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POSITRON REFLECTION FROM ELEMENTS AND ALLOYS

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The positron and electron reflection coefficients are compared for 17 elements with atomic numbers between 4 and 83 and for 7 alloys. The positron source was Na^{22} and the electron source Tl^{204}. The detector was a BFL-25 end-window counter with a 1.3 mg/cm^2 window or an ionization chamber. The ratio of the electron and positron reflection coefficients is close to 1.3 and is the same for intermediate and heavy elements. The ratio is appreciably larger for light elements. The Muller relation is valid for multicomponent mixtures of intermediate and heavy elements; no conclusion regarding the validity of this relation for light elements can be drawn from the experimental data.

INVESTIGATIONS of the reflection (backward scattering) of positrons from pure elements, unlike investigations of electron reflection, are very scanty, and their conclusions are based on a small number of measurements. Thus, Seliger[1] investigated the dependence of the reflection coefficients on the atomic number of the element, using only six reflector-targets. He established experimentally that the positron reflection coefficients η^+ differ greatly from the electron reflection coefficients η^-. He found that for large atomic numbers the ratio η^-/η^+ approaches the constant value 1.30 irrespective of the atomic number. On the other hand, at low atomic numbers Seliger's experimental data do not yield any dependence of this ratio on the atomic number.

Bisi and Braicovich[2] investigated the dependence of the reflection coefficients on the atomic number, using targets of only seven elements of the periodic system. They determined the positron reflection coefficients by the indirect method of registering with scintillation counters the γ quanta accompanying the creation and annihilation of the positron, using Na^{22} as the positron β source. They themselves did not determine the coefficients of electron reflection from the same targets, but compared the positron reflection coefficients with the electron reflection coefficients given by Paul and Steinwedel[3]. Bisi and Braicovich established that the ratio of the electron and positron reflection coefficients differs greatly for light and heavy elements. This ratio is close to unity for low atomic numbers and reaches the constant value 1.36 for $Z > 40$.

The positron reflection coefficients for targets made up of multicomponent compounds and alloys were never determined before. For electrons, as shown by Muller[4], the intensity of reflection from multicomponent mixtures, alloys, and chemical compounds is determined by the effective atomic number Z, calculated by the Muller formula

$$\bar{Z} = \sum Z_i p_i, \tag{1}$$

where Z_i are the atomic numbers of all the elements contained in the multicomponent substance and p_i are the fractions of the components by weight.

We measured the reflection coefficients of seventeen pure elements: Be, C, Al, Si, Ti, Fe, Ni, Cu, Zn, Zr, Nb, Mo, Cd, Sn, Ta, Pd, and Bi. In addition, we determined the reflection coefficients of three alloys of tin with lead, a tantalum-niobium alloy, two alloys of copper with zinc, and the alloy 79NM5 (permalloy) consisting of nickel, iron, molybdenum, and manganese.

The reflector-targets of both the pure elements and the alloys were made in the form of discs 55 mm in diameter and 2—5 mm thick, which is much larger than the saturation thickness for the reflection of β radiation from sources with maximum energies 0.5—3.0 MeV. The targets were stacked over a Plexiglas shelf with a round hole 54 mm in diameter at the center. This shelf was inserted in the upper slot of a special Plexiglas rack. In a lower slot of the same rack was inserted a Plexiglas shelf with the same hole, in the center of which a Plexiglas cylinder of 1 cm diameter was secured with the aid of four radial partitions. On this cylinder were placed, to reduce the background, a lead disc 1 cm in height and in diameter, wrapped in aluminum foil, and the container of the source. The container was an aluminum cylinder 1 cm in diameter and 0.5 cm high. The active layer was placed on the bottom of a cylindrical hole in the upper part of the container, of 5 mm diameter and 2.5 mm depth. Still lower on the rack was inserted a third shelf, on which a BFL-25 end-window Geiger counter was placed. The counter mica window was 1.3 mg/cm^2 thick and faced upward. The recording instrument was a B-3 radiometer with decade scaler, and the end-window counter was fed from the high-voltage block of a B-2 radiometer. An additional shelf, also with a central hole, could be placed between the source shelf and the end-window counter. Aluminum foils of different thicknesses, clamped with springs, were placed in succession on the additional shelf in order to plot the attenuation curves of the reflected radiation. The parameters of the setup were chosen such as to obtain a maximum ratio of the counting rate to the background (counting contrast). The background was defined as the counting rate obtained when the upper shelf was inserted without a reflector.

Measurements have shown that the most suitable distances (at a reflecting-spot diameter 54 mm) were 45 mm between the source and the counter and 57 mm between the counter and the reflector. The aluminum filters were placed 10 mm away from the counter window. The positron and the electron β sources were placed in identical containers and had an activity of several microcurie each.

We first determined the electron reflection coefficients using a Tl^{204} β source (E_0 = 765 keV). We then determined the reflection coefficients for the same samples in the same geometry, using an Na^{22} positron source (E_0 = 540 keV). This enabled us to avoid the errors found in the results of Bisi and Braicovich[2], which are connected with different states of sample surface and with different amounts of impurities.

The ratio of the electron and positron reflection coefficients as a function of the atomic number is shown in Fig. 1. For alloys, the effective atomic number was calculated by means of Eq. (1). As seen from Fig. 1, the results of Bisi and Braicovich, namely that the ratio of the reflection coefficients for light elements differs greatly from the ratio for medium and heavy elements, are confirmed. Equating this ratio for beryllium to unity, we see that for medium and heavy elements, starting with atomic numbers 25—30, it increases rapidly with increasing atomic number to a value close to the 1.30 obtained by Seliger[1]. The curve shown in Fig. 1 was obtained without additional filtration of the reflected radiation. Similar measurements were repeated by us many times with aluminum filters from 2 to 117 mg/cm^2 thick, placed in the path of the reflected radiation. In addition, similar curves were also plotted using an ionization chamber as the detector.

In all cases, the obtained reflection-coefficient-ratio curves were similar to that shown in Fig. 1. These curves show also a rapid growth of the coefficient ratio at small values of Z, and a nearly constant ratio at medium and large Z, although the magnitude of their ratio differed for different filter thicknesses, owing to the different maximum energies of the electron and positron sources.

As to the reflection of the positrons from multicomponent systems, the Muller relation[4] is satis-

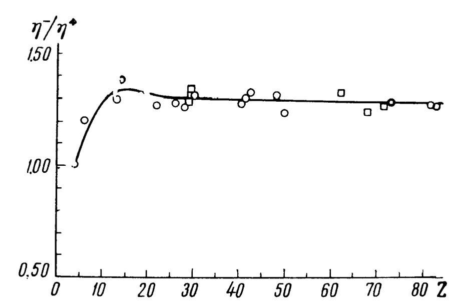

FIG. 1. Ratio of electron reflection coefficient (Tl^{204} source) to the positron reflection coefficient (Na^{22} source) as a function of the atomic number: ○ – element, □ – alloy.

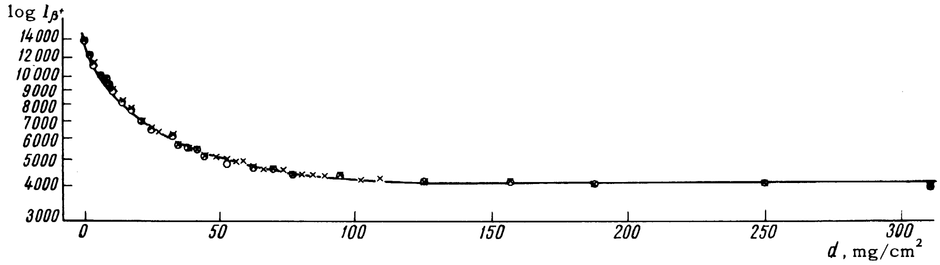

FIG. 2. Intensity of Na^{22} radiation reflected from a tin-lead alloy with effective atomic number 73 (calculated by Muller's formulas [4]) and from tantalum (atomic number 73) at different aluminum-filter thicknesses: o – tantalum, x – tin-lead alloy. The γ background was not subtracted from the instrument readings.

fied for heavy and medium elements. In this connection, the use of positron reflection for chemical analysis of multicomponent systems at such values of the effective atomic number yields no new information whatever concerning the composition of the substance, and cannot be used in conjunction with electron reflection for an analysis of three-component systems.

Nor does the use of filters allow the reflection due to the heavy component to be separated. Figure 2 shows the experimental plot of the attenuation of the positron radiation reflected from a two-component lead-tin alloy with effective atomic number 73, as calculated from formula (1), obtained for 37 different filter thicknesses from 0 to 314 mg/cm^2. The same figure shows for comparison the attenuation curve of the positron radiation reflected from pure tantalum, whose atomic number is also 73. As seen from the figure, the attenuation curves for the pure element and from the alloy coincide throughout. Nowhere on the curve is it possible to separate the intensity of the positrons reflected from the heavy component (lead). The same was established for the reflected-radiation attenuation curves for the 79NM5 alloy, whose effective atomic number is 28.6.

For light elements, where the change in the positron coefficient with change of the atomic number is governed by a different law than that for the electron reflection coefficients (Fig. 1), it would be premature to deduce the validity of the Muller relation for positron reflection. However, we were unable for the time being to establish the law of positron reflection from multicomponent systems in this interval, owing to the experimental difficulties connected with the presence of a strong γ background, low intensity of reflected radiation, etc., which become more pronounced in this interval.

Danguy[5] reported that nickel has an anomalous reflection coefficient, exceeding by 0.5% the reflection coefficient of the neighboring element in the periodic system, copper. We measured the intensity of reflected radiation using both positron and electron β sources, for three samples of nickel and three samples of copper, each of which was obtained in different places, so as to exclude any doubts concerning the chemical purity of the sample.

In all cases, using end-window counters and ionization chambers, with and without filters, the reflection intensity of both electrons and positrons was higher for copper samples than for nickel ones, thus contradicting Danguy's data.

[1] H. H. Seliger, Phys. Rev. 88, 408 (1952).

[2] A. Bisi and L. Braicovich, Nucl. Phys. 58, 171 (1964).

[3] W. Paul and H. Steinwedel, in: Beta and Gamma Spectroscopy, K. Siegbahn, ed. (Russ. transl.), Fizmatgiz, 1959, p. 19 [North Holland, 1955].

[4] R. Muller, Phys. Rev. 93, 891 (1954).

[5] L. Danguy, Inst. Internat. Sci. Nucl., Monograph No. 10, 1962.

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