# Resolving Power
# of the PHOIBOS Energy Analyzer Series

## Application Note

### Introduction

The line width of Xe and other rare gas levels using the SPECS gas cell UGC 10 and the SPECS UV-light source UVS 10/35 has been measured. The special geometry of the cell includes space charge compensation electrodes to demonstrate the ultimate energy resolution of the PHOIBOS analyzers.

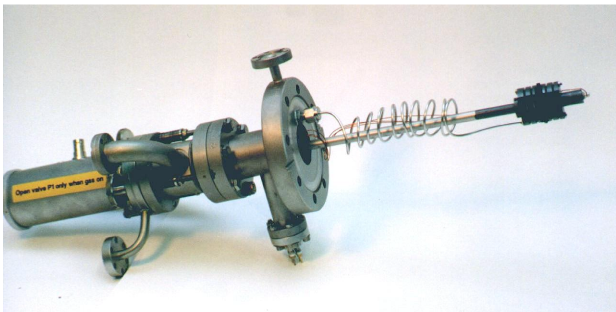


**Figure 1:** UGC 10 with UVS 10/35

### Measured line with

The measured line width includes the line broadening of the excitation source (about 3 meV) and the Doppler broadening of the target gas. Both contributions have a Lorentzian shape and the widths must be added for convolution. The Doppler broadening D$E_D$ of the target gas depends on the mass and the kinetic energy:

$$\Delta E_D = 0.7215\sqrt{\frac{E_{kin} \cdot T}{M}}$$

This expression ($\Delta E_D$ in meV ) is derived from the Boltzmann distribution, where $E_{kin}$ is the photoelectron energy in eV, T is the absolute temperature, and M is the molecular mass expressed in atomic mass units (see Ref. 1).

The tables below summarize the properties of typical rare gases. Different combinations of source and target gas give different Doppler broadenings.

| Excitation | Energy (eV) |
|---|---|
| He I | 21.2182 |
| Ne | 16.6710 |

**Table 1:** Main emission line energies of He and Ne

| Target | Binding Energy (eV) |
|---|---|
| He 1$s$ | 24.587 |
| Ne 2$p_{1/2}$ | 21.662 |
| Ne 2$p_{3/2}$ | 21.565 |
| Ar 3$p_{1/2}$ | 15.937 |
| Ar 3$p_{3/2}$ | 15.760 |
| Kr 4$p_{1/2}$ | 14.666 |
| Kr 4$p_{3/2}$ | 14.000 |
| Xe 5$p_{1/2}$ | 13.437 |
| Xe 5$p_{3/2}$ | 12.130 |

**Table 2:** Rare gas energy levels

| Excitation | Target | $E_{kin}$ | $\Delta E_D$ |
|---|---|---|---|
| He I | Xe 5$p_{3/2}$ | 9.0882 | 3.29 |
| Ne | Ar 3$p_{3/2}$ | 0.912 | 1.89 |
| Ne | Xe 5$p_{3/2}$ | 4.541 | 2.32 |
| He I | Ar 3$p_{3/2}$ | 5.4592 | 4.62 |
| Ne | Ar 3$p_{1/2}$ | 0.734 | 1.69 |
| Ne | Xe 5$p_{1/2}$ | 3.234 | 1.96 |
| Ne | Kr 4$p_{1/2}$ | 2.571 | 2.189 |

**Table 3:** Doppler broadening of different source/target gas combinations

## Results

The FWHM of an emission line as a function of the pass energy of the analyzer as well as the setting of the Iris aperture in the lens has been measured. With an Iris aperture in the diffraction plane of the analyzer the angular acceptance of the lens can be continuously adjusted. Together with an angular resolving mode the illumination along the non-dispersion direction can be restricted.

Fig. 2 shows the measured FWHM of the Xe $5p_{3/2}$ level exited with He I. Note that the measured line width is a convolution of the analyzer broadening with the instrumental broadening of the source and the Doppler broadening of the target gas (about 7 meV). The lines were measured with a PHOIBOS 150 MCD-9 analyzer with 0.2 mm entrance slit (s1) and an 0.25 mm exit slit (s2). The theoretical resolving power limit is RP = 4*150 mm / (s1+s2). The analyzer resolution limit is $E_p$/RP. For lower pass energies the resolving power behavior is described by a Gaussian convolution of the analyzer contribution with the gas/UV source contribution. For higher pass energies a Lorentzian convolution fits the data.

Thus, the measurements show that the resolving power of the analyzer must be described by an additional parameter for the contribution of the non-dispersive direction. The simple formula DE = (s1+s2)/(4R0) * $E_p$ is only applicable in the limit of short slit sizes.

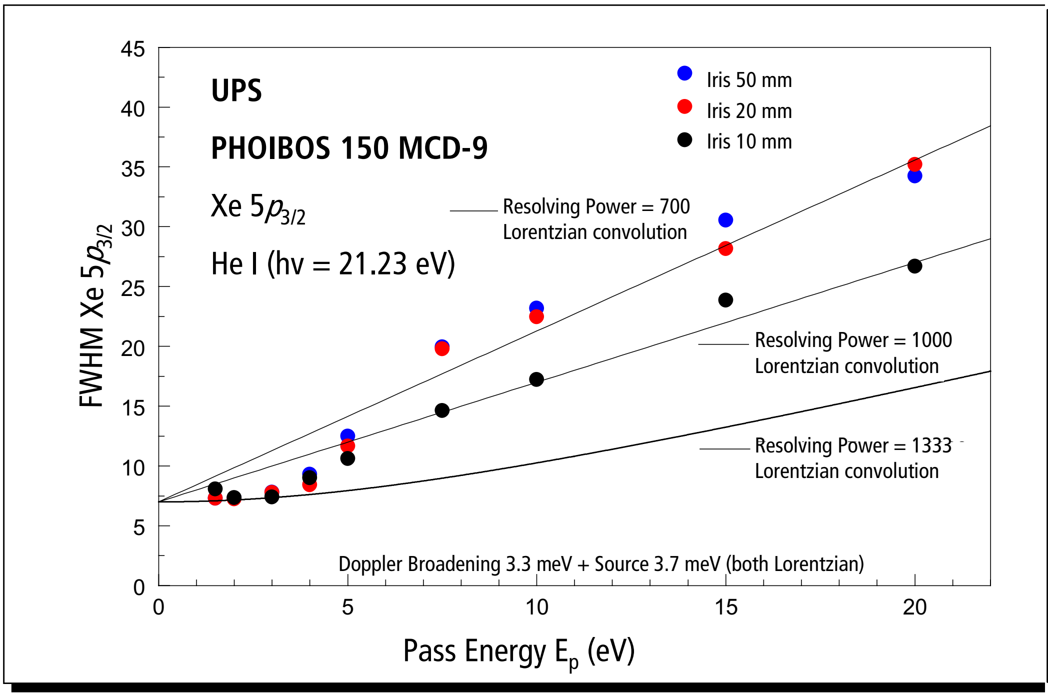


**Figure 2:** Measured FWHM of the Xe $5p_{3/2}$ level excited with He I at different Iris settings.

| Ep in eV | FWHM in meV<br>Iris 50 mm | FWHM in meV<br>Iris 20 mm | FWHM in meV<br>Iris 10 mm |
|---|---|---|---|
| 1.5 | 7.294 | 7.292 | 8.078 |
| 2.0 | 7.294 | 7.234 | 7.347 |
| 3.0 | 7.816 | 7.778 | 7.405 |
| 4.0 | 9.294 | 8.43 | 9.003 |
| 5.0 | 12.49 | 11.66 | 10.62 |
| 7.5 | 19.97 | 19.8 | 14.64 |
| 10 | 23.17 | 22.47 | 17.22 |
| 15 | 30.54 | 28.17 | 23.86 |
| 20 | 34.24 | 35.21 | 26.69 |

**Table 1:** Data of Fig. 2 in table format (FWHM with different Iris settings)

## High resolution measurements

In addition to the above measurements we have measured gas phase spectra with a synchrotron light source in order to show that the analyzer works reliably under conditions typical of our users facilities. The measurements have been performed at the 3m NIM-2 monochromator at the Berlin synchrotron radiation source BESSY together with Dr. D. Batchelor and Dr. P. Bressler. Fig. 3 shows a Xe spectrum acquired in these experiments.

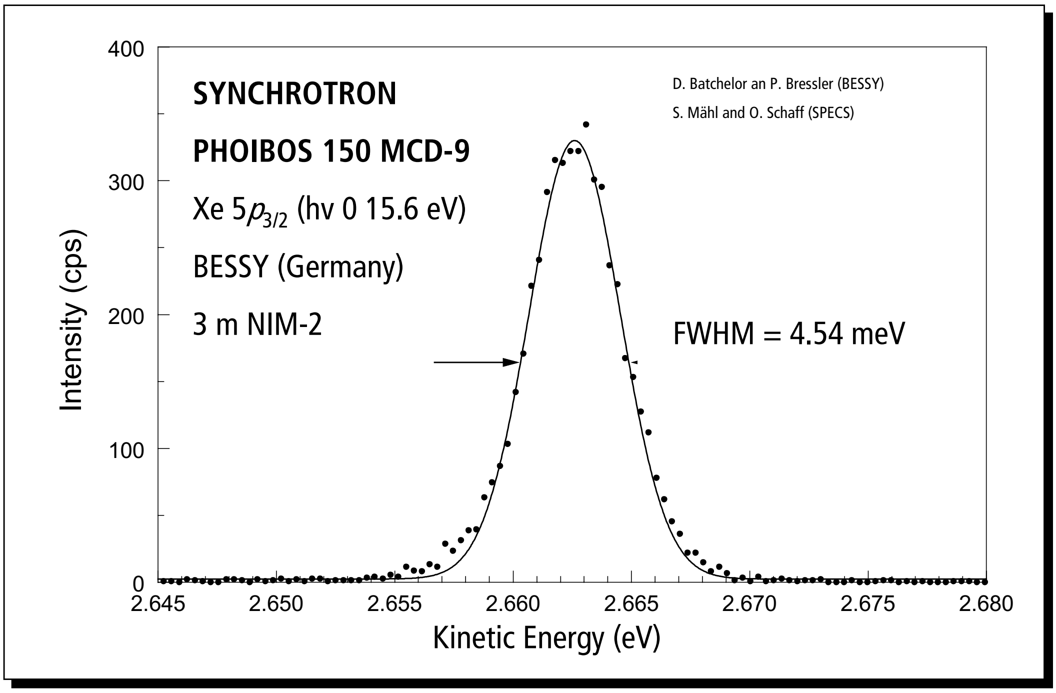


**Figure 3**: Xe line measured with synchrotron radiation

Fig. 3 shows data acquired with the PHOIBOS 100 CCD analyzer. This instrument is equipped with a 2-D CCD detector and is thus capable of simultaneous acquisition of angular/spatial and energy data (see 2-D CCD application note for more details). The two images have been acquired at the same analyzer settings and demonstrate the influence of the Doppler broadening on the line width. The CCD images are showing the 2-dimensional electron distribution at the exit plane. The horizontal axis is energy, the vertical axis is emission angle. These CCD camera images can be subdivided in energy channels to produce spectra like in Fig.4.

Fig. 4 shows a high resolution spectrum using this 2-D CCD detector at a pass energy of 1 eV. The Lorentzian shape of the line shows that the width of the spectrum is still determined by the Doppler broadening and the width of the UV line. If the analyzer resolution would have dominated the width, the spectrum would have Gaussian shape. The spectrum has been acquired in 10 seconds and the full exit slit length of 20 mm has been used.

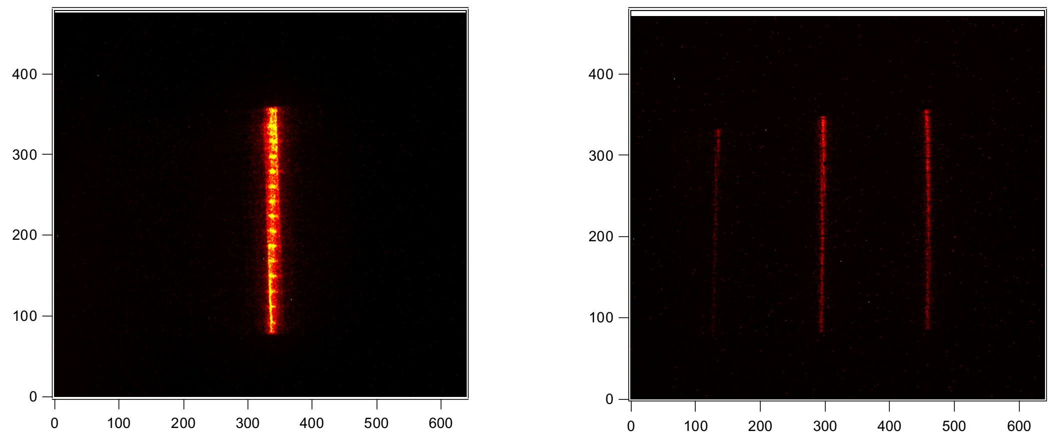


**Figure 4:** Xe (excited with He) and Ar (excited with Ne) measured with the same analyzer resolution (FAT 3) showing the smaller line widths of the Ar line. The measurement was done with a PHIOBOS 100 CCD analyzer.

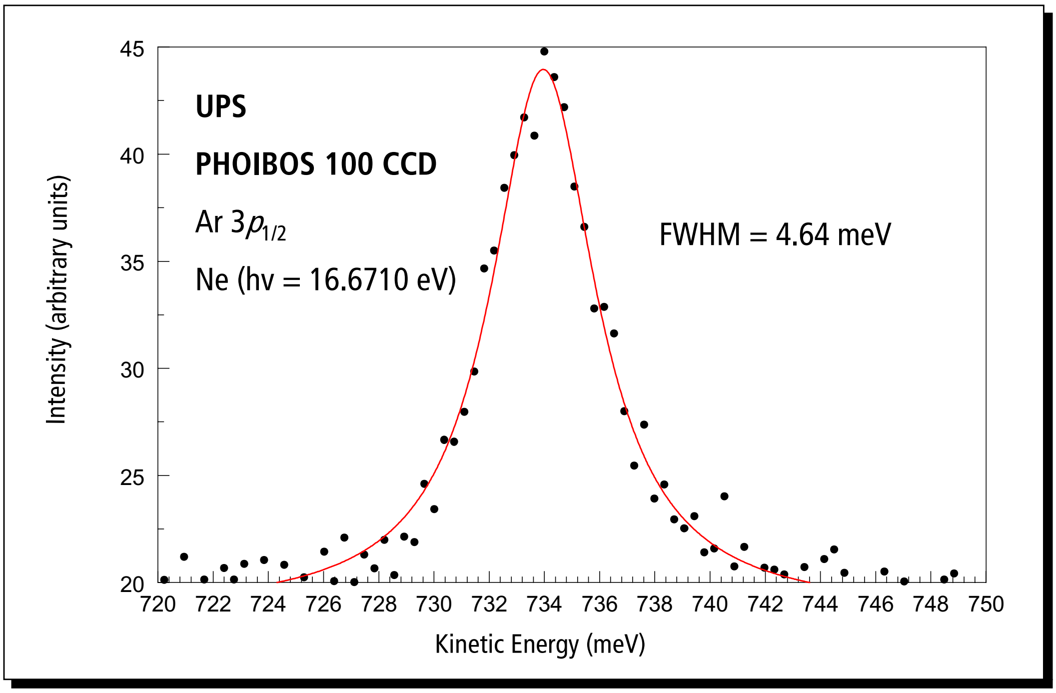


**Figure 5:** Ar 3 $p_{1/2}$ (excited with Ne) measured with FAT 1 . The fit was performed using a Lorentzian line shape. It shows the very high resolution capabilities of the PHOIBOS analyzer together with a 2D-CCD detector. The measurement was done with a PHOIBOS 100 CCD analyzer.

## References

[1] Resolution and signal-to-background enhancement in gas-phase electron spectroscopy, P. Baltzer et al., Rev. Sci. Instrum. 64, 2179, 1993.

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