Charge exchange of He^+, Ne^+ and Ar^+ in internal states of cadmium and zinc ions at low energies

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We investigated experimentally the charge exchange of He^+, Ne^+, and Ar^+ in internal excited states $4d^9 5s^2\ ^2D_{3/2,5/2}$ of Cd II and $3d^9 4s^2\ ^2D_{3/2}$ of Zn II in the energy interval 2–400 eV. It is established that the interacting particle pairs are characterized, at appreciable energy defects ~ 7eV, by high energy-transfer efficiency ($\sim 10^{-16}$ cm^2) and their charge-exchange cross sections exhibit a qualitatively different behavior at low energies. Calculation shows that the charge exchange makes a noticeable contribution to the population of the upper laser levels for $\lambda = 4415$ Å He-Cd lasers and $\lambda = 5894$ Å He-Zn lasers.

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The investigation of charge-exchange processes at low energies is of interest in collision theory and is of practical significance for laser-plasma physics. Many lasers are based on metal vapor mixed with inert gases. For many of them, the inverted population is produced via charge exchange of the inert-gas ions at low energies in a Penning reaction. [1–4]

We report here the first investigation of the charge exchange of helium, neon, and argon ions on the internal states of Cd II and Zn II. The measurements were made by a beam procedure using the apparatus described in[5]. The inert-gas ions were extracted from a plasmotron source and sorted with a cylindrical capacitor, while the Cd and Zn target atoms were obtained in a vapor-filled cell.

The principal excitation channels in the charge exchange are represented by the scheme

$$A^+ + B \nearrow A + (B^+)^* \pm \Delta E_1 \quad (1)$$
$$A^+ + B \searrow A^+ + (B^+)^* + e - \Delta E_2 , \quad (2)$$

where A^+ stands for He^+, Ne^+, or Ar^+ and B stands for Zn or Cd.

The reaction via channel (1) for He^+, Ne^+ + Zn, Cd at $+\Delta E_1$ is charge exchange of exothermal type, while for Ar^+ + Zn, Cd at $-\Delta E_2$ it is of the endothermal type; the reaction (2) characterizes impact ionization with excitation. The laboratory-frame energy defects ΔE for internal states excited by the ions He^+, Ne^+, and Ar^+ are listed in the table.

Figure 1 shows the main experimental results on the charge-exchange cross sections of slow singly-charged ions of helium, neon, and argon with cadmium and zinc atoms, with excitation of the internal states $4d^9 5s^2\ ^2D_{3/2,5/2}$ of Cd II and $3d^9 4s^2\ ^2D_{3/2}$ of Zn II. The absolute values of the charge exchange cross sections were determined directly in this experiment from the electron excitation. [5] The error in the absolute calibration is ± 20% and the relative-measurement error is 3%.

Exothermal charge exchange for the He^+ + Cd pair (Fig. 1a, curves 1 and 2) is characterized by high efficiency, $\sim 10^{-16}$ cm^2 at the threshold, and by a somewhat lower value $\sim 10^{-17}$ cm^2 for He^+ + Zn (curve 3); for both pairs, the cross sections increase in the region of low energies. The charge exchange Ne^+ + Zn, Cd (Fig. 1b), although also exothermal, differs fundamentally in its behavior from the He^+ + Zn, Cd pair, the main difference appearing both near the threshold and at high energies.

Thus, for exothermal charge exchange at low energies, the behavior of the cross sections is determined essentially by the properties of the interacting particles.

The charge exchange for the endothermal reaction Ar^+ + Zn, Cd (Fig. 1c) differs in its behavior from the exothermal one. The course of the curves in Fig. 1c, in the region 2–150 eV can be attributed to exchange interaction, i.e., to pure charge exchange (reaction 1), and the subsequent growth from 200 eV is obviously due to the turning on of reaction 2. Comparison of the charge-exchange effectiveness in the threshold region for cadmium (curves 1 and 2) indicates that a very important role is played in the exchange interaction by the screening, as a result of which the *d*-electron of Cd is weakly bound to the nucleus, and the exchange is facilitated.

The experimentally observed behavior of the charge exchange cross sections in the internal of Zn II and Cd II cannot be described by the known theoretical formulas derived for the ordinary ionic states of Zn and Cd. [6]

On the whole, analysis shows that the process of

λ, Å	Transition	ΔE_1, eV			ΔE_2, eV		
		He^+	Ne^+	Ar^+	He^+	Ne^+	Ar^+
4415	$4d^9 5s^2\ ^2D_{5/2} \to 5p\ ^2P^\circ_{3/2}$ Cd II	+7.2	+ 4.7	− 2.5	− 18.2	− 20.7	−23.8
3250	$4d^9 5s^2\ ^2D_{3/2} \to 5p\ ^2P^\circ_{1/2}$ Cd II	+6.5	+ 3.9	−3.4	− 18.9	−21.5	−24.8
5894	$3d^9 4s^2\ ^2D_{3/2} \to 4p\ ^2P^\circ_{1/2}$ Zn II	+7.5	+ 5.3	− 2.8	− 18.6	−22.9	−28.2

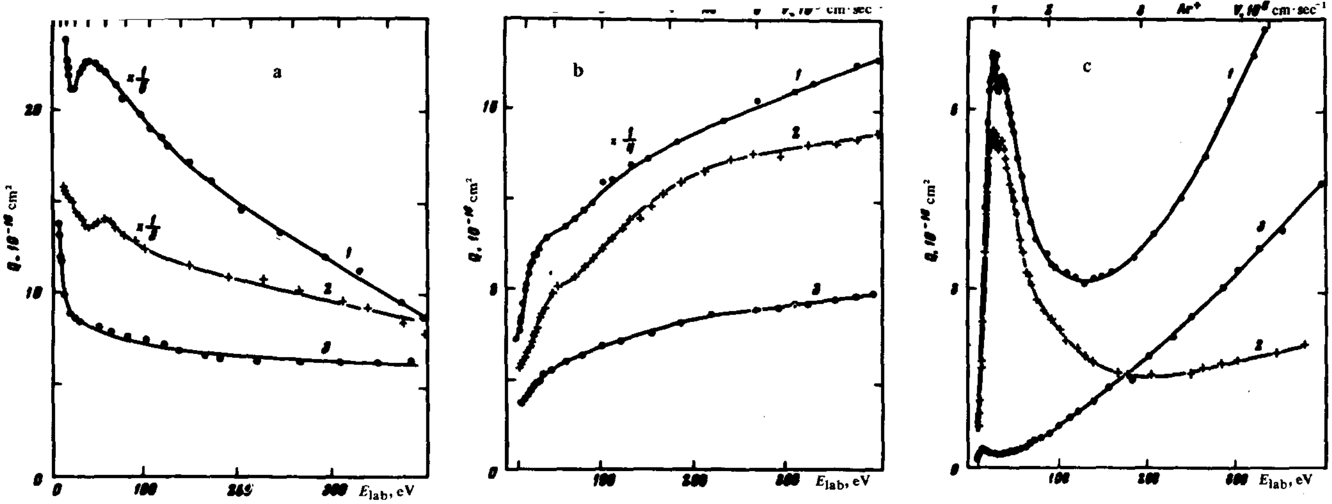

FIG. 1. Charge exchange cross sections of He^+ (a), Ne^+, and Ar^+ (c) with Cd and Zn atoms with excitation of the following internal lines: 1) 4415 Å of Cd II, 2) 3250 Å of Cd II, 2) 5894 Å of Zn II.

charge exchange with excitation of the internal electronic states of Zn II and Cd II by He^+, Ne^+, and Ar^+ ions is characterized by a highly variable behavior of the charge exchange cross section and is not as selective as hitherto assumed.[7-10] This raises, in particular, the question of theoretically describing the near-threshold behavior of the charge-exchange cross section and of a more complete explanation of the exchange-interaction mechanism.

The experimental data obtained in this study were used to determine the role of charge exchange in He-Cd and He-Zn lasers. Calculations based on the kinetic equations show that charge exchange makes a contribution of about 10% to the population of the upper laser levels for the 4415 Å and 5894 Å lines of the He-Cd and He-Zn lasers. This makes it possible to regard charge exchange as a competing process on a par with electronic excitation and the Penning reaction in a laser.

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[1]G. J. Collins, R. C. Jensen, and W. R. Bennett, Appl. Phys. Lett. **19**, 5, 125 (1971).
[2]A. J. Palmer and J. W. McGowan, J. Appl. Phys. **43**, 10, 4084 (1972).
[3]V. S. Aleĭnikov and V. V. Ushakov, Opt. Spektr. **33**, 214 (1972).
[4]E. L. Latush, V. S. Mikhalevskiĭ, and M. F. Sěm, *ibid.* **34**, 214 (1973).
[5]M-T. I. Soskida and V. S. Shevera, Ukr. Fiz. Zh. **18**, 1394 (1974).
[6]V. I. Bylkin, Opt. Spektr. **29**, 1036 (1970).
[7]J. M. Green and C. E. Webb, J. Phys. B Atom. Molec. Phys. **7**, 13, 1968 (1974).
[8]A. R. Turner-Smith, J. M. Green, and C. E. Webb, *ibid.* **6**, 1, 114 (1973).
[9]C. F. Melius, *ibid.* **7**, 3, 1692 (1974).
[10]I. L. Bogdanova, V. D. Marusin, and V. E. Yakhontova, Opt. Spektr. **37**, 4, 643 (1974).