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Charge transfer in He$^+$ + Li and He$^+$ + Cd collisions*

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The charge-transfer cross sections σ_{10} for He$^+$ ions on vapors of lithium and cadmium have been measured using the method of charge analysis of the fast products of the collisions in a magnetic field. The cross section for lithium falls with energy and that for cadmium rises with energy in the measured energy range 5–44 keV.

I. INTRODUCTION

The existing information on charge-transfer collisions of He$^+$ projectiles with different targets has been reviewed recently by Massey and Gilbody.[1] Theoretical estimates of the cross sections involved are unsatisfactory except for a few simple systems. The cross sections for collisions with targets of low ionization potential are particularly difficult to evaluate because of the existence of many pseudocrossings of the potential-energy curve describing the initial channel He$^+ + X$ (where X denotes the target atom) with the potential energy curves describing the final channels He$^* + X^+$ and He $+ X^{+*}$ (the asterisk denotes excited states). To these cases belong the collisions in which X is Mg or Pb, which have been recently reported.[2] In this paper we present measurements in two more targets, lithium and cadmium, in the energy range 5–44 keV.

II. APPARATUS

The experimental apparatus has been described in detail by Baragiola and Salvatelli.[2] In brief, it consists of an accelerator to produce mass-analyzed beams of He$^+$ ions, an oven in which the metal vapors used as targets are produced, and beam measuring equipment.

The stainless-steel vacuum oven contains the metal to be evaporated. The purities of the Li and Cd used were specified to be greater than 99.9% and 99.999%, respectively, by the manufacturer.[3]

After traversing the target cell the beam was separated into its He$^+$ and He components (He^{++} and He$^-$ ions were produced in negligible amounts) by a magnetic field. These components were collected in a movable detector with equal response for ions and atoms.[4]

The background pressures ranged from 4×10^{-7} to 9×10^{-7} Torr with the oven at 20 °C. The pressure in the region outside the target cell, with the oven at operating temperatures, was less than 3×10^{-6} Torr.

III. EXPERIMENTAL PROCEDURE

The growth of the fraction F_0 of the atoms with target thickness Π at low Π values (single-collision conditions) is given by[2]

$$F_0 = I_0/(I_0 + I_1) = \sigma_{10}\Pi ,$$

where I_i denotes the flux of particles with charge i, and σ_{10} is the charge-transfer cross section.

The target thickness Π is given by the effective length of the target cell, the vapor pressure of the target, and its temperature. The effective length is the geometrical length plus a correction (which amounts to less than 3%) due to effusion of the vapor through the beam entrance and exit apertures. The vapor pressure was obtained from its temperature using the data given by Hultgren *et al.*[5]

The values of the cross sections were obtained from the slopes of the observed linear growth of $F_0(\Pi)$ at Π values of $(0.2-2)\times10^{13}$ atoms/cm^2. Further details on procedures for the search and elimination of systematic errors can be found in Ref. 2.

IV. RESULTS AND DISCUSSION

The measured values of the charge-transfer cross sections with their errors are plotted in Fig. 1. These errors arise mainly from uncertainties in the initial slopes of the $F_0(\Pi)$ curves. Not included in the figure is the 20% uncertainty[5] in the vapor-pressure data which must be added to the statistical errors mentioned above to obtain the absolute accuracy of the results.

Most likely the maximum of the σ_{10} curve for collisions of He$^+$ ions on Li vapor was not reached; however, because of the large cross sections that we have measured, we can affirm that long-range interactions are produced between channels of low-energy separation at infinity, as pointed out by Peterson and Lorents[6] (in our case ΔE_∞ is of the order of 1 eV). Therefore, the near-resonant reactions

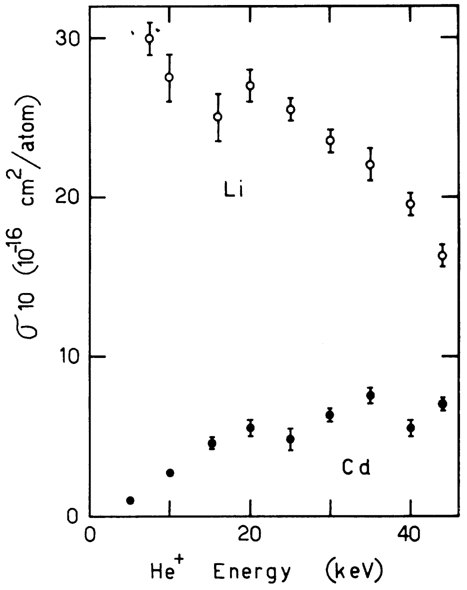

FIG. 1. Charge-transfer cross sections for He$^+$ ions on Li and Cd vapors.

$$\mathrm{He}^+ + \mathrm{Li} \rightarrow \mathrm{He}^* + \mathrm{Li}^+ + \Delta E$$

have a significant contribution to the total cross sections. On the other hand, according to Salop *et al.*[7] and Olson and Smith,[8] reactions of the type

$$\mathrm{He}^+ + A \rightarrow \mathrm{He} + A^{+*} + \Delta E,$$

where A are alkali-metal atoms, will contribute less than 5% to the over-all total charge-transfer cross section at energies of about 1.5 keV, but as the collision energy is increased much above this value, the excitation of the alkali-metal ions that requires charge transfer of the outer S electron and then excitation of a core electron, becomes more favorable. Then, the reactions

$$\mathrm{He}^+ + \mathrm{Li} \rightarrow \mathrm{He} + \mathrm{Li}^{+*} + \Delta E$$

may have an important contribution to the total cross sections measured in this work. Furthermore, as a result of the large ΔE, the reactions

$$\mathrm{He}^+ + \mathrm{Li} \rightarrow \mathrm{He} + \mathrm{Li}^+ + \Delta E,$$

$$\mathrm{He}^+ + \mathrm{Li} \rightarrow \mathrm{He}^* + \mathrm{Li}^{+*} + \Delta E,$$

with a long-range interaction between these initial and final states, are very improbable.

We conclude that the reactions which lead to the alkali-metal ion or the helium atom in an excited state are mainly responsible for the large σ_{10} cross sections that we have measured.

On the other hand, we have obtained rather small σ_{10} cross sections for collisions of helium ions with Cd vapors, and the maximum of the curves within the energy range of measurements is in the vicinity of 35 keV, both features indicating that short-range interactions produce the electron transfer. It is expected, however, that the cross section for Cd will rise again at very low energies because of the contribution of the near-resonant processes $\mathrm{He}^+ + \mathrm{Cd} \rightarrow \mathrm{He} + \mathrm{Cd}^{+*}$, which are known to be responsible for important transitions in the He-Cd laser as is pointed out by Turner-Smith *et al.*[9]

Some irregularities are observed in the total charge-transfer cross sections, but there are not sufficient experimental points to analyze this structure more deeply.

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