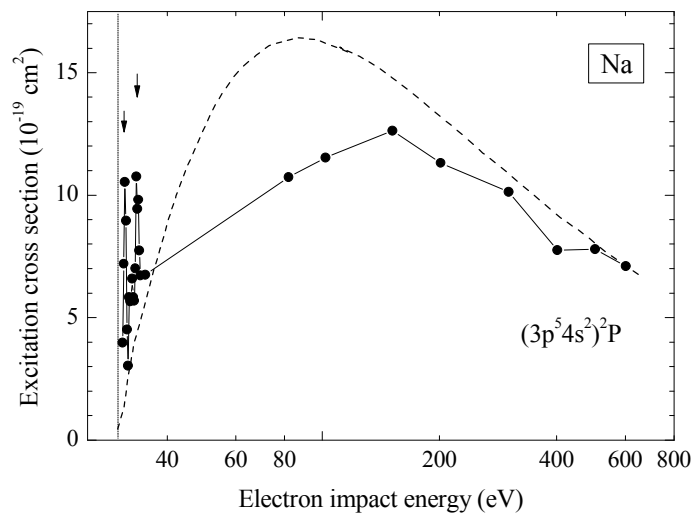


Fig. 1. The excitation function for the $(2p^5 3s^2)^2P$ autoionizing state in sodium: • present work; - - - calculation [2]. Dashed vertical line marks the excitation threshold at 30,77 eV [6]

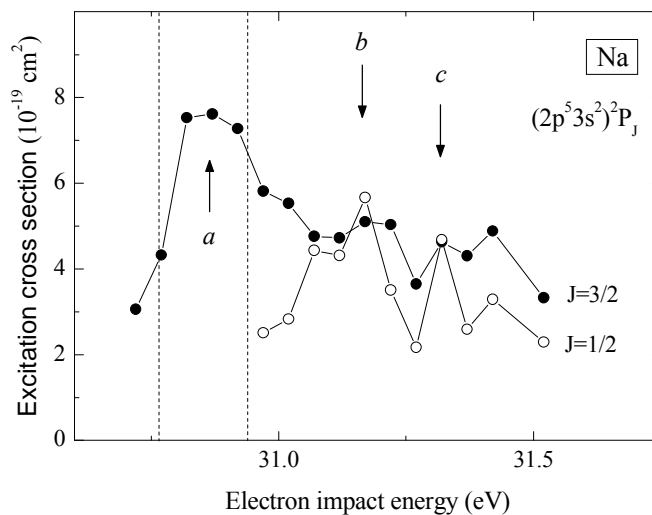


Fig. 2. The near-threshold parts of excitation functions for the components $J=3/2$ and $J=1/2$ measured at an energy resolution of 0,25 eV. Dashed lines mark the excitation thresholds at 30,77 and 30,93 eV [6]

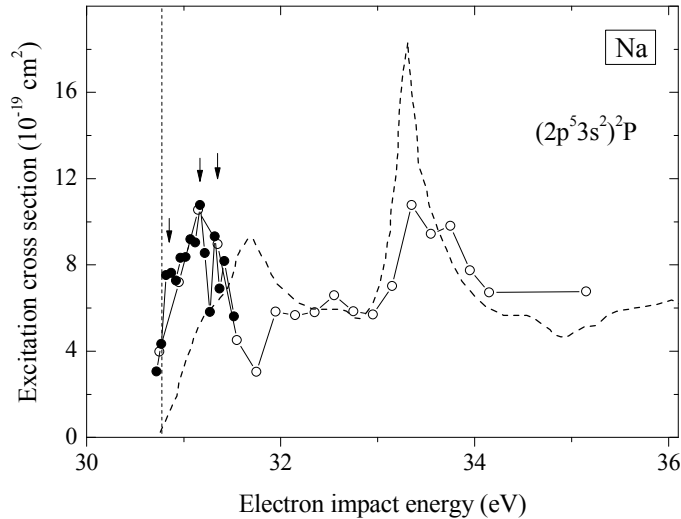


Fig. 3. The near-threshold part of the excitation function for the $(2p^5 3s^2)^2P$ state in sodium measured at different energy resolutions: \circ – 0,4 eV [3]; \bullet – 0,25 eV, present data; $---$ – R -matrix calculation [2]. Dashed vertical line marks the excitation threshold at 30,77 eV [6]

excitation cross section of the $^2P_{3/2}$ state does not reveal some remarkable additional structure. But in the excitation function for the $^2P_{1/2}$ state there is a resonance-like increase of the cross section at 31,12 eV (feature *c*).

The near-threshold regions for the $(2p^5 3s^2)^2P$ function, for the sum of $^2P_{3/2}$ and $^2P_{1/2}$ functions and for the R -matrix calculation [2] are shown in figure 3. As can be seen, an improvement of the resolution from 0,4 to 0,25 eV distinguish the ‘fine’ structure *a*, *b*, *c* in the first near-threshold resonance at 31,1 eV clearly to be revealed. The origin of this structure is probably related with the presence in this energy region at least of three negative-ion resonances based on the $(2p^5 3s^2)^2P$ autoionizing state. Comparing our data with the R -matrix calculations shows that the theory describes reasonably the observed structure only around the second resonance at 35,5 eV.

Summarizing the above discussion, we conclude that for impact energies close to the excitation threshold (i) the negative-ion resonances determine completely the electron impact excitation of the $(2p^5 3s^2)^2P$ autoionizing state, (ii) the known theoretical approaches do not describe adequately the experimental data. In this connection we hope that the present work will initiate a further development of theoretical investigations of autoionization processes in alkali atoms.

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ДОСЛІДЖЕННЯ ЕЛЕКТРОННОГО ЗБУДЖЕННЯ АВТОІОНІЗАЦІЙНОГО СТАНУ $(2p^5 3s^2)^2P$ АТОМІВ НАТРІЮ

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Одержані функції електронного збудження для компонент $^2P_{3/2}$ та $^2P_{1/2}$ автоіонізаційного дублетного стану $(2p^5 3s^2)^2P$ атомів натрію в біляпороговій ділянці енергій зіткнень, а також сумарна функція збудження цього стану в діапазоні енергій зіткнень від порога до 600 еВ. Виміри проведено методом електронної спектроскопії з енергетичною роздільною здатністю 0,25 та 0,4 еВ, відповідно. У біляпороговій області енергій зіткнень на функціях збудження компонент $^2P_{3/2}$ та $^2P_{1/2}$ вперше виявлено інтенсивну резонансну структуру, що свідчить про існування в атомів натрію станів негативного іона Na^- з конфігурацією $(2p^5 3s^2 \epsilon l)$. Аналіз поведінки перерізу збудження в діапазоні енергій від порога до 600 еВ довів, що його резонансна частина становить до 80% від його максимального значення $1,3 \cdot 10^{-18} \text{ см}^2$. Проведено порівняння одержаних даних з наявними теоретичними розрахунками в різних наближеннях.

Ключові слова: електрон-атомні зіткнення, автоіонізація, негативний іон.

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