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Abstract

A differentially pumped rare gas cell has been developed to suppress undulator harmonics on the Chemical Dynamics Beamline at the Advanced Light Source. Greater than 10^4 suppression of the harmonics has been demonstrated with no measurable (<5%) attenuation of the fundamental. The overall design is presented, and vacuum and optical performance are reported.

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I. INTRODUCTION

The Chemical Dynamics Beamline at the Advanced Light Source is an undulator beamline optimized for photons in the 6-30 eV range suitable for ionizing valence electrons. The undulator is intended to generate both VUV and soft x-rays, however, so the VUV region of the spectrum is obtained with the undulator operating at high K. Under these conditions, substantial radiant power is emitted in the higher harmonics, with harmonics higher than n=15 observed. For most experiments on the Chemical Dynamics Beamline these are undesirable, and some means of eliminating them must be found. A novel harmonic suppressor has been developed for this purpose.

The beamline has been described in detail elsewhere. [1] At present it employs an 8cm period undulator; this is to be replaced by a 10cm period device in the near future. The undulator radiation is focused first by a water-cooled spherical mirror (M1) that is shared with a separate branchline. A second retractable toroidal mirror (M2) directs the beam to the Chemical Dynamics beamline and focuses it into the gas cell of the harmonic suppressor. Most of the power in the higher harmonics is absorbed by these mirrors: photon energies above 70 eV are strongly attenuated, and those above 400 eV virtually eliminated. Following the harmonic suppressor is a retractable toroidal mirror (M3) that focuses the broadband (2%) beam into one endstation. When the M3 mirror is retracted, the beam passes into a high-resolution 6.65-m normal incidence monochromator, thence to a separate endstation. These dedicated endstations will exploit the intense VUV to perform soft ionization of reaction products in studies of crossed beam reaction dynamics, photochemistry, high-resolution photoelectron spectroscopy, and photoelectron-photoion coincidence experiments. In the crossed beam studies, for example, the "white" undulator VUV with its inherent 2% bandwidth will be used to achieve selective ionization of reaction products. These ions will then be mass selected and counted as a function of time or scattering angle by established techniques. It is important, in order to minimize background interference and allow selective photionization, that no high energy photons are present that can yield contributions

by dissociatively ionizing parent molecules or background gases. A high efficiency harmonic filter is necessary to take full advantage of the capabilities of the instrument.

Numerous approaches have been employed in the past to filter unwanted VUV light, particularly in synchrotron radiation applications. Typically these involve the use of either filters or multiple mirror reflections. [2] A variety of filters are commonly employed, notably semitransparent windows made of suitable materials. Ionic crystals are very efficient at absorbing harmonics, but there is a short wavelength transmission limit, 104nm for LiF, that limits their applicability. In addition, filters are also made from elemental films such as carbon or aluminum a few thousand angstroms thick. These generally have narrow windows of transmittance, with structured absorptions. A disadvantage of these filters is that the transmission of the fundamental may be only 50%. In addition, these structured absorptions lead to effective filtering for only a few harmonics for a given filter. Multiple filters may be employed, with corresponding attenuation of the fundamental. Rare gases are also used to filter VUV, but to date these have only been applied in cells with semitransparent windows. [2] The gases represent excellent filter media, since they are quite opaque above their ionization potentials, but virtually transparent below. Unfortunately, as indicated above, the window materials have strongly wavelength dependent absorption coefficients, and in any case absorb significantly throughout the VUV region. In addition at the high power associated with the undispersed undulator beam typical thin film windows would be prone to damage, and lithium fluoride windows would tend to form color centers. Differentially pumped rare gas filters have not been practical until recently since it is only with the advent of coherent undulator sources that the beam may be focused with small enough divergence to pass through the neccessary succession of conductance-limiting apertures.

Multiple mirror reflections are also used in synchrotron applications to filter unwanted radiation. [3] Much like thin film filters, however, mirrors provide limited attenuation in the VUV relative to the fundamental, and significant attenuation of the fundamental is unavoidable. One final drawback common to both thin film filters and mirrors is a gap ranging from the lithium fluoride cutoff at 11 eV to about 25 eV. On the Chemical Dynamics

Beamline, in particular, this region is of considerable importance.

These considerations have prompted us to develop a windowless harmonic filter employing rare gas (argon or neon) as the filter medium with differential pumping serving to preserve the beamline vacuum. This article outlines the design characteristics of the device and presents a summary of its performance measured using a Transmission Grating Spectrometer (TGS).

II. DESIGN

The competing requirements imposed by the need for a significant number density of gas in the absorption cell while preserving the beamline vacuum to $< 5 \times 10^{-9}$ Torr, dictate the design of the harmonic suppressor. Figure 1 presents a schematic view of the design. There are 3 differential pumping regions in addition to the gas cell. Each of these regions is separated by conductance limiting aperture tubes. The chamber and the differential regions are modified commercial copper-seal vacuum components. At the center is the gas cell itself, a 1.5 inch OD stainless steel tube, 8 inches long. The cell is separated from the first differential chamber on both ends by .040 inch ID tubes 2 inches long. These tubes are mounted on plates which are keyed onto the cell, ensuring they are coaxial. The cell aperture tubes include several features intended to inhibit formation of an atomic beam directed to the beamline. The ends of the tubes are cut at an angle yielding "sperm whale" nozzles that direct the gas flow at an angle to the beamline axis. In addition, numerous vent holes are provided to minimize the flow of gas out the end of the tubes.

The cell hangs from a reducing flange mounted on a CF10 6-way cross. This is connected at the downstream side to a CF10 Tee that will house a rotating chopper wheel. The wheel will be be used in future pulsed experiments to chop the undulator beam. These two components represent the first differential chamber, (Region I in fig. 1) which is pumped by a 1000 l/s high-throughput magnetic bearing turbomolecular pump (Seiko-Seiki H1000C). This pump is backed by a 14 cfm oil-free scroll pump (Edwards ESDP-30).

At the ends of each differential region, rings were welded in place on which are mounted aperture plates. The plates themselves have provision for mounting the apertures, but can be removed so that one may access the next inner aperture after assembly. The apertures are 2 inch long stainless steel tubes welded on 2"x2"x1/4" blocks. These are mounted on oversize viton o-rings on the plates, and clamped on and adjusted by retaining blocks with adjustment screws. These allow x and y translation as well as pitch and yaw adjustment for each aperture. Alignment of the apertures was accomplished using two cassitometers, each aligned with respect to the gas cell on either side of the system. Each aperture was aligned as it was installed using the cassitometers.

At each end of the first region there are 4-way crosses containing baffles as shown in fig. 1. These isolate the second and third differential regions, and support another pair of aperture tubes. The baffles are configured so that a single pump is used for both upstrem and downstream sides for each differential region. Both region II and region III are pumped by 400 l/s magnetic bearing turbomolecular pumps (Seiko-Seiki STP 400), and each of these pumps is exhausted into the next higher pressure region. A final aperture is located between the third differential region and the beamline on each end. The diameter of these apertures are indicated in the figures. The upstream apertures were coated with a phosphor to facilitate alignment of the undulator beam.

III. RESULTS

The pressures were monitored in the gas cell using a capacitance manometer, in region I using a convectron gauge, and in regions II and III using ion gauges. The vacuum performance of the system is presented in Table 1. Gas consumption under these conditions is approximately 4 Torr ltr s^{-1}, consistent with calculations based on the conductance of the aperture tubes. The migration of rare gas from the harmonic suppressor to the storage ring is a concern because of possible degradation of the lifetime of the electron beam. Residual gas analysis was performed in the beamline front end. Partial pressures of 3×10^{-12} and

2×10^{-12} Torr were observed for Ne and Ar, respectively.

The measurements of the performance of the harmonic suppressor were made with the Transmission Grating Spectrometer (TGS), which was designed for the characterization of undulator radiation. A detailed description of the design and calibration of the spectrometer has been presented elsewhere. [4] The TGS consists of a spherical focusing mirror, interchangeable gold transmission gratings of 2000 and 5000 lines/mm, and a Si n-on-p photodiode behind a slit. To increase the sensitivity of the spectrometer for these measurements, a slit with 250 μm width was chosen. In addition, the grating pinholes were removed, leaving the gratings fully exposed. The resolution of the spectrometer, determined by the slit width, was $\delta\lambda = 1$ Å. During the measurements the TGS was installed at the end of the first branch of the beamline, after the M1 and M2 mirrors, the harmonic suppressor and the M3 mirror. In order to protect the transmission gratings from damage, the radiation power density on the gratings was limited to 0.1 W/cm^2. This power restriction was accomplished in two ways: by measuring at large undulator gap (K = 0.11) with the normal ALS beam current or at low storage ring current (5 mA) and small undulator gap (K=5.24).

Measurements were made of the undulator spectrum at K=0.11, as a function of neon presssure in the cell. The results of integrating the undulator fundamental at four different neon pressures are shown in fig. 2. The Beer-Lambert law, $I/I_o = e^{-\sigma nl}$, is followed, where σ is the absorption cross section, n the number density and l the absorption length. The value of σ for Ne at the center of the undulator fundamental, 260 eV, is 5.52×10^{-19} cm^2/molecule, taken from the compilation of Henke et al. [5] The largest uncertainty is in the measurement for 30.6 torr because of the small signal from the harmonic in comparison with the background. The logarithm of the integrated current was fit to a line, which gave an effective absorption length l of 16.0 cm. This calculated value for l is less than the physical length of the gas cell, reflecting the decreasing density of gas in the entrance and exit tubes.

The undulator spectrum was measured at K=5.24 with and without 30 Torr Ne, and the results are shown in fig. 3. In the absence of gas, a number of undulator harmonics are observed, with additional peaks from higher orders of the transmission grating. The

intensity of the harmonics is modulated by the mirror reflectivities. In addition the TGS sensitivity is, to first order, inversely proportional to wavelength. Integration of the harmonic peaks in the spectrum with and without Ne shows a suppression of greater than four orders of magnitude. In the case of the third harmonic a suppression of 10^5 was observed. The measured absorption of the higher harmonics is limited by the background of scattered light in the TGS detector, consequently the experimental spectrum provides only a lower limit for the attenuation factor. Calculations from the absorption coefficient predict a suppression of 10^6 at 200eV, with dramatically increasing suppression at lower energies.

The fundamental was observed to have lower intensity when neon was present in the gas cell than when the gas was absent. However, the nth undulator harmonic in nth diffraction order of the transmission grating will be present at the same detector angle as the fundamental peak. This contribution is only present in the case without gas. Correcting the higher order contributions from a spectrum taken with the 2000 l/mm grating gave a fundamental intensity reduced by 4% by the Ne gas. Within the measurement uncertainty, the fundamental was unattenuated by the gas.

Argon was also studied as a filter gas for the harmonic suppressor with the pressure set to 30 torr. For the undulator spectrum at K = 5.24, the lower harmonics are observed to be suppressed by approximately a factor of 10^4, again limited by the TGS sensitivity and similar to the result for Ne. However, in the region near 250 eV, harmonics could still be observed. For example, the 12th harmonic was present at an intensity of 0.0014 compared with the case without gas. The different behavior of Ar and Ne can be understood as a result of the more steeply decreasing absorption cross section σ of Ar in this region.

Rare gases have Rydberg resonances below their ionization potentials that may influence the behavior of the harmonic filter on the fundamental. The undulator gap was set so that the fundamental wavelength coincided with the Ne transition $2p^6 \rightarrow 2p^5\ (^2P_{\frac{1}{2}})4s$ at 626.8 Å. Only a small dip, 2% of the integrated harmonic, was observed at the resonant wavelength owing to the small linewidth ($< 10^{-3}$ Å) of the Doppler broadened Ne transition. Three

other resonances, $2p^5$ ($^2P_{\frac{3}{2}}$)4s, $2p^5$ ($^2P_{\frac{3}{2}}$)3d, and $2p^5$ ($^2P_{\frac{1}{2}}$)3d fall within the width of the harmonic. For use in broadband ionization of reaction products it will generally not be necessary to avoid the Rydberg resonances of the gas in the harmonic suppressor. For the high resolution photoionization and coincidence studies, other gases must be substituted when the region of interest overlaps a Rydberg resonance.

The angular acceptance of the harmonic suppressor is determined by the diameters of the differential pumping aperture tubes, which set an upper limit of 0.8 mrad (from the source), and by the alignment. Measurements were performed for different widths of the horizontal and vertical apertures. The observed variation of the intensity of the fundamental with aperture dimensions suggests that the acceptance is at present 0.7 mrad, sufficient to accept the central cone (4σ) over the entire planned operating range.

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TABLES

TABLE I. Vacuum performance of harmonic filter. Pressures in Torr.

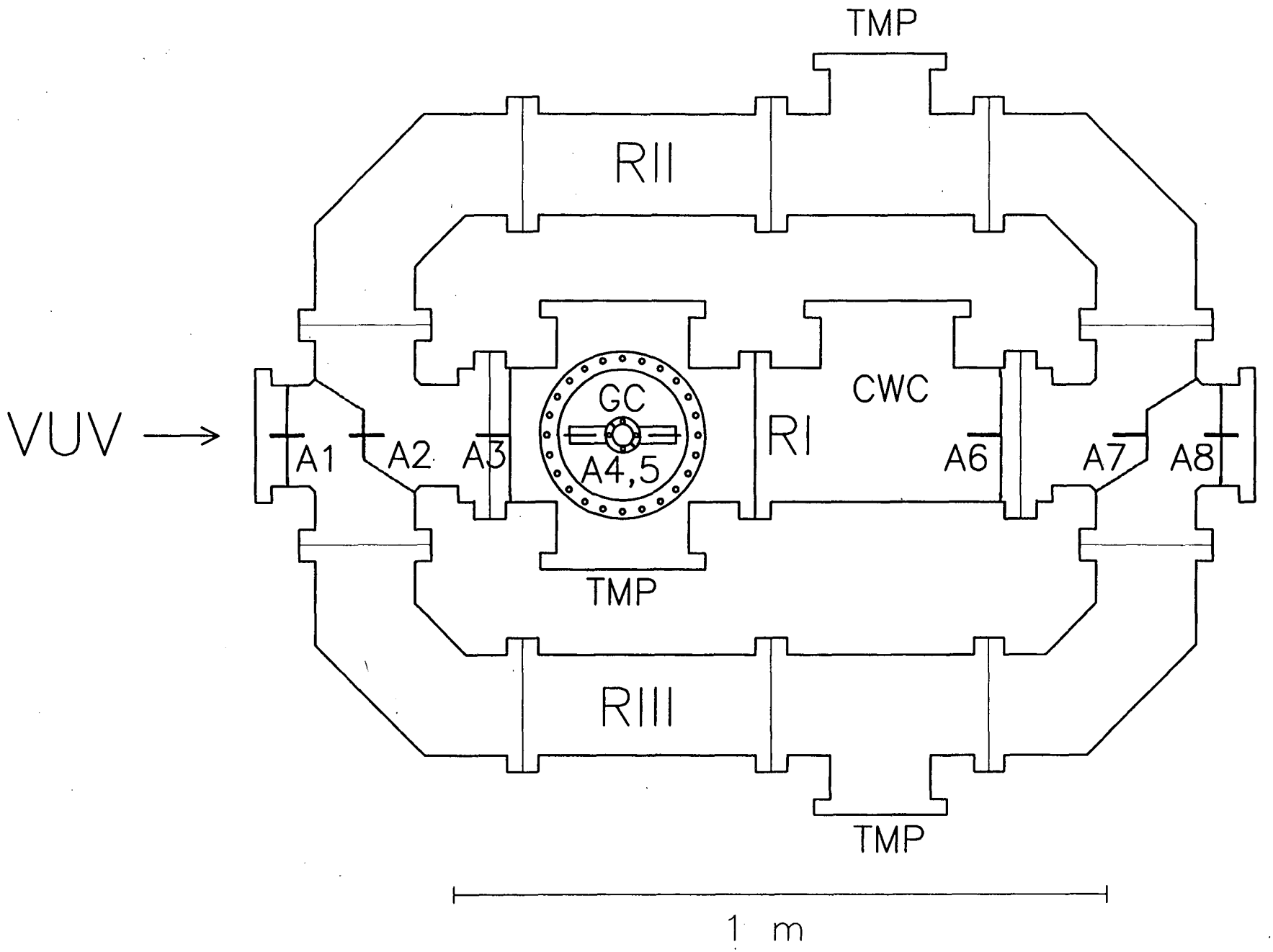
Region	No gas	Neon	Argon
Cell	0	30.6	30.8
RI	$< 10^{-3}$	9.7×10^{-3}	1.3×10^{-2}
RII	1.3×10^{-7}	3.4×10^{-6}	1.5×10^{-5}
RIII	9.3×10^{-9}	1.1×10^{-8}	1.7×10^{-8}

FIGURES

FIG. 1. Schematic view of harmonic suppressor. RI, II, III Region I,II,III; Apertures: $A1, A8$, 3mm dia, $A2, A6, A7$, 2mm dia, $A3, A4, A5$, 1mm dia.; GC, gas cell; CWC, chopper wheel chamber; TMP, turbomolecular pump.

FIG. 2. Beer-Lambert law plot of integrated undulator spectrum at K=0.11. Error bars for first three points are smaller than the circles shown.

FIG. 3. Undulator spectrum at K=5.24 recorded with and without 30.6 Torr Ne in the gas cell. First order contributions of the undulator harmonics are indicated. Contributions are also seen from higher grating orders.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RII
VUV
A1
A2
A3
GC
A4,5
RI
CWC
A6
A7
A8
TMP
RIII
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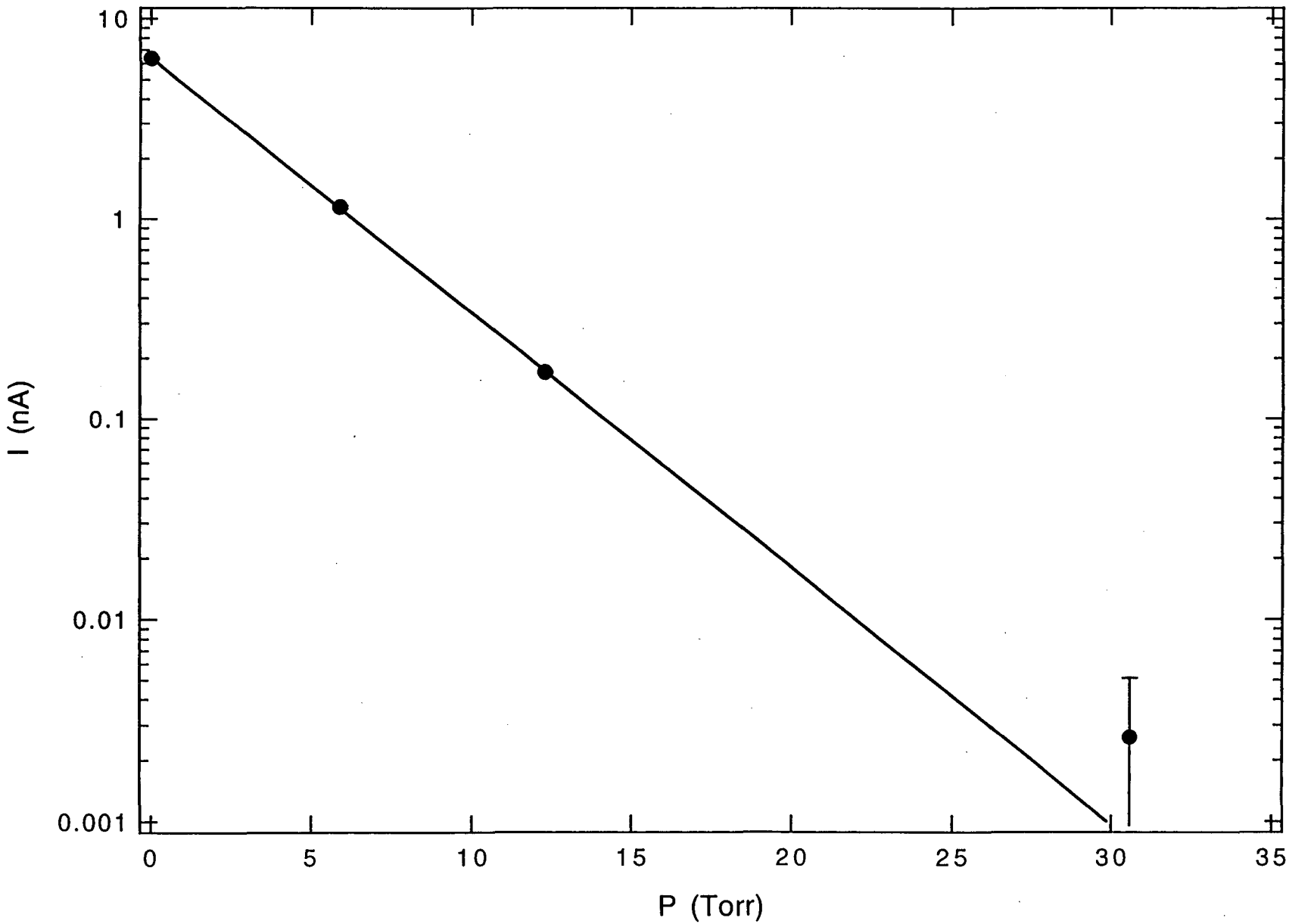
1 m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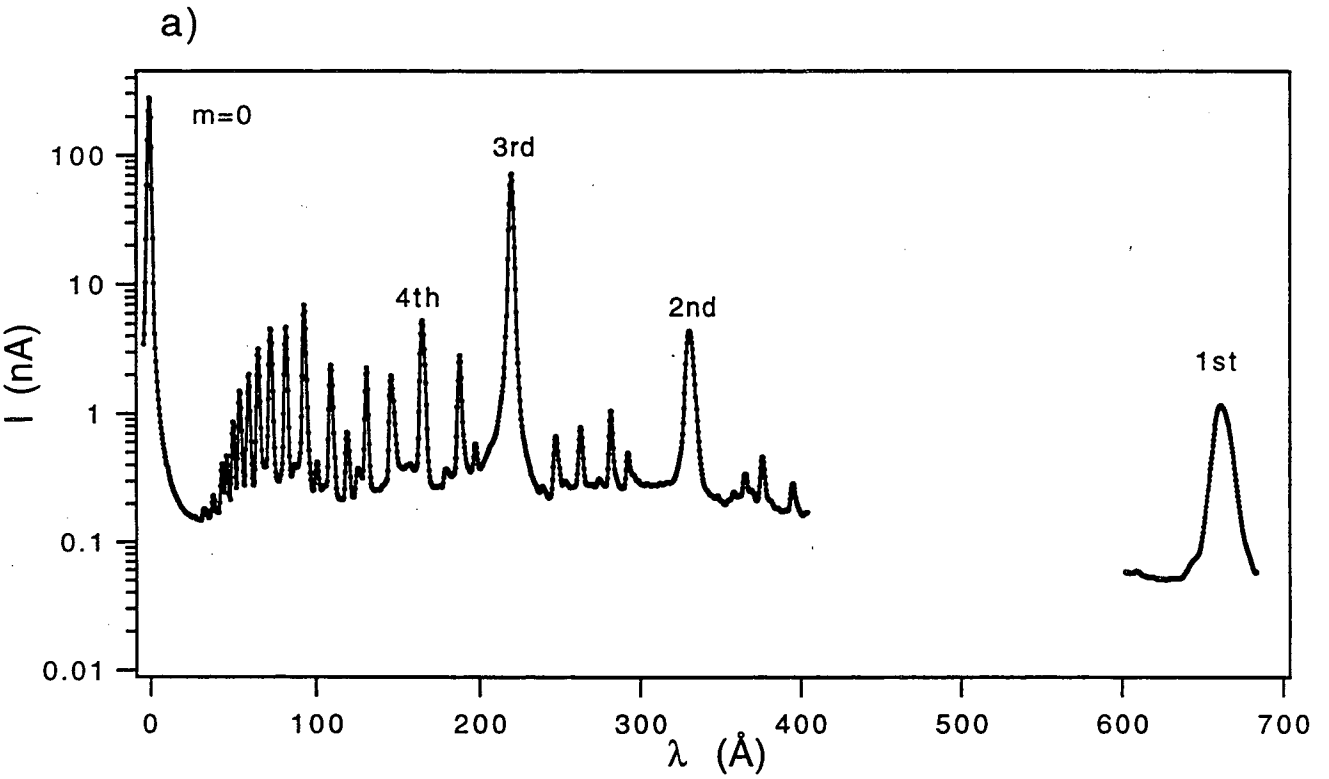
0.01
0.001
I (nA)
0
5
10
15
20
25
30
35
P (Torr)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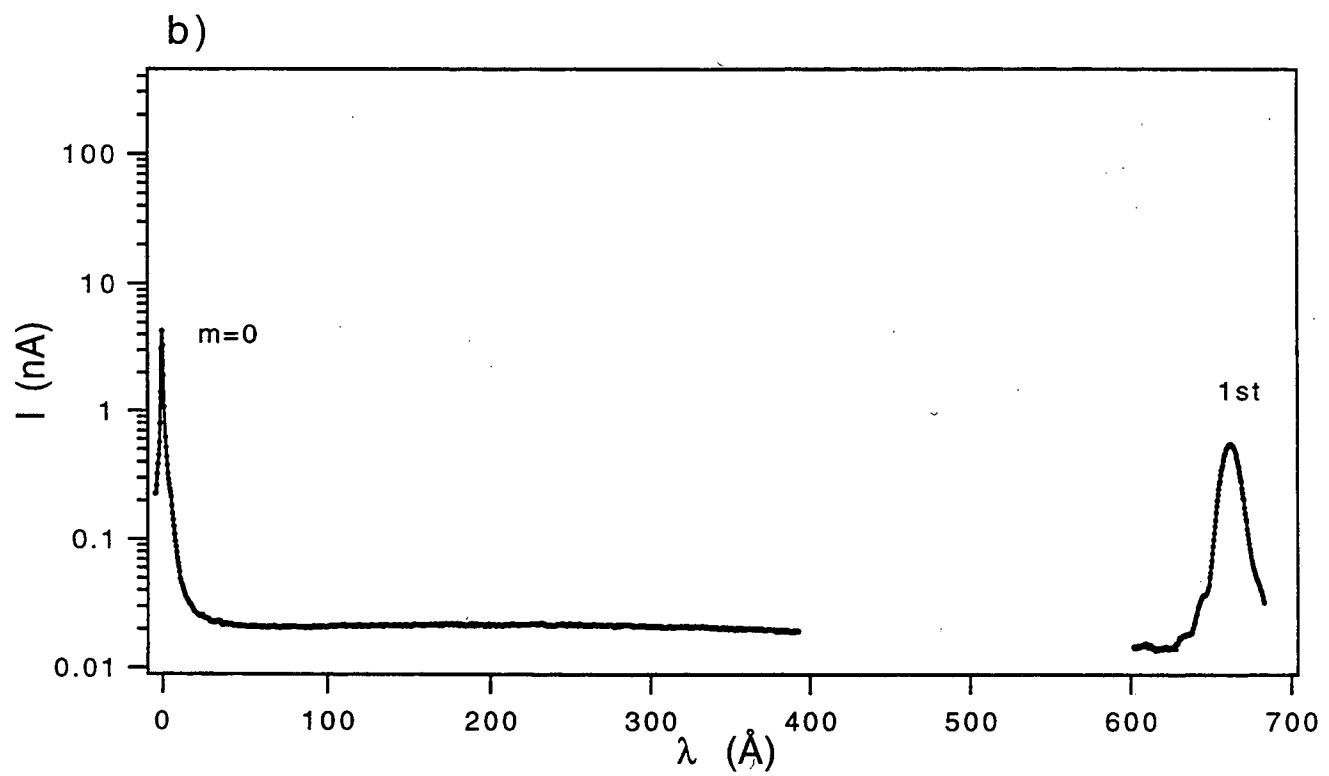
λ (Å)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