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G. P. BOROVIKOVA and M. I. KORSUNSKII

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Abstract

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G. P. BOROVIKOVA and M. I. KORSUNSKII

THE LINES $L\beta_3$ AND $L\beta_4$ IN THE SPECTRUM OF GERMANIUM

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The L-series of the characteristic spectrum of germanium has been studied in a number of works ([1–3]), carried out as early as 1921–1937. These works were performed mainly on high-vacuum X-ray spectrographs with Bragg focusing. A plane mica crystal was used as the X-ray analyzer. A metal X-ray tube with a primary excitation method was employed. In Gwin' s work an ion tube with hydrogen cooling was used. As a result of the investigations carried out, the following diagram and non-diagram lines of the L-series of germanium were discovered and studied: $L\alpha_{1,2}$, $L\beta_1$, Ll, $L\eta$ and $L\alpha'$, $L\alpha''$, $L\alpha'''$, $L\beta'$, $L\beta''$. From the above list of spectral lines it is evident that the L-series of germanium was studied incompletely. In particular, the lines $L\beta_3$ and $L\beta_4$ were not found in the spectrum of the L-series of germanium. It is known that the line $L\beta_3$ corresponds to the transition $L_\mathrm{I} \to M_\mathrm{III}$, and the line $L\beta_4$ to the transition $L_\mathrm{I} \to M_\mathrm{II}$. In the shell of the germanium atom in the normal state, the electrons are distributed over the levels as follows:

$$\begin{array}{cccccccc} (1s)^2 & (2s)^2 & (2p)^6 & (3s)^2 & (3p)^6 & (3d)^{10} & (4s)^2 & (4p)^2 \\ K & L_\mathrm{I} & L_\mathrm{II-III} & M_\mathrm{I} & M_\mathrm{II-III} & M_\mathrm{IV-V} & N_\mathrm{I} & N_\mathrm{II-III} \end{array}$$

The $M_\mathrm{II-III}$ level in germanium, therefore, is internal and completely filled. The line $K\beta_{1,3}$, corresponding to the transition $K \to M_\mathrm{II-III}$, has been found and its wavelength measured with sufficient accuracy. It becomes unclear why, in the L-spectrum of germanium, the lines corresponding to the transitions $L_\mathrm{I} \to M_\mathrm{III}$ and $L_\mathrm{I} \to M_\mathrm{II}$ are absent. The present work was carried out with the aim of discovering the lines corresponding to the indicated transitions (the lines $L\beta_3$ and $L\beta_4$), measuring their wavelengths, and estimating their intensity.

Apparatus and methods of investigation. The X-ray spectrum of the L-series of germanium was obtained with the aid of a Krasnikov-type tube ([4]) for fluorescence analysis. However, we cannot assert that the spectrum is purely fluorescent, since a small number of electrons still reached the secondary anode. The direct current was 1/20 of the total current through the tube and was equal to 0.5 ma. Such a small current, with a broad focus and intensive cooling by running water, could not appreciably heat the secondary anode on which the substance under investigation was placed. The temperature of the substance

Fig. 1

Figure 1: Fig. 1

under investigation was measured by a thermocouple in direct contact with the anode. In our experiments the temperature of the germanium did not exceed 50°. The primary anode of the tube was covered with an aluminum plate. The main exciting radiation was the radiation of the Al $K\alpha_1 K\alpha_2$ lines with wavelengths 8321.37 and 8323.82 X. Owing to the location of the secondary anode near the crystal inside the focusing circle, the entire focal spot took part in the formation of the spectrum. The tube operated at 5–3.5 kv and 10 ma; the exposure was from 9 to 12 hours. The resolution of the X-radiation into a spectrum was carried out with the aid of a high-vacuum luminosity spectrograph with a bent crystal

mica. The dimensions of the crystal were 10×40 mm, and the bending radius was 990 mm. The vacuum of the spectrograph was common with the vacuum of the X-ray tube and was equal to $5—6 \cdot 10^{-6}$ mm Hg. The spectrum was photographed on Agfa Isopan F photographic film. The film was protected from fogging by aluminum foil about 2μ thick. The spectra were photometered on an MF-4 recording microphotometer.

Results of the measurements. The possible value of the wavelength of germanium $L\beta_3$ was determined by interpolation, i.e., by constructing the dependence $\lambda = f(z)$, and was found to be 9570 X. For the investigation, pure single-crystal germanium was placed in the position of the secondary anode of the X-ray tube. When photographing the X-ray spectrum, in order to detect the $L\beta_{3,4}$ lines, the spectrograph was focused on the line at 9570 X. In all photographs of this region of the spectrum, obtained under various excitation conditions, two lines were found, located close to one another (Fig. 1). The wavelengths of the lines found were measured; they proved to be 9561 and 9620 X. The calculation of the wavelengths was carried out from microphotograms. The linear dispersion in the region of reflection angles considered was 35.4 X/mm. The comparison lines used were the $K\alpha_1$ and $K\beta_1$ lines of calcium in the third order. Calcium was taken in the form of the compound $CaCO_3$. In calculating the wavelengths, a correction was introduced for the deviation from the Wulff–Bragg law. The temperature correction was less than 0.1 X and therefore was not taken into account. The error in determining the wavelength was about 2 X.

Fig. 1

Comparison of the measured wavelength values with the known wavelength values for all elements (in all possible orders) showed that the lines found belong to germanium. This is also confirmed by the fact that the investigated samples of single-crystal germanium had a high degree of purity. From the microphotogram shown in Fig. 1 it is evident that the short-wavelength line is more intense than the long-wavelength one. From the literature data it is known that in the $L\beta_3 L\beta_4$ doublet the short-wavelength line $L\beta_3$, corresponding to the transition $L_\text{I} \to M_\text{III}$, is the more intense; its intensity is approximately 1.5 times greater than the intensity of the long-wavelength line $L\beta_4$, corresponding to the transition $L_\text{I} \to M_\text{II}$. The wavelength value of the short-wavelength line is closest to the value of the $L\beta_3$ wavelength determined by interpolation. On this basis, the most intense line with wavelength 9561 X was taken by us to be the germanium $L\beta_3$ line, while the line with wavelength 9620 X was taken to be $L\beta_4$. It should be noted that, with such an interpretation of the lines found, the doublet separation for germanium proves to be somewhat overestimated. For elements located above germanium, beginning with 37Rb, the difference in the wavelengths of the lines composing the $L\beta_3 L\beta_4$ doublet is 35 X. The value we found is 59 X. However, it must be borne in mind that germanium is not far from the group of elements in which the filling of the M-shell is completed, and therefore in this group of elements the separation between the M_II and M_III levels may prove to be somewhat greater than the usual value characteristic of heavier elements.

The ratio of the intensities of $L\beta_1$ and $L\beta_3 L\beta_4$ is difficult to establish, since a considerable difference was observed in the blackening densities of the lines being compared. At a density of $L\beta_3 L\beta_4$ sufficient for photometry, the $L\beta_1$ line proves to be overexposed. Therefore, the ratio of the intensities of the lines $L\beta_3, L\beta_4$ and $L\beta_1$ was only estimated by us by recalculating the intensity of $L\beta_1$, using data on the exposure time of the photograph on which the $L\beta_3, L\beta_4$, and $L\beta_1$ lines are present, and of the photograph on which the blackening density of the $L\beta_1$ line is equal to 0.44. According to this estimate, the ratio $IL\beta_3 : IL\beta_1$ proved to be 0.127. As is evident from the data obtained, the intensity of the $L\beta_3$ line, and consequently also of $L\beta_4$, is very small. Owing to such a low intensity of the lines and the considerable background in the primary method of investigation, the authors of earlier works apparently did not succeed in observing these lines.

Kharkov Polytechnic Institute
named after V. I. Lenin

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