Photoionization study of the $3pns$ and $3pnd$ $^1P_1$ resonances in Mg I

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The photoionization cross section of Mg I near threshold in the region between 160–100 nm was studied using synchrotron radiation, an atomic-beam technique, and a time-of-flight mass spectrometer for the selective detection of the Mg^+ photoions. Special attention was given to the signals of the double electron resonances $3pns$ and $3pnd$ $^1P_1$ in comparison with theoretical calculations and recent experiments.

The photoionization process from the $3s$ subshell of Mg I near the threshold shows strong deviations from the simple one-electron picture. This is due to the presence of two electrons in the valence shell and the correlations of these electrons. As the ground state $3s^2$ contains admixtures of other configurations such as $3p^2$, electric dipole transitions can connect the ground state with states of configurations such as $3pns$ ($n \geq 4$) or $3pnd$ ($n \geq 3$) which lie above the ionization limit and can decay via autoionization. These double electron resonances have a strong influence on the photoionization of the $3s$ subshell. For that reason we have concentrated our photoionization study on these resonances. Experimental work on the photoabsorption of Mg I near threshold (162.2 nm) has been performed by Ditchburn and Marr[1] in the restricted interval between 165–145 nm. A wider range up to 78 nm was investigated by Mehlman-Balloffet and Esteva[2] and by Esteva *et al.*[3] who used two vacuum sparks, one serving as a background source and the other for the production of the Mg vapor. They observed distinct resonance structures and identified the autoionizating levels of the series $3pns$ $^1P_1$ from $n=4$–13 and $3pnd$ $^1P_1$ from $n=3$–8. Baig and Connerade[4] reinvestigated the absorption spectrum of Mg I in the region between 200–270 nm using synchrotron radiation and a windowless-furnace technique. They extended the identification of the double excitation series to higher values of n ($n=18$ for $3pns$ $^1P_1$ and $n=11$ for $3pnd$ $^1P_1$) and found the new series $3pns$ $^3P_1$ ($n=4$–12) and $4snp$ $^1P_1$ ($n=3$–12).

As a comparison of the results of photoabsorption experiments with theoretical calculations of photoionization cross sections especially with respect to the intensities and widths of the signals can sometimes be difficult because of background variations, saturation effects or extraneous lines especially in the case of the tandem spark technique,[2,3] Preses *et al.*[5] recently performed a photoionization experiment for Mg I in the vicinity of the $3s$ threshold using synchrotron radiation, an atomic-beam technique, and the direct observation of the Mg^+ photoions with a quadrupole mass filter. In the wavelength range 110–120 nm they observed two signals (Fig. 2 of Ref. 5) of the transitions to $3p3d$ $^1P_1$ (116 nm) and $3p5s$ $^1P_1$ (113 nm). Both signals had a width of about 1 nm exceeding the 0.4-nm bandwidth of the synchrotron radiation which was monochromatized by a 0.5-m Seya-Namioka normal-incidence grating monochromator.

According to the calculations of Bates and Altick,[6] Burke and Moores,[7] and Froese Fischer and Saha[8] the width of the $3p5s$ $^1P_1$ resonance should be about 1.3 nm. For the $3p3d$ $^1P_1$ resonance, however, all three calculations[6–8] give a width which is much narrower than the experimental result of 1 nm.[5] The theoretical results are 0.014 nm,[8] 0.045 nm,[6] and 0.053 nm.[7] There is also a calculation of the width of the Mg I $3p3d$ $^1P_1$ resonance by Zatsarinnyi *et al.*[9] which gives 0.18 nm. The experimental result for the width of the $3p3d$ $^1P_1$ resonance by Preses *et al.*[5] is also in contradiction to the absorption experiments[2–4] which clearly show sharp $3pnd$ $^1P_1$ and broad $3pns$ $^1P_1$ resonances.

For that reason and following a suggestion of Froese Fischer[10] we have reinvestigated these double excitation resonances of Mg I in a photoionization experiment. We have used an atomic-beam technique, the synchrotron radiation of the 800-MeV electron storage ring BESSY in Berlin, which was monochromatized by a 1-m normal-incidence monochromator, and a time-of-flight mass spec-

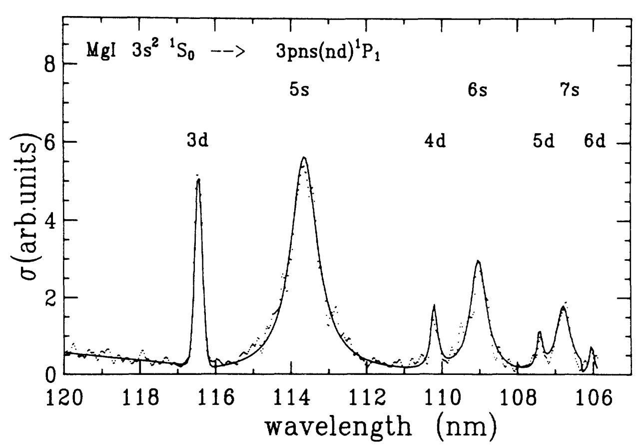

FIG. 1. Counting rate of Mg^+ photoions in the wavelength region between 120–106 nm showing part of the double excitation resonances $3pnd$ $^1P_1$ and $3pns$ $^1P_1$. The bandwidth of the ionizing radiation was 0.2 nm. The counting rate was corrected for the wavelength dependence of the incident photon flux.

TABLE I. Wavelengths (nm) of the transitions to the autoionizing Mg I $^1P_1$ states of the configurations $3pnd$ ($n=3-6$) and $3pns$ ($n=5-7$).

	Ion detection		Absorption		Theory		
Conf.	This work	Ref. 5	Ref. 3	Ref. 4	Ref. 6	Ref. 8	Ref. 9
$3p3d$	116.4	116.0	116.42	116.380	115	116.2	115.1
$4d$	110.2		110.13	110.160	109		
$5d$	107.4		107.35	107.351			
$6d$	106.0		105.88	105.910			104.5
$3p5s$	113.6	113.2	113.4	113.558	112	114.2	
$6s$	109.0		108.9	108.890	108		
$7s$	106.8		106.7	106.744			105.3

trometer for the selective detection of the Mg^+ photoions. The ions were extracted from the interaction region of the atomic beam with the synchrotron radiation by short pulses (800 ns) with a repetition rate of 25 kHz. After further acceleration by a continuously applied voltage of 170 V they entered a drift tube of 15 cm and were finally detected by a channeltron multiplier. After identification of the Mg^+ peak in the time-of-flight (TOF) mass spectrum which was observed by a multichannel analyzer, a time window was set by a pulse generator with a definite time delay with respect to the extraction pulse, and the counting rate within this time window was registered as a function of the photon energy. For the normalization of the counting rate the influence of the monochromator on the light intensity should be known. We have measured the photon flux as a function of wavelength by a photomultiplier after conversion of the vacuum ultraviolet (vuv) radiation into the visible region by a sodium salicylate-coated window. The natural decay of the synchrotron intensity was considered by recording a monitor signal of the beam current.

Figure 1 shows the normalized counting rate of the Mg^+ photoions in the wavelength region of 120–106 nm. There is clear evidence of the sharp $3pnd$ $^1P_1$ and the broad $3pns$ $^1P_1$ resonances in very good agreement with the absorption measurements[2–4] and the theoretical calculations.[6–9] The widths of the $3pnd$ $^1P_1$ resonances reflect the bandwidth of the incident photon flux of 0.2 nm. In Table I the positions of the resonances are listed in comparison with the results of the absorption experiments and theoretical calculations. The reason for the different widths of the $3pns$ and $3pnd$ $^1P_1$ resonances is not easy to understand. The widths should be proportional to the square of the Coulomb-matrix elements which couple the continuum and bound states. The calculations of Bates and Altick,[6] however, show quite strong coupling between, for example, the $3p3d$ $^1P_1$ and the continuum.

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