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Abstract

Full Text

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PHYSICS

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ENERGY AND INTENSITY IN MULTIPLE BACKSCATTERING OF BETA PARTICLES ON NUCLEI OF VARIOUS ELEMENTS

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The phenomenon of single backscattering of beta radiation by the nuclei of elements with different atomic numbers Z has been well studied ([1–4]). This phenomenon is widely used in technology both for determining the content of components in binary mixtures and for determining coating thicknesses ([3]). In ([5,6]) it was shown that the sensitivity of the first of these methods increases markedly when repeated backscattering of β-particles from another surface of the target under investigation is used. Still more promising is the application of multiple backscatterings.

Fig. 1. Schematic of the setup for obtaining multiple backscatterings of β-particles.
a —even number of backscatterings; *b* —odd number of backscatterings.
1 —investigated scattering targets; 2 —thallium-204 β-source; 3 —detector of backscattered β-radiation (BFL-25 counter); 4 —Plexiglas partitions; 5 —aluminum absorber-filters.

To carry out such multiple scatterings, the apparatus whose scheme is shown in Fig. 1 was used. Figure 1a gives the scheme of the apparatus when an even number of backscatterings is produced (the source is turned with its active layer upward), and Fig. 1b—when an odd number is produced (the source is turned with its active layer downward). According to this scheme, 1, 2, and 3 backscatterings of beta particles from the investigated targets with different atomic numbers Z were produced, and by the absorption method ([7]) the maximum energy of different numbers of times backscattered electrons was determined ([8]).

Fig. 2

Figure 2: Fig. 2

In addition, as was shown in ([6]), against the background of twice-backscattered β-particles, from attenuation curves one can determine the intensity and the maximum energy of β-particles that have undergone a fourfold backscattering, and for a lead target—a sixfold backscattering from

of the measured object, which also arises in such arrangements. Similarly, against the background of triply backscattered electrons for a lead target, one can determine the intensity and maximum energy of electrons that have undergone quintuple backscattering from the object under investigation.

A thallium-204 β-source was used; the measurements were made with a BFL-25 end-window counter. The results of determining the maximum energy for single and multiple backscatterings are given in Table 1 and in Fig. 2. Along the abscissa are plotted the atomic numbers Z of the targets investigated; along the ordinate, the ratios of the maximum energies of the backscattered β-particles to the maximum energy of the source (on a logarithmic scale).

Fig. 2. Dependence of the ratio of the maximum energy of backscattered β-particles E_i to the maximum energy of the β-source E_0 on the atomic number of the target Z, for different numbers of backscatterings i: 1 —single scattering; 2 —double; 3 —triple; 4 —quadruple.

As is seen from Fig. 2, just as in single backscattering ([9]), the relation between the ratio of the maximum energy of backscattered β-particles E_i to the maximum energy of the β-source E_0, as a function of the atomic number of the target Z, can be expressed by a power function:

$$E_i/E_0 = B_i Z^{k_i}, \tag{1}$$

where B_i is a constant coefficient.

The values of B_i, k_i for 1-4 backscatterings are given in Table 1, and also in Fig. 3. If for single backscattering the relation

$$E_1 = B_1 Z^{k_1} E_0, \tag{2}$$

is fulfilled for the maximum energy E_1, then for double backscattering the maximum energy E_2 must satisfy

$$E_2 = B_1 Z^{k_1} E_1 = (B_1)^2 Z^{2k_1} E_0$$

and for the maximum energy E_i of each i-th backscattering:

Fig. 3. Dependence on the number of backscatterings i of the exponents k and n in formulas (1) and (5), and of the coefficient B (on a semilogarithmic scale) in formula (1)

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$$E_i = (B_1)^i Z^{ik_1} E_0. \tag{3}$$

Table 1

Ratio of the maximum energy of backscattered β-particles to the maximum energy of the β-source, in percent, and values of the exponents k, n and coefficient B in formulas (1), (5), depending on the number of backscatterings i, according to experimental data

Backscatterings	i	C	Al	Ti	Fe	Ni	Cu	Mo	Cd	Sn	Pb	B_i in (1)	k_i in (1)	n_i in (5)
Single	1	50.5	57.8	–	63.4	–	65.2	–	–	68.0	73.5	0.39	0.144	0.67
Double	2	23.6	28.2	39.2	39.5	–	40.6	44.5	49.0	49.7	52.5	0.155	0.29	1.58
Triple	3	–	–	–	30.0	31.0	31.4	36.0	38.2	–	51.0	0.070	0.45	2.59
Quadruple	4	–	–	–	17.1	–	18.4	21.0	22.3	22.3	32.8	0.023	0.58	3.35
Quintuple	5	–	–	–	–	–	–	–	–	–	11.0	–	–	–
Sextuple	6	–	–	–	–	–	–	–	–	–	12.0	–	–	–

If formula (3) is valid, then the dependence of the constant coefficient B_i on the number of reflections i should be represented by a straight line on a semilogarithmic scale, and the dependence of the exponent k_i by a straight line on a linear scale. As can be seen from Fig. 3, such a regularity is indeed observed for 1-4 backscatterings, and these plots can be used to determine, by linear extrapolation, the coefficients B and k for a larger number of backscatterings. Let us estimate the maximum possible number of backscatterings of electrons when β-sources are used.

In Fig. 4, the experimental data on the maximum energies of backscattered β-radiation (in units of the maximum energy of the β-source) are extrapolated to the region of a larger number of backscatterings. For a lead target, the maximum energy for 5 and 6 backscatterings is given.

Fig. 3. Dependence on the number of backscatterings i of the exponents k and n in formulas (1) and (5), and of the coefficient B (on a semilogarithmic scale) in formula (1)

Let us conventionally take as the limiting energy of a multiply backscattered electron, at which it can still be registered, 1% of the maximum energy of the β-source. When a strontium-90 source is used, this will correspond to a maximum energy of 22 keV, and for ruthenium-106, 35 keV. As can be seen from Fig. 4, under this condition the limiting numbers of backscatterings are 6–7 for light elements (C, Al), 11 for medium elements (Cu), and 17 for heavy elements (Pb).

How valid these assumptions and extrapolations are will be shown by further experimental data, but the experimental material already available shows that the sixth reflection is not a limit for heavy elements.

The dependence of the intensity I on the atomic number of the target Z for single backscattering is also determined by the power-law dependence (8):

$$I_1 = A_1 Z^{n_1}, \tag{4}$$

where A_1 is a constant depending on the geometry of the setup.

Analogously to the derivation of formula (3), one should expect that for multiple backscatterings

$$I_i = \Omega (A_1)^i Z^{i n_1} = c_i Z^{n_i}, \tag{5}$$

where I_i is the intensity registered at the i-th backscattering; Ω is the geometric coefficient of utilization of the backscattered radiation; $c = \Omega(A_1)^i$ is a constant.

As can be seen from Fig. 3, where experimental data for 1–4 reflections are presented, the exponent n increases linearly with increasing number of backscatterings, i.e., formula (5) is valid.

The experimental data show that with each subsequent backscattering the output intensity, compared with the preceding backscattering, decreases by approximately a factor of 5 (depending on the geometry of the setup and on the atomic number of the target). For single backscattering, a source with an activity of 0.5 μcurie already has sufficient power for reliable registration; therefore, when sources are used

of the same power as in other γ- and β-methods, more than 10 backscatterings can be carried out.

Thus, the decrease in intensity at the entrance of the measuring device is not an obstacle to carrying out the number of backscatterings that is possible, under energy conditions, with the use of β-sources (Fig. 4). When electron accelerators are used, where it is possible to obtain a higher energy and a higher (pulsed) power of the electron beam, a larger number of backscatterings can be carried out than with the use of β-sources.

Fig. 4. Dependence of the ratio of the maximum energy of multiply backscattered β-particles E to the maximum energy of the β-source E for scattering

Fig. 4. Dependence of the ratio of the maximum energy of multiply backscattered β-particles E to the maximum energy of the β-source E for scattering targets of light (C; Al), medium (Cu), and heavy (Pb) elements. Logarithmic scale

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Thus, as a result of the experimental work carried out, the energy and intensity have been determined for 1–4 backscatterings (for heavy elements also 5 and 6 backscatterings), and empirical formulas have been derived that make it possible to calculate the maximum energy and intensity in multiple backscattering of electrons as functions of the atomic number of the scattering target and of the number of backscatterings.

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