ON THE EFFECTIVE CROSS SECTIONS FOR EXCITATION OF THE RESONANCE DOUBLETS OF CESIUM AND RUBIDIUM

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ON THE EFFECTIVE CROSS SECTIONS FOR EXCITATION OF THE RESONANCE DOUBLETS OF CESIUM AND RUBIDIUM

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In the literature dealing with electron excitation of alkali-metal atoms, there is partial information on effective cross sections only for the spectral lines of sodium and potassium ([1–5]). For the heavier elements—cesium and rubidium—experimental data on absolute excitation cross sections are absent.* This situation is due to the considerable difficulties of experimentally determining excitation cross sections of atoms ([8]). For resonance lines, an additional complication arises because of absorption of this radiation as it passes through its own gas (or vapor).

In the present note we report a method developed in our laboratory for studying the effective cross sections of resonance lines of atoms, and the results obtained for the absolute excitation cross sections, by slow electrons, of the resonance levels of cesium and rubidium.

The proposed method is based on the well-known law of attenuation of a beam of monochromatic radiation

$$I_\nu = I_{\nu 0} e^{-\chi_\nu l}, \tag{1}$$

where $I_{\nu 0}$ is the intensity of the unattenuated light beam; I_ν is the intensity of the light beam that has passed a distance l in the absorbing gas; $\chi_\nu = \sigma_\nu n_0$ is the attenuation coefficient, representing the product of the effective cross section for absorption of a photon σ_ν and the concentration of normal atoms n_0.

Let us write expression (1) in logarithmic form

$$\ln I_\nu = \ln I_{\nu 0} - \chi_\nu l, \tag{2}$$

from which it is evident that the dependence of $\ln I_\nu$ on l is graphically represented by a straight line. The intersection of this straight line with the vertical axis $\ln I_\nu$ directly gives us the sought value of the unattenuated flux $I_{\nu 0}$, corresponding to $l = 0$. Consequently, the question is essentially reduced to obtaining a rectilinear plot $\ln I_\nu = f(l)$ in absolute units of the light flux, which, in turn, is proportional to the effective excitation cross section of the observed line.

In order actually to construct such a plot, it is only necessary to provide, in the ordinarily used experimental setup, the possibility of varying the distance between the electron beam and the exit window of the excitation tube, between which there is an absorbing layer of normal atoms of the vapor under investigation, while simultaneously measuring the absolute intensity of the line under study.

For this purpose we designed and fabricated a combined excitation tube of glass and metal (Fig. 1), which makes it possible, within the necessary limits, to vary the thickness of the absorbing layer and thereby to take into account with sufficient accuracy the absorption of the resonance lines

* Relative measurements of the excitation cross sections of Cs and Rb lines as functions of electron energy are presented in works ([6,7]).

directly under operating conditions. The exit window of the excitation tube can be moved smoothly without breaking its seal, owing to a bellows, by guide rods rigidly connected with the body–

Fig. 1. Excitation tube: **1**–electron gun, **2**–movable exit window, **3**–bellows, **4**–micrometer screw, **5**–scale for reading the displacement of the exit window, **6**–dry shutter separating the tube from the vacuum system

–with the body of the excitation tube and with the micrometer screw. In this way the distance between the window and the electron beam can be varied from 25 to 2.5 mm and set at a given distance with an accuracy of 0.01 mm.

In order that absorption in the impact volume itself be negligibly small, a special electron gun is mounted in this tube, giving a thin (0.4 mm) ribbon beam instead of the ordinarily used cylindrical beam. Such an electron beam operates very stably, without changing its shape, and is sufficiently homogeneous in velocity (the spread lies within the interval 0.7-0.8 eV for 90% of all electrons). The degree of homogeneity (owing to the special design of the electron gun and the electron collector) is not at all impaired when the exit window is brought as close as 2.5 mm to the front edge of the beam. The entire setup, with the exception of the side arm containing the metal under study and the micrometer-screw handle, is placed in a single heated furnace; the side arm with the metal is heated to the required temperature by an independent furnace.

Fig. 2. Dependence of the apparent excitation cross sections of cesium lines on the thickness of the absorbing layer: **1** and **3**–8521 Å; **2** and **4**–8944 Å; **1** and **2**–$p = 8.5 \cdot 10^{-5}$ mm; **3** and **4**–$p = 3 \cdot 10^{-4}$ mm.

On such an apparatus, the apparent excitation cross sections of the resonance lines of cesium and rubidium were measured at various thicknesses l of the

Fig. 3

Figure 1: Fig. 3

Fig. 4

Figure 2: Fig. 4

absorbing layer of normal atoms*, and for cesium this was done at two different vapor pressures ($3 \cdot 10^{-4}$ and $8.5 \cdot 10^{-5}$ mm), while for rubidium it was done at one pressure ($4.9 \cdot 10^{-4}$ mm). In all measurements the current density in the electron beam was $2 \cdot 10^{-3}$ A/cm^2.

Fig. 3. Absolute excitation functions of the lines:
1 –8521 Å ($6^2S_{1/2}$—$6^2P_{3/2}$) Cs;
2 –7800 Å ($5^2S_{1/2}$—$5^2P_{3/2}$) Rb;
3 –8944 Å ($6^2S_{1/2}$—$6^2P_{1/2}$) Cs;
4 –7948 Å ($5^2S_{1/2}$—$5^2P_{1/2}$) Rb

As can be seen from Fig. 2, the experimental points–the apparent cross sections at the excitation maximum–fall well on straight lines corresponding to expression (2). The true maximum cross sections of both resonance components of cesium (corresponding to $l = 0$) are obtained as practically identical, independently of the magnitude of the vapor pressure in the tube.

Figure 3 presents the absolute excitation cross sections of the resonance lines of the atoms studied as functions of the electron energy.

To determine the effective cross sections of the resonance levels, it is necessary to exclude cascade transitions in accordance with equality (9)

$$Q_k(E) = Q_{km}(E) - \sum_{i=k+1}^{\infty} Q_{ik}(E), \tag{3}$$

where $Q_k(E)$ is the cross section of the doublet resonance level; $Q_{km}(E)$ is the total cross section of both components of the resonance radiation; $Q_{ik}(E)$ are the excitation cross sections of the lines corresponding to cascade transitions to the resonance levels (subordinate series).

The absolute cross sections of the lines of the subordinate series were also measured by us up to 6-10 members of each series for both elements. Therefore the last term of expression (3) can be calculated quite accurately. The corresponding calculation shows that the role of cascade transitions in the radiation of the resonance lines of cesium and rubidium is comparatively small and amounts to about 10% in the region of the excitation maximum (7-12 eV). The maximum excitation cross sections of the resonance levels prove to be $9.3 \cdot 10^{-15}$ cm^2 for the $6^2P_{1/2,\,3/2}$ Cs level and $4.5 \cdot 10^{-15}$ cm^2 for the $5^2P_{1/2,\,3/2}$ Rb level.

Fig. 4. 1 –absolute excitation function of the cesium resonance level $6^2P_{1/2,\,3/2}$;
2 –calculation ([10], [11]);
3 –calculation ([12])

As an example, Fig. 4 presents the absolute excitation function of the cesium resonance level and compares it with data from theoretical calculations performed in recent years ([10–12]). As can be seen, the difference between experiment and theory does not exceed 50%, which, taking into account the considerable–

* The influence of the effect of radiation trapping in the beam for $l \leq 12$ mm is insignificant.

the error of the method for measuring absolute intensities (up to 30%), is not significant. For rubidium the agreement with the calculations of L. A. Vainshtein (^12) is still better (a discrepancy of 10%). The behavior of the excitation functions, for both cesium and rubidium, calculated in (^12), is also close to our results.

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CITED LITERATURE

^1 G. Haft, Zs. f. Phys., **82**, 73 (1933).
^2 W. Christoph, Ann. d. Phys., **23**, 51 (1935).
^3 L. M. Volkova, Optics and Spectroscopy, **6**, 273 (1959); **11**, 755 (1961); **13**, 849 (1962).
^4 L. M. Volkova, Izv. AN SSSR, ser. fiz., **23**, 968 (1959).
^5 L. M. Volkova, A. M. Devyatov, Izv. AN SSSR, ser. fiz., **27**, 1952 (1963).
^6 I. P. Zapesochnyi, L. L. Shimon, Optics and Spectroscopy, **16**, 929 (1964).
^7 L. L. Shimon, Optics and Spectroscopy, **17**, 24 (1964).
^8 G. Massey, E. Burhop, *Electronic and Ionic Collisions*, IL, 1958.
^9 I. P. Zapesochnyi, L. L. Shimon, Ukr. Phys. J., **9**, 1943 (1964).
^10 R. Damberg, B. Kraulchenko, Izv. AN LatvSSR, No. 1 (150), 73 (1960).
^11 L. K. Hansen, J. Appl. Phys., **35**, 254 (1964).
^12 L. Vainshtein, V. Opykhtin, I. Presnyakov, ZhETF, **47**, 2306 (1964).

Note: Figure translations are in progress. See original paper for figures.