Nuclear Instruments and Methods in Physics Research B 369 (2016) 24–28

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

A method for intensity calibration of an electron spectrometer with multi-angle detection

Levente Ábrók [a,*], Ticia Buhr [b], Ákos Kövér [a], Róbert Balog [a], Dávid Hatvani [a], Péter Herczku [a], Sándor Kovács [a], Sándor Ricz [a]

[a] Institute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki), H-4001 Debrecen, Hungary
[b] Physikalisch-Technische Bundesanstalt (PTB), D-38116 Braunschweig, Germany

ARTICLE INFO

Article history:
Received 24 June 2015
Received in revised form 15 October 2015
Accepted 16 October 2015
Available online 26 October 2015

Keywords:
Photon
Atom
Collision
Electron spectroscopy
Photoelectron

ABSTRACT

A special electrostatic electron spectrometer designed for precise and unique experiments and an intensity calibration method for universal application in electron spectroscopy are presented. The upgrade of the analyzer enables the intensity calibration at arbitrary electron energies using elastically scattered electrons. In order to test the calibration procedure the double differential (in energy and angle) ionization cross sections (DDCS) of electrons ejected from 300 keV proton-argon collisions were measured and compared with the data of Rudd et al. [1]. The good agreement between the two data sets verifies the applicability of the calibration method.

1. Introduction

High energy resolution and angle-resolved electron spectroscopy is widely used to investigate various atomic processes (ionization, Auger decay, etc.). In the last 40 years several electrostatic electron spectrometers were developed at Atomki for studying ionization processes [2–7]. Two of them are special combination of a spherical and a cylindrical analyzer (marked as ESA-21 and ESA-22). Both of them were built for measuring simultaneously energy and angular distributions of electrons emitted from different collision systems [6,7]. These electron optical arrangements reduce the measuring time by more than a factor of ten relative to the earlier applied techniques [1]. However, the intensity calibration remains difficult. In this paper we present the results measured by the recently upgraded ESA-22 electrostatic electron spectrometer. The aim of this development was to reduce the difficulty of the intensity calibration independently from the kinetic energy of the electrons ejected from the collision region. A new calibration method has been developed which does not use any data published in the literature for determination of the relative detector efficiencies and the spectrometer transmission. In the present work elastic electron scattering process was applied for calibration. Argon gas target was bombarded with electrons of the kinetic energy of 205 eV.

2. The upgraded ESA-22 spectrometer

The ESA-22 electrostatic electron analyzer (Fig. 1) is a modified version of the ESA-21 [6]. Both of them consist of a spherical mirror analyzer (SMA) and a cylindrical mirror analyzer (CMA). The SMA focuses the electrons from the scattering plane to the entrance slit of the CMA performing the energy analysis of the electrons. The main difference between the two spectrometers is the construction of the CMA. The ESA-21 has a double pass ring-point-ring focusing analyzer while the ESA-22 has a single pass ring-ring focusing electrode system. Both spectrometers are characterized by second order focusing property. When position sensitive detectors, e.g. channel plates are applied in the ESA-22 the electrons are focused to either 20 mm or 70 mm diameters. An additional possibility is to use 24 channel electron multipliers (CEMs) at 90 mm focal diameter. In the present paper we employ CEMs for the calibration. Furthermore, the outer sphere and cylinder are cut into two halves resulting that the system is capable of measuring the angular distribution of electrons at two independent energies simultaneously in the polar angular (ψ) range of ±15° and ±165° relative to the beam direction (see Fig. 2a). This is achieved by applying different voltages on the outer sphere and cylinder parts. In the cutting plane field correction electrodes are positioned to reach near-ideal electrical fields for the half spectrometers.

The two detector systems can be employed parallel. The electrons in one half of the spectrometer can be focused to a 20 mm

* Corresponding author.

http://dx.doi.org/10.1016/j.nimb.2015.10.037
0168-583X/

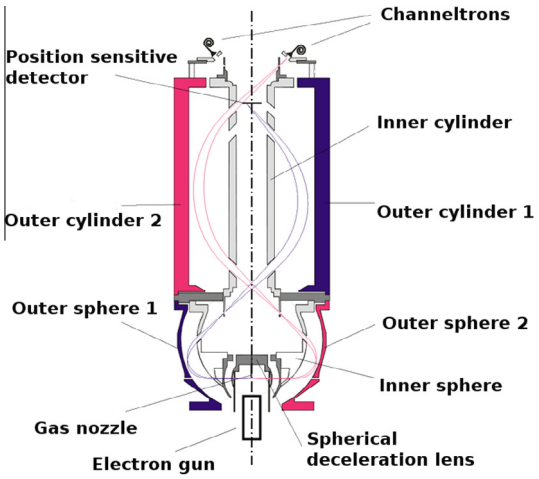

Fig. 1. Schematic cross section of the upgraded ESA-22 electron spectrometer.

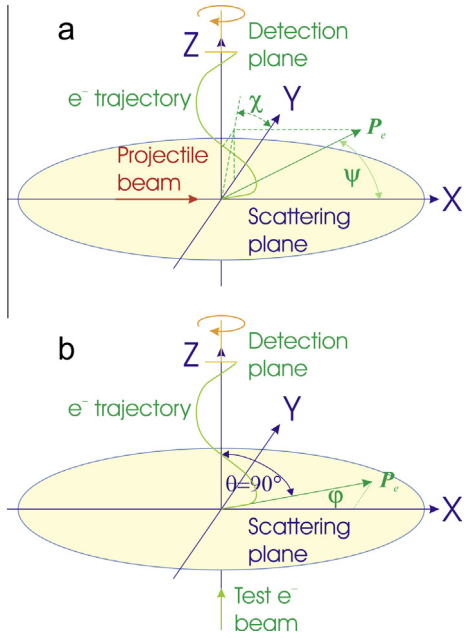

Fig. 2. Measuring geometry (a) in case of the incident beam directed towards the X axis and (b) using the electron gun placed along the spectrometer axis (Z axis) as excitation source. P_e denotes the momentum of the emitted electrons.

diameter ring while in the other half to a 90 mm diameter ring. According to this arrangement (see Fig. 1) the ESA-22 analyzer can be applied for electron–electron coincident experiments, as well [7]. A spherical deceleration lens is placed around the source region to improve the energy resolution of the system. The relative energy resolution is better than 2.8×10^{-3} without deceleration.

New UHV chamber, magnetic shielding and a special detector holder were designed and built. The analyzer and the interaction region are shielded from the Earth's magnetic field by one layer (3 mm thick) of μ-metal sheet. The residual magnetic field in the scattering plane and in the analyzer is less than 5 mG. The new vacuum chamber and the detector holder are continuously rotatable under UHV conditions around the beam direction (X axis in Fig. 2a) and the spectrometer axis (Z axis in Fig. 2), respectively. The rotation of the vacuum chamber enables to observe the electrons emitted from the target region at different emission planes, i.e. at different azimuthal emission angles (χ) and 3D angular distribution can be measured (see Fig. 2a). By rotating the detector holder the relative efficiencies of the individual detectors and the angle dependent transmission function of the analyzer can be easily determined at arbitrary electron energies. 24 new channeltrons (CEMs) are mounted on the holder at every 15°. The angular window of each CEM is ±1.7° in vertical and ±3.5° in horizontal direction. In the present calibration experiment the polar angle was constant and perpendicular ($\theta = 90° \pm 1.7°$) to the incoming electron beam and the angular distributions were measured as a function of the azimuth angle (φ in Fig. 2b). An electron gun along the spectrometer axis was installed (see Figs. 1 and 2b) which makes calibration possible at arbitrary electron energies using elastic and inelastic electron scattering processes. New software has been also developed in LabView to control the voltages on the electrodes of the spectrometer, the rotation of the detector holder as well as the data collection.

3. The relative calibration method

Different calibration methods exist in electron spectroscopy. In case of the absolute method all parameters (gas density, beam current, etc.) included in Eq. (1) are determined independently [8]. For relative calibration known cross sections are used to determine the measured unknown cross sections. In our photoelectron angular distribution experiments [9–11] the second method were applied for the determination of the detector efficiencies and spectrometer transmission by using the LMM Auger lines of argon. The experimental single differential cross section can be expressed in the following way:

$$\frac{d\sigma}{d\Omega} = \frac{I_d}{I_p n_t L T \eta \Delta\Omega}, \tag{1}$$

where I_d and I_p are the number of the detected electrons and the incident particles, respectively. n_t indicates the density of the target $[atom/cm^3]$, L is the target thickness $[cm]$ in the direction of the projectile beam and η is the detection efficiency of the individual CEMs. T denotes the transmission of the spectrometer, while $\Delta\Omega$ represents the solid angle $[sr]$. I_p can be obtained from the current recorded with a Faraday cup. The target density (n_t) for gas target can be measured with an absolute pressure gauge and L can be determined from an isotropic process (e.g. in our case the $L_{23}M_{23}M_{23}$ Auger group was measured at 2 MeV proton and 1.9 keV electron impacts). $\Delta\Omega$ is known from the geometry of the analyzer (from the slit size of the inner sphere and the open area of the channeltrons) and its value is $4.7(2) \times 10^{-3}$ sr (error in the brackets) for a single angular channel.

The transmission (T) is unity for an ideal spectrometer but not for a realistic electrostatic system. Its determination is difficult due to the lens effect at the slits of the inner sphere and cylinder, the residual magnetic field, the inhomogeneity in the conductivity of the electrodes surfaces, etc. Furthermore, the detector efficiencies also differ from each other due to the manufacturing procedure and the surface contamination (different vacuum conditions). The efficiency may change with the elapsed time as well. In the present calibration method the transmission of the spectrometer and the efficiencies of the detectors were experimentally determined using elastically scattered electrons on Ar target at 205 eV impact energy. The diameter of the electron beam is 0.6 mm at the target region. In this case only those electrons are detected which are emitted at polar angle $\theta = 90°$ relative to the momentum of the incident electron beam (see Fig. 2b). This means that the differential emission cross sections are the same for all observation angles (φ in Fig. 2b) due to the cylindrical symmetry of the collision process. It is true for both the elastic and the inelastic scattering processes. If the intensities detected with different