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# THE TRANSMISSION OF THE ELECTRON ANALYZERS DETERMINED BY ELASTIC PEAK ELECTRON SPECTROSCOPY

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Using the elastic peak electron spectroscopy (EPES), the transmission functions were determined for the 4-grid retarding field and the hemispherical analyzers, which are commonly used for surface physics experiments.

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## 1. Introduction

The spectral response (or transmission function)  $T(E)$  of an electron spectrometer corresponds to the ratio between the signal at the entrance of the apparatus to the one recorded by detector. Depending on the kinetic energy  $E$  of the particles,  $T(E)$  is an important parameter in quantitative surface analysis. The transmission of any electron spectrometer is determined by its electron optics and design dimensions and can be affected by the mode of operation [1]. Several methods have been used for determining  $T(E)$ , e.g. by applying an electron gun in front of the spectrometer, as it was described by Bas et al. for the cylindrical mirror analyzer (CMA) [2], Hughes et al. for the hemispherical analyzer (HSA) [3] and Schmid et al. for the retarding field analyzer (RFA) [4] or by using photoelectron signals excited by X-rays, as it was done for HSA by Osterwalder et al. [5].

The goal of our paper is to present a method which was applied to testing the spectral responses for two electron spectrometers: the RFA of the Riber

OPR 304 type and a nonconventional HSA. The spectral responses of conventional electron spectrometers have been already described by a number of authors [2-4]. In general, spectral responses of the retarding field analyzers are different due to differences in the construction of their grids. The spectral response of the HSA is mostly affected by its aperture system and operating parameters [5]. The calibration of the spectrometer with an electron gun requires a special gun with isotropic electron emission [2]. The method described in our paper can be applied to any type of electron spectrometer equipped with an electron gun, e.g. for Auger electron spectroscopy (AES). It is based on the elastic scattering of primary electrons on a sample surface.

The elastic peak electron spectroscopy (EPES) is a recent method of surface analysis [6-9], and deals with the elastic interaction of electrons in a thin surface layer. The practical formulation of EPES is based on the single elastic scattering approach and on the atomic layer model. The intensity of elastically reflected electrons, appearing in the elastic peak, is determined by the atomic numbers of the sample atoms, the energy of scattered electrons  $E$ , the angular conditions and also by the arrangement of the atomic planes [10]. This method of quantitative interpretation of EPES results was proved to be useful in studies of binary compounds [9].

Multiple elastic scattering is less important for a sample of low atomic number [11]. By using the Monte Carlo method, it is possible to deduce the quantity  $R(E)$  denoting the ratio of the number of multiple scattering events to those of signal elastic scattering.  $R(E)$  is determined by the sample material and the energy  $E$ . For carbon  $R(E)/R(400)$  is nearly constant in the energy range between 300 eV to 2000 eV, as shown in Fig. 1.

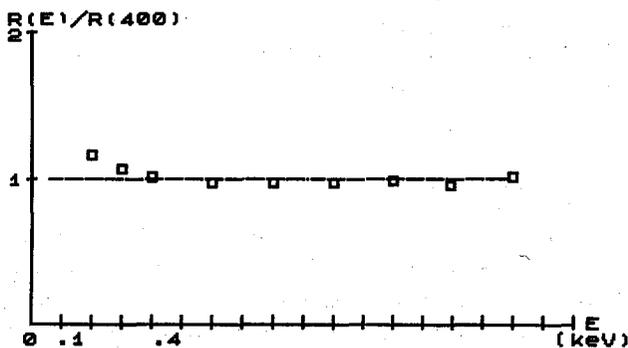


Fig. 1. The ratios  $R(E)$  for graphite sample versus kinetic energy  $E$  (compared arbitrarily to  $R(400 \text{ eV})$ ).

Using the single scattering approach  $T(E)$  can be determined for any experimental arrangement of the spectrometer and gun. In fact, using EPES, one gets a function proportional to  $T(E)$ . The normalized  $T(400) = 1$  distribution was used.

## 2. Description of the procedure

The parameters of elastic scattering and notations are as follows:

—  $\sigma_T$  is total elastic scattering cross section [7]:

$$\sigma_T = 2\pi \int_0^\pi f^2(\theta) \sin \theta d\theta \quad (1)$$

where  $\theta$  is elastic scattering angle and  $f(\theta)$  is the magnitude of direct scattering amplitude;

—  $\alpha_\beta$  is the attenuation coefficient of an electron escaping at  $\beta$  angle after an atomic elastic scattering event

$$\alpha_\beta = \exp(-d/\lambda_i \cos \beta) \quad (2)$$

where  $\lambda_i$  is the inelastic mean free path of the electron of energy  $E$  [13],  $d$  is the spacing of atomic layers and  $\beta$  is measured between the primary beam direction and the normal to the surface;

—  $J(\beta, \theta, E)$  is the current density reflected by all the atomic layers of the crystal and detected at  $(\pi - \beta - \theta)$  escape angle. According to [9]:

$$J(\pi - \beta - \theta, E) \sim \frac{f^2(\theta)}{\sigma_T} \frac{1}{1 - \alpha_\beta \alpha_{\pi - \beta - \theta}} \sin(\pi - \beta - \theta) = A(E). \quad (3)$$

The quantity  $A(E)$  represents the calculated intensity at the entrance of analyzer. The measured signal at the spectrometer output is equal to  $T(E)A(E)$ . Using the direct  $N(E)$  recorded distribution of the electrons emitted by the substrate, this quantity is proportional to the area of the elastic peak. For an RFA spectrometer with a large angular aperture Eq. (3) is easily integrated in all the directions considered.

In order to check the efficiency of the method we compared the direct measurement  $T(E)$  by our 4-grid RFA with the calculated values. The first one was carried out with the electron gun positioned in front of the grids and by measuring the primary current with a Faraday cup. The results are shown in Fig. 2.

In the next step of the experiment the gun was set back in its normal position (as used in the LEED mode of operation). The elastic peak and the current have been recorded simultaneously [8]. The percentage of elastically reflected electrons was determined. The experiments have been performed with a polycrystalline Ag sample. Evaluating experiments, after integration of Eq. (3) for the angular aperture of the analyzer ( $5^\circ$ ,  $55^\circ$ ), one gets the calculated  $T(E)$ , presented also in Fig. 2 (dashed line). The correlation between the two curves is reasonable.

The experiments must be performed always with polycrystalline samples to avoid possible diffraction effects [7]. However, for an analyzer with a narrow angular aperture the Ag sample is not advantageous for EPES, owing to the strong  $\theta$  dependence of  $f(\theta)$  [10]. In order to avoid this difficulty a pure graphite sample was used. Literature data are summarized in [7] and they are completed with some new data in [12]. The main problem with literature is that  $f(\theta)$  or corresponding Mott factor data are available merely for selected values of  $E$ . It was necessary to complete them for the evaluation of our experiments.

The calculated  $2\pi f^2(\theta) \sin \theta$  data for carbon are summarized in Fig. 3. The calculation of  $f(\theta)$  was based on the Thomas-Fermi-Dirac potential. The  $E$  covers

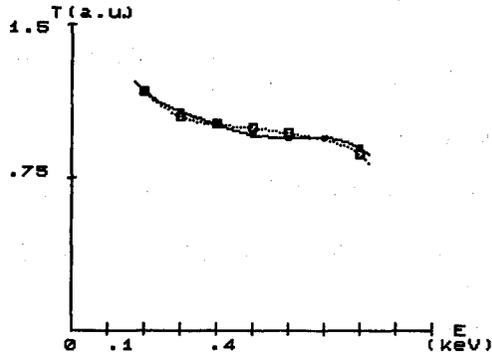


Fig. 2. The transmission curves of 4-grid analyzer: determined directly (dots) and calculated (dashed line).

the energy scale 200 eV–1600 eV,  $\theta$  is plotted in  $10^\circ$  steps,  $f^2(\theta)$  data are given in  $10^{-16}$  cm<sup>2</sup> units. The values of attenuation factor  $\alpha$  have been calculated and

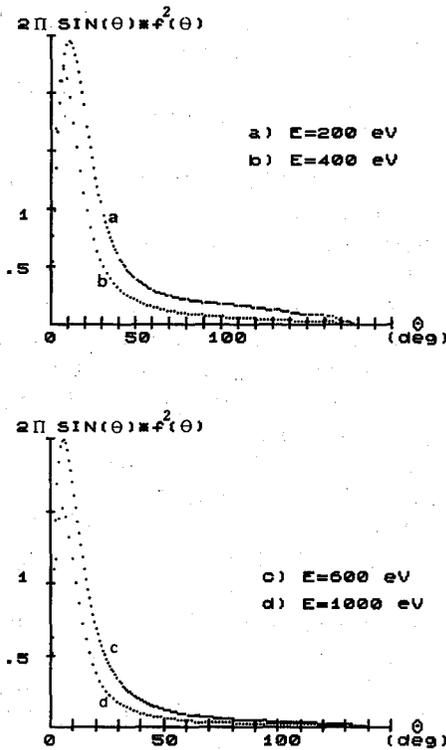


Fig. 3. Values of the magnitude of scattering amplitudes versus elastic scattering angle  $\theta$  for various energies  $E$  ( $f^2(\theta)$  in  $10^{-16}$  square centimeters).

applied to calculate  $T(E)$  of a high energy resolution HSA operated in the constant  $\Delta E$  mode [11]. Equation (3) was used with  $70^\circ$  entrance angle and perpendicular detection ( $\beta = 0$ ). The obtained values are presented in Fig. 4. Plots resulting from the Monte Carlo simulation are also shown in the figure and are in good agreement with those based on the simple scattering process.

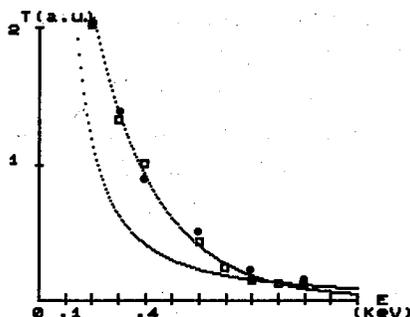


Fig. 4. The transmission curves  $T(E)$  of a hemispherical analyzer obtained using two mathematical fitting functions: for the low and high energies (see the text);  $\square$  — calculated plots from experimental data,  $\bullet$  — Monte Carlo results.

### 3. Discussion

For quantitative analysis of electron spectra the knowledge of the expression for  $T(E)$  is necessary. Using a single function fitting to experimental results a rough approximation was obtained. A better result was achieved using two intervals of the energy scale in Fig. 4. The final results obtained by the least mean square fitting have the following form:

$$T(E) \sim 5.1(1.2 \times 10^{-2})^E \quad \text{for } E < 0.75 \text{ keV}$$

and

$$T(E) \sim 0.098(E)^{-1.53} \quad \text{for } E > 0.75 \text{ keV}$$

where  $E$  is in keV units.

At low energies multiple elastic scattering can be important for the graphite sample. The power 1.53 is close to the values found for a HSA [5]. These results are shown in Fig. 3.

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