Georgian Electronic Scientific Journals: Physics #1(39-2)-2004

THE EFFICIENCY OF ELECTROSTATIC ENERGY ANALYZER IN ION-ATOM COLLISIONS

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Accepted for publication July, 2004

ABSTRACT. Collision spectroscopy method is used for study of inelastic processes in collisions of closed electron shell pairs. To obtain inelastic energy loss spectrum of primary scattering particles the "box" type electrostatic energy analyzer (ESA) is designed. For estimation of principal parameters K^+-Ar pair was tested as a typical example. The resolution ability of ESA is determined.

The experimental determination of absolute value of cross-section of an inelastic processes (ionization, charge exchange, excitation) occurring during ion-atom collisions is a subject of great interest. Such investigations are important for development of various branches of physics and techniques (plasma physics, astrophysics, gaseous discharge, etc.) it is also necessary for testing of theoretical models.

Complex investigation of such processes especially when it concerns the closed electron shell of colliding pairs (alkali metal ions, rare gas atoms) is connected with definite methodical difficulties. Due to the small collision parameter the scattering of primary particles at large angles take place and hence secondary recoil particles acquire large kinetic energy. This makes impossible the effective detection of particles. Moreover due to the large amount of inelastic channels their identification becomes problematic. Hence such investigations require perfect methods. Therefore taking into account the difficulty of physical task it was decided to choose the perspective of the so-called collision spectroscopy method.

Certainly there exists more sensitive methods e.g. electrical or optical spectroscopy but the circumstance that the mentioned

processes might be realized without detachment of electrons or without radiation, or lifetime of excited electrons to be sufficiently large (so-called metastable particles) the advantage was paid on a collision spectroscopy method.

This method is based on an investigation of scattering primary ion energy loss spectra resulting after collision with target gas atoms. The idea of this method schematically is explained in Fig.1.

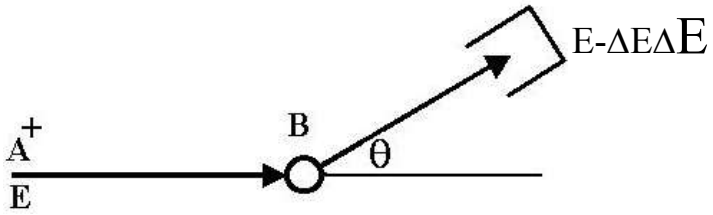

Fig.1. Schematic drawing of scattering

The fixed E-energy A^+ ions collide with B target particles, they are scatter on a definite angles and enter into the ESA.

The kinetic energy of scattered particles is measured in analyzer and therefore energy loss, that concerns the various inelastic channels are determined.

According to our task to obtain a necessary energy loss spectrum the definite condition was laid on a selection of measuring systems (analyzer). There are also a lot of types of electrostatic systems such as: analyzer with homogeneous electric field (plane condenser, capacitor), cylindrical and spherical mirror types, toroidal, parabolic etc. [1-4].

The aim of our work was to select such an analyzer which has small size, would be easy for construction, has a possibility for double focusing, large luminosity and, what is most important, optimal resolution ability $R=E/\Delta E$. Where E is energy of primary particles and ΔE minimum difference between observed peaks (shape curves) that can be distinguished by detector. In our case the “box” types dispersion electrostatic analyzer was used. Such systems compared to others have some advantage, particularly maximal localization of

fields surrounding the analyzer, full screening of outer fields and minimal losses on power supply.

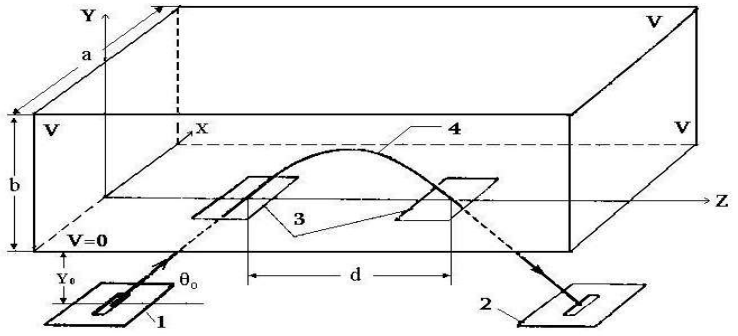

Fig.2. The "box" type electrostatic analyzer (ESA)

Schematic 3D drawing of "box" type electrostatic analyzer is shown in Fig.2. It consists of two pairs of parallel plane electrodes that are located so that its section gives right angle. The potential applied on the upper and side electrodes was equal to the acceleration potential of primary ions and on entering one the potential is zero.

According to the physical task the unique parameter selected in advance was resolution ability the value of which is equal to R = 500. It means that if energy of primary particles E = 2 keV then we can distinguish two inelastic channels from each other with 4eV difference. From this requirement we estimate all principal parameters of analyzer. The estimation of parameters and among them a potential distribution into analyzer and charge particle trajectory formed into analyzer was possible by solving the Laplace equation [5]. For simplification of solution calculations were made for that partial cases when potentials on a reflective and adjacent side electrodes were equal to each other and to acceleration potential V of entering ions into analyzer. Distribution of potentials and trajectory equation looks as below [1]:

$$\Phi(x,\mathrm{y}) = \mathrm{V} - \frac{2\mathrm{V}}{\pi}\operatorname{arctg}\left(\frac{\sin\pi x}{\mathrm{sh}\pi\mathrm{y}}\right) + 4\mathrm{V}\,\mathrm{sh}\left[\pi\mathrm{y}(2\mathrm{n}+1)\right]\times$$

$$\times\sum_{\mathrm{n}=0}^{\infty}\frac{\mathrm{e}^{-\pi\mathrm{b}(2\mathrm{n}+1)}\sin\left[\pi x(2\mathrm{n}+1)\right]}{\pi(2\mathrm{n}+1)\mathrm{sh}\left[\pi\mathrm{b}(2\mathrm{n}+1)\right]} \qquad (1)$$

$$x''(\mathrm{z}) = \frac{1}{2\Phi(x,\mathrm{y})}\left[1 + x'^{2}(\mathrm{z}) + \mathrm{y}'^{2}(\mathrm{z})\right]\frac{\partial\Phi(x,\mathrm{y})}{\partial x}\,, \qquad (2)$$

$$\mathrm{y}''(\mathrm{z}) = \frac{1}{2\Phi(x,\mathrm{y})}\left[1 + x'^{2}(\mathrm{z}) + \mathrm{y}'^{2}(\mathrm{z})\right]\frac{\partial\Phi(x,\mathrm{y})}{\partial\mathrm{y}}\,, \qquad (3)$$

where $\Phi(x,y)$ is the distribution of potential into analyzer and x''(z) and y''(z) are desired trajectory equations (see Fig.2). Relations between analyzer parameters are following:

$$\mathrm{d} = 1.67\mathrm{a}\,; \quad \mathrm{D} = 1.26\mathrm{d}\,; \quad \mathrm{b} = 0.96\mathrm{a}\,; \quad \Theta = 50^{\circ}45'\,;$$

$$\mathrm{y} = 0.25\mathrm{a}\,; \quad \mathrm{h} = 0.06\mathrm{d}\,; \quad S_{opt} = 0.87R^{-1}\mathrm{d},$$

where d is the distance between slits, D dispersion, a width of analyzer, b height, Θ entrance angle of primary beam in analyzer, y distance from source to electrodes, R resolution ability, S_{opt} optimal width of slit, h slits height. In our case d = 60 mm. By means of obtaining parameters we made "box" type electrostatic analyzer that have been used on a mass-spectrometric setup for studying of energy loss spectra (Fig.3).

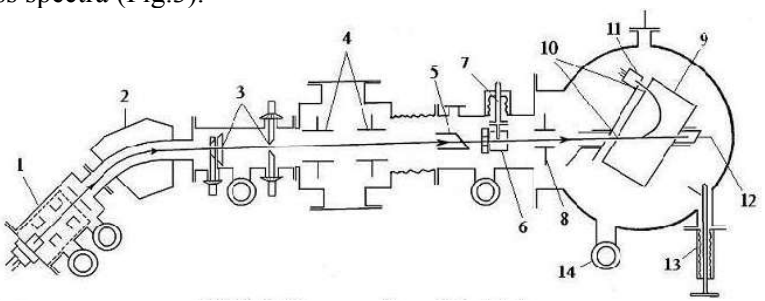

Fig.3. Experimental setup
1-ion source; 2- magnetic mass-analyzer; 3- collimating slits; 4- focusing system; 5- Faraday cup; 6- collision chamber; 7- effusion source of target particle; 8- capacitor; 9- analyzer; 10- entrance and exit slits of analyzer; 11- secondary electron multiplier; 12- collector of ions; 13- rotation system of analyzer; 14- diffu pumps.

The primary beam extracted from surface ionization ion source (1) after focusing was accelerated to the desirable energy, formed into mass-analyzer (2), according to q/m (q–ion charge, m-mass). Collimating by slits (3) ion beam was forwarded into collision chamber (6), where it was crossed by a target particle beam and entered into electrostatic analyzer (9). Automatic change of analyzer potentials gave possibility to investigate energy loss spectra into 0-100eV ranges and the rotation of an analyzer around the center of collision chamber differential cross section of scattering in 0-20^{o} angle ranges.

The ion signals were registered by secondary electron multiplier. Without introduction of target gas the pressure in collision chamber was kept below 10^{-6} torr and the typical pressure under operation was 10^{-4} torr. The investigation was performed in a single collision condition. The current of primary ions in collision chamber was I = 0,01 mkA.

To evaluate the resolution ability of electrostatic analyzer the test experiment of energy loss spectrum for K^{+}-Ar pair (as a typical example) was carried out. The spectrum of primary ions with fixed energy E = 2 keV and scattering angles Θ =3.5^{o} are shown in Fig.4. It seems that the spectrum has sharp discrete character. The reaction scheme corresponding to main inelastic processes is shown on Fig.5.

The first peak corresponds to the elastic scattering of colliding K^{+} ions, second one corresponds to the single electron excitation of argon atom on (4s, 4p, 3d) states with energy losses of ΔE =11.6-14 eV, third one corresponds to the excitation of K^{+} ions into the (4s, 3d) states with energy losses in ΔE = 20-22 eV range, the fourth one

corresponds to the single and double autoionization states of Ar with energy losses in ΔE = 30-32 eV range. As is seen from Figure the energy difference between two neighbor (second and third) peaks consists of 5 eV. They are well distinguishable from each other.

This result indicates that the preliminary idea concerning the creation of electrostatic analyzer with resolution ability R = 500 was solved successfully.

The obtained spectrum analysis shows that definite portion into ionization process have excitation of autoionization states. For identification of excitation states the analyze based on Gaussian distribution (dashed line in Fig.4.) was applied.

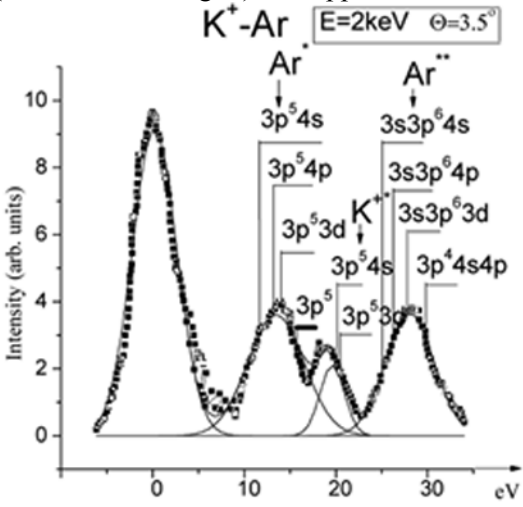

Fig.4. Energy loss spectrum

I) $K^+(3p^6) + Ar(3p^6) \rightarrow K^+(3p^6) + Ar(3p^6)$ $\Delta E=0$

II) $K^+(3p^6) + Ar(3p^6) \rightarrow K^+(3p^6) + Ar^*(4p)$ $\Delta E=11.6–14$ eV
$K^+(3p^6) + Ar^*(3d)$

III) $K^+(3p^6) + Ar(3p^6) \rightarrow K^{+*}(3p^5\,4s) + Ar(3p^6)$ ΔE= **20-22 eV**
$K^{+*}(3p^5\,3d) + Ar(3p^6)$

IV) $K^+(3p^6) + Ar(3p^6) \rightarrow K^+ + Ar^{**}(3s3p^63d)$ ΔE= **28-30 eV**
$Ar^+(3p^5) + e$

Fig.5. Reaction schemes for various inelastic processes

As is seen from Figure in a second peak the main portion has an excitation of Ar atom in 3d and 4p states, in third one the excitation of K^+ ions in a 4s and 3d states. In autoionization peak the definite portion has a single electron excitation of Ar atom in $3s3p^63d$ state.

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