Radiative decay of certain autoionized states of Mg I and Mg II

V. S. Vukstich, Yu. V. Zhmenyak, and E. N. Postoĭ
Uzhgorod State University

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In addition to the Auger decay a radiative decay of the $2p^53s^2$ state of MgII and single-photon, two-electron transition from the autoionized $2p^53s3p4p$ state of MgI were observed for the first time in the electron-atom collisions.

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In this work the spectroscopic method is used to study for the first time the excitation and decay of the auto-ionization states of MgI and MgII, which are accompanied by the emission of ultrasoft x-ray radiation. We used the method of intersecting electron and atom beams, a vacuum grazing-angle monochromator with a diffraction grid and with an effective spectral region of 10–40 nm, and a channel electron multiplier as a radiation detector. The concentration of the atoms in the collision region was approximately 10^{12} atoms/cm^3, the electron-beam density varied within the limits of

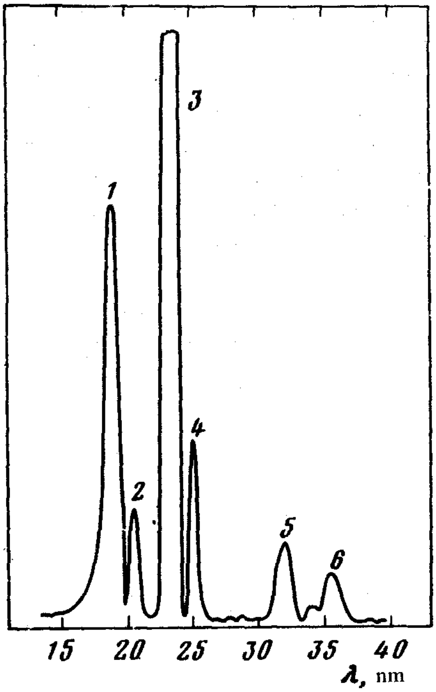

FIG. 1. Emission spectrum of magnesium at the energy of incident electrons $E = 500$ eV; 1—18.6/18.8 nm (MgIII); 2—20.4 nm (MgI); 3—23.1/23.4 nm (MgIII); 4—24.9 nm (MgII); 5—32.1/32.3 nm (MgIV); 6—35.1/35.5 nm (MgV).

1.2–2.5 A/cm^2 in the energy range of 50 to 1000 eV, and the energy inhomogeneity of the electrons was $\leqslant 2$ eV.

First, we investigated in detail the emission spectrum of magnesium in the range 10–40 nm. We identified the MgIII, MgIV, and MgV lines whose wavelengths and excitation thresholds are known,[1] and also two unidentified lines with the wavelengths 20.4 ± 0.1 and 24.9 ± 0.1 nm. To identify the latter, we examined the data on the energy levels of the magnesium atom and its ions,[1] the data of experiments on photoabsorption of magnesium vapor in the ultrasoft x-ray region of the spectrum,[2] and also the data on the energy spectra of electrons produced as a result of electron bombardment of magnesium atoms.[3] On the basis of these data we constructed a system of discrete energy levels of MgI, MgII, and MgIII (Fig. 2), which shows the states determined by (1) the excitation of one of the 3*s*- and 2*p*-electrons and simultaneous excitation of the two indicated electrons of the neutral atom and (2) the ionization of one or two electrons with a simultaneous excitation of an additional electron in the case of MgII and MgIII.

Subsequently, we investigated the energy dependences of excitation of the identified lines (Fig. 3), especially their near-threshold behavior. The energy scale was corrected with respect to a known[1] excitation threshold of one of the most intensive spectral lines 23.4 nm. Thus, we established the excitation thresholds of the identified 20.4- and 24.9-nm lines, which are equal to (61 ± 1) and (58 ± 1) eV, respectively. Figure 2 shows that the original levels of these lines may pertain to MgI or MgII. Taking into the account the fact that for the 20.4 ± 0.1-nm line the transition energy is 60.8 ± 0.3 eV, consistent within the experimental error with its excitation threshold of

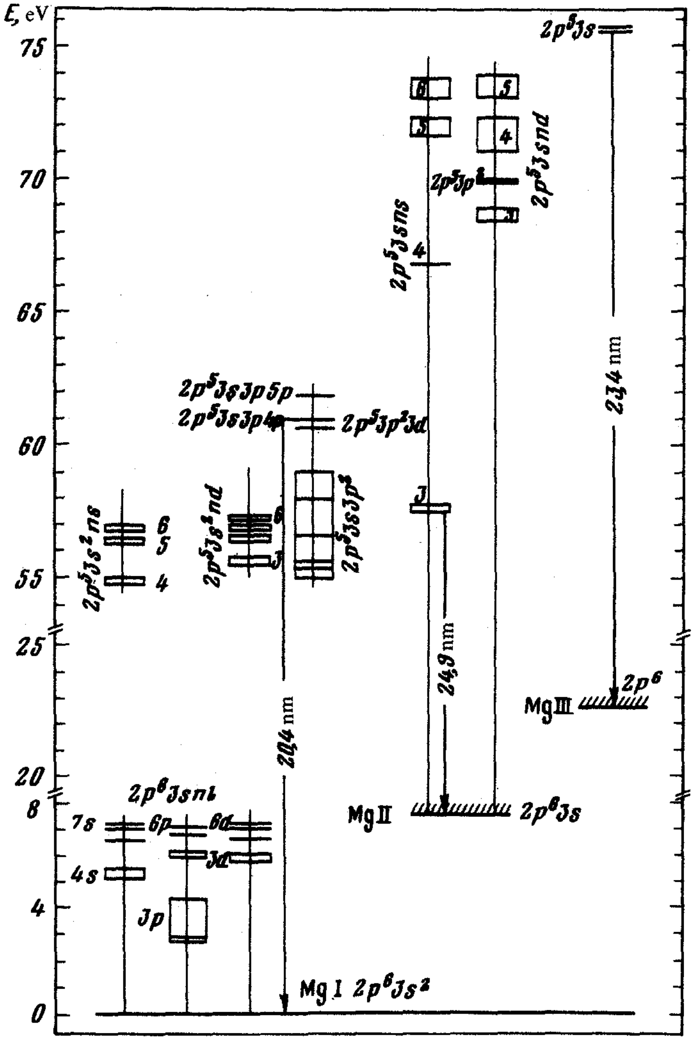

FIG. 2. Diagram of energy levels of MgI, MgII and MgIII.

61 ± 1 eV, we conclude that the ground state of the given spectral transition can be only the ground state of the atom. As seen from the level diagram (Fig. 2) only three known levels occupy the energy interval of 61 ± 1 eV [2]: $2p^5 3p^2 3d$, $2p^5 3s 3p 4p$ and $2p^5 3s 3p 5p$. Apparently, the $2p^5 3s 3p 4p$ state is the initial state of the 20.4-nm line, since excitation of the $2p^5 3s 3p 5p$ level is less probable, and excitation and decay of the $2p^5 3p^2 3d$ level requires an involved reconstruction of the shells.

Thus, we can state on the basis of analysis of the experimental results and of the literature data[1-3] that the 20.4-nm line is produced as a result of the two-electron, single-photon transition in the magnesium atom.

As regards the 24.9-nm line, it can be identified (given the excitation threshold of

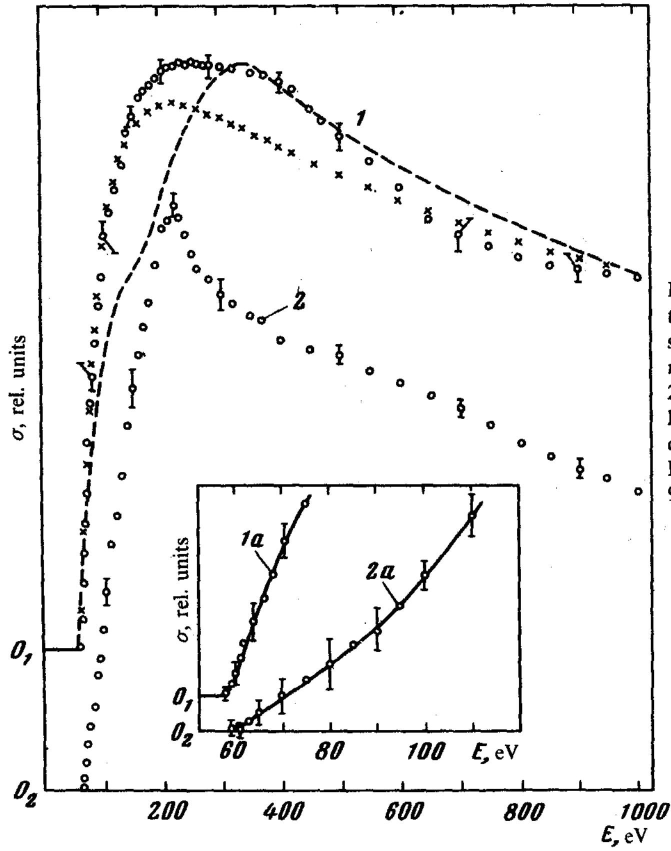

FIG. 3. Energy dependences of the effective excitation cross sections of the spectral lines of magnesium: 1 and 1a—24.9 nm, 2 and 2a—20.4 nm; dotted line—calculation[4]; ×—our calculations using the method in Ref. 5; vertical bars show the 90% confidence level.

58 ± 1 eV and the wavelength) as the result of the radiative decay of the autoionized $2p^5 3s^2$ state of MgII. The emission with similar wavelengths may also produce transitions between the $2p^5 3s^2 ns$, $2p^5 3s^2 nd$, $2p^6 3sns$, and $2p^6 3snd$ levels of the neutral atom. However, in the region of excitation energy of the 24.9-nm line ($E = 58 \pm 1$ eV), there are only highly-excited levels of those configurations, which, as is well known, are excited with a low probability, and their radiative decay cannot produce such a strong line (see Fig. 1).

The excitation function for the 24.9-nm line, which is normalized with respect to theoretical calculations[4,5] at $E = 1000$ eV (see Fig. 3), satisfactorily describes the $2p$ ionization process of magnesium. If the $2p^5 3s^2 nl$ state were the ground state of this line, then its excitation function would be expected to be similar to those of autoionized states of atoms of the other alkali-earth elements.[6]

We note that the $2p^5 3s^2$ state undergoes a nonradiative decay.[3] The lines corresponding to the $L_{2,3}$-$M_1 M_1$ transition are the most intensive lines in the Auger-electron spectrum. The probability ratio of the radiative and nonradiative decays of this state remains unexplained. By comparing intensity of the 24.9-nm line with that of the resonance doublet MgIII (23.1/23.4 nm) and taking into account the experimental value of the cross section of double ionization of magnesium,[7] we can obtain the excitation cross section of the 24.9-nm line in the maximum $\sim 5 \times 10^{-19}$ cm^2.

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