Experimental vs. calculated values of the total scattering cross section and the BGPL of different image gases in an ESEM

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Low Vacuum Electron Microscopy (LVSEM) and Environmental Scanning Electron Microscopy (ESEM) allows the investigation of non-conductive, organic and biological specimens without the need for additional sample preparation. The chosen imaging gas inside the specimen chamber is responsible for contrast formation by gas amplification and the generated positive gas ions suppress charging of the sample surface. But the gaseous environment inside the chamber is limiting the image quality of the microscope by elastic and inelastic collisions of the primary beam electrons (PEs) with the gas atoms or molecules. This so called skirt effect degrades the signal to noise ratio by generating gaseous secondary electrons (SEs) as well as SEs from regions far away from the focused probe. Therefore the primary beam loses electrons to a wide dispersed skirt exponentially along the beam gas path length (BGPL) [1]. The main parameter which describes the scattering of the PEs is the total scattering cross section (σ [m²]) of the imaging gas. This physical constant depends on the energy of the primary electrons and the type of the imaging gas (e.g. water vapour, ambient air, nitrogen gas, etc). The experiments were performed on a FEI Quanta 600 FEG ESEM in the low vacuum mode ($p < 130$ Pa) using the large field detector (LFD). No additionally mounted detector or cone was used, to simplify the gas flow of the vacuum system to the basic pressure limiting aperture (PLA) in the final lens assembly. An external electrometer (Keithley 616) was used to measure the probe current. A new Faraday cup was designed to measure the unscattered fraction of the electron beam (Figure 1) [2]. With this well-thought-out construction, the average number of interaction per electron between the PEs and the gas molecules (m) can be calculated as well as the effective BGPL [2]. Figure 2 shows the variation of the value m as a function of the BGPL. To obtain these measurements, the primary beam current was set to a fixed value in high vacuum and checked after each measurement. The linear relationship between m and the BGPL agrees very well with theory. The significant electron current loss starts in the region around the PLA [3]. The different gas density zones between the specimen and the electron column are depending on the microscope type, used detectors or cones – they work like additionally PLAs - and the chamber pressure. The differences between 10mm WD and the effective BGPL for low vacuum pressure conditions are shown in Figure 3. As was expected the effective BGPL increases with increasing chamber pressure. The effective BGPL shows the influence of the gas flow through the PLA in dependence on the chamber pressure and the microscope type [4]. The theoretical calculation of the total scattering cross section for monoatomic and molecular gases has been described by Danilatos [5].
Both the calculated and measured values of the total scattering cross sections for electron energies between 5 and 30keV are shown in Figure 4-6 for water vapour, nitrogen gas and ambient air as imaging gas. Especially the inelastic differential cross section increases

strongly with decreasing scattering angle, which clarifies that the accuracy of the measurements is dependent on the diameter of the apertures used in the Faraday cup. To ensure a good conformance of the experimental parameters (WD, aperture diameter) with theory the values are integrated between 0,001 rad and pi. That means that the information for events with smaller scattering angles is lost for this assembly. Because of the high ratio of nitrogen gas in ambient air the curves of nitrogen gas and ambient air are nearly identical.

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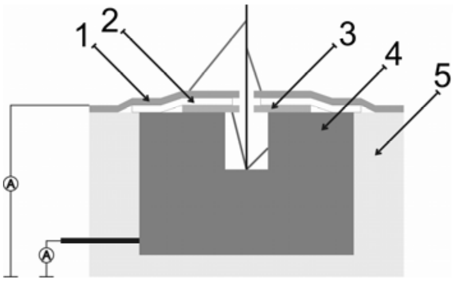
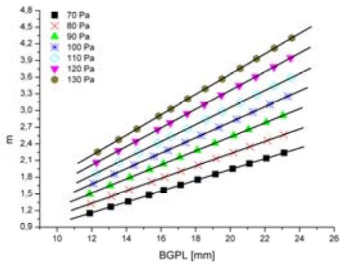




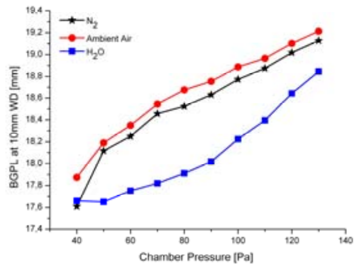
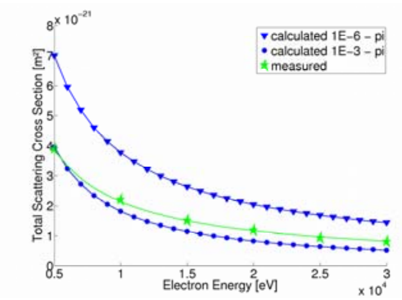
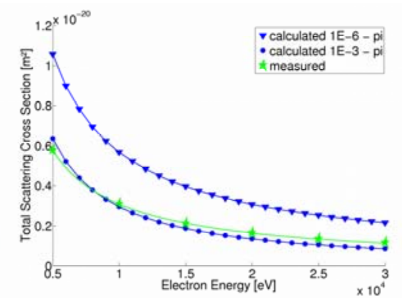


Figure 1. (left) Schematic drawing of the Faraday Cup – 10 µm aperture (1), insulator (2), second aperture (3), copper block (4) embedded in epoxy resin (5)

Figure 2. (middle) Average number of interactions m as a function of BGPL [mm] for nitrogen gas at a primary electron energy of 5 keV

Figure 3. (right) BGPL at 10 mm WD [mm] as a function of chamber pressure [Pa] for nitrogen gas, ambient air and water vapour at a primary electron energy of 20 keV





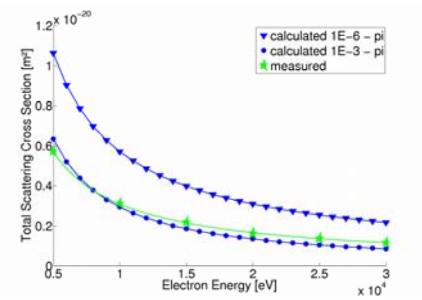


Figure 4. (left) Measured and calculated (integration limits 1E-6 rad to pi and 1E-3 rad to pi) total scattering cross section σ [m²] of water vapour as a function of electron beam energy E_0 [eV]

Figure 5. (middle) Measured and calculated (integration limits 1E-6 rad to pi and 1E-3 rad to pi) total scattering cross section σ [m²] of nitrogen gas as a function of electron beam energy E_0 [eV]

Figure 6. (right) Measured and calculated (integration limits 1E-6 rad to pi and 1E-3 rad to pi) total scattering cross section σ [m²] of ambient air as a function of electron beam energy E_0 [eV]

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