ENERGY DEPENDENCES OF ELECTRON EXCITATION CROSS SECTIONS FOR LOW-ENERGY Mg, Ca AND Sr ATOM LEVELS OUT OF THE METASTABLE STATES

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Using the crossed electron and metastable atom beam technique the excitation cross sections for low-lying levels of some alkaline-earth atoms out of the metastable states and their energy dependences have been measured. A comparison of experimental data with close-coupling calculations show a good agreement both in the general behavior and absolute values.

Introduction

Slow electron collisions with excited atoms play a significant role in the low-temperature plasma, which, in turn, is a working medium in different devices. This, in fact, stipulates the importance and necessity of knowing the constants of electron-excited atom interactions. At the same time the studies of electron-impact excitation of atoms out of the metastable states is much more complicated from the experimental viewpoint as compared to those with the ground-state atoms.

A quite scarce opportunity to compare the experimental and theoretical results that, eventually, improves the reliability of the obtained information, has a great importance in studying the elementary processes of electron interactions with the excited atoms.

Present papers deals with some regularities in the excitation cross sections and their energy dependences for several spectral transitions (ST) originating from the lower Mg, Ca and Sr levels, whose excitation out of metastable states is accompanied by the following changes in the initial and final state quantum numbers: $\Delta n=0$, $\Delta J=\pm 1$, $\Delta L=\pm 1$, $\Delta S=0$. For the above atoms these levels are the S- and D- levels. A comparison with the theoretical data [1,2] obtained earlier (the calculations were carried out by the six-state close-coupling method) was also performed.

Experimental

The experiments were carried out by an optical method with the use of a crossed electron-atom beam technique (see [1]). The

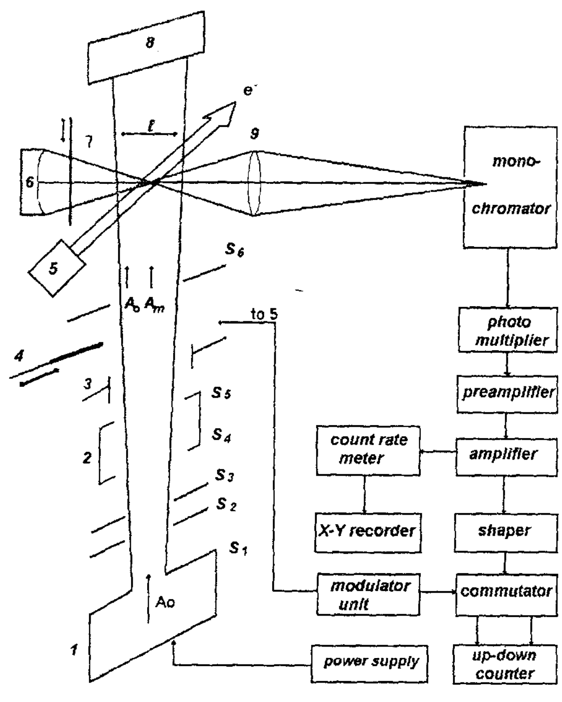

Fig. 1. Experimental set-up and associated electronics.
1 – effusion Mg, Ca, Sr atomic beam source;
2 – discharge chamber; 3 – electrostatic capacitor;
4 – atomic beam flag; 5 – electron gun; 6 – mirror;
7 – mirror flag; 8 – nitrogen trap; 9 – lens;
S_1–S_6 – system of collimating slits.

beams of the metastable Mg, Ca, Sr atoms were produced by a discharge method, their concentrations that reached (3–5)·10^9 cm^3 (dependent of the element under study) were determined by a spectral line self-absorption method. The electron beam current produced by means of a 5-electrode electron gun was ~30μA (at the 30 eV energy), while the energy spread was about 0.5 eV. The detection system was operated in the photopulse counting mode. The inaccuracy of determination of the absolute cross section values did not exceed 50%. A detailed description of the experimental setup and technique can be found elsewhere [1].

Results and Discussion

Table 1 shows the data on the absolute excitation cross sections for the transitions arising from these levels out of the metastable states. The large values of the excitation cross sections for given ST are due, in our opinion, to the fact that the excitation process occurs via the dipole interaction of electron with atom at the minimal change of a principal quantum number, and that these ST are the analogs of the resonance transitions. For comparison the same table also presents the excitation cross sections for the resonance levels of corresponding atoms excited from the ground states.

Table 1. Cross sections for the spectral transitions to the low-lying Mg, Ca, Sr levels excited out of the metastable $^3P_{0,2}$- states.

Element	Spectral transition	Q_{30}, 10^{-16} cm^2		Excitation process
		Experiment	Theory	
Mg	$3s3p^3P_J - 3s4s^3S_1$	10		m
	$3s3p^3P_J - 3s3d^3S_1$	3.6	–	m
	$3s^2\,^1S_0 - 3s3p^1P_1$	7.9		o
Ca	$4s4p^3P_J - 4s5s^3S_1$	9	2.9 [1]	m
	$4s4p^3P_J - 4s4d^3D_J$	3.4	5.8 [1]	m
	$3s^2\,^1S_0 - 3s3p^1P_1$	12		o
Sr	$5s5p^3P_2 - 5s6s^3S_1$	15	3.8 [2]	m
	$5s5p^3P_2 - 5s5d^3D_J$	6	4.5 [2]	m
	$3s^2\,^1S_0 - 3s3p^1P_1$	24	35 [2]	o

Note: Q_{30} – excitation cross section at 30 eV;
m – excitation out of the metastable states;
o – excitation from the ground state.

It is seen that these cross sections are comparable by magnitude. Moreover, it is of particular interest to compare the experimental data with the six-state close-coupling calculations (6CC) [1,2]. As is seen from table, for the above levels this method gives quite satisfactory results, which agree with experiment within the limits of measurement error, though for the S-levels the calculated cross sections are several times as low as the experimental ones. This fact is not quite clear and needs explanation. The cascade population (see [2]) can not lead to such result, since in experiment the transitions from the ^3P- levels (which may result in the main population of the ^3S and ^3D- levels), due to the low intensity of their excitation out of the metastable states, were not detected. In [2], the calculated excitation cross section for the $5s6s^3S_1$- level in Sr was calculated providing at 30 eV the ~1.4·10^{16} cm^2 value. Thus, it is seen that the maximum contribution (even provided one assumes that it fully decays to the $5s6s^3S_1$- level) is <10% of the experimental cross section. Therefore, the problem of disagreement of theory and experiment at the excitation of the S- level still remains unsolved.

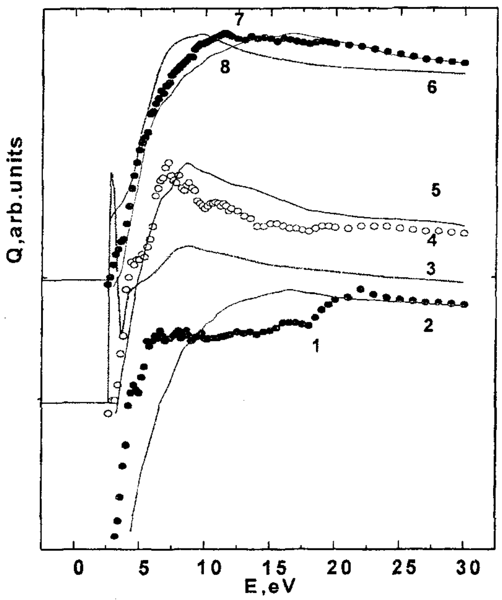

Fig. 2. EF for some spectral transitions in Mg, Ca, Sr atoms out of the metastable (curves 1,3,4,7,8) and ground (curves 2,5,8) states.

Mg: 1 – $3^3P_J - 3^3D_J$; 2 – $3^1S_0 - 3^1P_1$;
Ca: 3,4 – $4^3P_2 - 4^3D_J$; 5 – $4^1S_0 - 4^1P_1$;
Sr: 6,7 – $5^3P_2 - 5^3D_J$; 8– $5^1S_0 - 5^1P_1$

Figures 2 and 3 show the energy dependences of excitation cross sections (excitation functions, EF) for some spectral transitions (ST) – the first terms of the diffuse and sharp series. As is seen, for these ST, as a rule, the smooth EFs with maxima at few threshold units inherent in the dipole excitation are typical. It seems quite reliable that the above EFs are close (as a rule with no near-threshold features being taken into account) to those for the resonant ST excited from the atomic ground states (see Fig. 2). It should be noted that the excitation cross section values are also quite similar (close to 10^{-15} cm^2 [1]). For the sake of completeness, the same figure also shows the theoretical data on EF for some ST out of the metastable states (Fig. 2, curves 3, 6 and Fig. 3 curves 3,4). For Ca atom the calculated EF (Fig. 2, curve 3) indicates very clearly the presence of a near-threshold resonance observed first experimentally (Fig. 2, curve 4). In general, it should be noted that the results obtained testify a fairly good agreement of the data for the lower states.

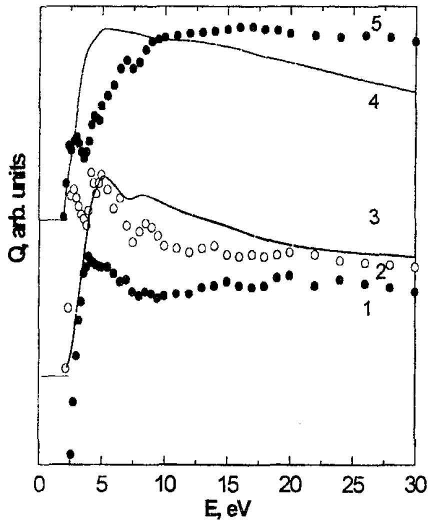

Fig. 3. EF for some spectral transitions in Mg, Ca, Sr atoms out of the metastable states.

Mg: 1 – $3^3P_J - 4^3S_1$;
Ca: 2,3 – $4^3P_J - 5^3S_1$;
Sr: 4,5 – $5^3P_2 - 6^3S_1$

References

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ЕНЕРГЕТИЧНІ ЗАЛЕЖНОСТІ ПЕРЕРІЗІВ ЕЛЕКТРОННОГО ЗБУДЖЕННЯ ДЛЯ НИЗЬКОЕНЕРГЕТИЧНИХ РІВНІВ АТОМІВ Mg, Ca І Sr З МЕТАСТАБІЛЬНИХ СТАНІВ

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Використовуючи метод перехресних пучків електронів та метастабільних атомів, виміряно перерізи збуджень для низькоенергетичних рівнів деяких лужноземельних атомів з метастабільних станів та їх енергетичні залежності. Порівняння експериментальних даних з розрахунками за методом сильного зв'язку виявило добре узгодження як загальної поведінки, так і експериментальних значень.