Resonance structure of the cross section for electron-impact excitation of the $3p\ ^2P$ level of the magnesium ion

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The resonance structure of the cross section for excitation of the $3p\ ^2P$ level of the Mg II ion has been studied in intersecting electron and ion beams at energies from the excitation threshold up to the Mg II ionization threshold. The experimental cross section agrees well with theoretical predictions calculated by a diagonalization method.

The need for accurate data on electron-impact excitation of ions is becoming progressively more urgent in plasma physics and related applied fields. An important role is played in these excitation processes by short-lived autoionization states, whose radiationless decay gives rise to a complicated resonance structure in the excitation cross sections. The magnesium ion is of particular interest in this regard, since processes involving alkaline-earth ions are exceedingly important in astrophysics and other fields of research. Only recently has it become possible to study how resonances affect the detailed behavior of the excitation function, thanks to sophisticated experimental apparatus, automated research, and the newest theoretical methods.

In the present experiments on the electron-impact excitation of the $3p\ ^2P$ level of the magnesium ion, we used an ultrahigh-vacuum apparatus. The magnesium ions were formed in a discharge source, shaped by an ion-optics lens system into a beam 2×2 mm in cross section, accelerated to 1 keV, and separated from neutral atoms by a 90° electrostatic capacitor. The ion beam then passed through the collision zone and was detected by a deep Faraday cup. In a vacuum of 10^{-8} torr, an ion beam with a current $\sim 4\ \mu$A was intersected at right angles by a ribbon-shaped electron beam with a cross section of 0.5×6 mm, a current of 4–30 μA, and an energy in the range 4–30 eV. The energy spread was $\Delta E_{1/2}\sim 0.3$ eV. A monoenergetic electron beam was produced in a 90° electrostatic electron selector.

The emission spectrum was resolved with an MDR-2 high-luminosity diffraction monochromator with a reciprocal linear dispersion of 2 nm/mm. Because of the slight (0.01-eV) multiplet splitting of the $3p\ ^2P$ term of Mg II, we were not able to spectrally resolve the components of the resonant doublet under these experimental conditions. We accordingly measured the total emission of the corresponding spectral transitions with $\lambda = 279.6 + 280.3$ nm. This emission was detected by an FÉU-106 photomultiplier in the photon-counting mode. A beam-modulation technique was used to distinguish the useful signal from the overall background from collisions of electrons and ions with residual gas atoms. The intensity of the useful signal was 6 count/s at a

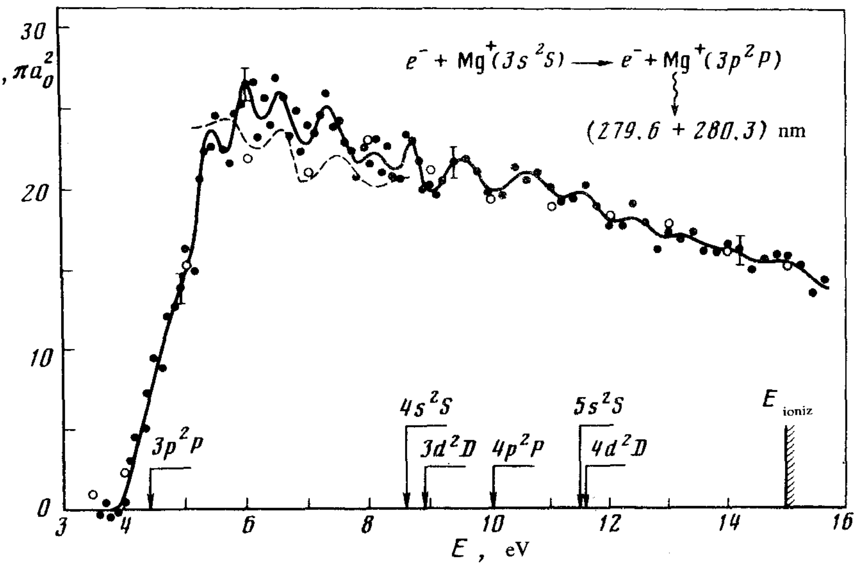

FIG. 1. Energy dependence of the excitation cross section of the $3p\ ^2P$ level of MgII. ●—Experimental data; solid curve—generated from the experimental data by digital filtering; ○—exerimental data of Ref. 3; dashed curve—results of the present calculations.

signal-to-total-background ratio of 1/5. The useful signal was integrated for a total time ~20 min for each experimental point.The experiments were carried out with the help of a control and measuring complex using an Élektronika 10/I minicomputer.[1] The following operations were performed automatically in accordance with a prespecified program: The electron energy was scanned cyclically over the interval 3.6–15.6 eV at steps of 0.1–0.2 eV; the results were measured, accumulated, and preliminarily analyzed.

Figure 1 shows the experimental energy dependence of the excitation cross section of the Mg II resonance level. The vertical error bars show the 90% confidence interval of the relative measurements. The solid curve was generated in a computer analysis of the experimental data by a digital filtering method.[2] The absolute cross sections were found by comparing the results with the results from an earlier study of this process with an electron energy spread[3] $\Delta E_{1/2} \sim 1$ eV. The dashed curve is a theoretical cross section averaged over the energy distribution of the beam electrons. The cross section for the excitation of the $3p\ ^2P$ level of Mg II at electron energies from the excitation threshold of this level (4.43 eV) up to the excitation threshold of the $4s$ ^2S level (8.66 eV) was calculated by a diagonalization method[4,5] proposed by Balashov *et al.* in a study of the resonance photoionization of atoms. The wave functions of the discrete states of Mg II were calculated in the single-configuration Hartree-Fock approximation by the MCHF 77 program.[6] The nonresonant part of the scattering amplitude was found by the IMPACT program.[7]

Figure 2 compares the cross section which we calculated for the excitation of the $3p\ ^2P$ level of Mg II with results calculated by the strong-coupling method[8–9] and the

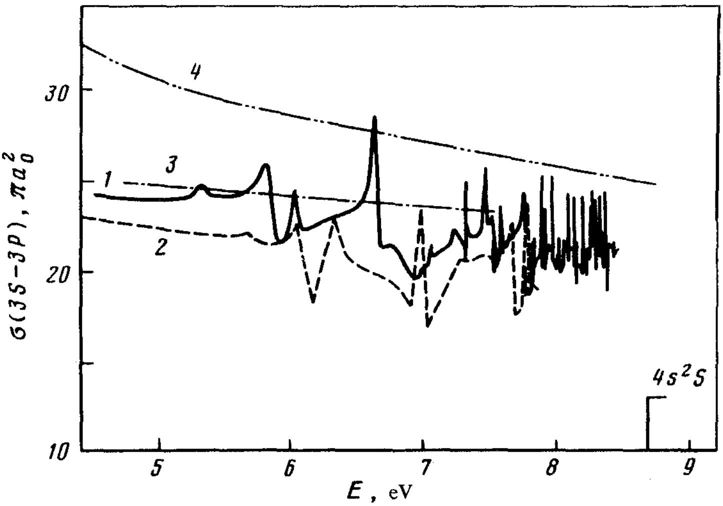

FIG. 2. Comparison of theoretical results on the excitation cross section of the $3p\ ^2P$ level of Mg II. 1—Present calculations; 2—Ref. 9; 3—Ref. 8; 4—Ref. 10.

Coulomb-Born method.[10] The resonances were not brought out at all in the calculations of Ref. 8; in the calculations of Ref. 9, the resonance structure of the excitation cross section found by the method of strong coupling of $3s$-$3p$-$4s$-$3d$ states has a shape which agrees well with the results of our calculations. On both curves, for example, there are peaks due to the $4s3d\ ^3D$, $4s4p\ ^3P$, and $3d\,4p\ ^3F$ autoionization states of Mg I (the electron peak at 6.65 eV, due to the $3d\,4p\ ^3F$ autoionization state, is particularly clear), and there are dips due to the $4s3d\ ^1D$ and $3d\,4p\ ^1F$ autoionization states of Mg I. The resonances found by the strong-coupling method, however, are shifted about 0.3 eV upward along the energy scale. The reason for this shift is that the calculations of Ref. 9 ignored the dipole polarizability of the $4s$ state of Mg II. In our calculations, this polarizability was taken into account by incorporating the $4pnl$ configurations of Mg I in the original expansion of the total wave function.[5] As can be seen from Fig. 1, this approach has resulted in a very good agreement between our theoretical cross section, averaged over the energy distribution of the beam electrons, and the experimental results.

In summary, the structure observed experimentally observed near the excitation threshold is due to the capture of bombarding electrons by magnesium ions, accompanied by the formation of short-lived atomic autoionization states. The structure at electron energies above the threshold for the excitation of the $4s\ ^2S$ level can be attributed to the combined contributions of cascade transitions from the corresponding levels of Mg II and the autoionization states of the magnesium atom.

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