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SOME APPLICATIONS OF THE ELECTRON BACKSCATTERING DIFFUSION MODEL

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ABSTRACT

Starting from a simple diffusion theory extended to oblique angles of incidence some empirical correction coefficients for electron backscattering have been found. These empirical coefficients have been used in calculations of backscattered electron surface density distribution, and good agreement with experimental data has been obtained.

Keywords: Electron scattering, diffusion theory, backscattered electrons, backscattering coefficient, surface density distribution.

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INTRODUCTION

Several theoretical and phenomenological approaches have been used for investigations of electron penetration into solid targets and the backscattering effects. Exact theoretical treatment of backscattering is very complicated. The best results have been obtained by means of Monte Carlo methods. These numerical methods are extremely laborious and require numerical evaluation for each particular case. Therefore, a simple and sufficiently accurate description of electron scattering in solids may be useful for many situations. One of the most simplified treatments is the diffusion sphere approach of Archard (1961) and modifications of his model by Tomlin (1963) and Kanaya and Okayama (1972). These theories are concerned with the backscattering coefficient at normal incidence. There were also attempts to extend the diffusion sphere approach. Radzimski (1978) obtained an equation for the backscattering coefficient as a function of angle of incidence.

The theoretical treatments of electron backscattering using the diffusion sphere models, apart from their simplicity, do not give accurate quantitative values for the backscattering coefficient. The results of Radzimski's work, based entirely on the Kanaya and Okayama theory, also fail when applied to a wide range of atomic numbers. There is very little hope that the diffusion model could be successfully used for accurate calculation of the backscattering parameters without major modifications. However, close examination of the results of Radzimski compared with experimental results indicates that introduction of proper empirical correction factors may be promising.

This work presents an attempt to improve the diffusion model by means of empirical coefficients and to apply this improved model for estimation of the backscattering coefficient for various angles of incidence using the Radzimski formula and also for calculation of the surface distribution of backscattered electrons.

BACKSCATTERING FOR VARIOUS ANGLES OF INCIDENCE

Radzimski (1978) presented an extension of the Kanaya and Okayama (1972) theory for backscattering coefficient η_B as a function of incidence angle, α. He obtained a formula similar to that of Bruinning used for secondary electrons (Darlington, 1975).

$$\eta_B = \eta_0 \exp [A_0 (1 - \cos \alpha)] \quad (1)$$

where η_0 is the backscattering coefficent at normal incidence and

$$A_0 = \gamma_B \frac{y_e}{1 - y_e} \quad (2)$$

the parameter $\gamma_B = n\gamma$ is the absorption coefficient for backscattered electrons,

$\gamma = 0.187\ Z^{2/3}$ is the absorption coefficient for forward scattered electrons,

n = 1.9 is coefficient, $y_\theta = x_\theta / R$ is the reduced maximum energy dissipation depth, and R is the electron range derived from the energy-loss equation

$$R = 5.025 \times 10^{-12} \frac{A \cdot E^{5/3}}{\varrho \cdot \lambda_s \cdot Z^{8/9}} \quad (3)$$

where A is atomic weight, Z is atomic number, E is the initial electron energy in eV, ϱ is the target density in gcm^{-3} and $\lambda_s = 0.182$ is an empirical constant.

The maximum energy dissipation depth is given by the formula

$$x_e = \frac{R (1 + 2\gamma - 0.21\gamma^2)}{2 (1 + \gamma)^2} \quad (4)$$

The maximum energy dissipation depth has been taken by Kanaya and Okayama (1972) as the depth of the diffusion sphere centre instead of the diffusion depth as in the Archard (1961) model.

Equation (1) underestimates the experimental results in the region of low atomic numbers and overestimates the results for the high values of Z up to 100%. Radzimski suggested that a better agreement should be obtained if the values of X_θ and γ_B were properly modified. Similar suggestions were made also by Neubert and Rogaschewski (1980). Following these suggestions an empirical formula for γ_B has been found

$$\gamma_B = k\gamma \quad (5)$$

where $k = (Z)^{(80/Z^2)}$

and subsequently a formula for corrected depth of diffusion sphere centre x_{RC}

$$x_{RC} = 2.558 \cdot R \cdot \left[1 - \exp \left(- (0.5 + 0.1Z) \right) \right]^2 \left(\frac{\ln Z}{Z^{2/3}} \right)^2 \quad (6)$$

The value of k for Al (Z = 13) is 3.367 and for U (Z = 92) is 1.043. In Fig. 1, the values for A_0 calculated from equation (2) using X_{RC}/R and k instead of y_θ and n are compared with those calculated from experimental results using equation (1). It should be noted that equations (2) with (5) and (6) give very good values of A_0 in the entire range of atomic numbers above Z = 10. Values of $\eta_B(\alpha)$ calculated from equations (1), (2), (5) and (6) compared with experimental results are shown in Fig. 2. The differences between calculated and experimental values do not exceed a few percent.

SURFACE DISTRIBUTION OF BACKSCATTERED ELECTRONS

The model for these calculations is based on that proposed by Kanaya and Okayama (1972) with corrections described in the previous section, i.e., the centre of the diffusion sphere is located at the depth x_{RC} (Fig. 3). The basic assumption is that the surface density distribution of backscattered electrons is the result of intersection of the sphere by the surface plane and the scattered electrons obey an exponential absorption law. Thus the electron density on the sphere surface is

$$\frac{d\eta_B}{d\Theta} = F(x_{RC}) = B \exp(-\mu x_{RC}) \quad (7)$$

where B is the density of scattered electrons on the surface of sphere with radius x_{RC} in the absence of absorption of electrons, Θ is the coordinate, and μ is the linear absorption coefficient.

An increase of sphere radius means a decrease of surface density due to the increased area of the sphere surface and also because of the increased thickness of the target material to be passed through. If the increased sphere radius is x, then

$$F(x) = F(x_{RC}) \cdot \left(\frac{x_{RC}}{x} \right)^2 \exp(-\upsilon x) \quad (8)$$

We are interested in the surface distribution of the backscattered electron density which may be found as a result of intersection of a sequence of concentric spheres by the surface plane. A suitable relation may be found from simple geometrical calculations:

$$F(r) = F(x_{RC}) \cdot \left(\frac{x_{RC}^2}{x_{RC}^2 + r^2} \right)^m \cdot \exp\left(- \mu \cdot \sqrt{x_{RC}^2 + r^2} \right) \quad (9)$$

For regular spheres with a uniform surface density distribution of electrons m = 3/2. However, it has been found that the best fit may be obtained for

$$m = \frac{5.34}{Z^{2/3} (0.23 + r/R)} \quad (10)$$

and

$$\mu = \frac{k (1 + \gamma)}{R} \quad (11)$$

Theoretical results compared with some experimental data are shown in Fig. 4.

DISCUSSION

Comparison of the experimental and theoretical results

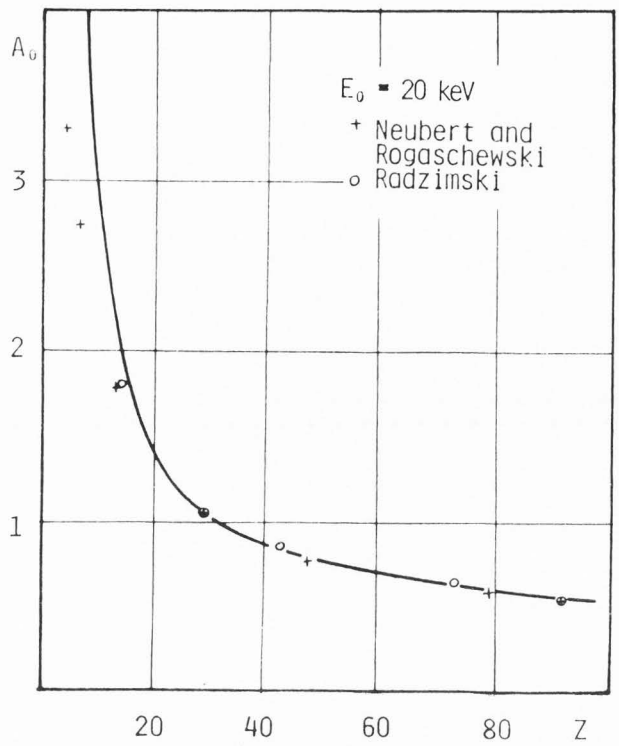

Fig. 1. Parameter A_0 vs atomic number (solid line) calculated from equations (2) using (5) and (6) compared with values of A_0 calculated from experimental data.

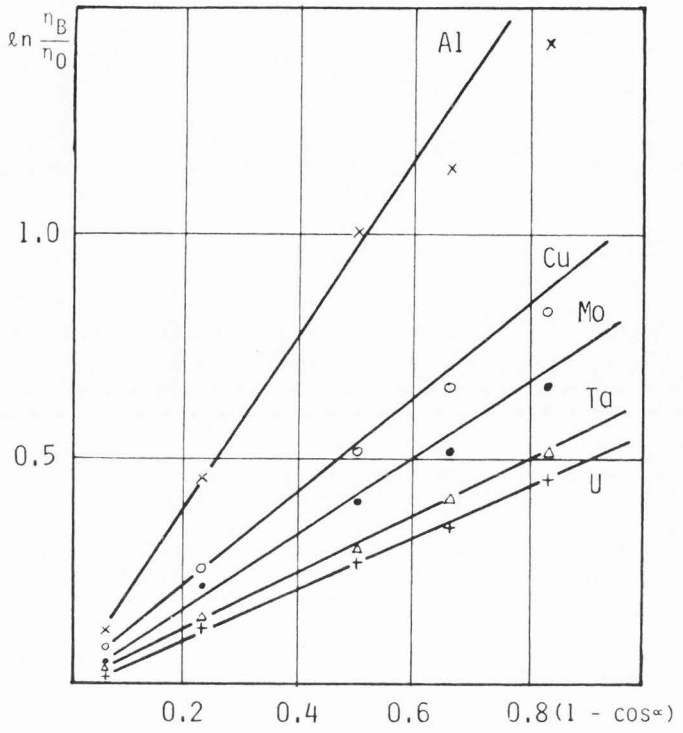

Fig. 2. $\ln \eta_b/\eta_0$ vs angle of incidence (solid line) compared with the data of Neubert and Rogaschewski (1980) for Al, and Radzimski (1978) for Cu, Mo, Ta and U.

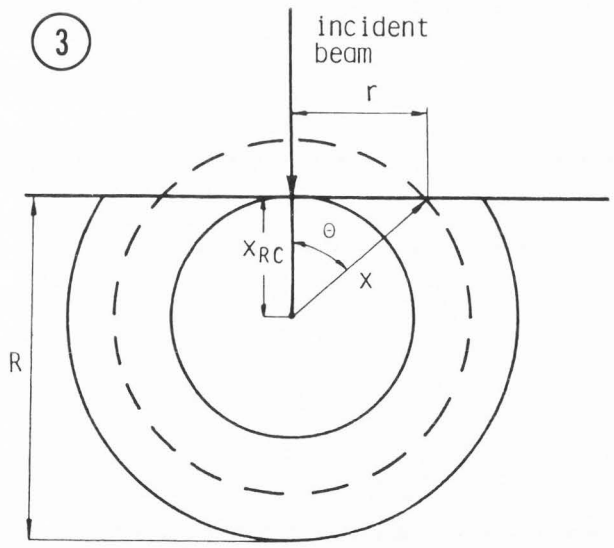

Fig. 3. Model for calculation of the surface distribution of the backscattered density.

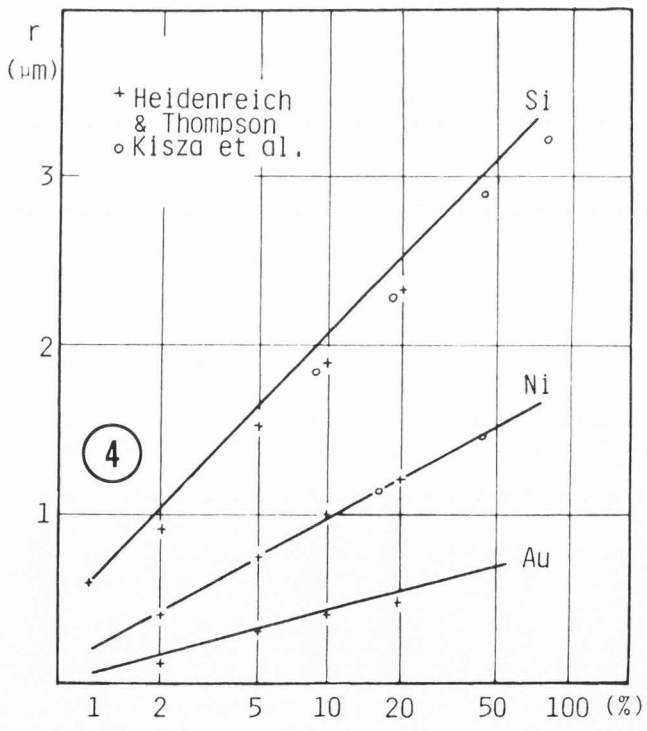

Fig. 4. Relative surface density of backscattered electrons with various distance ℓ from the point of incidence (solid line) compared with experimental results of Heidenreich and Thompson (1973) and Kisza et al. (1981).

shows a good agreement in both of the cases considered. It should be noted that in two entirely different problems the same empirical formulas for x_{RC} and k have been used. It does not mean that such a simple diffusion model gives a good qualitative idea of the physical process. However, the exponent m in equation (9) may have some physical meaning. For a regular sphere with uniform electron density distribution on its surface, the value of m should be 3/2. Deviation from this value may be considered as non-uniform density distribution on the sphere surface. This may explain why the backscattering coefficient calculated with the diffusion model does not agree with experimental values for both high and low atomic numbers of elements.

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