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Dependence of α-particle backscattering on energy and source backing

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Abstract

Measurement of α-particle sources using 2π counting detectors requires corrections for backscattering, and these depend on the material used as source backing and on the α-particle energy. This dependence has been analyzed theoretically by some authors, although assuming some simplifying approximations. In this work, we analyze the dependence of the backscattering coefficient B on energy and source backing, but by means of the Monte Carlo simulation code SRIM, thus avoiding the simplifying approximations assumed in the theoretical models. To study the dependence on the backing, we simulated ^{210}Po point sources deposited on various backing materials with atomic numbers ranging from 4 to 79. The dependence on energy was studied by simulating α-particle point sources deposited on a platinum backing, with energies between 3 and 8 MeV. We found that the dependence of the backscattering coefficient B on α-particle energy and also on the mass number A of the backing approximately follows power function laws, in concordance with the theoretical models, although with exponents somewhat different from those established theoretically. In addition, although it was found that the scattering angle distribution is not Gaussian, our results confirm that there is a linear relationship between the backscattering coefficient B and the mean scattering angle Φ, as suggested by the Crawford theory.

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1. Introduction

As is known, in the measurement of α-particle sources, some particles emitted towards the backing may undergo large-angle deviations from the incident direction, mainly due to the cumulative effect of many weak scattering events with the backing nuclei. As a consequence, some α-particles are backscattered from the backing material, with the counting rate then being greater than one-half of the disintegration rate if 2π counting detectors are used for these measurements.

The first theory of α-particle backscattering was developed by Crawford [1], who assumed a multiple scattering process consisting of a large number of weak collisions with an approximately Gaussian distribution for the scattering angles. His work provided a lower limit for the backscattering coefficient. Lucas and Hutchinson [2] proposed a Gaussian scattering model to obtain an expression equivalent to that of Crawford. All these theoretical treatments have the limitation of assuming the multiple scattering process to be the only cause of the backscattering effects and, as a consequence, the strict assumption of a Gaussian distribution for α-particle scattering. In addition, the experimental determination of the backscattering coefficient is not straightforward and is subject to large uncertainties because the net contribution of the backscattered particles to the total count is low.

The main aim of this work is to study the dependence of the backscattering coefficient on energy and source backing, but using Monte Carlo simulation. This technique avoids the approximations made in the theoretical treatments of backscattering, and also the limitations and uncertainties associated with the determination by experimental measurements.

2. Monte Carlo simulation

We used the well-known Monte Carlo code SRIM, developed by Ziegler [3], version SRIM2003. The output

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of the program provides data on backscattering, recoil, sputtering, radiation damage, etc. This code has already been used by us for the study of scattering and self-absorption in the field of α-particle spectrometry [4–6].

Backscattering coefficients were obtained by simulating α-particle point sources located just on the surfaces of the backings. In each simulation, a total of 90,000 α-particles were assumed to be emitted towards the backing, being uniformly distributed over a solid angle of 2π sr. The SRIM program follows the track of each particle in the backing and keeps their final characteristics in various result files. The corresponding backscattering coefficient was calculated dividing the number of backscattered particles (number directly provided by SRIM) by the total of particles emitted towards the backing. Each value of the backscattering coefficient was obtained as the mean of the results of three individual simulations, using different random number seeds. The simulation time for each individual simulation was of the order of 2 h on a personal computer.

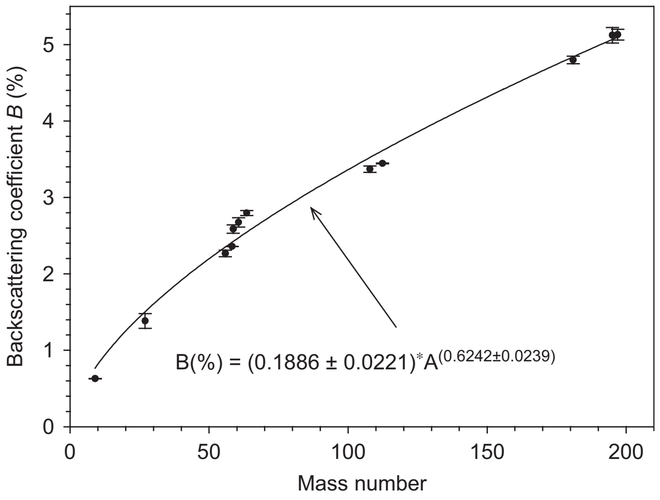

Fig. 1. Values of the backscattering coefficient for ^{210}Po α-particles in various backing materials versus mass number. Uncertainties correspond to one standard deviation. The line represents the fit to the equation $B = a\,A^b$.

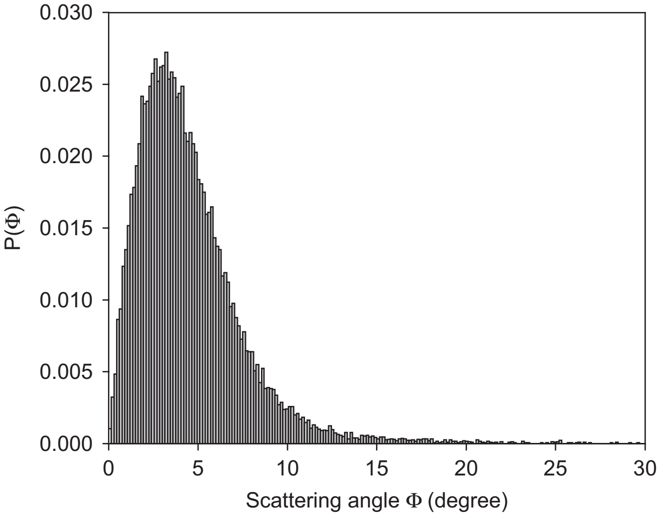

Fig. 2. Scattering angle distributions for a 5.305 MeV α-particle beam, which penetrates into an Ag target normally to the surface. The distribution is normalized to unity.

3. Results and discussion

3.1. Dependence of source backing

To analyze the dependence of the backscattering coefficient on the source backing, we considered a ^{210}Po point source (5.305 MeV) deposited onto 11 different supports, from Be to Au, with the purpose of covering materials with a wide range of mass numbers. The composition of the stainless steel backing was 56% Fe, 22% Co, and 22% Ni. The values obtained for the backscattering coefficients are shown in Fig. 1 versus the mass number of the backing. In agreement with the Crawford theory, the dependence on the backing is reasonably well represented by an equation of the type $B = aA^b$, with A being the mass number of the backing material. Fig. 1 shows the best fit to this equation, giving a correlation coefficient $r^2 = 0.9916$ and an exponent $b = 0.6242 \pm 0.0239$. This value of the exponent b is in agreement with the value obtained by Berger in an earlier study [7] ($b = 0.628$), who considered a ^{210}Po point source (5.305 MeV) deposited onto 37 different supports. However, it is slightly different from that given by the Crawford theory ($b = 0.75$). This small discrepancy could be explained by taking into account that the value of 0.75 was derived theoretically by Crawford by assuming the Bragg–Kleeman law to be exact, although it may have an uncertainty of up to 15%. Because this law is less imprecise when it is applied to a narrower range of atomic weights, we fitted independently the values corresponding to the heaviest metals (Ag, Cd, Ta, Pt, and Au) and those corresponding to the lightest materials (Be, Al, Fe, stainless steel, Ni, and Cu). The results of the fits to the aforementioned equation are now more in agreement with the value given by Crawford for the exponent b

$$b = 0.7044 \pm 0.0113 \quad r^2 = 0.9993 \quad (A = 108 - 197)$$
$$b = 0.7664 \pm 0.0831 \quad r^2 = 0.9814 \quad (A = 9 - 64).$$

Crawford theory is also based on the assumption that the scattering angle distribution is Gaussian. In order to study this aspect, we have also simulated a beam of ^{210}Po α-particles impacting normally on the surface of each backing. Target thicknesses were chosen in order for the particles to be stopped into the material. Analyzing the final positions of the particles in the targets, we obtained the scattering angle distributions. Fig. 2 shows, by way of example, one of these distributions, which is clearly asymmetrical and non-Gaussian. This last discrepancy

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