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Spectrometer for the study of electron-assisted processes

Czesław Szmytkowski*, Paweł Możejko

Atomic Physics Division, Faculty of Applied Physics and Mathematics, Technical University of Gdańsk, ul. G. Narutowicza 11/12, 80-952 Gdańsk, Poland

Abstract

Equipment built in our laboratory, for the study of the phenomena related to the electron-scattering processes, is described. The apparatus consists of an electron-scattering spectrometer, target flow system and systems for detecting and handling the electronic and/or ionic signal. As examples of the spectrometer application, the presented results are the electron energy-loss spectrum for N_2 , differential cross section for vibrationally inelastic electron scattering from OCS, vibrational excitation function of N_2 and total cross section for electron scattering from NO. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Electron scattering; Cross section; Electron spectrometer

1. Introduction

In the last century, a considerable amount of work has been done in the field of electron collision physics which enabled extensive study of the electron induced phenomena and allowed for many fundamental discoveries [1]. In our laboratory, experimental studies concerning the collision processes by the electron impact have been conducted for over 25 years. For this purpose an electron spectrometer was designed and constructed. The philosophy underlying our design was the development of a versatile instrument which would, in spite of its relative simplicity, satisfy the requirements of the specific measurements over some time with minor modifications only. Another important requirement for the present spectrometer was to

operate in a wide energy range, from a few tenths up to some hundreds of electronvolts.

The paper describes the construction of the electron spectrometer and, as a demonstration of its performance, presents some results obtained in different modes of operation.

2. Electron spectrometer

The electron beam is formed, transported and detected by an electron-optical system (Fig. 1) composed of a number of electrostatical elements: electron gun (EG), electron monochromator (M), systems of electron lenses (EL), electron energy analyzer (A) and electron collector (EC).

The electron gun consists of a thermionic thoriated tungsten emitter (F), a reflector and an anode [2]. Low filament current (1–1.3 A) and hairpin shape of the cathode minimize the effect of the current-induced magnetic field on the electron

* Corresponding author.

E-mail address: czsz@mif.pg.gda.pl (Cz. Szmytkowski).

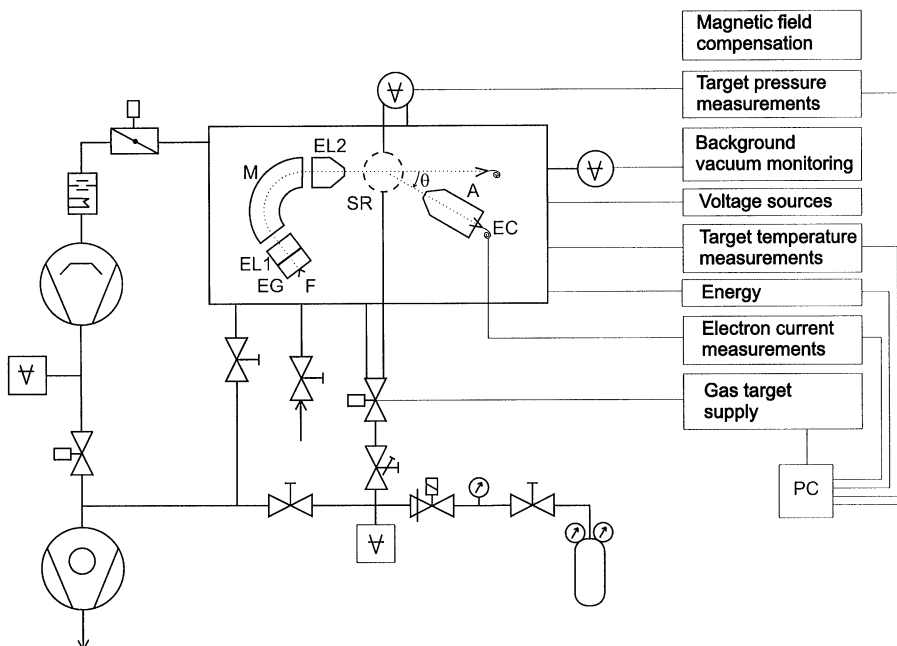


Fig. 1. The layout of the electron spectrometer: F—filament; EG—electron gun; EL1, EL2—electron lenses; M—electron monochromator; SR—scattering region; A—analyzer, EC—electron collector.

beam. A reflector acts as a repeller to favor the forward electron emission.

The multistage electrostatic electron lens (EL1) focuses the emitting tip of the filament into the entrance aperture of the monochromator (M). Two electrodes of the lens are split into two halves to serve also as the beam deflectors for the alignment of the electron beam. The second lens module (EL2) accelerates electrons leaving the monochromator to the required impact energy and directs them into the interaction volume. Application of zoom electro-optic lenses has enabled a slowly varying transmission to be achieved over an energy range from some tenths up to hundreds of electronvolts. The design and operating conditions for the electron lenses were derived from the calculations by Harting and Read [3] and then optimized with the use of the SIMION [4] code. Only minor voltage adjustments were needed in the course of experiments.

The energy dispersive element of the spectrometer is of the 127° cylindrical electrostatic deflector type [5]. A detailed description of operation for the

cylindrical selector can be found in [6]. Special attention has been given to the optimization of its performance according to the fringing field effects [7] and space charge due to stray electrons. To compensate for the distortion of the electrostatic field at the ends of the deflecting electrodes and near the apertures the deflecting angle was reduced according to the considerations by Oshima et al. [8]. The space charge effect was reduced by means of gridded, highly transparent deflecting electrodes accompanied with collectors of stray electrons.

In the transmission mode of operation, electrons of a given energy are directed into a reaction chamber. The electrons which leave the scattering cell are energy discriminated with a planar retarding field filter (RFF) [9] consisting of three circular apertures. The filter ensures that electrons which lost the energy in the scattering or were scattered at high angles do not reach the Faraday cup collector.

In a crossed electron-target beam configuration the second, similar electrostatic cylindrical deflector, combined with electron lenses, is employed for energy analysis of the electrons scattered from

a target beam at a given scattering angle. After the analysis the electrons are transported to a cone of the single channel electron multiplier. The analyzer and associated optics were mounted on a support which can be rotated about the axis of the target beam.

To reduce the residual magnetic flux in the spectrometer all the components are made of non-magnetic materials. The earth magnetic field is reduced by surrounding the whole spectrometer with three mutually orthogonal Helmholtz coil pairs. The magnetic field has been measured to be less than $0.1 \mu\text{T}$ in the whole region of electron optics. To ensure shielding of the electron beam against stray electric field and electrons, monochromator, electron lenses, interaction region, analyzer, and electron collector are guarded by metal envelopes.

The spectrometer is housed in a vacuum container with the background pressure of $10 \mu\text{Pa}$. When the target sample is leaked into the reaction volume the pressure in the electron optics region increases to $0.1\text{--}1 \text{ mPa}$. Such a change of the pressure may alter transmission properties of the electron optics and, if target particles are chemically aggressive, they may strongly affect emission from the filament, thus influencing the measured cross

sections. In order to reduce these effects, the target sample is supplied alternately into the scattering volume or into the electron-optics in such a way that conditions along the path of the electron beam outside the interaction region are stable throughout the experiment, irrespective the target is supplied or absent in the collision region.

All components of the electron optics were manufactured of copper, gold plated, and if exposed to the electron beam coated with colloidal graphite. This essentially reduces contact potentials, reflection of electrons from the surfaces of electron-optics and secondary electron production. Contact potentials were found to be rather independent of the sample particles being studied but varied slightly with pressure and time. Care was taken to shield all insulating surfaces from the electron beam to avoid the charge build-up problem.

The energy scale is calibrated with reference to the 2.3 eV oscillatory resonant structure in N_2 and/or 19.3 eV resonance in He. It was possible to make measurements using the incident electron energies between 0.5 and 350 eV .

Handling the target, energy setting and processing ingoing data may be operated either manually or under computer control.

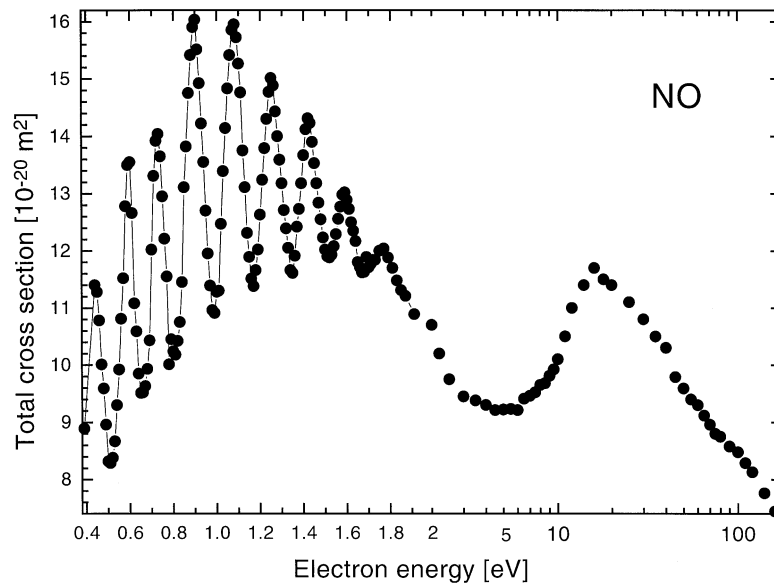


Fig. 2. Total cross section for electron scattering from NO [10]. Note a change of the energy scale at 2 eV .

When *transmission measurements* are carried out, unscattered electrons of a given energy are collected. The attenuation of the incident electron current as measured at the detector can be related

to the total cross section for all scattering processes (Fig. 2).

In the electron-target beam configuration, the spectrometer can be operated in either of two differ-

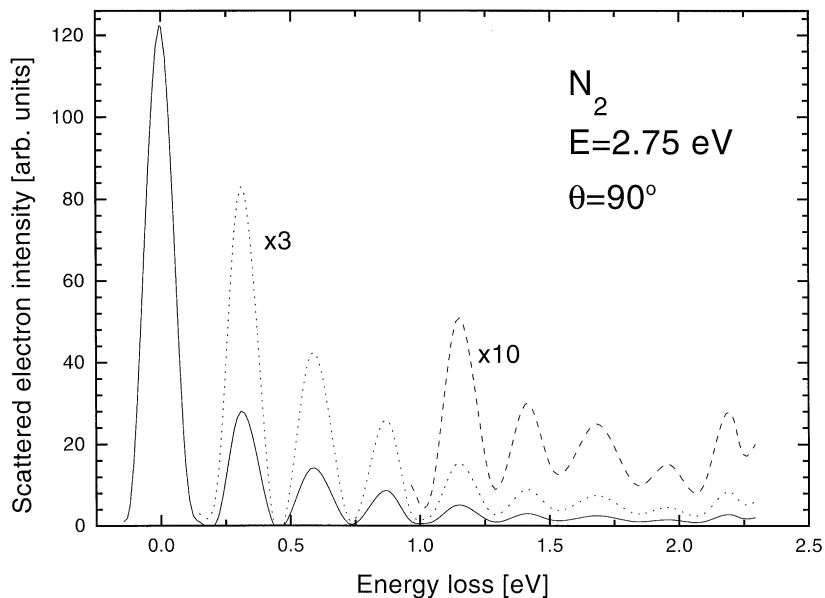


Fig. 3. Electron energy-loss spectrum for N_2 .

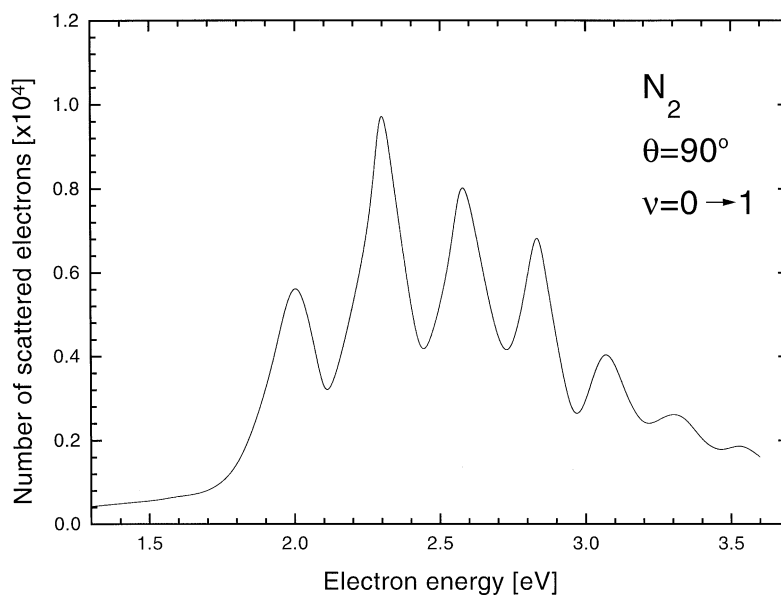


Fig. 4. Differential vibrational ($\nu = 0 \rightarrow 1$) excitation function for the $e^- - N_2 (X^1\Sigma_g^+)$ scattering.

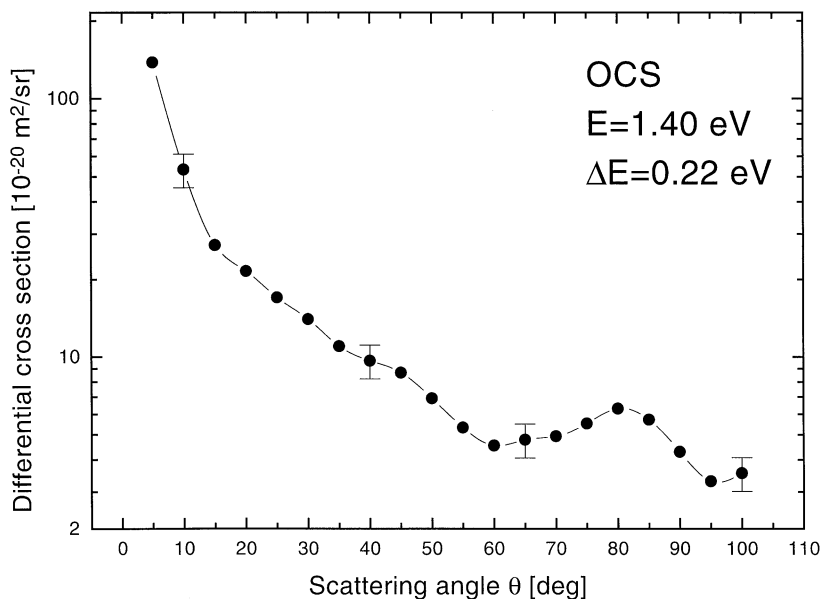


Fig. 5. Vibrationally inelastic differential cross section for e^- -OCS scattering.

ent ways: (i) an electron *energy-loss* spectrum is measured by varying the voltage applied to analyzer, while keeping the electron impact energy and scattering angle fixed; in this mode of operation the location of the observed features represents the energy-level scheme of the target (Fig. 3), while their intensities are related to the corresponding cross sections; (ii) in *impact energy* mode the incident electron energy is varied while the analyzer is tuned to transmit a particular energy loss; the resulting intensity distribution of scattered electrons represents the energy dependence of a particular cross section (Fig. 4). Angle-dependent measurements are made by the rotation of the analyzer around the target beam direction (Fig. 5).

By making use of the different modes of the spectrometer operation, it is possible to perform a wide variety of elastic and inelastic scattering experiments.

3. Conclusions

In this paper a versatile electron spectrometer for low and intermediate energies has been described.

The spectrometer was successfully employed to study electron scattering on atoms and molecules in the electron detection mode (e.g. [10,11]). The analysis of other reaction products, e.g. ions is also possible. After some modification the spectrometer can be used for solid surface studies.

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