Experimental Energy Resolution of A Paracentric Hemispherical Analyzer for Different Entry Positions and Bias

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Abstract

A specially designed hemispherical deflector analyzer (HDA) with 5-element input lens having a movable entry position R_0 suitable for electron energy analysis in atomic collisions was constructed and tested. The energy resolution of the HDA was experimentally determined for three different entry positions R_0 = 84, 100, 112 mm as a function of the nominal entry potential (bias) $V(R_0)$ under pre-retardation conditions. The resolution for the (conventional) entry at the mean radius R_0 = 100 mm was found to be a factor of 1.6-2 times *worse* than the resolution for the two (paracentric) positions R_0 = 84 and 112 mm at particular values of the bias $V(R_0)$. These results provide the first *experimental* verification and a proof of principle of the utility of such a paracentric HDA, while demonstrating its advantages over the conventional HDA: greater dispersion with reduced angular aberrations resulting in better energy resolution without the use of any additional fringing field correction electrodes. Supporting simulations of the entire lens plus HDA spectrometer are also provided and mostly found to be within 20%–30% of experimental values. The paracentric HDA is expected to provide a lower cost and/or more compact alternative to the conventional HDA particularly useful in modern applications utilizing a position sensitive detector.

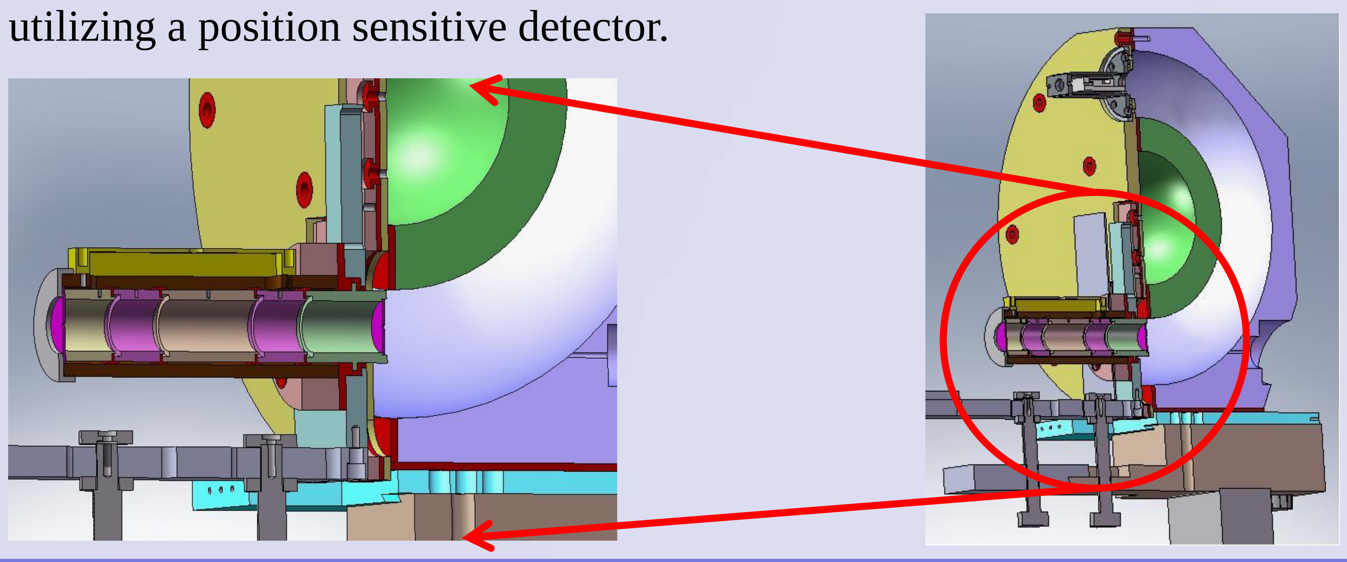

Figure 1. The paracentric entry HDA was designed based on previous simulation works [2,3,4]. The analyzer was constructed according to AutoCAD and Solidworks in e-COL laboratory at Afyon Kocatepe University.

Experimental Setup

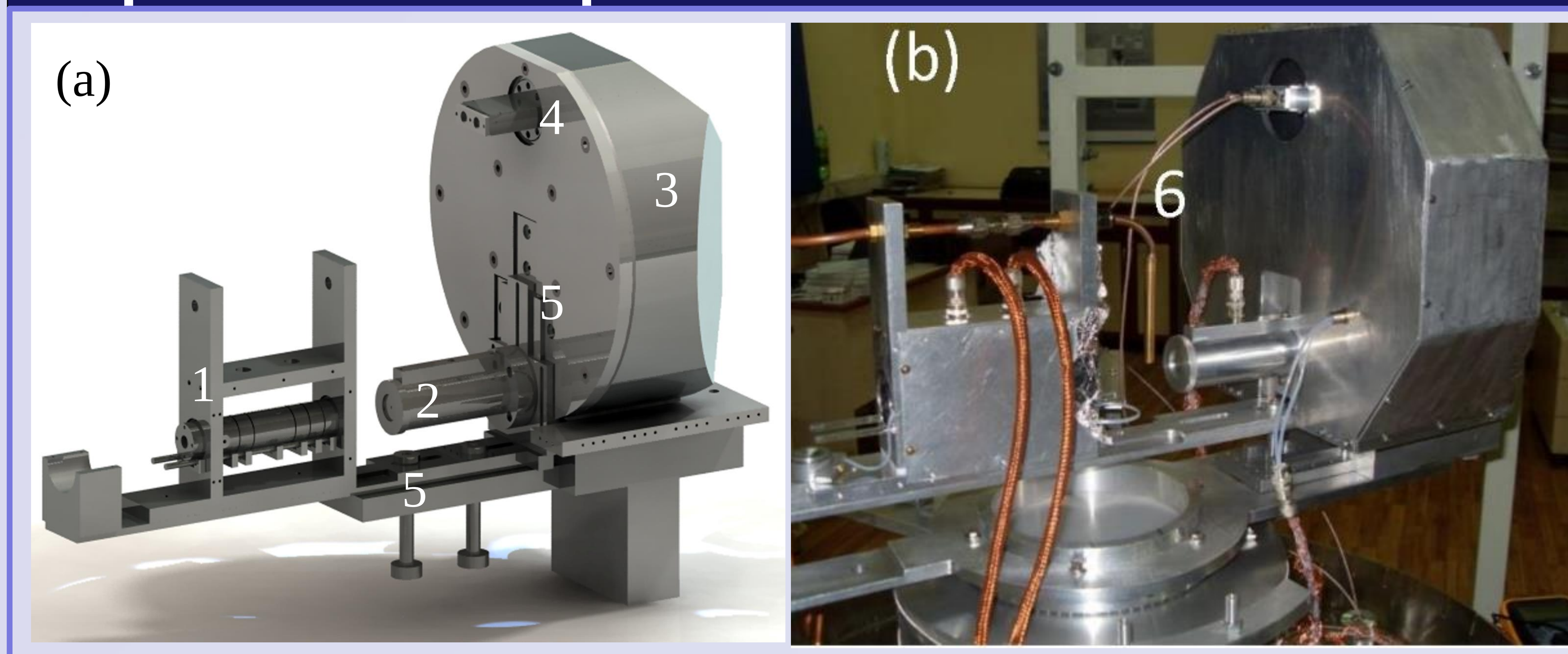

Figure 4. (a) 3D drawing of the complete analyzer system, showing its five main parts: (1) electron gun, (2) input lens, (3) HDA, (4) detector CEM assembly, and (5) movable supporting rail. (b) Photograph of the actual setup also showing the vertical gas nozzle jet target (6).

A mounting plate supported the input lens, hemispheres, and detector. The input lens was mounted on a rail. A screw was used to position the lens system, which could be moved up and down along the dispersion direction thus allowing the entry distance R0 to be effectively varied. The electron gun was also mounted on the same rail and therefore both e-gun and lens remained aligned on the lens axis as they were both moved up or down together.

The performance of the analyzer was tested by energy analyzing the elastic electron scattering peak for different γ values of the entry bias at the three entry positions, R_0 = 100 mm, 84 mm, and 112 mm, respectively. From the recorded electron line shape the effective resolution of the analyzer was directly determined. In all measurements described here the energy of the electrons emitted from the electron gun was set to E_{s0} = 200 eV. Measurements were then carried out to obtain the peak structure of electrons for pass energies E_0 = 30, 40, 50, 60 eV.

Fringing Field Correction

Hemispherical deflector analyzers (HDAs) combined with a cylindrical input-lens-system are characterized by good energy and angular resolutions. Fringing fields introduce departures from ideal field behavior leading to distorted trajectories, the degradation of first order focusing and a corresponding loss in transmission. This is one of the main disadvantages of this type of analyzer. The two (paracentric) positions R_0 = 84 and 112 mm for particular values of the bias $V(R_0)$ were predicted [2] from our previous simulation work [3, 4] to correspond to positions of optimal energy resolution for the right entry bias.

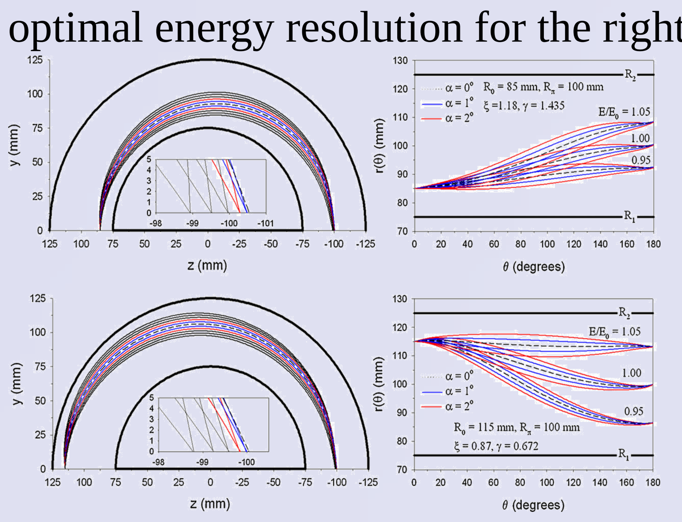

Figure 2. Optimized trajectories through the biased paracentric HDA for (a) R_0 = 85mm with γ = 1.435 and (b) R_0 = 115mm with γ = 0.672. The fields were computed using BEM with high accuracy [2].

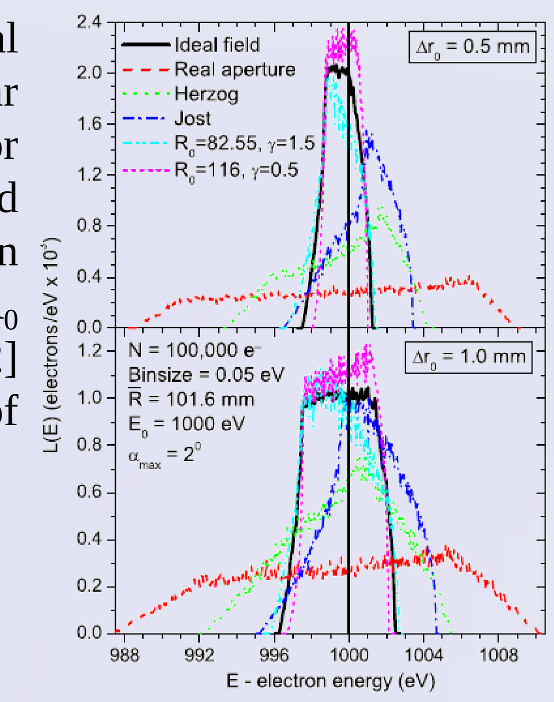

Figure 3. Line shapes for ideal field, real aperture, Herzog correction, Jost correction, and two paracentric entry HDAs [4].

Results

For the simulations, we used the latest 2012 SIMION 8.1 version to simulate the combined HDA plus 5-element input lens. The first simulation approach, termed the "beam width" method, was used to determine the maximal beam width $\Delta r_{\pi max}$ and dispersion D_γ. $\Delta r_{\pi max}$ measured the maximum beam width along the dispersion direction (x-axis) on the plane of the exit aperture.

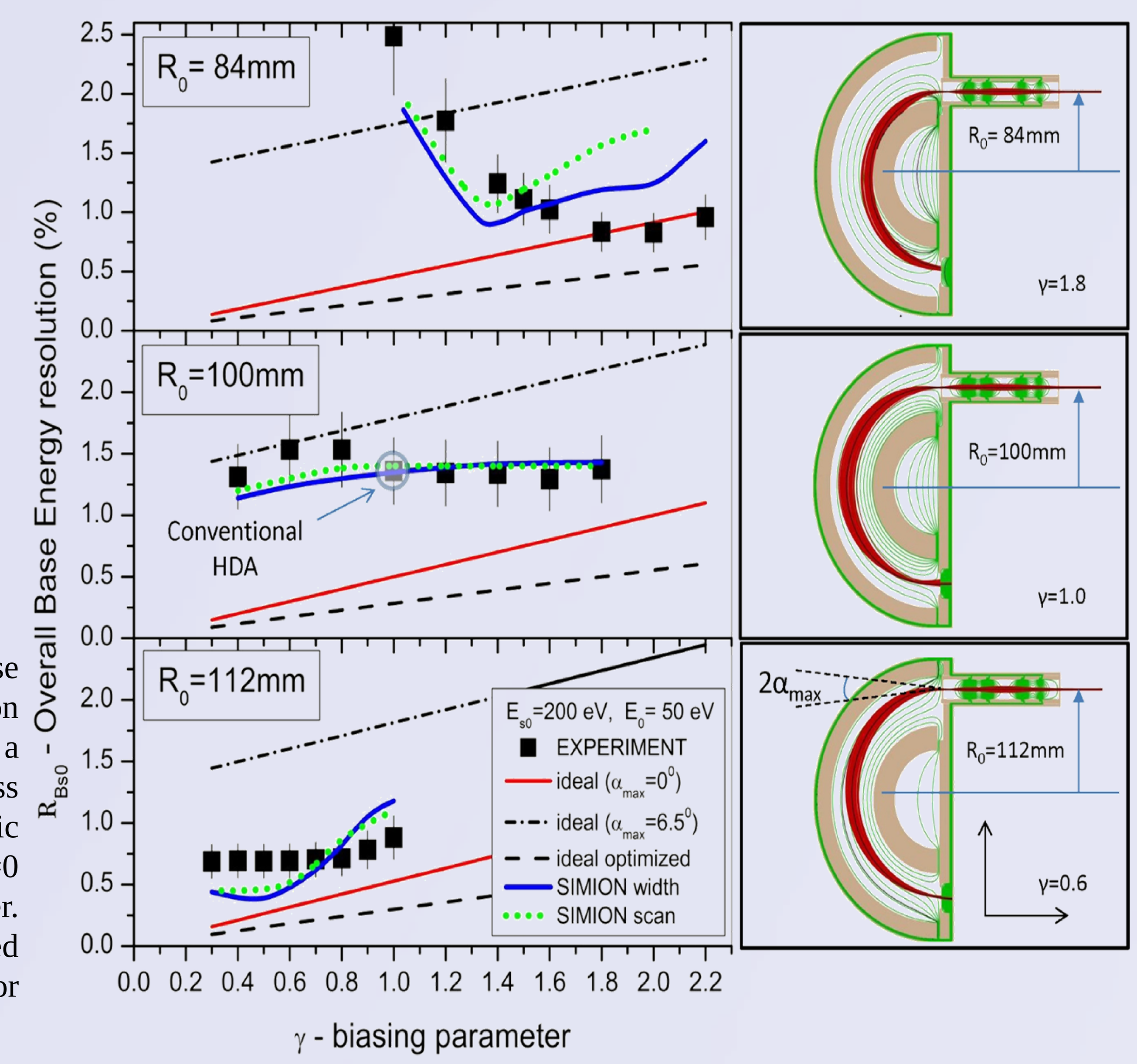

Figure 5. (Left) HDA overall base energy resolution plotted as a function of the biasing parameter γ for a source energy E_{s0} = 200 eV and pass energy E_0 = 50 eV. (Right) Schematic of SIMION simulations in the Y=0 dispersion plane of the spectrometer. Electron trajectories are shown in red and equipotentials in green for specified values of γ.

The second approach termed the "voltage scan" method was almost identical to the way the experimental spectrum line profile was obtained by stepping the voltages of the HDA and recording the number of electron trajectories that go through the exit aperture for each step. The base energy ΔE_B of the line profile could be directly determined from the final energy spectrum to compute the overall base resolution. These results are shown in Figure 5 as the dotted green line.

The conventional HDA energy resolution (circle in blue (see Figure 5) at R_0 = 100 mm and γ = 1) is clearly seen to be worse (larger) than both biased paracentric cases for R_0 = 84 mm and R_0 = 112 mm depending on γ. Best experimental paracentric resolutions are seen to occur for R_0 = 84 mm at γ = 1.8 and for R_0 = 112 mm at γ = 0.6. Also shown in Figure 5 are the resolutions obtained from SIMION simulations of the full HDA plus input lens. Agreement with experiment is fairly consistent between the two different simulation approaches.

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The spectrometer setup used to test our analyzer is based on the crossed-beams principle and basically consists of a high intensity electron gun, a gas beam target, and the HDA. A near-monoenergetic beam of electrons produced by an e-gun was focused onto the target beam and collected in a Faraday cup, while the scattered electrons were detected as a function of their kinetic energy and the angle through which they were scattered.

Three spectrometers have been installed in the lab to study electron-atom/molecule collisions. Currently, we are studying electron-impact ionization of Helium, Argon atoms and Hydrogen, Nitrogen and Methane molecules. Further work is planned on atmospheric and biological molecules using our new paracentric hemispherical analyser.

Conclusion

The energy resolution of a biased paracentric HDA seems to be at least a factor of 1.7–2 times better than the resolution of a conventional HDA. This measured improvement in energy resolution is particularly remarkable as it is conveniently attained without the use of any type of additional fringing field correction electrodes, but simply by taking advantage of the strong intrinsic lensing properties of the existing HDA fringing fields as determined and optimized by the particular paracentric entry position and bias control. Clearly, the use of fewer electrodes in the paracentric design reduces its operational complexity and lowers the overall cost of construction and HV power supplies. Improvement in energy resolution also means that paracentric HDAs of smaller size and therefore weight could replace larger conventional HDAs of equal resolution, particularly attractive to outer space instrumentation applications where both size and weight are invaluable. Finally, not having to introduce cumbersome additional correction electrodes that could partly block transmission, especially when used with a position sensitive detector, is clearly a big advantage.

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