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GRAPHICAL ANALYSIS FOR RUTHERFORD BACKSCATTERING SPECTRA*

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ABSTRACT. A graphical method was developed to relate data from Rutherford Backscattering Spectrometry to sample characteristics, such as thickness and concentration profiles. The method was then applied to analyse characteristic of a gold film. (Author)

RESUMO. Um método gráfico foi desenvolvido para determinação de características de uma amostra, tais como espessura e perfis de concentração, a partir de dados obtidos na Espectrometria de Ions por Retroespalhamento de Rutherford. O método gráfico foi então aplicado para determinação de espessuras de um filme de ouro. (Autor)

I. INTRODUCTION

The Rutherford Backscattering Spectrometry (RBS) has been increasingly applied as an analytical tool for sample analysis. Several approaches are employed to relate experimental information to sample properties such as thickness and concentration profiles of component elements$^{1)}$.

The experimental data from RBS are essentially the energy of the scattered ions and the corresponding scattering yields. The incident ion before being actually scattered in a nuclear collision (NC) looses energy in multiple collisions with atomic electrons, and a similar process occurs, after the NC, along the outgoing path. As a consequence, the

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energy of the detected particles do not correspond to the energy of those particles scattered undergoing only one elastic NC.

The energy E_o of the incident particle before penetrating the sample, and the energy E_1 of the colliding ion just before the NC can be related by the following expression:

$$E_1 = E_o - \int_0^{t/\cos\theta_1} (dE/dx)dx \qquad (1)$$

where dE/dx is the stopping power of the sample material along the ingoing path, t is the depth lenght at which the NC takes place, and θ_1 is the angle of incidence of the particles, as illustrated in figure 1.

The energy E_s of the emerging particle can be evaluated similarly from the energy E_2 of the ion just after the NC, taking into account the energy loss along the outgoing path. Hence, E_s can be expressed as:

$$E_s = E_2 - \int_0^{t/\cos\theta_2} (dE/dx)dx \qquad (2)$$

where dE/dx is the stopping power along the outgoing path, and θ_2 is the particle angle of emergence, as illustrated in figure 1.

The energy E_2 is usually expressed as:

$$E_2 = KE_1 , \qquad (3)$$

where the kinematic factor K is given by

$$K = \left(\frac{\cos\theta + \sqrt{\mu^2 - \mathrm{sen}^2\theta}}{1 + \mu}\right)^2$$

$\theta = \pi-(\theta_1+\theta_2)$ is the scattering angle measured in the laboratory frame of reference, and μ is the ratio of the atomic mass of the target element to the mass of the incident ion.

The present work proposes a graphical method to determine promptly the particle energies E_1 and E_2, and the depth length t where the NC occurs from the observed scattered particle energy, E_s, and the incident particle energy, E_o.

II. THE GRAPHICAL METHOD

The energy loss due to collisions with atomic electrons can be determined with the aid of the energy variation as a function of penetration depth, the energy depth curve, which is obtained from tabulated data for range and stopping power$^{2)}$ for specific incident ions and target samples.

The input data to apply the proposed graphical method are the incident ion energy, the measured scattered energy and the energy-depth curve.

Figure 2 represents a hypothetical energy-depth curve. The depth associated to the incident energy E_o is chosen to be $x_o = 0$; the depth associated to the emerging energy E_s is called x_s. The intermediate energies E_1 and E_2, such that $E_2 = KE_1$ correspond to depths x_1 and x_2 respectively. Assuming that x_1 and x_2 are chosen, in such a way that these values simulate an actual experiment, one can write

$$\frac{x_1}{x_s - x_2} = \frac{\cos\theta_2}{\cos\theta_1} = \beta \qquad (4)$$

and therefore the depth length t where the NC occurred can be written as

$$t = x_1 \cos\theta_1 = (x_s - x_2)\cos\theta_2 \tag{5}$$

The values of E_1, E_2 and t which correspond respectively to x_1 and x_2 to satisfy equations (1), (2) and (5) can be obtained by means of successive iteractions.

Starting the iteractive process with an arbitrary length Δx_{in} along the ingoing path with origin on the target surface and the related length $\Delta x_{out} = \beta^{-1} \Delta x_{in}$ along the outgoing path, measured from the NC site towards the target surface. The first values for Δx_{in} and $(x_s - x_{out})$ correspond to energies E_o^1 and E_s^1, respectively. If the ratio $E_s^1/E_o^1 \neq K$, new lengths Δx_{in} and Δx_{out} are chosen to start another iteraction, and the procedure in repeated n times until $E_s^n/E_o^n = K$.

In practice Δx is chosen as a small increment. Thus, one can write,

$$x_o^n = x_o + n\,\Delta x_{in} \tag{6}$$

where n is an integer.

Analogously

$$x_s^n = x_s - n\beta^{-1}\,(\Delta x_{in}) \tag{7}$$

The difference $x_s^n - x_o^n$ represents the thickness of a ficticious slab of the material for which the incident energy is E_o^n and the emerging energy is E_s^n. It represents the energy lost in the NC.

The ratio E_s^n/E_o^n is checked for each value of n, if $E_s^n/E_o^n \neq K$ we take the next value of n until the equality is obtained. Then the depths x_o^n and x_s^n correspond to x_1 and x_2, respectovely, and E_1, E_2 and t are determined.

Graphically the procedure described above can be easily implemented by taking a pair of axis defined by the ingoing energies (the set E_o^n) as y-axis and by the outgoing energies (the set E_s^n) as the x-axis. Figure 3 shows the graphical procedure applied to determine E_s^n for 38.8 MeV ^{40}Ar ions backscattered on a Cu sample, as example. The intersection of the curve E_o^n as function of E_s^n by the straight line with slope equal to K defines the pair of energies (E_1, E_2) just before and after the NC. Taking these energies to the E(x) curve of Figure 2, one can determine x_1 and x_2, to insert into equation (5) to find t (thickness of the sample).

APPLICATION

A gold film deposited into a mylar backing was bombarded with a 2 MeV proton beam produced by a 4 MV Van de Graaff accelerator. The scattered particles were detected by a sillicon barrier detector (15 KeV-FWHM, at 5.4 MeV of Am^{241}) at an angle of 135° relative to the direction of the incident beam.

The gold film thickness was determined from the scattered particle spectrum by two different methods, the numerical method developed by Dhere et al[3]) and the graphical method described in the proceeding section. The mylar backing thickness was determined from the peak corresponding to scattered protons by Carbon nuclei of the mylar.

The results obtained by the two methods for the thickness of both the gold film and the mylar backing are presented at Table I. The error associated to the graphical method is essentially due to the error in the stopping power values and to the scale used for the curves. The energy of the incident ion on the gold-mylar interface was considered as the beam incident energy corrected for the energy loss in the gold layer along the ingoing path. The scattered ion energies due to collisions on mylar film back interface were determined from experimental scattered energies corrected for the energy loss on gold film. These data, E_s^n and E_o^n, were then used to determined the thickness of the mylar backing foil.

IV. CONCLUDING REMARKS

The graphical method, introduced in this article, besides providing a fast answer for thickness determination, can be easely developed into a computational code where the energy-depth curve E(x) is replaced by a polinomial adjusted function. A code was developed accordingly and implanted into a PDP-11/40 computer.

REFERENCES

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TABLE I - Thicknesses of gold and mylar films in mg/cm^2 obtained by graphical method and numerical integration. The two indications for the mylar are for the thicknesses as measured by carbon and oxigen data.

Film		Graphical Method mg/cm^2	Numerical Integration mg/cm^2
Au		0.96±0.10	0.96 ± 0.12
Mylar	C	0.58±0.05	0.96 ± 0.07
	O	0.60±0.05	-

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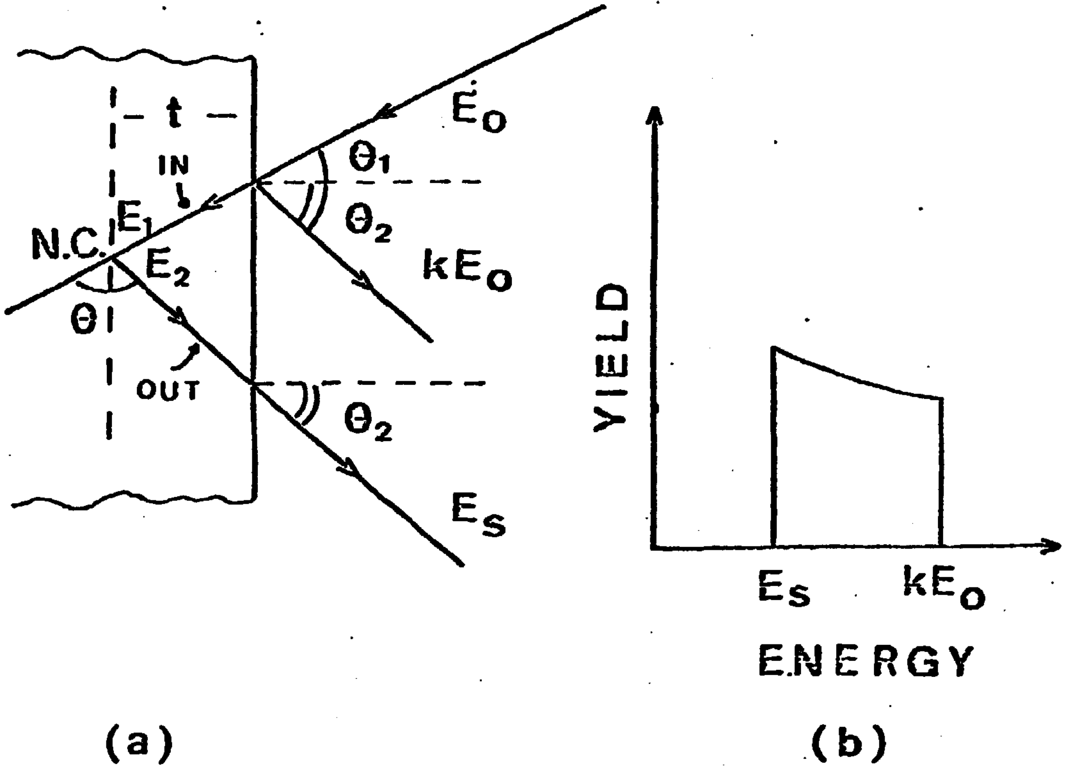

Figure 1. (a) Schematic representation of a IRBS experimental; (b) schematic representation of an energy spectrum of detected particles.

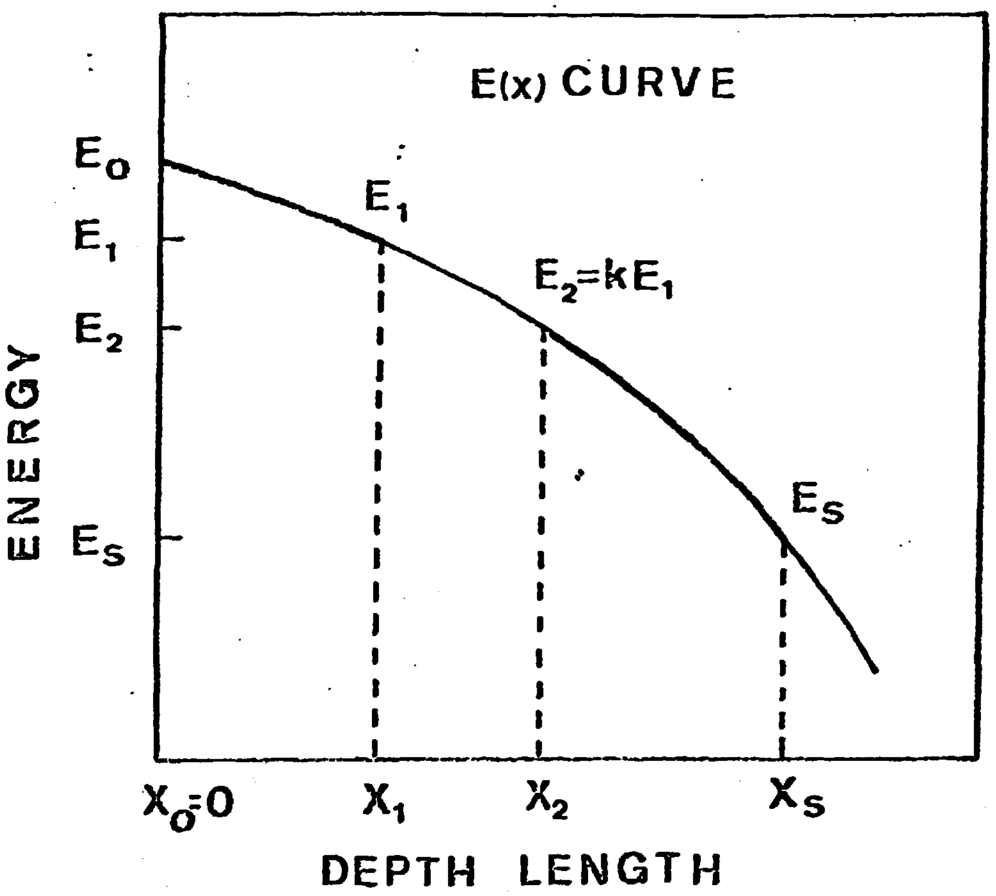

Figure 2. Hypothetical energy depth curve.

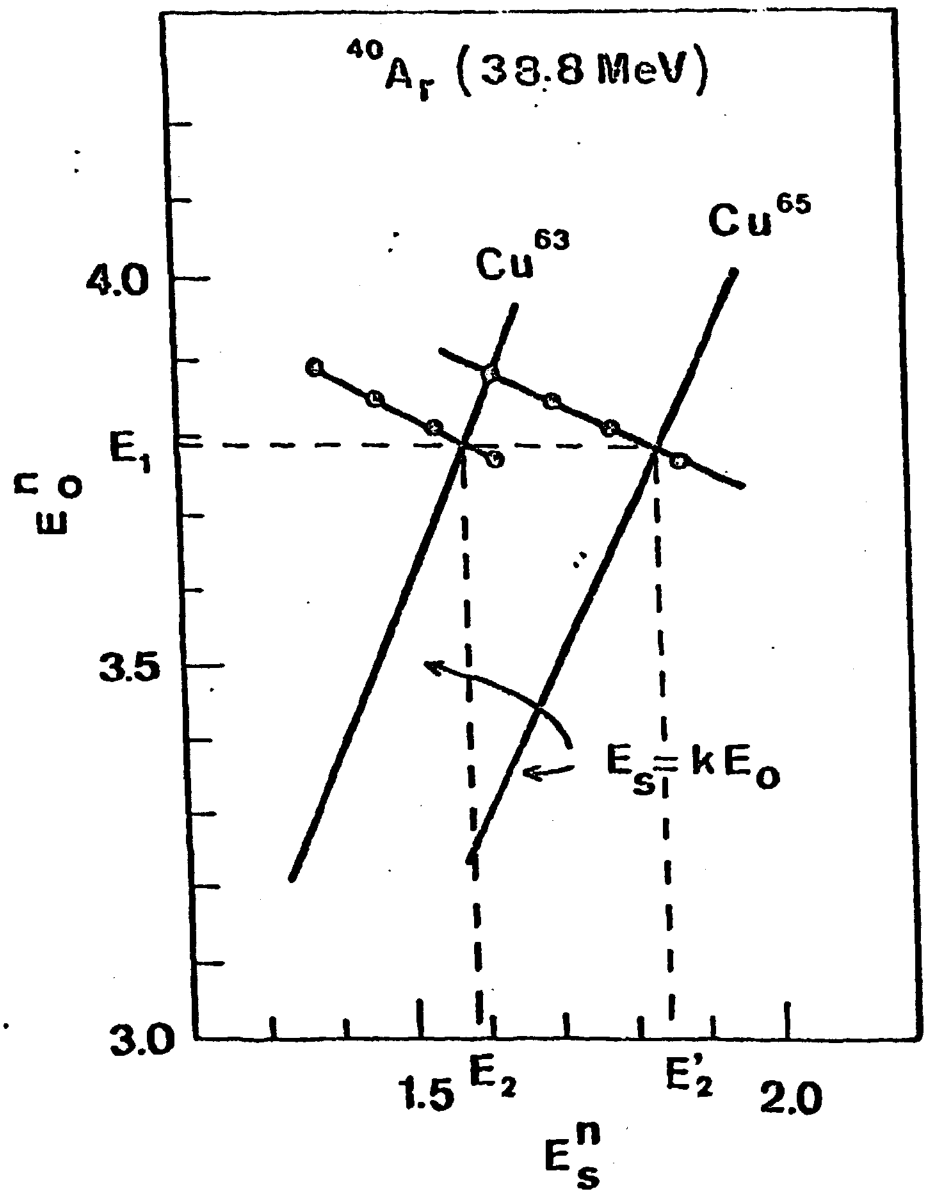

Figure 3. Graphical procedure to determine E_s. The two values E_2 and E_2' are the energies after the nuclear collision of an Ar^{40} ion with Cu^{63} and Cu^{65} nuclei in a copper sample.