HIGH ACCURACY ELECTRON-IMPACT PHOTOEMISSION CROSS SECTION MEASUREMENTS
FOR THE EUV RADIOMETRIC STANDARD

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This project was concerned with high-accuracy measurements of electron-impact photoemission cross sections for transitions of atoms and molecules in the EUV spectral region (30 nm to 200 nm). The spectrometer-detector system that was employed in the measurements was calibrated using well-parameterized synchrotron radiation. The 58.4 resonance line of He was chosen to establish the overall accuracy of the apparatus and data collection procedures. The measurement of this line can be compared to accurate theoretical calculations and to one other experimental cross section measurement in which a different excitation channel was observed.

The effort concentrated on finding the cause of the discrepancy in our measurement of the He I cross section compared with the "bench mark" theoretical-experimental value. Independent of the photoemission cross section measurements, a measurement of the transmission of resonance radiation as function of gas pressure also served as a good test of the performance of the non-optical apparatus and procedures. The pressure dependence of the absorption of resonance radiation is directly related to the atomic oscillator strength, the temperature of the gas, and the distance the radiation travels through the gas cell. Measurements made before May of 1987 resulted in a value for the transmission cross section that was about 30% too low. The discrepancy in both the He I photoemission cross section and in the transmission cross section could result from a faulty determination of the He gas density in the collision cell. The inaccurate measurement of the gas density may be the result of a poor definition of the gas temperature in the collision

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cell because of non-equilibrium conditions, non-linear behavior of the ion gauge, or systematic errors associated with the absolute calibration of the ion gauge.

Large temperature gradients are introduced into the collision chamber by the hot filament in the electron gun. In a first effort to divert some of the heat produced in the electron gun, a thick copper wire was used to conduct the heat from the electron gun filament holder to an electrically insulated water cooling duct. This did not result in a significant reduction of the temperature inside the collision cell as monitored by the various temperature probes mounted in the cell. Next an indirectly heated hollow dispenser cathode was installed in the electron gun. This cathode operated at half the power as the previous filament did. With this cathode, however, our electron gun would not produce a steady current. Furthermore, the cathode lost its electron emission capacity after only two weeks of operation. The regular filament was therefore reinstalled in the electron gun.

In June of 1987 the following measurements were made at the NIST synchrotron facility (SURF II):

NIST June 1987 Cross Section Measurement Results

He 58.4 nm	300 eV	$5.2 \times 10^{-18} \text{ cm}^2$ (accepted value is $7.5 \times 10^{-18} \text{ cm}^2$)
He 53.7 nm	300 eV	$1.3 \times 10^{-18} \text{ cm}^2$ (accepted value is $1.8 \times 10^{-18} \text{ cm}^2$)
Ar 92.0 nm	300 eV	$4.1 \times 10^{-18} \text{ cm}^2$ ($5.1 \times 10^{-18} \text{ cm}^2$, normalized to 100 eV)

The synchrotron facility experienced some technical difficulties during this period, giving us a reduced amount of beam time. This limited the amount of data that could be taken for calibrating the spectrometer-detector system and the integrity of our results was reduced because the procedure requires the detector efficiency calibration to be done in conjunction with the electron source emission measurements.

After this calibration trip it was decided to solve the heating problem by redesigning the electron gun with proper heat shielding. In the new design the filament and electrostatic lens elements are enclosed in a copper housing with only a small opening for the electrons to pass through. The housing is water cooled. It is also differentially pumped so that gas entering the housing through the opening is pumped away and not readmitted into the collision cell. Cross section measurements as well as transmission results improved significantly with the use of the water-cooled electron gun.

In March of 1988 the cross section measurements at the NIST with this newly designed water-cooled electron gun, gave the following results:

N.B.S. March 1988 cross section measurement results

He 58.4 nm	300 eV	6.5×10^{-18} cm ²
He 53.7 nm	300 eV	1.6×10^{-18} cm ²
Ar 92.0 nm	100 eV	6.2×10^{-18} cm ²

The values obtained for the He 58.4 nm and the He 53.7 nm lines are now about 12% too low as compared with the accepted values. The previous discrepancy was 30%. The transmission measurements also improved. The apparent transmission cross section is now about 20% too low, compared to a 30% discrepancy earlier.

The absolute calibration of the ion gauge was also improved. Before 1988 a capacitance manometer was used to calibrate the ion gauge that is used to continuously monitor the target gas pressure during a measurement. Calibration was done at pressures ranging from 10^{-3} Torr to 10^{-4} Torr. The accuracy of the capacitance manometer at 10^{-3} Torr is very good, calibration of the ion gauge is reliable to within a few percent. But with a sensitivity of about 10^{-6} Torr the manometer can not be used for accurate pressure measurements below 10^{-4} Torr. By assuming that the ion gauge is linear with pressure, the calibration was extrapolated to the lower pressures. As seen in Fig. 1 below this assumption is not correct. A spinning rotor gauge was incorporated into

the ion gauge calibration procedure. The SRG is capable of measuring gas pressures with an absolute accuracy of 1.5% at 10^{-6} Torr. The ion gauge is now calibrated against the SRG at the gas pressures that will be used during cross section measurements or transmission measurements. Because the He 58.4 nm and 53.7 nm lines are resonance lines, measurements involving these lines must be done at very low pressures (typically 10^{-6} Torr) to avoid radiation trapping.

Fig. 1. Ratio of ion gauge readout to SRG pressure as function of He gas pressure.

In April of 1988 the point on the tertiary table to which the horizontal scanning lead screw was attached was moved by 1". This resulted in a more uniform rotation rate of the grating when scanning the beam of synchrotron radiation horizontally across the grating during the efficiency calibration.

In May of 1988 we investigated the effect of reemission of absorbed resonance radiation on the transmission measurements of the He 58.4 nm line. Absorption as well as reemission increase with He pressure. The total contribution of reemission to the detected photon flux depends on the geometry of the gas cell and is difficult to evaluate numerically. To reduce the reemission of absorbed radiation a metal cylinder was

placed around the electron beam in the interaction region. A small slot in the cylinder allowed radiation to pass only to the spectrometer entrance slit. With this setup the transmission measurement resulted in an apparent absorption cross section that was about 15% too low, an improvement over the 20% discrepancy without the radiation baffle.

The linearity of photon flux with electron beam current was verified. Also the residual magnetic field strength near the interaction region between the electron gun and the Faraday cup was measured. The magnetic field is less than 0.1 gauss throughout the interaction region. This residual field is small enough to ensure that the electrons produced by the gun are not significantly deflected as they travel through the interaction region at any of the energies that we use.

In August of 1988 a commercial quadrupole mass analyzer on loan was used to look for variations in the background gas pressure as the target gas pressure was changed. Unfortunately this test had to be abandoned because the sensitivity of the mass analyzer for various species appeared to be dependent on the gas composition and the gas pressure.

Two more scheduled cross section trips to the NIST were made before the end of 1988, with the following results:

NIST October and December 1988 cross section measurement results

		October	December
He 58.4 nm	300 eV	$6.3 \times 10^{-18} \text{ cm}^2$	$6.2 \times 10^{-18} \text{ cm}^2$
He 53.7 nm	300 eV	$1.7 \times 10^{-18} \text{ cm}^2$	$1.6 \times 10^{-18} \text{ cm}^2$
Ar 92.0 nm	300 eV	$6.0 \times 10^{-18} \text{ cm}^2$	$6.0 \times 10^{-18} \text{ cm}^2$
H ₂ 121.6 nm	100 eV	$7.6 \times 10^{-18} \text{ cm}^2$	$7.0 \times 10^{-18} \text{ cm}^2$

The results for the He and Ar lines were close to the values obtained in March 1988. The last two H₂ values were strongly affected by instability of the ion gauge in the hydrogen environment.

The photoemission cross sections as measured by our apparatus is calculated using the step size of the spectrometer scanning drive. The

step size must therefore be accurately determined in the region of each line that is measured. In the beginning of 1989 spectra of various lines for various gases (H₂, He, Ar, Kr, N₂, SF₆, CO, CO₂) were recorded. However in many cases strong isolated lines were not available from any of these gases near wavelengths of interest so that only a rough picture was obtained of the variation of the spectrometer step size over its spectral range. A better characterization of the spectrometer step size as function of wavelength is needed. Even better would be the installation of a drive mechanism that provides a more uniform scanning rate and a detection system that actually measures the angular orientation of the grating.

In March of 1989 a calibration trip to the NIST gave the following results:

N.B.S. March 1989 cross section measurement results

He 58.4 nm	300 eV	6.1×10^{-18} cm ²
He 53.7 nm	300 eV	1.5×10^{-18} cm ²
Ar 92.0 nm	100 eV	5.9×10^{-18} cm ²
H ₂ 121.6 nm	100 eV	7.6×10^{-18} cm ²

These results basically confirm the previous results. The two He cross sections are 19% and 14% respectively lower than the accepted values. The Ar cross section is close to the mean value obtained in measurements since 1983. The H₂ value reproduced the result of October 1988.

In the summer of 1989 the transmission curve for the He 58.4 nm was remeasured, this time with the entire collision cell heated uniformly to 145°C. This was done to test the temperature dependence of the absorption cross section. The result however was similar to previous results, the apparent absorption cross section being 20% too low. At this time a phenomenon was observed that gave reason for concern. The ratio of the detected signals normalized for current and gas density of the Ar 92.0 nm and 93.2 nm lines is now different from what it used to be. The ratio should be close to 2.0 and it was in the early years of

the VUV project. The ratio is now 2.2. A cause has not been found. It could be caused by the drive mechanism.

In the fall of 1989 the inside surface area of the collision chamber was greatly reduced in order to obtain a lower background pressure. This reduction was possible by replacing the XYZ manipulator, which contained a bellows, with a flange. Also a bellows which provides the flexible connection between the moving (when scanning a beam of synchrotron radiation across the grating) collision chamber and the stationary beam line at the NIST was temporarily replaced with a flange. After baking the collision cell at 150°C for a few days a background pressure of about 3×10^{-7} Torr was obtained. Previously the background pressure was typically 2×10^{-6} Torr. Even with this improvement of the residual gas pressure, the absorption cross section is still 20% too low.

The cause of the anomalous He I cross section and transmission results has not been found. We propose to measure the transmission of argon (106.7 nm, 104.8 nm) and krypton (123.6 nm, 116.5 nm) resonance lines. We hope that the use of different gases will show whether the measurement of the gas pressure is responsible for our spurious absorption results. Also the contribution of reemission of resonance radiation will be carefully investigated. The lower background pressure and the water-cooled electron gun should greatly improve the quality of our measurements. Next the spectrometer step size will be accurately determined as function of wavelength. An accurate knowledge of the step size is especially needed at the wavelengths where cross section measurements are done. Once our method and apparatus are established by reproducing the He I (58.4 nm and 53.7 nm) cross sections to within 5%, we will be able to measure the absolute cross section of almost any line in the EUV with unprecedented accuracy.

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