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TRIPLE BACKSCATTERING OF ELECTRONS

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Abstract

Full Text

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PHYSICS

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TRIPLE BACKSCATTERING OF ELECTRONS

(Presented by Academician E. K. Zavoisky, 10 IV 1967)

The phenomenon of single backscattering of electrons from targets made of substances with different atomic numbers has been well studied^(1,2). This phenomenon is widely used in technology both for monitoring the thickness of films and coatings⁽³⁾ and for chemical analysis of two-component compounds, alloys, solutions, and powder mixtures⁽⁴⁾. In work⁽⁵⁾ it was shown that the sensitivity of chemical analysis will be considerably higher when double backscattering of electrons from the sample being measured is used.

Even more promising is the use for this purpose of the phenomenon, first obtained in the present work, of triple backscattering of electrons from the substance under study.

Before the experimental work was carried out, it could be assumed that the intensity of triple reflection depends considerably more strongly on changes in the atomic number of the element being measured, Z (in the case of a multicomponent compound or mixture, on the effective atomic number \bar{Z} , calculated by Mueller's formula⁽¹⁾), than in single or double backscattering, which should substantially increase the sensitivity of determining the composition of the sample being measured. However, only experiments could show whether the energy and intensity of the triply backscattered electrons would be sufficient for registration.

Fig. 1. Diagram of the apparatus for obtaining triple backscattering of electrons. **1, 2** —target-scatterers under investigation; **3** —sources (thallium-204); **4** —source holders; **5** —annular partition made of Plexiglas; **6** —source holders; **7** —exit aperture in the upper scatterer; **8** —aluminum-foil filters; **9** —detector (BFL-25 counter with mica-window thickness of 1 mg/cm²); **10** —lead plate for

protecting the detector when scatterer **2** is changed. Installation parameters: distance between scatterers **1, 2** –2.3 cm; counter **9**–scatterer **1** –6.8 cm; source–scatterer **2** –1 cm; between sources –11.8 cm; inner diameter of partition **5** –5 cm, height –1 cm; diameter of plates **1, 2** –14 cm; diameter of aperture **7** –1.8 cm.

Trajectories of registered electrons

The arrangement of the apparatus for obtaining triple backscattering of electrons is shown in Fig. 1. Plates made of the substance under investigation, **1** and **2**, were placed in parallel. An aperture **7** was drilled in the upper plate. The sources of electron β -radiation **3** (thallium-204) were placed around the periphery of the gap between the plates, with the active layer downward. The total ac-

The activity of the sources was 2 mCi. The source casings **4** shielded the upper scatterer **2**, and the annular Plexiglas partition **5** shielded the part of the surface of scatterer **1** located inside the partition from direct radiation from the source and allowed detector **9** to register electrons that had undergone triple reflection from the object being measured, whose trajectories are shown in Fig. 1, whereas streams of electrons scattered once or twice could not reach the detector. Absorbing filters **8** of aluminum foil of various thicknesses could be placed in the path of the electrons scattered three times backward. Along with the intensity of triple backscattering, detector **9** also registers the background. To determine the magnitude of the background intensity at each filter thickness, a second measurement was made in which a plate of a substance with a low reflection coefficient (Plexiglas, beryllium) was placed on the surface of the scatterer inside the annular partition. The intensity of triple backscattering was determined as the difference between these two measurements.

Fig. 2 Fig. 3

Fig. 2. Attenuation curve of the intensity of triple backscattering and of the background in aluminum filters (the scatterer is lead). **a** –total intensity of triple backscattering and background; **b** –background intensity

Fig. 3. Dependence of the maximum energy of triple-backscattered electrons on the atomic number of the scatterer

As can be seen from Fig. 1, with this measurement method only the third backscattering from the substance under investigation is excluded, and the identity of the conditions is fully preserved for such background components as the γ -background (bremsstrahlung of the source) and the background intensity due to scattering in the air gap between the plates of β particles that have undergone fewer than three backscatterings from the substance under investigation. Control experiments, in which, when measuring the background, the part of the specimen located inside partition **5** was cut out (in this case the beryllium plate was replaced by a column of air), showed that the background values measured with the air column practically completely coincide with the background values

measured with beryllium plates. This is natural, since the coefficients of single backscattering from beryllium (1,2) are an order of magnitude smaller than the reflection coefficients of the targets studied.

Figure 2 gives, in semilogarithmic coordinates, a characteristic attenuation curve of the intensity of the total radiation and of the background for different filter thicknesses. As is seen from Fig. 2, at small filter thicknesses the total intensity greatly exceeds the background, which indicates that the apparatus registers predominantly acts of triple scattering.

We take the filter thickness at which the total-intensity curve merges with the curve for the background intensity to correspond to the maximum range of electrons that have undergone triple backscattering, for example 120 mg/cm² for lead plates (Fig. 2). Knowing the maxi-

the minimal path length, by the Flammersfeld formula ⁽⁶⁾ we calculate the maximum energy of electrons of triple backscattering.

The attenuation curves of the intensity of triple backscattering of electrons in aluminum filters were taken using, as scatterers, targets made of 6 pure elements: lead, cadmium, molybdenum, copper, nickel, and iron. The thickness of the samples exceeded the saturation thickness of single backscattering, starting from which any further increase in the thickness of the layer under study no longer leads to an increase in the intensity of the backscattered radiation ⁽³⁾.

The results of determining the maximum energy of the spectra of electrons of triple backscattering are presented in Fig. 3 in logarithmic coordinates. As can be seen from Fig. 3, the dependence of the maximum energy of triple backscattering E_3 on the atomic number of the scatterer Z can be expressed by the formula

$$E_3 = 0.70Z^{0.45}E_0, \quad (1)$$

where E_0 is the maximum energy of the source electrons ($E_0 = 765$ keV).

The maximum energy of electrons that have undergone triple backscattering varies from 51% (for lead) to 30% (for iron) of the maximum energy of the source. When harder sources than thallium-204 are used, it will be possible to record the intensity of triple backscattering even with cylindrical counters of the STS type.

In Fig. 4, in logarithmic coordinates, the dependence is presented of the intensity of triple backscattering $I_{3\beta}$ (after subtraction of background) on the atomic number of the scatterer Z , for different absorber thicknesses in the path of the triply backscattered electrons to the counter. The upper straight line corresponds to filtration of the backscattered radiation only by the air gap between the lower scatterer 1 and the counter 9 (Fig. 1), as well as by the mica window of the end-window counter, whose thickness is equal to 1 mg/cm²; the other

three straight lines correspond to measurements in which aluminum filters were added to this initial thickness of absorbers.

Fig. 4. Dependence of the intensity of triple electron scattering (after subtraction of background) on the atomic number of the scatterer.

a – filter thickness 9 mg/cm², $n = 2.30$; *b* – 12 mg/cm², $n = 2.59$; *v* – 15 mg/cm², $n = 2.65$; *g* – 25 mg/cm², $n = 2.84$

As can be seen from Fig. 4, for the interval of atomic numbers 26–48 the dependence of $I_{3\beta}$ on Z can be expressed (as also for the intensity of single backscattering⁽³⁾) by a power function:

$$I_{3\beta} = AZ^n, \quad (2)$$

where A is a constant depending on the activity and maximum energy of the source, and also on the geometry of the setup. The exponent n varies for triple backscattering from 2.30 at an absorber thickness of 9 mg/cm² to 2.84 with an absorber of 25 mg/cm². It is substantially higher than the exponent n for single (0.67) and double (1.80) backscattering^(3,5).

The values of the intensity of triple backscattering for lead, as can be seen from Fig. 4, at all filter thicknesses lie much lower than the straight-

corresponding to equation (2). Whether such a deviation from the exponential dependence is explained by oxidation of the lead surface, or whether in this range of atomic numbers the dependence for other elements as well is not expressed by formula (2), can be established by measuring the intensity of triple backscattering from noble metals (gold, platinum), whose surfaces do not oxidize.

Thus, it has been experimentally demonstrated that the energy and intensity of triple backscattering of electrons are sufficient for registration by Geiger counters and, consequently, that on the basis of the phenomenon of triple backscattering sensitive methods can be developed for the analysis of two-component mixtures and chemical compounds.

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