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EQUILIBRIUM DISTRIBUTIONS OF THE CHARGE OF Li, Na, *AND* K *IONS IN* Cd, Mg, *AND* Zn *VAPORS*

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The equilibrium distributions of the charge fractions were measured in beams of Li, Na, and K particles after traversing Mg, Zn, and Cd vapors, at energies of 20—155 keV. The results obtained made it possible to establish certain relationships characteristic of the interaction of the investigated ions and target atoms. In the investigated range of energies considerable differences were found between the relative values of the charge fractions for different types of incident ion and target atom.

1. INTRODUCTION

A great deal of information is already available on the equilibrium distributions of the charge in ion beams which have passed through gases.[1-4] Considerably less is known about equilibrium beams of ions which have interacted with condensed targets.[1,3-5] There are practically no data on the charge state of ion beams which have suffered collisions with the atoms of vapors. Nevertheless, the investigation of the processes of the loss and capture of electrons by ions, in metal vapors in particular, is of considerable scientific and practical interest.

In the present investigation, a study was made of the equilibrium distributions of the charge in beams of lithium, sodium, and potassium ions after they had passed through targets consisting of cadmium, magnesium, and zinc vapors.

The results are reported of the measurements of the equilibrium charge fractions of Li, Na, and K particles in the energy range 20—155 keV.

2. EXPERIMENTAL APPARATUS AND MEASUREMENT METHOD

In the present investigation we used basically the same apparatus as we employed earlier to investigate the interaction of lithium ions passing through condensed targets in the form of celluloid and carbon films.[5]

The method of measuring the intensities of the charged constituents of a beam was the same as in the earlier investigation. Therefore, we shall describe only the modifications introduced into the experimental apparatus. A collision chamber, in which the necessary metal vapor pressure was established, was placed in the path of an ion beam between its exit from an accelerator tube and an electrostatic analyzer. The collision chamber was a furnace whose construction is shown schematically in Fig. 1. The chamber, in which the metal vapor pressure was established, was made of stainless steel and was in the form of a cylindrical tube 1 of 16 mm diameter and a total length of 235 mm. The entry to and the exit from the collision chamber were through channels 50 mm long. These channels were made of 0.2 mm thick stainless-steel diaphragms with a central aperture of 1 mm. The diaphragms were mounted, 1.33 mm apart, in a cylindrical centering casing 2; they were separated by spacing rings and tightly gripped by a nut screwed into the end of the casing.

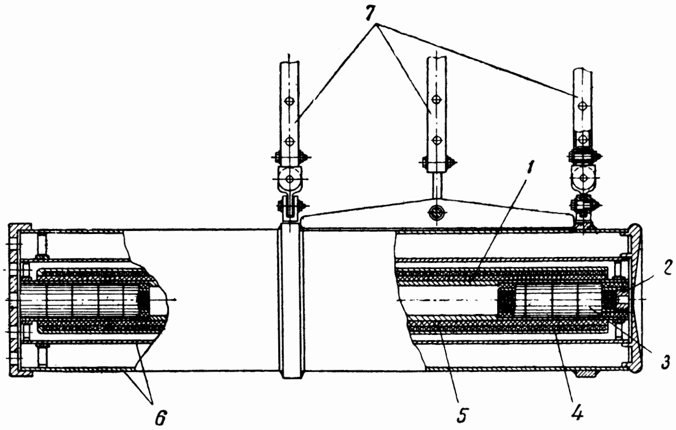

FIG. 1. Schematic diagram of the collision chamber.

This construction of the channels, which ensured sufficient definition of the vapor stream effusing from the collision chamber, also had the advantage that it reduced the number of ions reflected from the inner surfaces in the channels. Each of the two stainless-steel cylindrical casings was placed in the collision chamber and was sealed by graphite rings 3, as in the work of Allison et al.[2]

The heating element was in the form of a thin-walled corundum cylinder 5 with an external nichrome wire winding 4. The wire was wound in such a way that the distance between one turn and the next gradually decreased from the middle to the ends of the heater and, therefore, the temperature in the channels of the chamber was higher than that in other parts of the chamber. This extra heating of the channels prevented the condensation of the evaporated substance on the diaphragm edges - a condition which might block the apertures.

To reduce the power consumed by the furnace and to prevent the rest of the apparatus from being heated, the heater was shielded externally by two coaxial cylindrical radiation shields 6 and by flat shields, placed at the ends, which had central apertures for the admission of the beam. The shields were made of stainless steel sheet 0.2 mm thick. The pressure in the collision chamber was deduced from temperature measured with a chromel—alumel thermocouple.

The collision chamber, together with the heater and shields, was attached by hinges and adjustable braces (made of German silver tubes) to a massive base, which was part of a laboratory vacuum chamber. The collision chamber was aligned with respect to the ion beam by adjusting screws 7, which were vacuum-sealed. Therefore, the necessary adjustments could be made without disturbing the vacuum.

Before inserting the metal charge whose vapor was to be used as the target, the collision chamber was outgassed at 550—600°C. The degree of outgassing - removal of residual gases - on heating was checked from the charge-exchange of ions after passing through a heated collision chamber. The outgassing was assumed to be complete when the number of charge-exchanged ions at the collision temperature of 600°C did not exceed 1—1.5%.

To avoid the influence of the non-vaporized metal residue from a previous run on the results of the investigation of the next target, a separate collision chamber was used for each of the investigated metals. Control measurements showed that after the exposure of the collision chamber to air at atmospheric pressure for 3 hours, the chamber was outgassed again by heating to 600°C for 2 hours.

A metal charge weighing 3—4 g was placed in the chamber as quickly as possible (0.5 hours). The metal was outgassed by heating the chamber at temperatures 50—60 deg higher than the working temperatures, for 2—3 hours. This ensured the removal of gases adsorbed on the metal under investigation. The outgassing process was also checked with a manometer. To determine the equilibrium distribution of the charge in ion beams, we recorded the dependence of the charged fractions on the collision chamber temperature for each type of ion and target.

Over a certain range of temperatures, the relative fractions of the charged constituents in a beam were practically constant. As the working temperature, we selected the lowest temperature in this range, which still ensured a steady-state distribution of the charge in the beam. The working temperatures in the coldest part of the collision chamber were 460°C for magnesium, 360°C for zinc, and 280°C for cadmium.

The scintillator crystal of the counter, placed in the direct beam, was shielded from the atoms of the target by an electromagnetic shutter located in the path of the ion beam, immediately in front of the counter. This shutter was removed from the ion beam only for the very short time necessary to measure the intensity of the neutral particle beam and the total beam intensity.

3. RESULTS OF MEASUREMENTS AND DISCUSSION

In all the measurements carried out in the present investigation, we used beams of singly-charged ions, Li^7, Na^{23}, K^{39}, and chemically pure metals, Mg, Zn, and Cd in vapor form. When the metal vapor pressure which ensured an equilibrium distribution of the charge in the ion beam was reached, we measured the relative fractions of the charged constituents $F_{0\infty}$, $F_{1\infty}$, and $F_{2\infty}$. The constituents containing singly-doubly-charged ions, $F_{1\infty}$, $F_{2\infty}$, were separated by an electrostatic analyzer and their intensities were measured with a scintillation counter. The intensity of the neutral constituents of the beams F_{∞} was measured with a scintillation counter placed on the axis of the primary beam. The same counter was used to measure the total beam intensity before its separation into the charged constituents.

Figures 2—4 show the results of the measurements in the form of curves representing the energy dependence of the charged fractions of

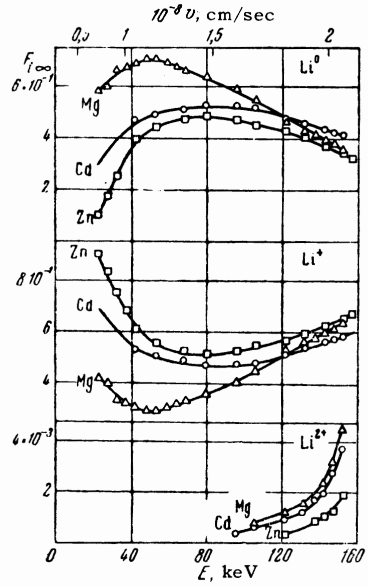

FIG. 2. Charge distribution in an equilibrium beam of lithium particles after passing through magnesium, cadmium, and zinc vapors, plotted as a function of the ion energy.

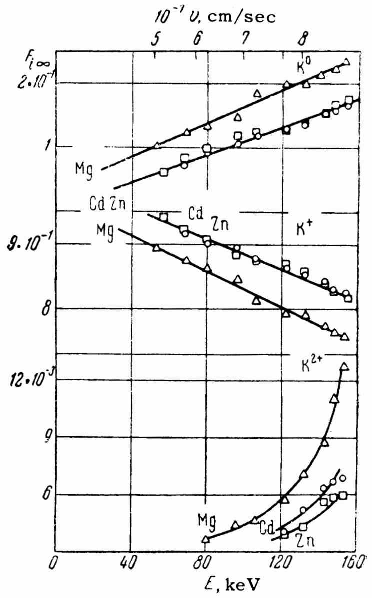

FIG. 4. Charge distribution in an equilibrium beam of potassium particles after passing through magnesium, cadmium, and zinc vapors, plotted as a function of the ion energy.

equilibrium beams of lithium, magnesium, and potassium particles after having passed through magnesium, zinc and cadmium vapors.

It is evident from Figs. 2—4 that the dependences of the equilibrium charged fractions $F_{i\infty}$ on the relative ion velocity were similar for all three ions.

As the atomic number of the ions increases from Li to K, we observe for constant values of the energy-a systematic decrease in the relative content of the neutral particles $F_{0\infty}$ and a considerable increase in the fraction of the doubly-charged particles $F_{2\infty}$. The value of the equilibrium fraction of neutral particles $F_{0\infty}$ in magnesium was different from those observed in zinc and cadmium. For magnesium, the fraction $F_{0\infty}$ was smaller than for zinc and cadmium, while the fractions $F_{0\infty}$ for zinc and cadmium were practically identical in magnitude with those for Na and K ions and differed very little in the case of Li ions. The equilibrium fractions $F_{2\infty}$ were largest in magnesium and smallest in zinc.

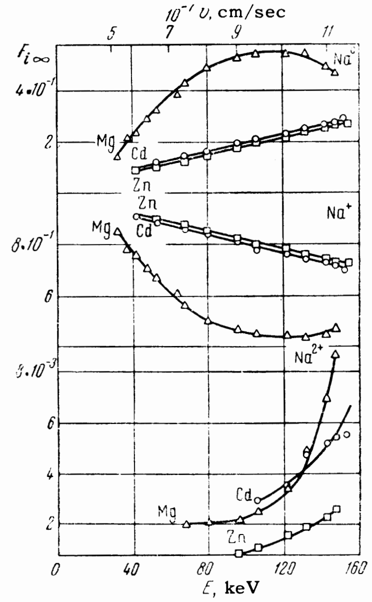

FIG. 3. Charge distribution in an equilibrium beam of sodium particles after passing through magnesium, cadmium, and zinc vapors, plotted as a function of the ion energy.

Since the equilibrium charged fractions $F_{0\infty}$, $F_{1\infty}$, and $F_{2\infty}$ were governed by the relations between the corresponding effective electron capture and loss cross sections, it was difficult to interpret the results obtained without knowing these cross sections. However, it was still possible to note some features of the interaction between the particles considered. Thus, for example, it was worth noting the very weak dependence of the value of the equilibrium fraction $F_{0\infty}$ on the atomic number of zinc and cadmium. On the other hand, the value of the fraction $F_{0\infty}$ for magnesium was considerably greater than the values for zinc and cadmium.

This was most likely related to the fact that the probability of the charge-exchange process rose as the first ionization potential of the target atom fell. These potentials were 7.64, 8.99, and 9.39 eV for magnesium, cadmium, and zinc, respectively.[6] The ionization potentials of cadmium and zinc were quite close. Over the whole investigated range of energies, the relative value of the fraction $F_{2\infty}$ remained very small and, therefore, the average ion charge $\bar{i} = \Sigma i F_{i\infty}$ was governed by the fraction $F_{1\infty}$. It could easily be shown that the average charge passed through a minimum, which shifted toward higher energies as the atomic number of the ions rose on going from Li to K, and its value at the minimum increased from Li to Na.

It was worth noting the high values of the relative fraction of neutral particles after interaction with the investigated targets, particularly magnesium. Thus, for example, for lithium particles in magnesium the value of $F_{0\infty}$ at the maximum was 3–4 times greater than in H_2, N_2, He,[2] and 1.5 times greater than in celluloid or carbon films.[5]

It should be mentioned that more definite conclusions about the relationships governing the processes of electron loss and capture in the cases considered of interaction between ions and atoms could be drawn if data were available on the effective cross sections σ_{10} and σ_{12}, or on the cross sections σ_{01} and σ_{21}, which would be used in conjunction with the data reported in the present paper.

In conclusion, we regard it as our pleasant duty to thank Academician of the Ukr. S.S.R. Academy of Sciences A. K. Val'ter for his interest in this investigation.

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