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VOLUME CORRECTION FACTOR IN ELECTRON-INDIUM ATOM SCATTERING EXPERIMENTS

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Abstract. *In crossed electron beam - Indium atom beam scattering experiments the measured signal arises from a spatial region (the 'interaction volume') defined by the overlap of the electron and target atom beam and the view cone of the detector. The exchange of the interaction volume with the scattering angle, named a volume correction factor is discussed. The approach of R. T. Brinkmann and S. Trajmar (J. Phys. E* ***14****, 245-254 (1981)) is adopted for our experimental conditions to determine the volume correction factor and accordingly to transfer angular distributions of scattered electrons to relative differential cross sections.*

Key words: *Volume correction factor*

INTRODUCTION

A scattering geometry changes with the scattering angle in the crossed beam experiments and that is why the effective volume correction factor has to be introduced. In early scattering experiments the correction problem was resolved by the correction factor of $sin\theta$. However, this procedure yields proper normalization only if the electron beam entering scattering region and the detected scattered electron beam have small angular divergence.

L. Vušković *et at.* [2] gave the confirmation whence the simple $1/\sin\theta$ correction should not be used for the differential cross section determinations. They introduced the most general volume correction model which has been used in differential scattering experiments with tape shaped electron beams and cylindrical electron beams geometry. In the case of cylindrical electron beams, if the experimental parameters is known (electron beams divergence angle (2α), the analyzer view angle (2β), electron gun (r) and the de-

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tector (R) distances) a mathematical model for the interaction volume at any scattering angle θ could be derived. From that model, if the ratio $V(\theta^o)/V(90^o)$ versus scattering angle θ is known, the effective geometrical factor could be determined by calculating the interaction volume at 90^o. They showed that for scattering angles smaller then $\theta=25^o$ and a larger then $\theta=130^o$, the simple $1/sin\theta$ correction for the differential cross section calculations from experimental data gives a very rough approximation.

A more detailed analysis of the volume correction factor which is used in the crossed beam experiments is given in well known work by R. T. Brinkmann and S Trajmar [1]. This calculation treatment is derived by the relationship between scattering intensity, cross section and the geometrical integral called “effective path length". The effective path length is normalized to unity at 90^o nominal scattering angle. Volume correction factor is the reciprocal of effective path length.

The electron beam is considered to originate from a distant point with small divergence and the atom beam with substantial divergence. The intersection of these circularly symmetric beams within the view cone of the detector represents the scattering volume (see Eqs.(1) and (2)).

These correction factors depend on the kind of molecular target under investigation, geometry applied in the experiment, flow conditions of the effusive beam, and the steepness of differential cross sections (DCS). Here, we present our experimental apparatus and results for volume correction in electron-indium atom scattering.

EXPERIMENTAL PROCEDURE

In the crossed–beam arrangement, the electron beam has been perpendicularly crossed by effusive indium atom beam. This experimental set-up has been described elsewhere [3,4,5]. The scattering geometry involved in our electron-atom beam experiments has been illustrated in Fig. 1. The intersection of the electron and indium atom beam within the view cone of the detector represents the scattering volume.

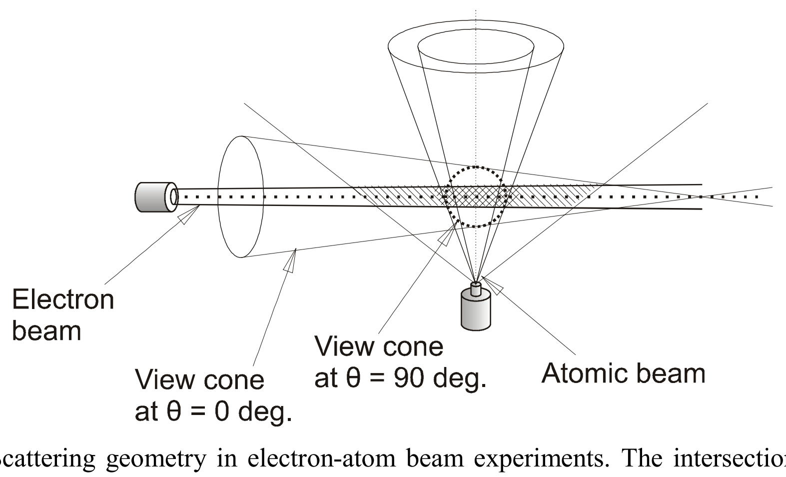

Fig. 2. Scattering geometry in electron-atom beam experiments. The intersection of the indium atom beam, electron beam and view cone of the detector presents the interaction volume.

The monoenergetic electron beam was emitted from a hairpin cathode, with the current at the end of the hemispherical monochromator of the order of 1 to 10 nA. The lens system has been adjusted in order to provide a small divergence of the electron beam. The maximum distribution of the electron flux is along the beam axis and it is assumed to fall off as a Gaussian function with respect to the axis. Figure 2 presents the angular distribution of the primary electron beam for $E_0 = 20$, 40 and 80eV impact energies. The full width at half maximum (FWHM) of the primary electron beam decreases with the increasing the incident energy, and at $E_0 = 80$eV amounts 1.5°.

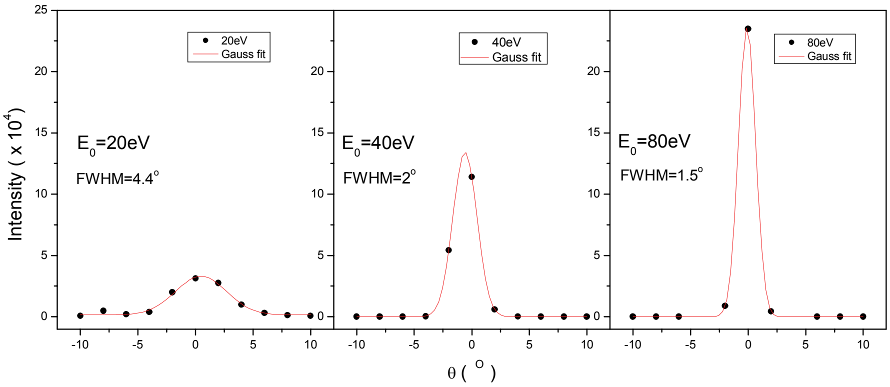

Fig. 2. Angular distribution with Gauss fit of the primary electron beam at E_0=20, 40, and 80eV.

The indium vapour beam was produced by heating the oven crucible containing In metal. The oven has been modified in order to achieve higher temperatures. The oven consists of two separate heaters with the same diameters, one for the top of the stainless steel crucible and nozzle, and the other for the body of the crucible, and their temperatures were controlled by two thermocouples. The heating currents of those heaters were 5.3 A and 3.4 A, respectively. They provided a variable temperature difference between the top and the bottom. The nozzle was maintained at approximately 100° higher temperature. The atomic beam was effused through a L=20 mm long channel in the cap of the oven crucible that has an inner diameter of 2a=2.5 mm. The aspect ratio was large (γ=0.125). The evaporation temperature of the indium was approximately 1300 K and the metal-vapor pressure was about 10 Pa (0.07 Torr).

The monochromator is fixed, and the analyzer can rotate around the atomic beam axis. The real zero position was determined by checking the symmetry of the inelastically (excitation of the $^2S_{1/2}$-state) scattered electron distribution around the mechanical zero at positive and negative angles (from -10° to +10°). The energy loss scale was determined by the positions of the elastic feature and resonant peak of the 6s $^2S_{1/2}$ excitation of indium at 3.022 eV according the value from Tables by Moore [6].

The relative DCSs for the elastic or inelastic scattering of the electrons are obtained as follows. For a given incident energy E_0, the position of the analyzer was changed from 10° to 150° and the signal of the angular distribution of scattered electrons was measured.

A channeltron was used for single electron counting. The signal intensity of the scattered electrons is obtained according to Brinkmann and Trajmar [1] relation:

$$I(E_0,\theta) = DCS(E_0,\theta)F(E_0)V_{eff}(\theta) \tag{1}$$

where *DCS* is the angular distribution averaged over the energy distribution of the incoming electron beam and the detector energy and angular resolution. The $F(E_0)$ is the response function of the detector for detecting electrons of the energy E_0 (transmission function), and the $V_{eff}(\theta)$ is the effective scattering volume given by:

$$V_{eff}(\theta) = \int_r \rho(r) f(r) \Delta\Omega(r) G[\theta(r)] dr \tag{2}$$

where ρ(r) is the spatial distribution of the target beam, $f(r)$ the spatial distribution function of the incident electron flux, $\Delta\Omega(r)$ the solid angle subtended by the electron detector at the scattering point r, $G[\theta(r)]$ the assumed angular dependence of the initial electron beam in the region of interest.

RESULTS AND DISCUSSION

We used the procedure suggested in [1] in order to convert the data of angular distributions of scattered electrons into relative DCSs data. The interaction volume in our measurement is defined by the overlap of the target atomic beam, electron beam and the detection view cone.

The aspect ratio of the inner diameter and the length of the channel in the cap of the oven crucible amounts $\gamma = 0.125$, and the range of the validity of the γ:

$$\gamma < K_{nL} < 10 \tag{3}$$

is satisfied. K_{nL} is Knudsen number based upon an dimension of the tube at the crucible exit:.

$$K_{nL} = \frac{\langle\lambda\rangle}{L} = \frac{1}{\sqrt{2}L\sigma}\frac{RT}{pN_0} \tag{4}$$

The mean free path of the vapor atoms in the source reservoir for the temperature of 1300K amounts $\langle\lambda\rangle = 10.9$mm.. It is smaller than the dimension of the tube at the crucible exit (L=20mm). We obtained for the $K_{nl} = 0.543$ accordingly to the Eq. (4), for our experimental conditions. The obtained value for K_{nl} satisfies the necessary condition given by Eq. (3).

We use as a starting point the effective path length correction factor from ref. [1] (see Fig.11 in [1]) for a large-aspect-ratio tube for hypothetical species with gas kinetic cross section of $r = 2.2$ Å^2 and $r = 100$ Å and at $p = 0.1$ and $p = 10$ Torr tube back pressure. In our cases the curve type B is used (Fig.10 in [1]). That type B corresponds to DCSs which decrease by approximately as $10^{0.0322}$ (three orders of magnitude) with increasing of scattering angle from $\theta = 0^o$ up to $\theta = 90^o$. Volume correction factor is normalized to unity at 90^o. From these curves we apply the linear extrapolations to our experimental conditions (p= 0.07 Torr and gas kinetic cross section for indium atom is $\sigma = 12.56$ Å^2). The atomic radius is r = 2Å (taken from [7]), and the kinetic cross section is obtained according the formula $\sigma = r^2\pi$. The obtained results are presented in Fig. 3 and Tab. 1.

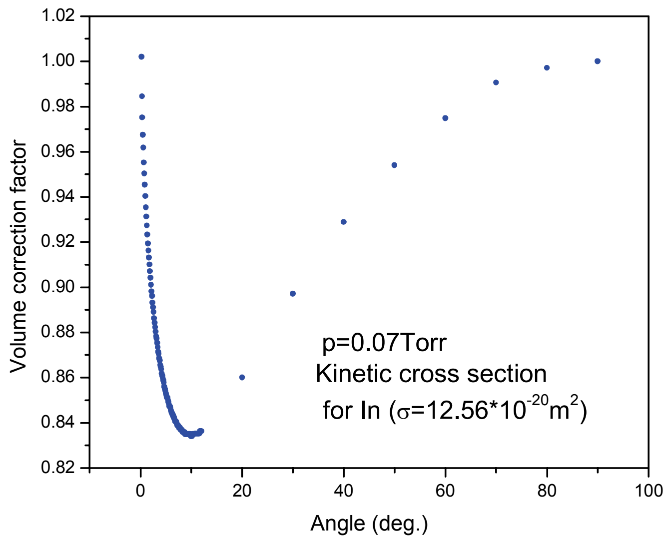

Fig. 3. Volume correction factors for an indium atom kinetic cross section of $\sigma = 12.56$Å^2 and pressure of $p = 0.07$ Torr.

Tab. 1. Volume correction factors

Angle. (deg.)	**Volume Corr. Factor**	**Angle. (deg.)**	**Volume Corr. Factor**
1	0.9404	10	0.8342
2	0.9041	20	0.8601
3	0.8803	30	0.8971
4	0.8646	40	0.929
5	0.8531	50	0.954
6	0.8454	60	0.9749
7	0.8406	70	0.9906
8	0.8369	80	0.9971
9	0.835	90	1

It can be seen from Fig.3 that the variations of the correction factor at small scattering angles are very pronounced. The slope of the curve decreases very fast from 0^o up to 10^o. However, for the large scattering angles, from 10^o up to 90^o the volume correction factor increases more slowly.

The obtained volume correction factors are multiplied with the measured angular distribution of scattering electrons for specific energy loss feature in order to obtain DCSs in relative units. Recently, we published the joint paper together with the theoretical group from National Academy of Sciences of Ukraine of the elastic-electron-indium-atom scattering in the intermediate energy range [8]. The comparison of the calculated and measured behavior of DCSs for elastic-electron scattering by indium atom at E_0=40eV impact energy is shown in Fig. 4. The relative values of the measured DCSs are normalized to the theoretical calculations (SEPASo). This theoretical approach is based on complex phenomenological optical potential (OP) with allowance made for spin-orbit interaction. The real part of this potential without absorption is called below the SEPSo approximation, and consists of static, local exchange, polarization and spin-orbit potentials. The SEPASo approximation is the imaginary part of OP and takes into account the absorption effects.

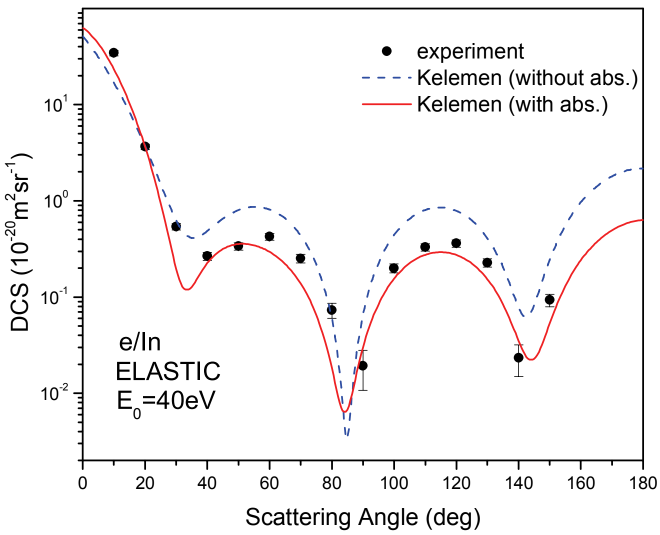

Fig. 4. Differential elastic electron-indium atom scattering cross sections (in units of 10^{-20} m^2sr^{-1}) at E_0=40eV impact energy. The dashed line shows the results obtained by SEPSo theory (without absorption). The solid line shows the results of SEPASo theory (with absorption). Filled circles with error bars represent the experimental results normalized at 20° to the SEPASo.

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ZAPREMINSKI KOREKCIONI FAKTOR U EKSPERIMENTU RASEJANJA EELEKTRONA NA ATOMU INDIJUMA

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U eksperimentima rasejanja elektrona na atomima indijuma koristili smo tehniku ukrštenih mlazeva. Mereni signal potiče iz oblasti prostora „interakcione zapremine" koja je definisana presekom mlaza elektrona, mlaza atoma mete i vidnog ugla detektora. U ovom radu smo prikazali kako se interakciona zapremina menja sa uglom rasejanja i ta promena je opisana zapreminskim korekcionim faktorom. Pristup opisan u radu R. T. Brinkmann-a i S. Trajmar-a (J. Phys. E 14, 245-254 (1981)) primenili smo na naše eksperimentalne uslove u cilju određivanja zapreminskog korekcionog faktora, pomoću koga su ugaone raspodele rasejanih elektrona prevedene u relativne diferencijalne preseke.