# MEASUREMENT OF CROSS SECTION OF SUPERELASTIC ELECTRON SCATTERING FROM MAGNESIUM

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The experiments of the measurement of the cross section of superelastic electron scattering from magnesium and establishing the mechanisms of their transferring were carried out. The energy dependences of the differential cross section of superelastic electron scattering by the metastable $3\,^3P_{0,2}$ states of magnesium atom in the region of the scattering angles approximating to zero were obtained for the first time. It has been shown that superelastic electron scattering passes through the intermediate stage of the formation and decay of the negative ion.

## Introduction

With the interaction of the slow incident electron and atom in the excited state the following process is possible: the atom passes from this excited state into the energetically lower excited one, and the surplus of liberated energy at this non-radiative transfer is imparted to the electron. As a result the electron kinetic energy is increased. Such a process belongs to the inelastic collisions of the second kind. In modern scientific literature this process was given the term "superelastic electron scattering on the excited atoms".

Schematically the superelastic process can be described by the reaction:

$$e^-(E) + A_j^* \to \tilde{e}^-(E+\Delta E) + A_i^*, \quad (1)$$

$$\Delta E = E(A_j^*) - E(A_i^*), \quad (2)$$

where $e^-(E)$ is the slow incident electron with the energy $E$; $A_j^*$ is the atom in the excited $j$-th state with the energy $E(A_j^*)$; $A_i^*$ is the atom in the excited $i$-th state with the energy $E(A_i^*)$ and the $E(A_j^*) > E(A_i^*)$; $\tilde{e}^-(E+\Delta E)$ is the high-speed superelastically scattered electron with the energy $(E+\Delta E)$.

## Experiment

The given article describes the essence of our experiments and the obtained results of superelastic electron scattering by metastable magnesium atoms for the scattering angle close to zero.

The experiments have been carried out on the original experimental setup in the conditions of the crossed electron and atomic beams. The electron spectrometer has been used. It was composed of the source of monoenergetic beam of electrons of regulated energies, the analyzer of scattered electrons energies and the system of the registration. The scheme of the experiment is given in Fig.1.

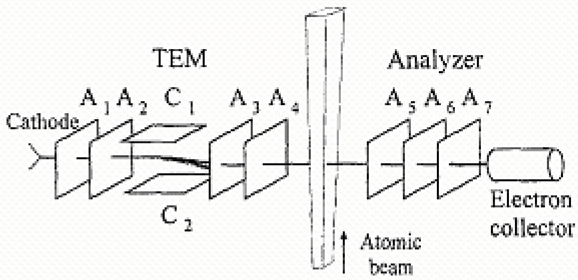


Fig.1. The scheme of the experiment.

A trochoidal electron monochromator (TEM) was used as the electron beam source. This monochromator was created the basis of works of Stamatovic and Schulz [1] as well as Shpenik and his collaborators [2].

In monochromators of this type selection of electrons according to the energies is carried out in the interperpendicular electric and magnetic fields. The intensity of electric field and the induction of the magnetic field were $\sim 1.2\cdot10^{2}$ V/m and $\sim 1.5\cdot10^{-2}$ Tl, respectively. The non-uniformity of the TEM beam was ~ 0.1 eV (at the half maximum) for energies 2 eV and current $\approx 5\cdot10^{-8}$ A.

The analyzer of the scattered electron energies is of the retarding type. It is the system of three flat electrodes with round diaphragms. The potentials of the edge electrodes are identical and equivalent to the accelerating potential. A retarding potential is applied to the middle electrode. The relative distribution of the analyzer at the energy of 2 eV is equivalent to $5\cdot10^{-2}$.

The system for registration of electrons, having passed the analyser, consists of an electron collector, an electrometric amplifier, a X-Y recorder.

The discharge of excitation technique was used to obtain the beams of metastable magnesium atoms. It means that the beam of Mg atoms being obtained by thermal effusion in the ground state passes through the discharge space, where atoms transit into excited states under the conditions of discharge electrons. The method of obtaining of metastable atom beam is described in [3].

In the process of the performed investigation the parameters of the atomic beam in the region of its interaction with the beam of electrons were the following: the concentration of metastable atoms of Mg in 3s3p $^3P_{0,2}$ state was $\approx 6\cdot10^{15}$ m$^{-3}$, concentration of Mg atoms in the ground state $3s^2\,{}^1S_0$ is $\approx 5\cdot10^{16}$ m$^{-3}$, the angle of divergence of the atomic beam was $\sim 8.7\cdot10^{-2}$ rad. The research was carried out in the vacuum $\sim 6.5\cdot10^{-6}$ Pa.

## Results

In the performed investigation the energetic dependence of the cross section of the superelastic electron scattering on metastable Mg atoms is determined for the first time. In our experiments the superelastically scattered electrons were detected and the energy dependence of their formation cross section ($Q^s$) was determined by measuring the ratio of the scattering electron current ($i^s$) to the electron beam current ($i_e$), i.e. $Q^s = i^s/i_e$.

The result of the experiments is presented in Fig.2, where the ordinate axis corresponds to the superelastic electron scattering cross section in arbitrary units, whereas the abscissa axis – to the electron energy in eV. The relative uncertainty in determining $Q^s$ ordinate was ~ 8%, the energy scale calibration error – 0.1 eV.

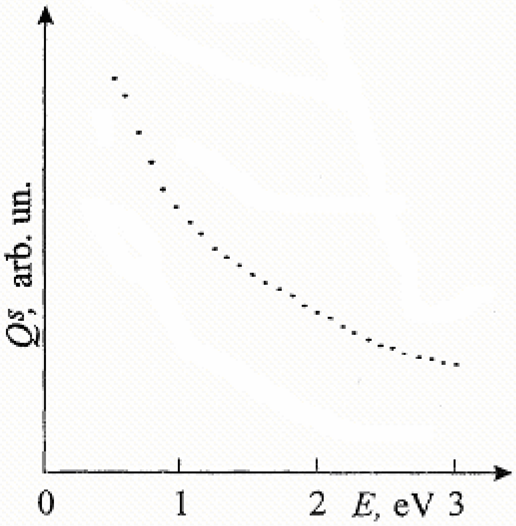


Fig.2. Energy dependence of the differential cross section of superelastic electron scattering by metastable 3 $^3P_{0,2}$ states of magnesium atom

## Discussion

Magnesium atoms have two triplet metastable states 3s3p $^3P_0$, 3s3p $^3P_2$ with the excitation energies 2.71 eV, 2.72 eV, respectively. Both of these metastable states were present in the atomic beam, while the ratio of their concentration $N^m$ (3s3p $^3P_0$) / / $N^m$ (3s3p $^3P_2$) = 1/5.

As a result of the superelastic electron scattering atoms may pass from the metastable state to the ground state $3s^2\,{}^1S_0$. The corresponding reactions can be written in the form:

$$\mathrm{Mg}(3s3p\,{}^3P_0)+e\rightarrow\mathrm{Mg}(3s^2\,{}^1S_0)+e', \qquad (3)$$

$$\mathrm{Mg}(3s3p\,{}^3P_2)+e\rightarrow\mathrm{Mg}(3s^2\,{}^1S_0)+e'', \qquad (4)$$

where $e$ is the incident electron with the energy $E$, $e'$ and $e''$ – superelastically scattered electrons with $(E+2.71)$ eV and $(E+2.72)$ eV energies respectively. Taking into account that the difference between the energies of the scattered electrons is 0.01 eV, it must be said that the result shown in Fig.2 reflects the average cross section (3) and (4).

In the course of searching for the model of the phenomenon of superelastic electron scattering on the metastable atoms, a certain idea appeared. According to it the superelastic process runs at the following scheme:

$$e^-(E) + A_j^* \rightarrow A^{-*} \rightarrow \tilde{e}^-(E+\Delta E) + A_i^*, \quad (5)$$

where $A^{-*}$ is the negative ion in the excited state.

For Mg atom the reaction (5) can be written in the following way:

$$e(E) + Mg(^3P_2) \rightarrow Mg^{-} \rightarrow \begin{cases} Mg(3^3P_2) + e(E); \\ Mg(3^1S_0) + e(E+\Delta E_1); \\ Mg(3^3P_0) + e(E+\Delta E_2); \\ Mg(3^3P_1) + e(E+\Delta E_3); \\ \quad \hookrightarrow Mg(3^1S_0) + h\nu. \end{cases} \quad (6)$$

We are limited only by the consideration of the metastable 3 $^3P_2$-state.

The scheme of the reaction proposed permits the experimental checking. To do it the above experimental setup was supplemented with two additional groups: the system of the ion registration and the system of the photon registration.

In our experiments negative ions were detected and the energy dependence of their formation cross section ($Q_i^-$) was determined by measuring the ratio of the negative-ion current ($i^-$) to the electron beam current ($i_e$), i.e. $Q_i^- = i^-/i_e$.

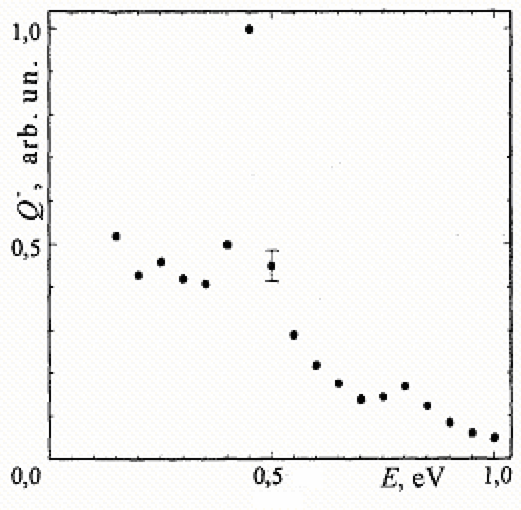


Fig.3. Energy dependence of the effective cross section of Mg⁻ negative ions formation.

The result of the experiments is presented in Fig.3, where the ordinate axis corresponds to the negative-ion formation cross section in arbitrary units, whereas the abscissa axis – to the electron energy in eV. The relative uncertainty in determining the $Q_i^-$ ordinate was ~ 8%, the energy scale calibration error – 0.1 eV.

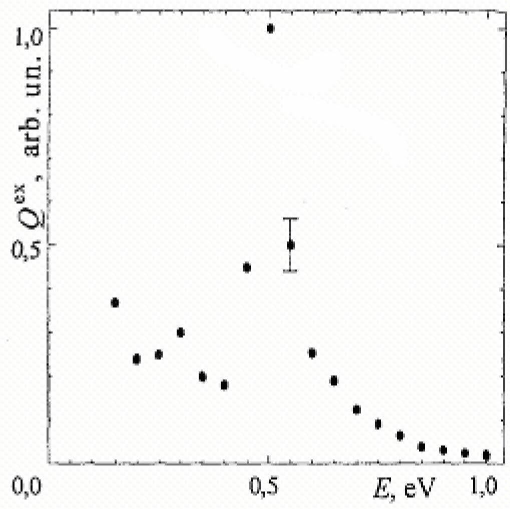


Fig.4. Excitation function of spectral transition 3 $^1S_0$-3 $^3P_1$ (λ 457.1 nm).

In our experiments the spectral line radiation, produced by the interaction of the crossed electron and atomic beams was detected and the excitation function of spectral transfer $3\,^1S_0$-$3\,^3P_1$ (λ 457.1 nm) was determined. This result is presented in Fig.4, where the ordinate axis corresponds to the cross section of excitation of spectral line in arbitrary units, whereas the abscissa axis – to the electron energy in eV. The relative uncertainty in determining the $Q_i^-$ ordinate was ~ 12%, the energy scale calibration error – 0.1 eV. In our opinion, this radiation could be caused by the decay of the excited states of the negative ions into excited $3\,^3P_1$-state of Mg atom.

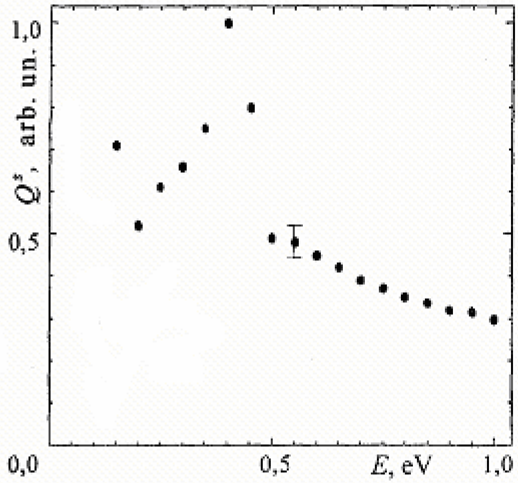


Fig.5. Energy dependence of the differential cross section of superelastic electron scattering by metastable $3\,^3P_{0,2}$ states of magnesium atom.

The analysis of Figs.3 and 4 shows that the form of curves changes considerably in the energy region less then 0.5 eV. Thus, the investigation of the superelastic process in this field becomes especially important. Hence, the additional experiments on superelastic electron scattering in the region of energies 0.15-1.0 eV have been carried out. The obtained result is shown in Fig.5, where the ordinate axis corresponds to superelastic electron scattering cross section in arbitrary units, whereas the abscissa axis – to the electron energy in eV. The relative uncertainty in determining the Qs ordinate was ~ 8%, the energy scale calibration error – 0.1 eV.

The examination of Figs.3, 4, 5 indicates the *similarity of the curves given*. The *logical* explanation of this fact may be the validity of the model proposed here. According to this model, the process of superelastic electron scattering from metastable atoms includes an intermediate stage of formation and decay of the negative ion (see reaction (6)).

**References**

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# ВИМІРЮВАННЯ ПЕРЕРІЗУ НАДПРУЖНОГО РОЗСІЮВАННЯ ЕЛЕКТРОНІВ НА АТОМАХ МАГНІЮ

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Проведено експерименти з вимірювання перерізу надпружного розсіювання електронів на атомах магнію та встановлення механізмів його перебігу. Вперше отримано енергетичну залежність диференціального ефективного перерізу надпружного розсіювання електронів на метастабільних $3\,^3P_{0,2}$ станах атома магнію в області кутів розсіювання, близьких до нульового. Показано, що надпружне розсіювання електронів проходить через проміжковий стан – утворення та розпад негативного іона.