Standard Guide for
Background Subtraction Techniques in Auger Electron Spectroscopy and X-ray Photoelectron Spectroscopy[1]

This standard is issued under the fixed designation E 995; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The purpose of this guide is to familiarize the analyst with the principal background subtraction techniques presently in use together with the nature of their application to data acquisition and manipulation.

1.2 This guide is intended to apply to background subtraction in electron, X-ray, and ion-excited Auger electron spectroscopy (AES), and X-ray photoelectron spectroscopy (XPS).

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

E 673 Terminology Relating to Surface Analysis

E 996 Practice for Reporting Data in Auger Electron Spectroscopy and X-ray Photoelectron Spectroscopy

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology E 673.

4. Summary of Guide

4.1 *Relevance to AES and XPS*:

4.1.1 *AES*—The production of Auger electrons by bombardment of surfaces with electron beams is also accompanied by emission of secondary and backscattered electrons. These secondary and backscattered electrons create a background signal. This background signal covers the energy spectrum and has a maximum (near 10 eV for true secondaries), and a second maximum for elastically backscattered electrons at the energy of the incident electron beam. An additional source of background is associated with Auger electrons, which are inelastically scattered while traveling through the specimen. Auger electron excitation may also occur by X-ray and ion bombardment of surfaces.

4.1.2 *XPS*—The production of electrons from X-ray excitation of surfaces may be grouped into two categories—photoemission of electrons and the production of Auger electrons from the decay of the resultant core hole states. The source of the background signal observed in the XPS spectrum includes a contribution from inelastic scattering processes, and for non-monochromatic X-ray sources, electrons produced by Bremsstrahlung radiation.

4.2 Various background subtraction techniques have been employed to diminish or remove the influence of these background electrons from the shape and intensity of Auger electron and photoelectron features. Relevance to a particular analytical technique (AES or XPS) will be indicated in the title of the procedure.

4.3 Implementation of any of the various background techniques that are described in this guide may depend on available instrumentation and software as well as the method of acquisition of the original signal. These subtraction methods fall into two general categories: (*1*) real-time background subtraction; and (*2*) post-acquisition background subtraction.

5. Significance and Use

5.1 Background subtraction techniques in AES were originally employed as a method of enhancement of the relatively weak Auger signals to distinguish them from the slowly varying background of secondary and backscattered electrons. Interest in obtaining useful information from the Auger peak line shape, concern for greater quantitative accuracy from Auger spectra, and improvements in data gathering techniques, have led to the development of various background subtraction techniques.

5.2 Similarly, the use of background subtraction techniques in XPS has evolved mainly from the interest in the determination of chemical states (binding energy values), greater quantitative accuracy from the XPS spectra, and improvements in

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

data acquisition. Post-acquisition background subtraction is normally applied to XPS data.

5.3 The procedures outlined are popular in XPS and AES. General reviews of background subtraction techniques have been published **(1 and 2)**.[3]

6. Apparatus

6.1 Most AES and XPS instruments either already use, or may be modified to use, one or more of the techniques that are described.

6.2 Background subtraction techniques typically require a digital acquisition and digital data handling capability. In earlier years, the attachment of analog instrumentation to existing equipment was usually required.

7. Common Procedures

7.1 *Linear Background Subtraction (AES and XPS)*—In this method, two arbitrarily chosen points in the spectrum are selected and joined by a straight line **(1)**. This straight line is used to approximate the true background and is subtracted from the original spectrum. For Auger spectra, the two points may be chosen either on the high-energy side of the Auger peak to result in an extrapolated linear background or such that the peak is positioned between the two points. For XPS spectra, the two points are generally chosen such that the peak is positioned between the two points. The intensity values at the chosen points may be the values at those energies or the average over a defined number of channels or energy interval.

7.2 *Integral (or Shirley) Background Subtraction (AES and XPS)*—This method, proposed by Shirley **(3)**, employs a mathematical algorithm to approximate the inelastic scattering of electrons as they escape from the solid. The algorithm is based on the assumption that the background is proportional to the area of the peak above the background at higher kinetic energy. This basic method has been modified to optimize the required iterations **(4)**, to provide for a sloping inelastic background **(5)**, to provide for a background based upon the shape of the loss spectrum from an elastically backscattered electron **(6)**, and to include a band gap for insulators **(1)**.

7.3 *Inelastic Electron Scattering Correction (AES and XPS)*—This method, proposed by Tougaard **(7)**, uses an algorithm which is based on a description of the inelastic scattering processes as the electrons leave the specimen. The scattering cross section which enters in the algorithm is taken either from a simple universal formula which is approximately valid for some solids, or is determined from the energy spectrum of a backscattered primary electron beam by another algorithm **(8)**. Alternatively, the parameters used in the universal formula may also be permitted to vary in an algorithm so as to produce an estimate of the background **(9)**. This background subtraction method also gives direct information on the in-depth concentration profile **(10 and 11)**.

7.4 *Signal Differentiation, dN(E)/dE or dEN(E)/dE (AES)* **(12 and 13)**—Signal differentiation is among the earliest methods employed to remove the background from an Auger spectrum and to enhance the Auger features. It may be employed in real time or in post acquisition. In real time, differentiation is usually accomplished by superposition of a small (1 to 6-eV peak-to-peak) sinusoidal modulation on the analyzer used to obtain the Auger spectrum. The output signal is then processed by a lock-in amplifier and displayed as the derivative of the original energy distribution *N(E)* or *EN(E)*. In post-acquisition background subtraction, the already acquired *N(E)* or *EN(E)* signal may be mathematically differentiated by digital or other methods. The digital method commonly used is that of the cubic/quadratic differential as proposed by Savitzky and Golay **(14)**.

7.5 *X-ray Satellite Subtraction:* **(15)** (XPS)—In this method a fixed satellite structure associated with any given channel intensity such as a K X-ray line so that, starting at low kinetic energies, intensity is removed from higher kinetic energy channels at the spacing of the $K\alpha_{3,4}$, $K\beta$, etc. satellite positions from the $K\alpha_{1,2}$ main peak to remove their contribution to the spectrum. This subtraction proceeds through the spectrum and removes the satellite peaks associated with the photoelectron peaks. It may also erroneously remove an equivalent intensity from any Auger peaks present in the spectrum.

8. Less Common Procedures

8.1 *Deconvolution (AES and XPS)* **(16-19)**—Deconvolution may be used to reduce the effects due to inelastic scattering of electrons traveling through the specimen. This background is removed by deconvoluting the spectrum with elastically backscattered electrons (set at the energy of the main peak) and its associated loss spectrum. The intensity of the loss spectrum, relative to that of the backscattered primary, is sometimes adjusted to optimize the background subtraction. Deconvolution is usually accomplished using Fourier transforms or iterative techniques.

8.2 *Linearized Secondary Electron Cascades (AES)*—In this method, proposed by Sickafus **(20 and 21)** the logarithm of the electron energy distribution is plotted as a function of the logarithm of the electron energy. Such plots consist of linear segments corresponding to either surface or subsurface sources of Auger electrons and are appropriate for removing the background formed by the low energy cascade electrons.

9. Rarely Used Procedures

9.1 *Secondary Electron Analog (AES)* **(22 and 23)**—In this method, a signal that is an electronic analog of the secondary electron cascade is combined with the analyzer signal output so as to counteract the secondary emission function. It is particularly useful for retarding field analyzers in which low-energy secondary emission is prominent.

9.2 *Dynamic Background Subtraction (DBS) (AES)* **(24 and 25)**—Dynamic background subtraction may be used either in real time or post acquisition. It involves multiple differentiation of an Auger spectrum to effect background removal, followed by an appropriate number of integrations to reestablish a background-free Auger spectrum. The amount of background removal depends on the number of derivatives taken, although two are usually sufficient. In real-time analysis, a first derivative of the Auger electron energy distribution obtained using a phase-sensitive detector is fed into an analog integrator,

[3] The boldface numbers in parentheses refer to the references at the end of this standard.