INVESTIGATION OF PECULIARITIES OF THE ELECTRON-IMPACT EXCITATION FUNCTIONS FOR LINES OF THE PRINCIPAL SERIES OF MAGNESIUM ATOM

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The excitation functions (EF) for spectral lines of a magnesium atom originating from the $3snp\,{}^1P_1^{\rm o}$ levels ($n = 4 \div 7$) are investigated in the case of electron-atom collisions in the energy range from the thresholds to $\sim$ 25 eV and at an energy dispersion of $\sim$ 0.7 eV. A number of structural features related to autoionizing and autodetaching states are revealed in the EFs above the ionization potential. The most prominent features (the maxima lying close to the position of the $3p4s\,{}^1P_1^{\rm o}$ autoionizing state) have specific shifts toward higher energies. The magnitude of the shifts grows with increasing n, which is explained by the mechanism of the population of the initial levels of lines with the involvement of this state due to the post-collision interaction. Based on the classical model, a theoretical analysis of the experimental results is performed. The energies of the autodetaching states that manifest themselves in the EFs are estimated.

1. Introduction

Optical EFs present the information on both the direct process of excitation of the initial level of an investigated spectral line and all additional processes possible at a given electron energy [1]. According to data of works [2–4], these processes of excitation of a magnesium atom manifest themselves in EFs jointly in the form of peculiarities – maxima and shoulders.

Due to the improvement of monoenergeticity (within 0.1 eV) of exciting electrons, one managed to observe the peculiarities of the magnesium EF [3] that lay below and above the ionization potential (IP) and had a width close to the magnitude of electron energy dispersion. It turned out that they were mostly linked with the processes of population of the initial levels by means of the formation of short-lived intermediate states of various nature – autodetaching states (ADS) of a negative ion and autoionization states (AIS) of an atom. The structures above the IP can also arise due to the effect of the post-collision interaction (PCI) related to the excitation of AISs. To a smaller extent, these peculiarities can possibly represent a result of the interference of two or more channels of excitation of the initial levels.

In the course of experimental investigation of the EFs for four spectral lines of the MgI principal series ($3s^2\,{}^1S_0$ – $3snp\,{}^1P_1^{\rm o}$, where n = 4, 5, 6, 7), that lie in the vacuum ultraviolet region: 202.6, 182.8, 174.8, and 170.7 nm, correspondingly – we found manifestations of the PCI effect [4]. A more detailed consideration of this process is performed in our recent work [5]. In the given work that supplements the latter, we proceed with the theoretical analysis of the structure observed in these EFs. In particular, both peculiarities arising due to the PCI effect and those related to the formation of short-lived states of a magnesium negative ion are considered. The energies of two states of this kind are estimated with the help of the modified Rydberg formula (MRF).

2. Theoretical Conceptions of the PCI Effect in the Case of Excitation of Atomic States

In works [6,7] (see also a short mentioning about this process in [8]), the manifestation of the PCI effect in the case of excitation of atomic states is considered. The evidence of PCI as an additional channel of population of an atomic level is the appearance of a maximum in the EF of the atomic level that lies below the IP in the case where the energy of incident electrons E is higher than

the atomic IP. At such electron energies, the excitation of AIS can take place. It is the electron decay of AIS accompanied by the further interaction (PCI) between the ejected and scattered electrons with capture of the latter to a bound atomic state that results in the formation of peculiarities in the EFs.

According to the classic model [7], the position of the maximum is determined by the energy E_a and the width Γ_a of the AIS as well as the binding energy E_b of the discrete level. These characteristics satisfy the equation

$$(3E_1 + E_b)\Gamma_a \left(\frac{R}{E_1}\right)^{1/2} = (E_1 + E_b)(5E_1 + E_b). \qquad (1)$$

Here, $E_1 = E - E_a$ is the residual energy of the scattered electron after excitation of the AIS, R is the Rydberg constant (13.6058 eV). The energy E of the incident electron, at which the EF has a maximum, equals

$$E_{\max} = E_a + E_1. \qquad (2)$$

Formula (2) implies that the maximum in the EF can mismatch the AIS energy. The magnitude of the shift E_1 of the "imaginary" position of the AIS is determined by the autoionization (AI) width and the binding energy of the level populated (excited) due to the PCI process.

Equation (1) has no analytical solutions $E_1(\Gamma_a$ and $E_b)$. However, under certain restricting conditions, one can obtain a number of approximate formulas [5]. For example, at the threshold of the AIS excitation, at $E_1 \ll E_b/2$, which holds true for low-lying levels close to the ground state, the influence of PCI is inessential. In this case, we derive from Eq.(1):

$$E_1 = \frac{\Gamma_a^2 R}{E_b^2}. \qquad (3)$$

At the somewhat less rigid condition $E_1 \ll E_b$, relation (1) yields

$$E_1 = \frac{E_b}{A}\left[\left(1 + 2A\Gamma_a^2 R/E_b^3\right)^{1/2} - 1\right], \qquad (4)$$

where the constant A can be equal to 4, 8, and 12. Within the validity limits of the given approximation, it turns out that the formula with a lower value of A is less accurate than that with a higher one. As a whole, formula (4) implies a less strong dependence of the PCI shift E_1 on the binding energy.

For small values of the binding energies and large shifts, i.e. high AI widths, where the condition $E_b \ll 5E_1$ is satisfied, Eq. (1) can be solved iterationally. This way allows one to obtain the following expression for the PCI shift that accompanies the capture of a slow electron to the following highly excited atomic states:

$$E_1 = E_1^{\max}\Big\{\Big(1 - \frac{2E_b}{3E_1^{\max}}\Big)^{2/5} + \frac{E_b}{3E_1^{\max}} - \\ - \frac{E_b}{E_1^{\max}}\Big(1 - \frac{2E_b}{3E_1^{\max}}\Big)^{3/5}\Big\}^{2/5}. \qquad (5)$$

Here, $E_1^{\max} = (9\Gamma_a^2 R/25)^{1/3}$ is the maximal PCI shift (at $E_b = 0$).

The given formulas were used for the determination of the AIS energies E_a and widths Γ_a with the help of the experimental energies of the maxima in the EF. In contrast to the method of approximation of experimental data used in [5] for the determination of characteristics of these AISs, we calculate them directly. According to this calculation technique, we firstly use the experimental energies $E_{\max}$ of the two lowest levels (for example, $n_1 = 4,5$ for $3sn_1s\,{}^3S_1$ [3]; $n_2 = 3,4$ for $3sn_2d\,{}^3D_{1,2,3}$ [3]; $n = 4,5$ for $3snp\,{}^1P_1^{\rm o}$) [5]. Based on them, we use (2) and (3) for the determination of the AIS energy E_a and width Γ_a, as well as the shift E_1 of the lowest of these levels. The magnitude of this shift E_1 determines the shifts of all the following levels. After that, based on the obtained E_1 of each level and formulas (2)–(4) and numerically solving Eq. (1), one determines the AIS widths Γ_a. For the highly lying levels (e.g., $n = 5 \div 7$ for $3snp\,{}^1P_1^{\rm o}$ and $n_1 = 6$ for $3sn_1s\,{}^1S_0$), the widths were also estimated with the use of formula (5).

3. Experimental Setup

As a whole, the experimental setup used in the work is similar to that described in [9]. It consisted of a radiation source and a spectrometer with photoelectric registration. In the spectrometer, a monochromator assembled according to the Seya–Namioka optical scheme was used. A dispersing element of the monochromator was a concave toroidal diffraction grating for the vacuum ultraviolet region manufactured at an aluminum layer and protected with a layer of magnesium fluoride. Its radii of curvature were $R_m = 500$ mm and $R_s = 333$ mm, while the groove density amounted to 1200 line/mm. The radiation source was presented by electron and atomic beams that were intersected at the right angle.

As a source of the electron beam, we used an electron gun with a ribbon oxide cathode and three anodes in the form of flat diaphragms with rectangular apertures (1×8 mm^2). It formed a ribbon electron beam with

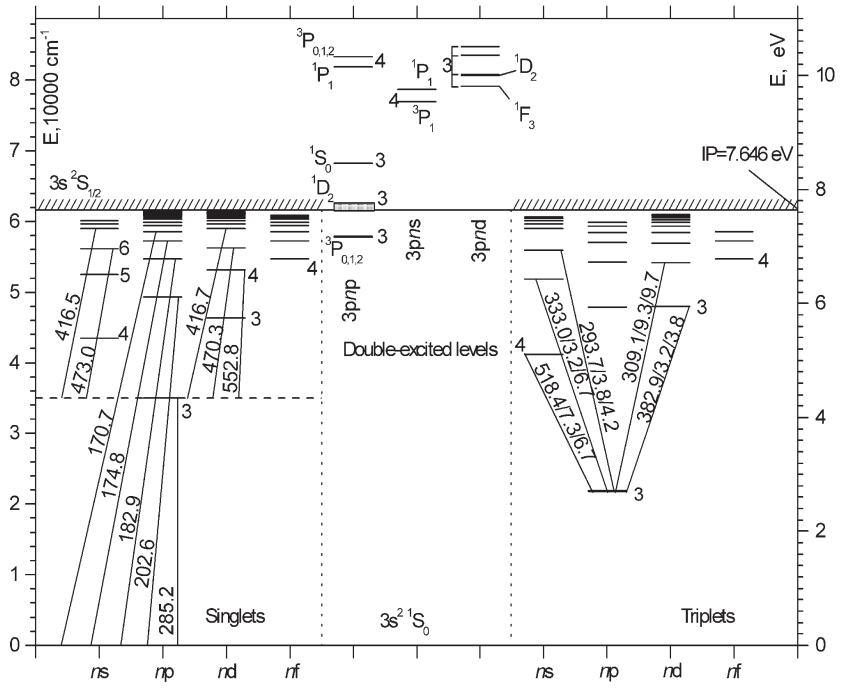

Fig. 1. Diagram of the bound states and AISs of a magnesium atom [10]

the current density $\sim 10^{-3}$ A/cm^2. In the energy range 6–10 eV, the half-width of the electron energy distribution was equal to ~ 0.7 eV.

In order to obtain the atomic beam, we used a source of the effusive type. The beam was formed by an effusive channel with a round cross section of 1 mm in diameter and 8 mm in length. The concentration of atoms in the collision region didn't exceed 10^{12} cm^{-3}.

For the detection of radiation, a "solar-blind" photoelectric multiplier operating in the photon-counting mode was used. The procedure of measurements was automatized with the help of a personal computer and a standard CAMAC modular system.

4. Data on the AISs of a Magnesium Atom

Between the first (7.645 eV) and the second (22.67 eV) IPs, there lie the AISs formed in the case of the simultaneous excitation of the both valence electrons of the atom. For today, the database of the National Institute of Standards and Technology (NIST), USA, contains information on 43 AISs of this kind [10]. They correspond to the $3p^2$, $3pns$, $3pnp$, $3pnd$, and $4snp$ electron configurations. Experiments on photoabsorption [11] and photoionization [12] of magnesium in vacuum ultraviolet represented the basic source of the data on its odd AISs, whereas experiments on electron-atom collisions with the use of electron spectroscopy [13, 14] supplement them with the data on even AISs. In order to identify AISs, one uses theoretical calculations performed by various complicated techniques [15–19]. The values of the AIS energies obtained in this case usually well agree, while the magnitudes of their widths essentially differ (up to an order of magnitude).

It's worth noting that the most problematic AIS under consideration is the $^1D_2$ state, the lowest AIS in the $3p^2$ configuration. The energy obtained for it in [15] amounts to 7.675 eV, which is only 0.03 eV higher than the IP, while the AI width is anomalously large according to the evidence of the authors (the lifetime of the state is small). Experiments [14] didn't discover this state in the continuous spectrum. In [16], the calculations in the approximation of strong channel binding also didn't give a resonance related to this state. This fact allowed the author of [16] to conclude that such an AIS has a large width and hence does not represent a well-defined state due to the strong interaction [17] with the $3snd\ ^1D_2$ bound states and the adjacent continuum.

Based on data of work [10] on the AISs and bound states of magnesium atoms, we adduce a diagram of levels (see Fig. 1) with indication of the spectral transitions investigated in our paper and in [3].

5. Experimental Results and Discussion

Table 1 gives the values of energies for peculiarities a, b, and c in the EF (see Fig. 2) of the spectral lines of a magnesium atom originating from the initial levels $3snp\,{}^1P_1^o$ ($n = 4 \div 7$) located above the IP.

5.1. EF peculiarities related to PCI

In work [5], the role of two AISs, $3p^2\,{}^1D_2$ and $3p4s\,{}^1P_1^o$, responsible for the presence of peculiarities a (steps) and c (maxima) in the EF was discovered. In this paper, the AI widths were found by means of the approximation of experimental data (Table 1) using the least-square method and formulas (2)–(5) (formula (4) was used only for A = 4). To estimate the width of the $3p4s\,{}^1P_1^o$ AIS, the experimental energies of the EF maxima for the lines emerging from the $3sn_1s\,{}^3S_1$ (n_1 = 4–6) and $3sn_2d\,{}^3D_{1,2,3}$ (n_2 = 3, 4) levels of the magnesium atom were also used [3]. It's worth noting that the excitation of the $3snp\,{}^1P_1^o$ levels from the ground state (that was observed in our work) occurs through a dipole transition without change of the spin, whereas the $3sn_1s\,{}^3S_1$ and $3sn_2d\,{}^3D_{1,2,3}$ levels in [3] are excited through monopole and quadrupole transitions with change of the spin.

An alternative to the approximation procedure is the technique of direct calculation of AI widths based on experimental data. We will use it for the estimation of the quantity Γ_a for the both AISs indicated above that manifest themselves in the EF through the PCI effect.

Table 2 presents such estimates based on the use of the energies of the maxima from work [3] for the $3p4s\,{}^1P_1^o$ AIS. The results are given in the order of improvement of the accuracy of approximations. Based on the $3sn_1s\,{}^3S_1$ levels, we obtained that the AIS energy E_a = 9.58 eV, while based on the $3sn_2d\,{}^3D_{1,2,3}$ levels, we got E_a = 9.56 eV. One can see that, for the both groups of the initial levels, the AIS energy is the same. The improvement of the approximation accuracy gives a slight increase of the AI width. The quantity Γ_a obtained with the use of (4) with $A = 12$ is very close to the value obtained by the numerical solution of Eq. (1). As the $3sn_1s\,{}^3S_1$ and $3sn_2d\,{}^3D_{1,2,3}$ levels are low-lying (except for $3s6s$), the calculation of the width using formula (5) doesn't give a satisfactory result. Thus, for the AI width, we obtain 0.313 eV (based on $3sn_1s$) and 0.222 eV (based on $3sn_2d$), which is somewhat less than the value of 0.46 eV from [3].

Table 3 presents the estimates of the AI widths for the AISs responsible for the peculiarities a and c performed in the same way as above based on the data

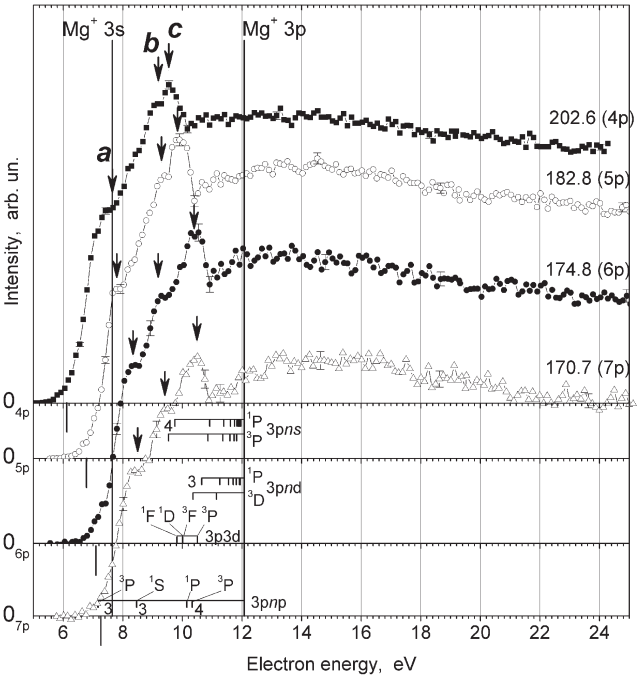

Fig. 2. Excitation functions for the lines of the principal series MgI ($n = 4 \div 7$)

of our experiment. Using the values of the shifts E_1, we've obtained that the energies of the $3p^2\,{}^1D_2$ and $3p4s\,{}^1P_1^o$ AISs are equal to 7.57 eV and 9.40 eV, correspondingly. One can see that, according to both our data and those from work [3], the energy of the second AIS is lower than the value of 9.751 eV corresponding to $3p4s\,{}^1P_1^o$ [10]. Moreover, the energies of 9.58 and 9.56 eV obtained using [3] are close to the energy of 9.538 eV of the $3p4s\,{}^3P_1^o$ triplet [10]. Possibly, initial levels in [3] are populated just by way of this triplet. In our case, one can consider that the more possible ${}^1P_1^o$ singlet AI term [5], which populates the singlet initial states, is excited. The average energy (over spin states of these two AI terms) is equal to 9.59 eV. This looks as if the maximum c (at an energy of 9.54 eV) has no attributes of separation just due to the significant electron energy dispersion ($\sim$ 0.7 eV).

T a b l e 1. Energies of peculiarities a, b, and c in the EFs of spectral lines of a magnesium atom beyond the ionization limit (error ±0.20 eV)

Initial level	E_{ex}, eV	E_b, eV	Energies of peculiarities, eV		
			a	b	c
$3s4p\,{}^1P_1^o$	6.117	1.528	~7.645	9.20	9.54
$3s5p\,{}^1P_1^o$	6.782	0.863	7.80	9.30	9.84
$3s6p\,{}^1P_1^o$	7.093	0.552	8.36	9.20	10.39
$3s7p\,{}^1P_1^o$	7.262	0.383	8.51	9.40	10.49

In [5], the approximation according to formulas (3) and (4) at $A = 4$ and (5) based on three and four points gave the values of the energies for these AISs in the ranges 7.08–7.67 eV ($3p^2\,{}^1D_2$) and 8.80–9.64 eV ($3p4s\,{}^1P_1^o$). In work [12], the energy obtained for the $3p4s\,{}^1P_1^o$ level was equal to 9.703 eV, whereas the $3p4s\,{}^3P_1^o$ level wasn't observed at all.

One can see that, in the same way as above, the calculated values of the AI widths E_1 for all PCI shifts monotonously increase when passing from the simple formula (3) to (4), after that to (5), and the numerical solution of Eq. (1). Tables 2 and 3 imply that, in contrast to formulas (3) and (4) that can be formally used beyond the domain of their applicability, formula (5) is strictly valid only for large E_1 (sufficiently large widths Γ_a) and small E_b. From Tables 2 and 3, one can also see that formula (4) at $A = 12$ is valid for a large interval of values of E_1 and E_b, i.e. it has a wider domain of applicability that it does at $A = 4$ and 8. The numerical solution of Eq.(1) represents a criterion of applicability of all the used formulas.

Formula (3) and formula (4) close to it with $A = 4$ describe small shifts E_1 and correspondingly give close to one another but small values of the AI widths Γ_a. The description of high shifts with the help of more accurate formulas (4) with A = 8, 12 and (5) result in larger values. It's natural, as the value of the PCI shift is directly determined by the AI width. At high Γ_a (small AIS lifetime), the interaction of electrons takes place at essentially smaller distances from one another and from

T a b l e 2. Energies of maxima $E_{\max}$ [3], PCI shifts E_1, and AIS widths Γ_a (the widths are obtained according to formulas (3)–(5) and numerically from Eq. (1) using data in [3] on peculiarities in EFs of the $3sn_1s\,{}^3S_1$ and $3sn_2d\,{}^3D_{1,2,3}$ levels of a magnesium atom)

Initial level	E_{ex}, eV	E_b, eV	Formula	Constant A	$E_{\max}$, (E_1), Γ_a, eV $3p4s\,{}^1P_1^o$
$3s4s\,{}^3S_1$	5.107	2.538	–	–	9.63
			(3)	–	(0.053)
			(3)	–	0.158
			(4)	4	0.162
			(4)	8	0.165
			(4)	12	0.168
			(1)	–	0.168
$3s5s\,{}^3S_1$	6.431	1.214	–	–	9.81
			–	–	(0.233)
			(3)	–	0.159
			(4)	4	0.187
			(4)	8	0.211
			(4)	12	0.233
			(1)	–	0.235
$3s6s\,{}^3S_1$	6.929	0.716	–	–	10.04
			–	–	(0.463)
			(3)	–	0.132
			(4)	4	0.200
			(4)	8	0.250
			(4)	12	0.292
			(5)	–	0.226*
			(1)	–	0.313
$3s3d\,{}^3D_{1,2,3}$	5.945	1.700	–	–	9.64
			(3)	–	(0.081)
			(3)	–	0.131
			(4)	4	0.137
			(4)	8	0.143
			(4)	12	0.149
			(1)	–	0.149
$3s4d\,{}^3D_{1,2,3}$	6.718	0.927	–	–	9.83
			–	–	(0.271)
			(3)	–	0.131
			(4)	4	0.165
			(4)	8	0.193
			(4)	12	0.217
			(1)	–	0.222

N o t e: * – the condition $E_b \ll 5E_1$ of applicability of formula (5) isn't satisfied

T a b l e 3. PCI shifts E_1 of maxima and AIS widths Γ_a (the widths are obtained according to formulas (3)–(5) and numerically from Eq. (1) using the energies of the maxima (see Table 1) in EFs of the $3snp\,{}^1P_1^o$ levels of a magnesium atom)

Initial level	E_{ex}, eV	E_b, eV	Formula	Constant A	(E_1) Γ_a, eV $3p^2\,{}^1D_2$	$3p4s\,{}^1P_1^o$
$3s4p$	6.117	1.528	(3)	–	(0.073)	(0.140)
			(3)	–	0.112	0.155
			(4)	4	0.117	0.169
			(4)	8	0.122	0.181
			(4)	12	0.127	0.193
			(1)	–	0.127	0.194
$3s5p$	6.782	0863	–	–	(0.228)	(0.44)
			(3)	–	0.112	0.155
			(4)	4	0.138	0.221
			(4)	8	0.160	0.271
			(4)	12	0.180	0.313
			(5)	–	<0.002*	0.185*
			(1)	–	0.182	0.329
$3s6p$	7.093	0.552	–	–	(0.788)	(0.99)
			(3)	–	0.133	0.149
			(4)	4	0.261	0.319
			(4)	8	0.344	0.426
			(4)	12	0.411	0.511
			(5)	–	0.433	0.579
			(1)	–	0.497	0.650
$3s7p$	7.262	0.383	–	–	(0.938)	(1.09)
			(3)	–	0.101	0.108
			(4)	4	0.244	0.280
			(4)	8	0.330	0.381
			(4)	12	0.398	0.461
			(5)	–	0.502	0.614
			(1)	–	0.550	0.666

N o t e: * – the condition $E_b \ll 5E_1$ of applicability of formula (5) isn't satisfied

the ion than at low widths. At last, the numerical solution of (1) gives the maximal value of Γ_a. In this case, we can also see that the corresponding calculated values of the AI widths obtained with the use of the shifts of positions of the experimental EF maxima of two high initial $3s6p$ and $3s7p$ levels coincide rather satisfactorily. Thus, one can ascribe large AI widths to the AISs responsible for the maxima in the EFs of $3snp\,^1P^o_1$ levels (and their shift with increase in n): the first one ($3p^2\,^1D_2$) –0.550 eV, the second ($3p4s\,^1P^o_1$) – 0.666 eV. From the data of experiments [3] presented in Table 2, one can see that, for the second AIS, $3p4s\,^1P^o_1$, the width is equal to 0.313 eV, which is lower than the value from Table 3 by approximately a factor of 2. However, this value is almost equal to the value of 0.329 eV from Table 3 obtained by using the shift for the line emerging from the $3s5p$ level. It's worth noting that, in [3], the AI width for the given AIS is equal to 0.46 eV. In [5], the approximation procedure gives the value of 0.433 eV for $3p^2\,^1D_2$ and 0.453 eV for $3p4s\,^1P^o_1$. In [12], the AI width obtained for the $3p4s\,^1P^o_1$ level amounts to 0.383 eV. It's interesting that the only theoretical calculation cited in this work gives a large value – 1.198 eV.

One can see that the given technique of direct calculation of Γ_a based on experimental PCI shifts is very sensitive to the accuracy of their determination. It's especially important at low shifts (which corresponds to either high binding energies or low AI widths). An advantage of the described technique lies in the possibility of its application even in the case of a small number of measured points. A merit of the approximation procedure consists in the fact that it allows one to draw an averaged curve $E_1(\Gamma_a, E_b)$, but based on a considerable number of experimental points.

5.2. EF peculiarities related to the ADSs

Let's consider two more peculiarities in the EF. The first one manifests itself in the form of a slight step in the EF of the line emerging from the $3s4p$ level in the neighborhood of the IP and is located below it at energies $\sim$ 7.22–7.45 eV and close to shoulder a (see Fig. 2). The energy position of the second peculiarity, b, that has a form of a slight bending in all EFs is almost invariable and amounts to $\sim$ 9.20 eV (see Fig. 2 and Table 1).

One can associate the first peculiarity with the formation of the $Mg^{-**}(3p^3)$ ADS – the Feshbach resonance. The nonempirical calculation of the energies of such triply excited electron states is very complicated. That's why let's estimate the energy of this configuration semiempirically with the help of the MRF [9, 20]. For the energies of three $3p$ electrons in the field of the ion core, one can use the expression

$$E(3p^3) = I_1 + I_2 - \frac{3(Z_c - 2\sigma^{3p}_{3p})^2}{(3-\delta_{3\mathrm{p}})^2}R. \qquad (6)$$

As an ion core, we consider here the ground state of the Mg^{2+} ion (charge $Z_c = 2$); σ^{3p}_{3p} presents the mutual two-electron screening of two $3p$ electrons located in the field of the ion core; δ_{3p} is the quantum defect of one $3p$ electron in the field of the core; I_1 and I_2 stand for the ionization potentials of the atom. The quantum defect $\delta_{3p} = 0.735$ is calculated based on the energy $E(3p\,^2P^o) = 12.0763$ eV [10] of the excited state of a Mg^+ ion. The screening constant σ^{3p}_{3p} is found from MRF (6) applied to the energy of the two-electron configuration:

$$E(3p^2) = I_1 + I_2 - \frac{2(Z_c - \sigma^{3p}_{3p})^2}{(3-\delta_{3p})^2}R, \qquad (7)$$

where δ_{3p} is used. In (7), we used the value of the average energy of the $E(3p^2)$ configuration equal to 7.426 eV that was found based on its terms ^3P_J ($J = 0, 1, 2$; the energies are 7.167, 7.169, 7.174 eV, respectively), $^1S_0$ (8.464 eV) [10], $^1D_2$ ($\sim$ 7.675 eV) [14]. So we obtain that the screening constant σ^{3p}_{3p} equals 0.304. Taking into account these data, we obtain the energy of the $3p^3$ configuration of the negative ion $E(3p^3) = 7.265$ eV. One can see that the energy of this three-electron state is 0.161 eV lower than that of the two-electron $3p^2$ configuration. If we use the value of 7.40 eV, which is approximately equal to the mean value from the energy range indicated above (7.22–7.45 eV), as the energy of the $^1D_2$ term, then $E(3p^2) \approx 7.332$ eV, and we obtain that the screening and the energy are lower – $\sigma^{3p}_{3p} = 0.299$ and $E(3p^3) \approx 7.05$ eV. Thus, the energy of the $3p^3$ configuration lies approximately in the interval between 7.05 and 7.27 eV.

It's worth pointing out that the $3p^3$ configuration of a negative magnesium ion is present in review [21] devoted to characteristics of negative ions. The calculations adduced there show that, for example, the $^4S^o$ level of this configuration has the lifetime of 1.4 ns with respect to the decay to the $3s3p^2\,^4P$ level with a wavelength of $\sim$ 289.5 nm (see [21] and references therein).

To our mind, the second peculiarity can be also associated with the Feshbach resonance which is formed as the incident electron is captured to the $3p4s^2$ Mg^- configuration in the case of excitation of the AIS. The resonance lies lower than the $3p4s\,^1P^o_1$ AIS, while its

electron decay can populate the $3snp\,{}^1P_1^o$ initial states. For the semiempirical estimation of the energy of the $3p4s^2$ configuration according to the MRF [9, 20] (see also (6) and (7) above), let's use the expression (Mg^{2+} core, $Z_c = 2$)

$$E(3p4s^2) = I_1 + I_2 - \frac{(Z_c - 2\sigma_{3p}^{4s})^2}{(3-\delta_{3p})^2}R -$$

$$-2\frac{(Z_c - \sigma_{4s}^{4s} - \sigma_{4s}^{3p})^2}{(4-\delta_{4s})^2}R. \qquad (8)$$

Based on the energy of the excited state of the one-charged Mg^+ ion $E(4s\,{}^2S) = 16.2998$ eV [10], we determine the magnitude of the quantum defect $\delta_{4s} = 1.079$. In the same way as above, two-electron screenings are found using the energies of the $4s^2$ and $3p4s$ AI configurations. For example, based on the energy $E(4s^2) = 13.39$ eV [15] and a formula of type (7), we obtain $\sigma_{4s}^{4s} = 0.293$. It's worth noting that the energy of 13.04 eV of this AIS from [19] gives the value $\sigma_{4s}^{4s} = 0.262$. By analogy, using the mean energy of 9.645 eV (obtained on the basis of the ${}^3P_1^o$ and ${}^1P_1^o$ [10] terms) of the $3p4s$ AI configuration as well as the MRF

$$E(3p4s) = I_1 + I_2 - \frac{(Z_c - \sigma_{3p}^{4s})^2}{(3-\delta_{3p})^2}R -$$

$$-\frac{(Z_c - \sigma_{4s}^{3p})^2}{(4-\delta_{4s})^2}R, \qquad (9)$$

we determine the mutual screenings: σ_{3p}^{4s} – the 3p electron is screened by the 4s electron and σ_{4s}^{3p} – vice versa. Let's consider three cases here: 1) $\sigma_{3p}^{4s} = 0$, $\sigma_{4s}^{3p} \neq 0$; 2) $\sigma_{3p}^{4s} \neq 0$, $\sigma_{4s}^{3p} = 0$; 3) the screenings are equal – $\sigma_{3p}^{4s} = \sigma_{4s}^{3p}$. In these cases, we correspondingly obtain: 1) $\sigma_{3p}^{4s} = 0$, $\sigma_{4s}^{3p} = 0.766$; 2) $\sigma_{3p}^{4s} = 0.416$, $\sigma_{4s}^{3p} = 0$; 3) $\sigma_{3p}^{4s} = \sigma_{4s}^{3p} = 0.248$. With regard for these data, the energy of the $3p4s^2$ state of a negative ion takes on the following values: 9.25, 9.77, and 9.89 eV. One can see that, in the first case, the state is located 0.4 eV lower than the $3p4s$ AI configurations, whereas it lies somewhat higher in the second and the third cases – by 0.12 and 0.24 eV. By assuming that the 4s electron still screens the 3p electron (though slightly), i.e. $\sigma_{3p}^{4s} \neq 0$ but $\sigma_{4s}^{3p} > \sigma_{3p}^{4s}$, we estimate that this state can lie practically lower by 0.1–0.2 eV than the $3p4s$ configurations.

6. Conclusions

The excitation functions for the spectral lines of a magnesium atom originating from the $3snp\,{}^1P_1^o$ levels ($n = 4 \div 7$) are investigated in the case of electron-atom collisions for the energy range from the thresholds to ∼25 eV and the energy dispersion of ∼ 0.7 eV. A number of peculiarities related to autoionizing and autodetaching states are revealed in the excitation functions above the ionization potential. The most significant peculiarities (the maxima lying close to the position of the autoionizing $3p4s\,{}^1P_1^o$ state) have specific considerable (up to ∼ 1 eV for $n = 7$) shifts toward higher energies with increase in n. They are associated with the mechanism of population of the initial levels of the lines with the involvement of this state due to the post-collision interaction. Based on the classical model, the theoretical analysis of experimental results gives an estimate of the autoionizing width of the $3p4s\,{}^1P_1^o$ state not higher than 0.67 eV, which well agrees with other theoretical data. Two step-like features in the excitation functions, whose positions practically don't depend on n, are identified with negative states of a magnesium ion. The energies of these states are estimated based on the modified Rydberg formula.

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ДОСЛІДЖЕННЯ ОСОБЛИВОСТЕЙ НА ФУНКЦІЯХ ЗБУДЖЕННЯ ЕЛЕКТРОНАМИ ЛІНІЙ ГОЛОВНОЇ СЕРІЇ АТОМА МАГНІЮ

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Р е з ю м е

Для спектральних ліній атома магнію, що виходять з рівнів $3snp\ {}^1P_1^o$ ($n = 4 \div 7$), досліджено функції збудження (ФЗ) при зіткненнях атомів з електронами в області енергій від порогів до ~ 25 еВ та розкидом за енергією $\sim 0,7$ еВ. Вище потенціалу іонізації на ФЗ знайдено низку особливостей, пов'язаних з автовідривними та автоіонізаційними станами. Найбільш помітні серед них (максимуми поблизу положення автоіонізаційного стану $3p4s\ {}^1P_1^o$) мають характерні зсуви у бік більших енергій. Величина зсувів зростає із збільшенням n, що пояснюється механізмом заселення вихідних рівнів ліній з участю цього стану через взаємодію після зіткнення. На базі класичної моделі виконано теоретичний аналіз результатів експерименту. Зроблено оцінку енергій автовідривних станів, що проявляються на ФЗ.