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EFFECTIVE METHODS TO STUDY IONIZATION AND CHARGE - EXCHANGE PROCESSES IN $\mathrm{Rb}^{+} + \mathrm{Ar,Xe}$ COLLISIONS IN 0.7-10 KeV.

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Abstract

In the present work the refined version of capacitor method as well as collision spectroscopy method are used to study inelastic processes in collision of closed electron shell particles. To obtain energy loss spectra of primarily scattered particles the "box" type electrostatic energy analyzer is elaborated and designed. For revealing and estimation of portion of various inelastic reactions realized in these collisions an energy loss spectrum for $Rb^{+}(3p^{6}3d^{10}4s^{2}4p^{6}) \; - \; Ar(3s^{2}3p^{6})$*, colliding pair was tested as a typical example.*

Keywords: Ionization. Charge-Exchange, Excitation, Capacitor, Energy loss.

Introduction

The ion-atom collisions have been an attractive subject and are of considerable interest in atomic physics due to its importance in many fields, such as environmental science, laboratory and astrophysical plasmas [1], radiation physics, collisionand radioactive processes in the Earth's upper atmosphere [2, 3].

Complex investigation of such processes, especially when it concerns to the closed electronshell of colliding pairs (alkali metal ions rare gas atoms) is connected with definite methodological difficulties. The reason is that, due to the small collision parameter (particles are approaching each other as close as possible) the scattering of primary particles at largeangles take place and hence secondary recoil particles acquire large kinetic energy. This circumstance makes almost impossible to detect effectively the particlesthose are responsible for the mentioned above processes. Moreover, due to the large amount of realizing reactions their identification becomes problematic. In order to discussquantitatively the realizing processes one has to evaluate the parameters responsible for elastic and inelastic processes and reveal the contribution of separate reactions for the investigated processes by using effective experimental methods.

Despite many studies of collisions $of\ Rb^{+} \; - \; Ar, Kr\ ,Xe$ pairs which have been carried out by various methods [4-7], available data for the mentioned above processes are contradictory [4, 6, 8] and, in somecases, unreliable [9].

Charge–exchange cross sections for the similar collision pairs $(K^{+} - Ar, K^{+} \; - \; Kr, K^{+} \; - \; Xe)$ were measured in Ref. [9] using the detection of fast neutral particles within a definite interval of scattering angles. However, as it was shown in Ref. [10], the restriction on the interval for collision angles in Ref. [9] underestimated the measured charge exchange cross sections by a factor of ten for $K^{+} + Ar, Kr, Xe$ collision pairs over the entire energy range considered, The Charge-exchange cross sections reported in Ref. [9] might also have been underestimated for $Rb^{+} \; - \; Ar, Xe$ collisions. Hence, it was necessary to carry out measurements for $Rb^{+} - Ar, Xe$collisions in wider and complete interval of scattering angles using a method that is free of this deficiency.

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One of the objectives of this work is to show that in many cases the information extracted from complicated experiments can be obtained using simple method, namely by measuring the energy loss spectra of incident particles (kinetic energy difference of particles before and after collisions). Such spectra can be measured in a wide range of scattering angles and energy losses, and the problems of collection of scattering particles do not arise here.

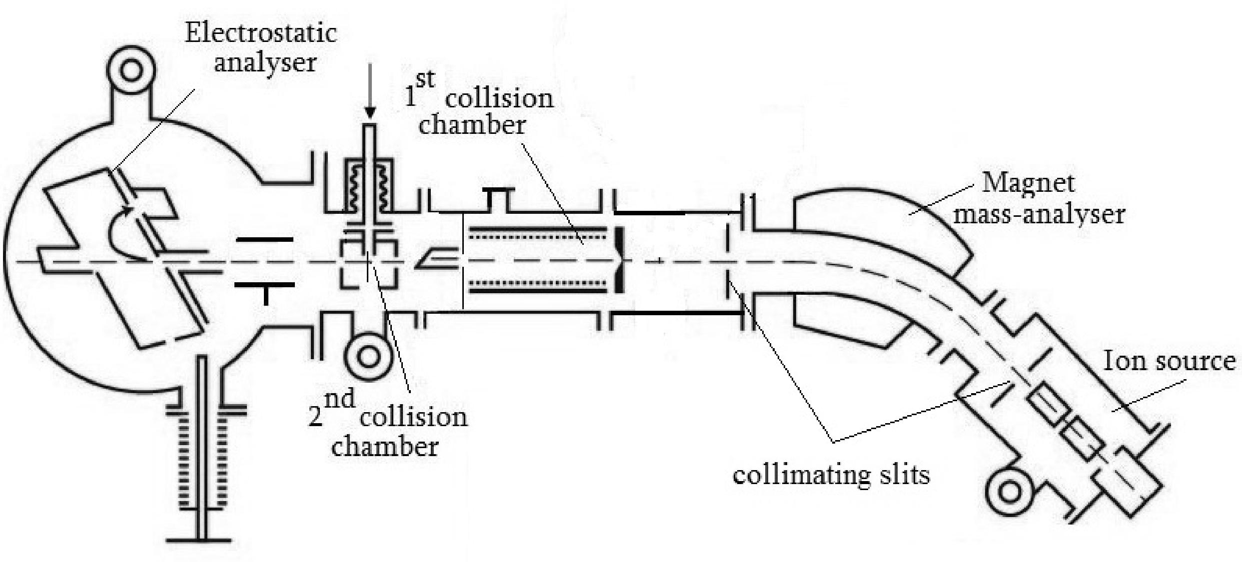

Fig.1

Methodology

The measurements are performed on a mass-spectrometric device, schematic view of which is shown in Fig. 1. The primary beam of Rb^+ ions from a surface – ionization ion source after focusing was accelerated to the desirable energy, formed into magnetic mass-analyzer, according toq/m (q-ion charge, m- mass). Collimating by slits ion beam was forwarded into 1st collision chamber. When Rb^+beam enters into the collision chamber filled with the target gas the measurement for the charge –exchange and ionization processes occur. These processes were measured by refined version of the capacitor method [3] (schematic view and explanation see below). In the earlier paper [4] the measurements are performed by the standard transfer electric field method. The customary procedure of this standard method is to use one of the central electrodes as the measurement electrode. We consider that such approach is the reason for significant errors in their measurements because scattering particles may strike the measurement electrodes. To avoid this deficiency we accordingly used a refined version of the transfer electric field method. In this refined version the effect ofscattering on the measured results is substantially reduced. In the present experiment we moved near to the first electrode. To avoid fringing effects, peculiar for the capacitor a system of auxiliary electrodes between the fist electrode and the entrance slit were installed. This auxiliary electrodes imposer a uniform potential near the first electrode. The first electrode, the auxiliary electrodes, and the entrance slit are all positioned as close together as possible. This close arrangement limits the scattering region on the beam-entrance side. The primary ions are detected by the Faraday cap. Collision particles (scatted positive ions and free electrons) are detected by a collector. Collector consists of two rows of plate electrodes that run parallel to the primary ion beam (Fig.2.). A uniform transverse electric field, responsible for the extraction and collection of particles realized in collision processes, is created by the potential applied to the grid (see G_1, G_2 on Fig.2.). This method yields direct measurements of the cross sections σ^+ for the production of singly positive ions and σ^- for electrons as the primary beam passes through the gas under study. These measured quantities are related in an obvious way to the capture cross section σ_c and the ionization cross section σ_i, and are to be determined as

$$\sigma^+ = \sigma_c + \sigma_i; \quad \sigma^- = \sigma_s + \sigma_i \qquad (1)$$

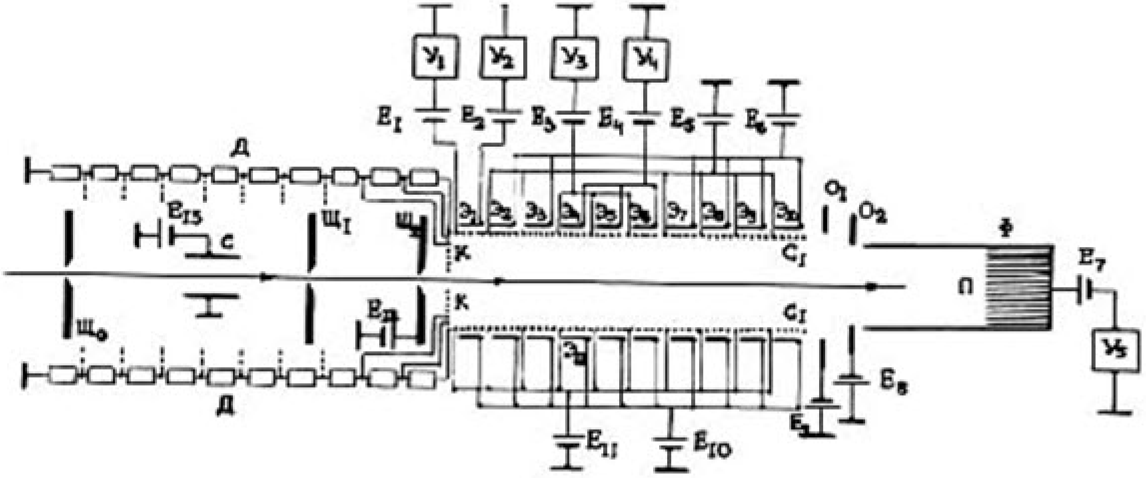

Fig.2.

In (1) σ_s is the cross section for the stripping of the incident ion.

Another remarkable method used for study inelastic processes in $Rb^+ + Ar, Xe$ is the collision spectroscopy method. This method is based on an investigation of scattering primary ion energy loss spectrum resulting after collision with target gas atoms. The idea of this method schematically is explained on Fig.3.

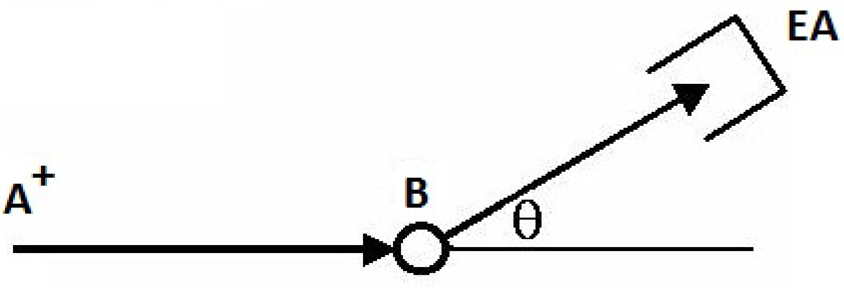

Fig. 3

The fixed$E$ –energy A^+ ions collides with B targets, they are scatter on a definite angles and enter into Electrostatic Analyzer (EA). The automatic adjustments of analyzer potentials gave the possibility to investigate the energy loss spectra in energy range from 0 – to 100eV. Angular distribution of scattering particles was possible by rotation of analyzer around the center of collisions at the angle range between 0 and 25° degrees (see Fig.1.).

Schematic 3D drawing of a “box” type electrostatic analyzer is shown on Fig.4. It consists of two pairs of parallel plane electrodes those are located so that their section gives right angle. The potential applied on the upper and side electrodes were equal to the acceleration potential of primary ions and potential on the entering one to be zero. The estimation of parameters and among them a potential distribution into analyzer, as well as charged particle trajectory formed inside analyzer was possible by solving the simple equation.

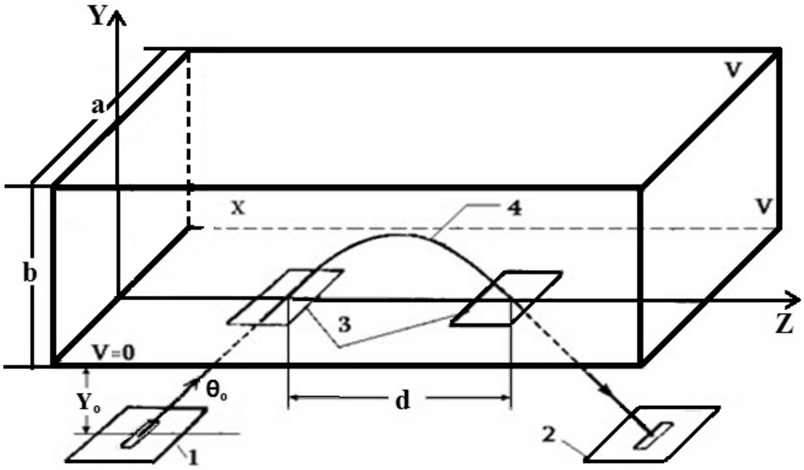

Fig.4.

Relations between analyzer parameters are as following:
D=1.67a; D=1.26d; b= 0.96a; $\Theta_0 = 50^0 45^/$; y= 0.25a; h=0.06d; $S_{opt} = 0.87R^{-1}d$.
Were d- is the distance between slits; D- dispersion; a – with of analyzer; b – height; Θ_0 – entrance angle of primary beam in analyzer; y – distance from source to electrodes; R – resolution ability; S_{opt}. – optimal with of slit; h – slits height. In our case d= 60 mm.
For the measurements of charge exchange cross section the charge component of scattered primary particles realized in collision chamber is separated by the electric field and particles with captured electron (neutral component) particles is registered by the secondary electron multiplier. In addition, the measured energy loss spectrum gives a detailed information that is related to the intensity of inelastic processes (ionization, chargeexchange, excitation)
It should be mentioned that, according to our task, which means to obtain a necessary energy loss spectrum the definite condition was laid on a selection of measured systems (analyzer). The aim of our work was also to select such kind of analyzer which has small size, and double focusing, large luminosity and what is most important, optimal resolutionability $E\ /\ \Delta E$. Where E is energy of primary particles and ΔE minimal difference between observed peaks that could be distinguished by the analyzer.
In our case the "box" type dispersion electrostatic analyzer was used. Such systems compare to others have some advantage, particularly maximal localization of fields surrounding the analyzer, full screening of outer field, minimal losses of power supply.

Results of measurements and discussion

Collision of Rb^+ ion beam withArgas atoms leads to mainly following processes: charge exchange reaction:

$$Rb^+ + Ar \to Rb + Ar^+ \qquad (2)$$

whenRb atom and Ar^+-ion can be in the ground state or in different excited state:

$$Rb^+ + Ar \to \begin{cases} Rb^+ - Ar^* \\ Rb^{+*} - Ar \end{cases} \qquad (3)$$

that include different channels for excitation ofAratom or/and Rb^+ ion; different channel for the stripping:

$$Rb^+ + Ar \to Rb^{++} + Ar + e \qquad (4)$$

and ionization

$$Rb^+ + Ar \to Rb^+ + Ar^+ + e \qquad (5)$$

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To evaluate the methods for study of inelastic processes realized the test experiment of energy loss spectrum for $Rb^+ - Ar$pair (as a typical example) was carried out. The spectrum of primary ions with fixed energy E=2keV and scattering angles $\theta = 3{,}5^0$ are shown in Fig.5. It seems that the spectrum has sharp discrete character. The first maximum at zero energy loss is attributed to the elastic scattering of Rb^+ ions. The second maximum at $\Delta E \approx 13eV$ is ascribed to the excitation of Ar atom into $3p^54s$,$3p^54p$, $3p^53d$ states, excitation of Rb^+ion into $4p^54s$, $4p^54d$, $4p^54f$ states and ionization of Ar. With less excitation probabilities are realized process of double excitation statesof Ar–atom($\Delta E \approx 33eV$). Such detailed explanation of the channels considered leads us to get information about absolute value of the charge-exchange and ionization cross sections.

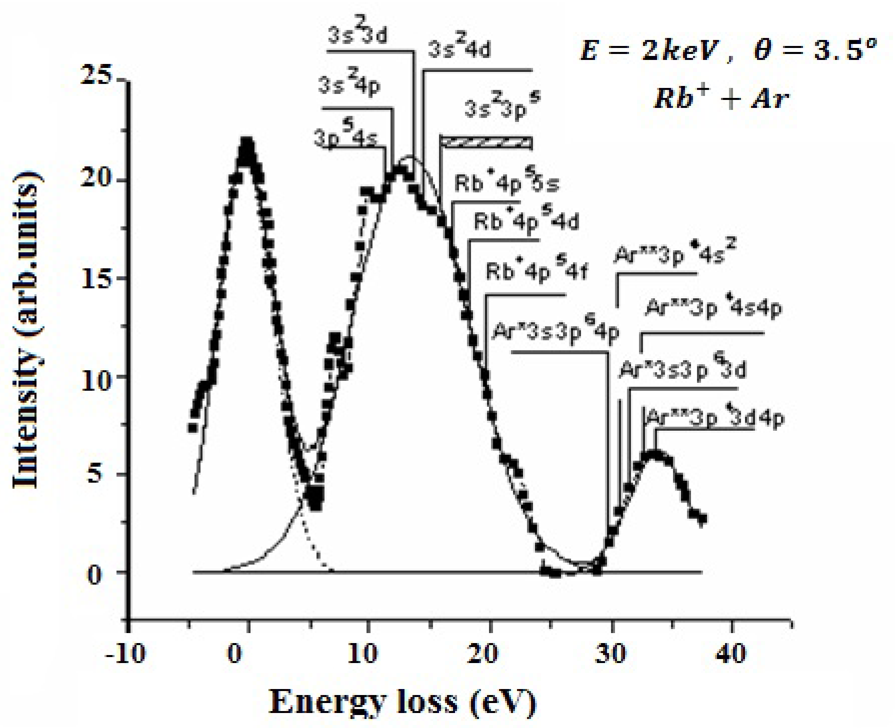

Fig.5

Conclusions

Using refined experimental methods that include a condensed plate and energy-loss methods we have measured absolute value of the charge exchange and ionization cross sections.

The charge exchange processes in $Rb^+ + Ar$ collisions mostly occurs through channel

$Rb^+(4p^6) + Ar(3p^6) \to Rb(5s) + Ar^+(3p^5)$ end results from the capture of the electron to the ground (5s) state of the atom.

Using collision spectroscopy method permitted to observe high excited states of argon and xenon atoms in the energy loss spectrum.

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