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Absolute differential cross sections for charge-transfer of KeV-energy H\(^+\) and O\(^+\) ions with atomic oxygen

Schafer, David Allen, Ph.D.
Rice University, 1989
RICE UNIVERSITY

ABSOLUTE DIFFERENTIAL CROSS SECTIONS FOR CHARGE-TRANSFER OF KEV-ENERGY H⁺ AND O⁺ IONS WITH ATOMIC O₂ GEN

by

David A. Schafer

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

DOCTOR OF PHILOSOPHY

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ABSTRACT

ABSOLUTE DIFFERENTIAL CROSS SECTIONS FOR CHARGE-TRANSFER
OF keV-ENERGY H\(^+\) AND O\(^+\) IONS WITH ATOMIC OXYGEN

by

David A. Schafer

The major constituent in the atmosphere of the Earth at altitudes between
200 and 500km is atomic oxygen.\(^1\) Collisions involving atomic oxygen are
therefore important in this region of the atmosphere. Due to the difficulty in
producing atomic oxygen in the laboratory, there are very few reported
measurements of scattering cross sections with an atomic oxygen target.\(^2-6\)
We have undertaken an experimental program designed to measure
absolute differential cross sections for various collision processes involving
atomic oxygen. The oxygen atoms are produced through dissociation of O\(_2\)
in a microwave discharge, producing a target of atomic and molecular
oxygen whose densities are inferred from measurements with an electron
impact time of flight mass spectrometer.
Acknowledgements

The time I have spent at Rice University will never be forgotten. During this time I have grown both as a student and scientist, and as a person. I would like to thank all of the people with whom I have shared this time. First I would like to express my appreciation to my research advisors Dr. Stebbings and Dr. Smith. You both have been very patient with me and have helped me develop as an experimental scientist. Your experience and insights have continued to amaze me. I could not imagine any laboratory anywhere that could have prepared me for the future better than the atomic physics lab. I would also like to thank those people that I worked with in the lab. These people learned alongside me the importance of asking the right questions and searching for the answers. To my friends in the lab, Jim Newman, Yansong Chen, Larry Wald, Ru-shan Gao, Charlie Hakes, Lee Johnson, Chetan Chitnis, Gerry Smith, and Pascal Renault I say thank you.

To Elaine and Ryan, my future, I can only say that I love you. You have supported me in the final push, and have stood by me when I needed you. You both add a special joy to my life.

To Mom and Dad and all of my family, I did it! Thank you for your support through the hard years. You have given my financial and emotional support when I needed it most. I have no words that can say any more except that I love you and thanks.
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CHAPTER I
INTRODUCTION

Differential cross sections (DCS) for charge-transfer are of fundamental interest in atomic collision physics. In addition, they are useful in modeling systems ranging from planetary atmospheres to fusion reactors.\textsuperscript{7-9} Charge-transfer collisions have been studied for many years, however, most of the measurements were of total cross sections or low resolution differential cross sections.\textsuperscript{2-6} Recent advances have allowed us to measure high resolution differential cross sections for stable gas targets.\textsuperscript{10-12} We now adapt this technique to the more difficult task of measuring absolute DCS's for atomic oxygen.

Atomic oxygen is the major constituent in the Earth's atmosphere at altitudes greater than 150\text{km}.\textsuperscript{1} Modeling of processes in the upper atmosphere therefore requires knowledge of collision cross sections for these atoms. During geomagnetic activity, energetic ring current ions (H\textsuperscript{+}, O\textsuperscript{+}, O\textsuperscript{++}, and He\textsuperscript{+}) precipitate into the atmosphere.\textsuperscript{13} In 1972, Shelley \textit{et al}.\textsuperscript{14} measured O\textsuperscript{+} fluxes that provided a thermospheric energy input as large as 0.4 erg/cm\textsuperscript{2}/sec/sr. Several models have attempted to predict atmospheric heating and particle loss due to these precipitation events.\textsuperscript{8,9,15,16} In their first publication on this topic Torr \textit{et al}.\textsuperscript{8} used theoretically calculated cross sections for charge transfer with atomic oxygen. Subsequently, Kozyra \textit{et al}.\textsuperscript{15} found that by using more forward
peaked collision cross sections, the calculated altitude of maximum heating due to the precipitation is lower than predicted by Torr et al. Ishimoto et al. improved on the calculation of Torr et al. by using information derived from measured DCS's for elastic scattering of He with N₂, O₂, H₂, and He. These data clearly show the forward scattering nature of these collisions which leads to deeper penetration of the precipitating particles. Measured differential cross sections for H⁺ and O⁺ scattering with atomic oxygen are needed to improve the results of the model. In addition, the model of Ishimoto et al. has used the total cross section (TCS) data of Rutherford and Vroom for the O⁺ - O charge transfer collision.

While our apparatus is primarily designed to measure differential cross sections, simply summing all the fast neutral products that are detected gives the integral cross section for charge transfer within the angle subtended at the exit aperture of the target cell by the detector. These integral cross sections can then be compared to the existing total cross sections (TCS) in the literature. Due to the difficulty of such measurements, there are only a few reported investigations for both H⁺ - O and O⁺ - O collisions. There is some discrepancy in the reported TCS for H⁺ - O between recent measurements of Williams et al. and the measurements of Stebbings et al. and of Rutherford and Vroom which are in excellent agreement. For the O⁺-O collision, the only reported TCS's are those of Stebbings et al. and of Rutherford and Vroom, and these two measurements are again in excellent agreement. The TCS's determined in our present experiment are compared to these previously reported total cross sections.
The remainder of this thesis is organized as follows. Chapter 2 discusses the experimental method used to measure the absolute DCS's for atomic oxygen. This chapter includes discussion of ground state ion beam production, atomic oxygen target production, and determination of the atomic oxygen target density. Chapter 3 presents the first results of the measurements along with a comparison with TCS's in the literature. In chapter 4, future improvements in the experiment are outlined.
CHAPTER II
EXPERIMENTAL TECHNIQUE

When a beam of particles passes through a target of thickness $dx$, the number of beam particles that undergo collisions is proportional to the density of the target gas $n(x)$, the particle beam flux $I(x)$, and $dx$ i.e.

$$dl = \sigma n(x) I(x) dx$$  \hspace{1cm} (1)

where the constant of proportionality $\sigma$ is the total collision cross section and has units of area. Integration of the above equation over the length of the target $L$ gives:

$$I = I_0 e^{-\sigma \int_0^L n(x) dx}$$  \hspace{1cm} (2)

where $I_0$ is the initial beam flux.

In the case of charge-transfer collisions, the flux of neutrals produced, denoted by $S$, is similarly

$$S = I_0 (1 - e^{-\sigma \int_0^L n(x) dx})$$  \hspace{1cm} (3)

Where $\sigma$ is now the total cross section for charge transfer.
Recent studies by Newman et al\textsuperscript{11} have demonstrated that for the scattering cell used in this experiment, the total target thickness $\int n(x)dx$ is accurately given by the product $nL$, where $L$ is the physical length of the cell. Under single collision conditions, i.e. $n\sigma L \ll 1$, equation 3 becomes:

$$S^\prime = I_0 \sigma nL$$

(4)

The laboratory-frame differential cross section (DCS) $\frac{d\sigma(\theta,\phi)}{d\Omega}$ is defined in terms of $S(\Omega)$, the number of particles scattered into the solid angle $\Delta\Omega$ in the $\theta,\phi$ direction from the scattering center (see Figure 1), as:

$$\frac{d\sigma(\theta,\phi)}{d\Omega} = \frac{S(\Omega)}{\Delta\Omega \ I_0 \ nL}$$

(5)

![Diagram](image)

Figure 1 - Laboratory scattering geometry
The DCSs are independent of $\phi$, the azimuthal angle about the beam axis, since neither the targets nor the projectiles are polarized. The total scattering cross section defined above is then the integral of the differential cross section over the entire range of possible scattering angles.

For scattering experiments involving atomic oxygen, the target will generally contain O and $O_2$. The total scattering signal and the scattering signal at a given angle are then given by:

$$S = \sigma_1 I_0 n_1 L + \sigma_2 I_0 n_2 L$$  \hspace{1cm} (6a)

$$S(\Omega) = \frac{d\sigma_1}{d\Omega} I_0 n_1 L + \frac{d\sigma_2}{d\Omega} I_0 n_2 L$$  \hspace{1cm} (6b)

where $n_1$ is the density of atomic oxygen, $\frac{d\sigma_1}{d\Omega}$ is the DCS for charge-transfer with atomic oxygen, $\sigma_1$ is the total cross section for charge transfer with atomic oxygen, and the subscript 2 refers to the same quantities for the molecular target. Solving equations 6a,b for the atomic target cross section gives:

$$\sigma_1 = \frac{1}{n_1 L} \left[ \frac{S}{I_0} - \sigma_2 n_2 L \right]$$  \hspace{1cm} (7a)

$$\frac{d\sigma_1}{d\Omega} = \frac{1}{n_1 L} \left[ \frac{S(\Omega)}{I_0 - \frac{d\sigma_2}{d\Omega} n_2 L} \right]$$  \hspace{1cm} (7b)
The following sections describe an apparatus which has been constructed to produce a partially dissociated oxygen target, and measure the quantities in equation 7b.

**The Apparatus**

Figure 2 shows schematically the apparatus for studying differential scattering of \( H^+ \) and \( O^+ \) ions from atomic oxygen. This experiment is different from other scattering experiments by virtue of the combination of several features. First, we produce highly collimated, state selected, primary ion beams, second the target in this experiment contains atomic oxygen, and third the angular distribution of the scattered particles is measured to determine differential cross sections. While previous experiments have included one or two of these three features, this is the first report of any measurement designed to include all three. The following sections describe in detail the apparatus and method used to measure these scattering cross sections.

**Primary Ion Beam Production**

Ions are produced in a medium-pressure magnetically confined electron impact source. Oxygen or hydrogen is introduced into the source in order to produce \( O^+ \) or \( H^+ \) ions respectively. Ions are extracted from the source and are electrostatically focused into a parallel beam which is then
momentum analyzed by two $60^\circ$ sector magnets, and collimated by a pair of apertures (AP1 and AP2 in Figure 2). These two apertures are 20 and 30 microns in diameter respectively, and are separated by 10 cm yielding a geometrically limited maximum beam divergence of less than $0.02^\circ$.

Plasma type ion sources produce ions in both ground and excited states. While there are of course no excited states of protons, $O^+$ can be produced in several excited states. Two of these ($^2D,^2P$) are metastable with unperturbed radiative lifetimes longer than the transit time to the detector. Previous work in this laboratory has shown that under typical operating conditions our ion source typically produces $O^+$ beams containing 50-60% ground state ions with the remainder in the $^2D$ excited state. The actual ground and excited state fractions depend upon the source conditions. While collisions involving metastable $O^+$ ions are of interest, the focus of the present experiment is on ground-state $O^+$ ions colliding with ground state $O$ atoms. The following section describes the technique used to produce a predominantly ground state $O^+$ ion beam.

Equation 2 gives the remaining ion flux after a beam of identical ions traverses a thin scattering target. If, however, the beam is composed of two (or more) different types of particles (either different ion species or ions of the same species in different states) equation 2 must be modified to:

$$ I = \sum_i f_i I_0 e^{-\sigma_i L} $$

(8)

where $f_i$ is the fraction of the primary ion beam in state $i$, and $\sigma_i$ is the cross section for removal of ions of state $i$ from the beam. From equation 8, the
fraction of beam ions in the different states is altered by scattering with a gas
target that has different cross sections for removal of the different ions. A
filter cell (labeled FC in Figure 2), of length L, is inserted after the
electrostatic lens to confine such a target gas. The FC gas density, n, is
determined through measurement of the pressure with an MKS Baratron
capacitance manometer.

Stebbings et al.\textsuperscript{17} and Turner et al.\textsuperscript{19} have investigated O\textsuperscript+ ion beams
in detail. Stebbings et al.\textsuperscript{17} produced O\textsuperscript+ ion beams through electron impact
ionization using electrons of known energy, and found that at an electron
energy corresponding to the threshold for production of O\textsuperscript+(2D) ions the
measured TCS for charge transfer of the resulting O\textsuperscript+ beam in N\textsubscript{2} increased
dramatically. Subsequent measurements by Moran et al.\textsuperscript{20} and Schafer\textsuperscript{18}
confirmed that the cross section for charge transfer of O\textsuperscript+(2D) with N\textsubscript{2} is much
larger than for O\textsuperscript+(4S) with N\textsubscript{2}. This is precisely the situation desired to
produce predominantly ground state (4S) O\textsuperscript+ ion beams, and therefore N\textsubscript{2} is
used in the filter cell. In addition to predominantly removing the excited state
ions the filter cell also allows determination of the unfiltered beam state
composition which could then in principle be used to determine DCS’s
involving 2D oxygen ions.\textsuperscript{18}

If the cross sections $\sigma_i$ are significantly different, it is possible to
determine the $f_i$'s and $\sigma_i$'s by measuring $\frac{I}{I_0}$ as a function of $n$.\textsuperscript{18} Figures 3
and 4 show the measured ion current ratio as a function of FC pressure for
1500 and 5000eV O\textsuperscript+ beams. These curves have been fit to the form of
equation 8 assuming $i=2$, i.e. that there are only two states in the ion beam.
Figure 3 - Attenuation Curve for 1500eV O\textsuperscript{+} Beam
Figure 4 - Attenuation Curve for 5000eV O+ Beam
The results of a 3-parameter non-linear least squares fits $^{21}$ are shown in Table 1. The fits are shown as the solid lines in Figures 3 and 4.

<table>
<thead>
<tr>
<th>Beam Energy</th>
<th>$f_1$</th>
<th>$\sigma_1$</th>
<th>$\sigma_2$</th>
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<tr>
<td>1500 eV</td>
<td>0.73</td>
<td>7.6</td>
<td>33.2</td>
</tr>
<tr>
<td>5000 eV</td>
<td>0.50</td>
<td>2.1</td>
<td>17.7</td>
</tr>
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The fit to the form of equation 8 for a two state beam is quite good giving credence to the assumption that the primary beam contains only two states. It is possible, however, that the beam could contain ions in other states whose cross section for removal is nearly the same as that for either the $^2D$ or $^4S$ ions. Replacing the N$_2$ in the FC with another gas serves to test for the presence of these other states. Previous measurements by Ziegler$^{22}$ found only two states in an O$^+$ beam produced with the same type of ion source.

From equation 2 the flux of ions remaining in state i at a given FC density $n$ is $f_i l_0 e^{-n\sigma_i}$. For our two state beam, the fraction of the remaining beam that is in the ground state at a given density $n$ is therefore:

$$\frac{f_1 e^{-n\sigma_1}}{f_1 e^{-n\sigma_1} + (1-f_1) e^{-n\sigma_2}}$$  \hspace{1cm} (9)

where $f_1$, $\sigma_1$, and $\sigma_2$ are determined from the fitting routine. With filter cell pressures of 26 mtorr and 34 mtorr the ion beam is 98% ground state for
1.5keV and 5.0keV respectively. These state selected beams enter the target cell which contains the mixture of atomic and molecular oxygen.

**Atomic Oxygen Target**

Molecular oxygen is introduced through a variable leak valve into a quartz discharge region wherein atomic oxygen is produced in a microwave sustained discharge (Figure 5). The quartz discharge region is connected to a flow tube that contains the gas as it flows to the target cell. The tube is either quartz or Pyrex and is pumped by a 2-liter/sec mechanical vacuum pump.

The microwave source is a modified conventional microwave oven with associated high voltage power supply. The 2.54GHz output of the oven magnetron is coupled into a coaxial cable which is connected to a tunable Evenson microwave cavity. A standing wave bridge on the coaxial line measures the forward and reflected microwave power. Tuning of the cavity to minimize reflected power protects the magnetron and serves to increase the discharge intensity and improve the discharge stability. The discharge region is cooled by an external fan and by compressed air flowing directly into the microwave cavity.

The partially-dissociated oxygen flows approximately 50cm from the microwave discharge to the scattering target. While traversing this distance, the atoms undergo gas phase and wall collisions. These collisions effectively thermalize the gas as indicated by the flow tube wall temperature measured 20cm from the discharge region. Oxygen atoms can recombine
Figure 5 - Flow Tube and Discharge region
to form O₂ molecules via three-body gas-phase collisions, or through collisions with the surfaces of the flow tube. Calculations of the recombination of atomic oxygen by Brake and Kerber²⁵ in a flow tube at higher total gas density indicate that the reactions with the surfaces of the flow tube are the most important. Hakes²⁶ studied the effect of several surfaces on the measured dissociation fraction and found that coating of the Pyrex surfaces of the flow tube with phosphoric acid reduces the recombination of atomic oxygen. This result agrees with previously reported results of Sampson et al.²⁷ In addition, we have found that any metal surfaces in the flow tube also greatly reduce the atomic oxygen density in the target cell.

Figure 6 shows an expanded view of the actual scattering target region. The target cell walls are made of 25μ thick tantalum with centrally located laser drilled apertures. The metal surfaces are coated with a type P-92-1014Bk-2 fluorocarbon compound.²⁸ This Teflon like compound reduces the recombination of the atomic oxygen in the target region.

**Measured Quantities**

Recalling equation 7b we must measure the quantities S(Ω), ΔΩ, I₀, \(\frac{dσ_2}{dΩ}\), σ₂, n₁, n₂, L, in order to determine the DCS for scattering with atomic oxygen. The following sections describe the methods used to measure these quantities.
Figure 6 - Expanded View (20:1) of Scattering Region
The scattering signal $S(\Omega)$ in a given $\Delta \Omega$, and the total scattering signal $S$ are measured by applying a transverse voltage to deflection plates DP (Figure 2) allowing only fast neutral collision products to strike a position sensitive detector (PSD). The PSD has an active area of 2.5 cm and is located 27.2 cm from the exit aperture of the TC limiting the maximum observable scattering angle to 2.6°. The PSD is a single particle detector employing 2 microchannel plates and a resistive anode (see appendix I for a description of the PSD and its operating conditions). The PSD output consists of two 8-bit digital signals proportional to the X and Y impact positions of a single particle on its surface. The PSD also outputs a pulse, indicating the arrival of a particle, which is used for timing purposes. The 8-bit X and Y signals are latched by a BIRA 2322 parallel input module and read into a Motorola MVME1131XT microcomputer through the CAMAC interface. An element in a 256x256 array in computer memory is incremented corresponding to the X and Y position of impact of the single particle on the PSD surface.

The detector signal during charge transfer measurements (gas-in) consists of neutral particle impacts from the charge transfer scattering with the target gas, as well as background counts. Background sources include charge-transfer with the background gas, neutrals produced by collisions of the primary beam with surfaces, and random detector noise due to photons, cosmic rays or other sources. A second 256x256 element array (gas-out array) is accumulated with the target cell evacuated. The counts in this array are due to all of the noise sources described above. These two arrays constitute the raw data produced in the experiment. The beam center is
found by fitting the scattering distribution to a Gaussian curve and locating the peak. These two arrays are summed into annular rings\textsuperscript{11} around this peak to take advantage of the azimuthal symmetry in the scattering distribution. Subtraction of the corresponding ring sums of these two arrays results in an array of ring sums representative of scattering $S(\Omega)$ from the target gas only.

**Measurement of $I_0$.**

The primary ion flux, $I_0$, is measured by periodically removing the voltage from the deflection plates, allowing all of the charged particles to impact the PSD. The high collimation of the primary beam results in high intensity on the detector. Appendix I shows that this increased intensity can change the absolute detection efficiency, and therefore the charged particles are spread out by applying an AC voltage on the deflection plates. The number of particles detected by the PSD is then counted for 1 sec. This process is repeated up to six times per minute giving an accurate measure of the average primary beam flux since most of the elastically scattered primary beam is collected.\textsuperscript{12,29} A correction is necessary because the PSD electronics has a characteristic conversion time of about 16 $\mu$sec. During this 'dead' time, the detector electronics is busy computing the position of the last registered valid particle impact, and does not register events, resulting in a lower output count rate than actually present in the apparatus. If the measured signal rate is A Hz, then, to first order, the 'dead' time corrected signal rate is
\[ A' = \frac{A}{1-A(1.6 \times 10^{-5})} \]  

(10)

A problem arises because the primary particles are ions, and the scattered particles are neutrals, and the PSD may have a different detection efficiency for ions and neutrals. The relative detection efficiency is thus required to obtain absolute cross sections. The detection efficiency of the PSD is related to the probability that an incident particle will eject an electron from the surface of the channel in which it strikes. This electron will then be accelerated by the applied electric field in the channel, causing an electron cascade. Therefore, the absolute detection efficiency depends on the secondary electron ejection coefficient \( \gamma \) (\( \gamma^+ \) for ions and \( \gamma^o \) for neutrals) for the particle striking the channel wall. Previous work in this laboratory\(^{19}\) showed that 1500eV O and O\(^+\) are detected with the same relative efficiency. It is reasonable to assume that the same will hold true for 5.0keV O and O\(^+\). Gao\(^{29}\) has measured TCS for charge transfer involving 250-1500eV protons, assuming equal detection efficiency for H and H\(^+\). These data agree quite well with previously reported TCS measurements. Throughout this work we have assumed that ions and neutrals are detected with the same efficiency and therefore the dead time corrected total number of events counted when the deflection voltage is removed is the total number of primary ions \( I_0 \).
Measurement of Target Cell Length

The target cell length, $L$, is measured with a microscope. Focussing on the exit aperture and measuring the microscope travel needed to focus down to the entrance aperture with a precision micrometer gives a measurement of the cell length. This procedure is repeated five times, and the average result is used as the actual target cell length. Typical data indicate that the error in this measurement of the target cell length is about 3%.

Measurement of DCS for molecular oxygen

We measure both the differential and total cross sections for molecular oxygen using the same technique previously described by Gao.\textsuperscript{30} Molecular oxygen is admitted to the TC through a variable leak valve. The density of $O_2$ is determined through measurement of the pressure in the TC with an MKS Baratron capacitance manometer. $S(\Omega)$, $\Delta\Omega$, $I_0$, and $L$ are determined as described in the previous sections, and equations 4 and 5 give the TCS and DCS respectively for scattering with molecular oxygen. These stable gas target DCS's have been measured previously in this laboratory, but must be repeated due to differences in apparatus geometry. Figure 7 show the DCS measured with the present apparatus and those measured using a higher resolution apparatus.\textsuperscript{29} The agreement is excellent.
Figure 7 - Comparison with Earlier Results for DCS of

\[1500\text{eV } \text{H}^+ + \text{O}_2 \rightarrow \text{H} + \text{O}_2^+\]
Measurement of $n_1$ and $n_2$

The MKS baratron does not accurately reflect the pressure in the target cell when the microwave discharge is turned on. It remains then to determine the target densities $n_1$ and $n_2$ when the microwave discharge is on. As a test of the dissociation of $O_2$ in the microwave discharge, raw data have been accumulated under both discharge on and off conditions. Figure 8 shows the raw data. With the discharge off, the distribution is characteristic of scattering with molecular oxygen. With the discharge on, the distribution is a combination of that for atomic oxygen and molecular oxygen. These raw data along with the measurements of $L$ and $I_o$ would allow for the determination of the DCS for atomic oxygen if the densities $n_1$ and $n_2$ were known. Simple integration of the scattered signal on the detector gives the total signal $S$ needed to determine the TCS. This section describes in detail a time of flight mass spectrometer (TOF-MS) and the procedures used to determine $n_1$ and $n_2$ from the TOF-MS data.

An electron impact ionization time of flight mass spectrometer is used to determine the atomic and molecular oxygen density in the target cell. The TOF MS consists of an electron gun$^{30}$, ionization region, ion acceleration region, ion drift region, and PSD (Figure 9). Electrons are accelerated away from an indirectly heated cathode with a 100kHz pulse on the video grid of the electron gun. The video pulse is short (~10ns FWHM) with the baseline set to about -10V and a peak height of 5V. The extractor grid of the electron gun is operated at a DC voltage chosen to pass only those electrons removed from the cathode when the video grid voltage is positive, producing
Figure 8 - Raw Data
Figure 9 - Time Of Flight Mass Spectrometer
a short pulse of electrons which is then accelerated to the desired final kinetic energy of typically 1800eV. An additional deflection voltage (on plate DP) changes the direction of the electron beam as it enters the ionization region to insure that the beam enters the Faraday cup. Collisions between the electrons and both the background gas and the thermal beam of atoms and molecules effusing from the exit aperture of the target cell produce ions through the following collisions:

\[
e + O \rightarrow 2e + O^+ \quad (11a)
\]

\[
e + O_2 \rightarrow 2e + O_2^+ \quad (11b)
\]

\[
\rightarrow 2e + O^+ + O \quad (11c)
\]

There are other positive-ion-forming collisions (for example, double ionization), but the cross section for these collisions is small compared to that for collisions of type 1-3.\textsuperscript{22} The positively charged ion collision products are accelerated towards the PSD by the extraction field. Ions of different mass are accelerated to different final velocities and arrive at the PSD at different times, with each singly charged ion reaching a final kinetic energy of 1800eV. For each detected particle, the PSD outputs a timing pulse which starts a time to digital converter (TDC). The TDC measures the elapsed time between a start and stop pulse with variable resolutions of 5, 2, or 1 nsec. The TDC stop pulse is supplied by an Evans electronics programmable digital delay (see timing diagram Figure 10). This reverse timing scheme is useful because the TDC is only busy following a valid particle impact on the detector. From Figure 10, the flight time \(T_f\) is equal to \(T_d - T_m\) where \(T_d\) is the delay time and \(T_m\) is the measured time from the
[Figure 10 - Timing Diagram for TOF-MS]
TDC. The 10 bit TDC output is read by the computer and the corresponding element in an array in memory is incremented. Figure 11 shows a sample TOF spectrum for O\textsubscript{2}. The different mass peaks are identified by their flight times. Electron impact ionization results in a direct ionization peak at mass 32 (equation 11b), and a dissociative ionization peak at mass 16 (Equation 11c). The mass 16 peak is broadened due to the initial kinetic energy of the ions produced through dissociation ionization. In addition there are peaks from H\textsubscript{2}O at mass 18 and 17 (H\textsubscript{2}O\textsuperscript{+} and OH\textsuperscript{+} product respectively). The water is present as a background contaminant in the vacuum chamber.

The distance from the electron beam to the exit aperture of the target cell is 8mm. With a typical background gas pressure of 3x10\textsuperscript{-6} Torr, and a target cell pressure of 20mtorr, approximately half of the ions formed are from electron collisions with the background gas. In order to determine the TOF signal from only the thermal beam of atoms and molecules effusing from the target cell, we employ a background subtraction technique. A mechanical flag (shown in Figure 9) is closed to fully block the thermal beam, and the resulting TOF signal is representative of the background gas only. The flag is then opened, and the TOF signal now includes a contribution from the thermal beam as well as from the background gas. Equations 12a and 12b give the signal in any chosen mass peak from direct ionization processes only for the flag open and flag closed conditions respectively.

\[
S_{+(\text{open})} = n(t) \sigma \kappa_l + n(b)\sigma \kappa_b l. \tag{12a}
\]

\[
S_{+(\text{closed})} = n(b) \sigma \kappa_b l. \tag{12b}
\]
Figure 11 - Sample Time Of Flight Spectrum
where \( n(t, \text{ or } b) \) is the density of that type of particle in the TC or BG (\( t \) for target and \( b \) for background), \( \sigma \) is the cross section for electron impact ionization, \( I \) is the total number of electrons passing through the collision volume, and \( \kappa \) includes both a geometric factor related to the collision volume and the detection efficiency of the PSD for that particular energetic ion. Gao \textit{et al.} \(^{10}\) have determined that the PSD absolute detection efficiency is the same for \( H^+, \text{He}^+ \) and \( \text{O}^+ \) for ion energies above about 1keV. The absolute detection efficiencies for these ions is also equal to the percentage of open area on the entrance microchannel plate (60%). Therefore any particle of energy greater than 1keV that enters a channel is detected with the same efficiency independent of the particle mass for masses from 1 to 16. While we have not measured the absolute detection efficiency for \( \text{O}_2^+ \) ions, it is reasonable to assume that the detection efficiency is the same for 1800eV \( \text{He}^+, \text{O}^+ \) and \( \text{O}_2^+ \) ions.

The parameter \( \kappa \) also accounts for differences in velocity distribution, and therefore effusion properties, of different mass atoms and molecules in the target cell. The flux of particles of a given mass effusing through an aperture in molecular flow is given by \( \Phi = \frac{1}{4} n \bar{v} A \) where \( n \) is the density of the gas, \( \bar{v} \) is the average velocity of the particles, and \( A \) is the area of the aperture.\(^{31}\) However, the density of gas in the collision volume is proportional to \( \Phi / \bar{v} \), and therefore proportional to the density of the gas in the target cell. The factor \( \kappa \), therefore, is independent of the mass of the particles coming out of the cell.
In order to subtract out the background events, the total flux of electrons, \( I \), must be the same for the flag open and flag closed conditions. We insure this condition by introducing He gas into the background and counting the number of events in the He\(^+\) mass peak. Because the He density in the background is unchanged, the same total number of electrons will result in the same total He\(^+\) signal. Scaling the flag open and flag closed measurements to the same total number of He\(^+\) events therefore insures the same total electron flux for all TOF MS measurements.

The determination of the atomic and molecular oxygen density in the target cell with the discharge on requires 4 separate TOF-MS measurements. The four measurements are: 1) discharge off, and the flag open, 2) discharge off, flag closed, 3) discharge on, flag open, 4) discharge on, flag closed.

Equations 13a-d give the measured O\(_2^+\) TOF signal (\( S_{O_2^+} \)) for each measurement where the subscript 2 refers to the O\(_2\) molecule and the subscript O refers to atomic oxygen.

\[
S_{2^+(open)} = n_{2}(t) \sigma_{2} \kappa_{t} I + n_{2}(b) \sigma_{2} \kappa_{b} I. \quad (13a)
\]
\[
S_{2^+(closed)} = n_{2}(b) \sigma \kappa_{b} I. \quad (13b)
\]
\[
S'_{2^+(open)} = n'_{2}(t) \sigma_{2} \kappa_{t} I + n'_{2}(b) \sigma_{2} \kappa_{b} I. \quad (13c)
\]
\[
S'_{2^+(closed)} = n'_{2}(b) \sigma \kappa_{b} I. \quad (13d)
\]
where the primed equations are for the discharge-on case, and the cross section $\sigma_2$ is for direct ionization of $O_2$ to form $O_2^+$. It is assumed that this cross section is the same for both the discharge-on and discharge-off conditions. The validity of this assumption will be discussed in some detail later. Subtraction of the appropriate backgrounds and solving for $n'_2(t)$ gives:

$$n'_2(t) = \frac{S'_{2^+(open)} - S'_{2^+(closed)}}{S_{2^+(open)} - S_{2^+(closed)}} n_2(t)$$

(14)

Measurement of the quantities on the right side of equation 14 allow determination of the $O_2$ density with the discharge on. Determination of the atomic oxygen density in the TC with the discharge on is more complicated.

Equations 15a-d give the total $O^+$ signal from the four TOF measurements:

$$S_{O^+(open)} = n_2(t) \sigma_3 \kappa_1 I + n_2(b) \sigma_3 \kappa_b I.$$  

(15a)

$$S_{O^+(closed)} = n_2(b) \sigma_3 \kappa_b I.$$  

(15b)

$$S'_{O^+(open)} = n'_0(t) \sigma_1 \kappa_1 I + n'_2(t) \sigma_3 \kappa_1 I + n'_2(b) \sigma_3 \kappa_b I.$$  

(15c)

$$S'_{O^+(closed)} = n'_2(b) \sigma_3 \kappa_b I.$$  

(15d)

Where the symbol $\sigma_3$ is the cross section for dissociative ionization (process 11c) of $O_2$ to form $O^+$, and $\sigma_1$ is the cross section for direct ionization of $O$ to form $O^+$. TOF-MS measurements of the background gas only have demonstrated that there is no atomic oxygen in the background presumably
due to recombination processes on chamber surfaces. Subtracting the flag closed signal from flag open signal gives:

$$S_{O^+ (open)} - S_{O^+ (closed)} = n_2(t) \sigma_3 \kappa_1 l. \quad (16a)$$

$$S'_{O^+ (open)} - S'_{O^+ (closed)} = n'_O(t) \sigma_1 \kappa_1 l. + n'_2(t) \sigma_3 \kappa_1 l. \quad (16b)$$

For simplicity define:

$$S_{O^+} = S_{O^+ (open)} - S_{O^+ (closed)}$$

i.e. $S_{O^+}$ is the signal of $O^+$ due to gas in the target cell with the discharge off. This $O^+$ signal is due only to dissociative ionization. Similarly for the discharge on case define:

$$S'_{O^+} = S'_{O^+ (open)} - S'_{O^+ (closed)}$$

where this signal now is due to dissociative ionization of residual $O_2$ in addition to direct ionization of atomic oxygen in the TC. Using this new notation and rearranging equation 16b we have:

$$n'_O(t) \sigma_1 \kappa_1 l. = S'_{O^+} - n'_2(t) \sigma_3 \kappa_1 l. \quad (17)$$

Under the assumption that the $O_2$ has the same cross section for dissociative ionization with the discharge on and off (discussed later), then the signal from dissociative ionization is proportional to the $O_2$ density in the
TC. With the discharge off, this dissociative ionization is the only process producing \( O^+ \), therefore:

\[
\frac{\dot{n}_2(t)}{n_2(t)} \sigma_3 \kappa_1 l = \frac{\dot{n}_2(t)}{n_2(t)} S_{O^+} \tag{18}
\]

Substituting equation 18 for \( \dot{n}_2(t)\sigma_3 \kappa_1 l \) in equation 17 we get:

\[
\frac{\dot{n}_O(t)}{n_O(t)} \sigma_1 \kappa_1 l = S'_{O^+} - \frac{\dot{n}_2(t)}{n_2(t)} S_{O^+} \tag{19}
\]

This equation basically states that the \( O^+ \) signal from direct ionization of atomic oxygen from the TC with the discharge on is equal to the total \( O^+ \) signal with the discharge on (both direct and dissociative ionization) minus the contribution to the \( O^+ \) signal from dissociative ionization of \( O_2 \). Defining the \( O^+ \) signal from atomic oxygen, as \( S'_{O \rightarrow O^+} = \frac{\dot{n}_O(t)}{n_O(t)} \sigma_1 \kappa_1 l \) and solving for the atomic oxygen density we get:

\[
\dot{n}_O(t) = \frac{S'_{O \rightarrow O^+}}{S_{2^+}} \frac{\sigma_2}{\sigma_1} n_2(t) \tag{20}
\]

where \( S'_{O \rightarrow O^+} \) is found from equation 19. The density \( n_2(t) \) is measured with the MKS Baratron with the discharge off. The signal \( S_{2^+} \) is determined from the discharge off measurement. The two electron impact ionization
cross sections $\sigma_1$ and $\sigma_2$ are not measured in the present experiment, however these cross sections have been previously measured by other researchers.\textsuperscript{32-34} The uncertainty in the measured atomic oxygen density comes from the cross section values used in equation 20 as well as from statistical considerations in the subtraction of the peak sums. Typical counting time for each of the four TOF-MS spectra is about 5 min resulting in a statistical uncertainty in the O density of approximately 5%. Figure 12 shows the background subtracted TOF-MS with the discharge off and on respectively. Both the decrease in $O_2^+$ and increase in $O^+$ signal can be seen in the Figure.

Brook et al\textsuperscript{32} measured the cross section, $\sigma_1$, for $e + O \rightarrow e + O^+ + e$ from threshold to 1000 eV. Above 500 eV the measured cross sections agree well with a Born approximation calculation.\textsuperscript{35} We therefore use the calculated value for $\sigma_1$ at our typical electron energy of 1800 eV in equation 20.

Rapp et al\textsuperscript{33} measured the total ion production cross section due to electron impact ionization in $O_2$. This cross section is essentially the sum of the direct and dissociative ionization cross sections (assuming other ion forming collisions are negligible). They have also measured the production of ions with initial kinetic energies greater than 0.25 eV.\textsuperscript{32} If one assumes that all $O^+$ ions from dissociative ionization have greater than 0.25 eV, then this second measurement is representative of the dissociative ionization of $O_2$. Subtraction of the dissociative ionization cross section from the total ion production cross section then gives the direct ionization cross section. The measurements of Rapp et al\textsuperscript{32} are over the range of electron energies from
threshold to 1000eV. Theoretical calculations are available only for total ion production, therefore the measured dissociative ionization cross section must be extrapolated to 1800eV. While this extrapolation may lead to increased error in the measurement of the O density, it must be true that the atomic oxygen density measured by the TOF MS does not depend upon the energy of the ionizing electron beam. Therefore as a consistency check the O density has been calculated using equation 20 with data measured for electron energies from 800eV and 2500eV. This test shows no dependence of O density upon electron energy.

The major source of error in the above technique rests in the use of previously measured electron impact ionization cross sections. Rapp et al.\textsuperscript{32} indicate that their dissociative ionization measurement are not expected to be extremely accurate.

**Excited States in the Target cell**

In addition to atomic oxygen, electrical discharges have been reported to produce oxygen molecules in the a\textsuperscript{1}Δ metastable state, as well as changing the relative number densities of molecules in different rotational and vibrational levels.\textsuperscript{36,37} These metastable molecules, if present, can cause problems with the previously described method for determining atomic oxygen DCS in several ways.

The first problem arises in determination of the target densities for O and O\textsubscript{2} with the discharge on. The previous derivation of the atomic and
molecular oxygen densities $n_1$ and $n_2$ from the TOF MS measurement assumes that the electron impact ionization collisions, both direct and dissociative, are the same whether the discharge is on or off. By operating our electron beam at far from threshold for ionization of $O_2$, it is assumed that the electron impact ionization cross sections for ground and excited state $O_2$ are the same. As stated earlier, the measured $O$ and $O_2$ densities do not change as a function of electron energy, indicating that either there are negligible amounts of excited state molecules present, or at least that the direct and dissociative ionization cross sections are independent of the initial state of the molecule. A better test of the independence of the electron impact ionization cross sections on the state of the $O_2$ molecule involves running the discharge under conditions such that no atomic oxygen can reach the target cell. Several experiments with discharge conditions resulting in negligible atomic oxygen densities in the target cell were performed. Comparison of the discharge on and off TOF MS indicate no change in the size or shape of either the $O$ or $O_2$ peaks, indicating either that there are no excited molecules in our system, or that at least the electron impact ionization cross sections are independent of the initial molecular state.

Another problem presented by the presence of excited states of $O_2$ is that the subtraction technique employed to determine the $O$ target DCS assumes that the $O_2$ with the discharge on has the same cross section for charge transfer with the primary beam as the ground state $O_2$ with the discharge off. The only test for this assumption is to operate the microwave discharge under different conditions (i.e. a range of gas pressure, different
input microwave power, different distances from discharge to target). Measured cross sections for these different discharge conditions would not agree if the different discharges produce different $O_2(a^1\Delta)$ densities, and the $O_2(a^1\Delta)$ DCS is different than for ground state $O_2$. 
CHAPTER III
RESULTS AND DISCUSSION

Preliminary absolute differential cross sections (CTDCS) are presented for the following charge transfer collisions:

\[
\text{H}^+ (0.25, 0.50, 1.5, \text{ and } 5.0 \text{ keV}) + O \rightarrow \text{H} + \text{O}^+
\]

\[
\text{O}^+ (1.5, 5.0 \text{ keV}) + O \rightarrow \text{O} + \text{O}^+
\]

Figure 12 and 13 show typical TOF-MS spectra that have been used to determine both the atomic and molecular oxygen density in the TC. Figures 14-19 show the resulting differential cross section calculated from equation 7. The error bars are due to a combination of statistical error and error associated with determination of the atomic and molecular oxygen target densities. The latter is mainly due to the error in previously reported electron impact ionization cross sections. There is an additional systematic error in the presented DCS's due to the presence of H₂O in the target cell with the discharge on. The TOF-MS spectrum in Figure 12 clearly shows this H₂O. Equation 21 gives the H₂O density in the TC:

\[
N(\text{H}_2\text{O}) = \frac{S_{\text{H}_2\text{O}}}{S_{\text{O}_2}} \frac{\sigma_{\text{O}_2}}{\sigma_{\text{H}_2\text{O}}} N(\text{O}_2)
\]  
(21)
Figure 12 - Discharge off TOF spectrum
Figure 13 - Discharge on TOF spectrum
Figure 14 - H\(^+\) (250eV) + O → H + O\(^+\)
Figure 15 - H⁺ (500eV) + O → H + O⁺
Figure 16 - $\text{H}^+ (1500\text{eV}) + \text{O} \rightarrow \text{H} + \text{O}^+$
Figure 17 - $H^+ (5000eV) + O \rightarrow H + O^+$
Figure 18 - O⁺ (1500eV) + O → O + O⁺
Figure 19 - $O^+(5000eV) + O \rightarrow O + O^+$
where $\sigma_{O_2}$ and $\sigma_{H_2O}$ are the electron impact ionization cross sections for $O_2$ and $H_2O$ respectively, $S_{O_2}$ and $S_{H_2O}$ are the TOF signals for $O_2$ with the discharge off and $H_2O$ with the discharge on, respectively, and $N(O_2)$ is the discharge off $O_2$ density measured with the MKS baratron. The total cross section for the collision $e + H_2O \rightarrow e + H_2O^+ + e$ are from Schutten et al., and as in the determination of the atomic oxygen density previously described, we again use the results of Rapp et al. for electron impact ionization of $O_2$. The DCS's presented include neutral products from charge transfer collisions with these water molecules, and subtraction of this background to obtain DCS's for atomic oxygen is not possible due to the lack of previous data for charge transfer with a water target. There is, however, some hope of salvaging the measured total cross section data.

Table 2 compares the results of the present measurement, along with corrections for the presence of water in the target cell where available, with previously reported TCS data. The correction for the water is calculated by expanding equation 6a for three targets, i.e.

$$S = I_0\sigma_1n_1L + I_0\sigma_2n_2L + I_0\sigma_3n_3L$$

(22)

where the $\sigma_3$ is now total cross section for charge transfer with $H_2O$, as measured by Koopman et al.\textsuperscript{39}

The data of Stebbings et al.\textsuperscript{2} are taken from their best fit to the form $Q^{1/2} = A - B\text{Log}(E)$, where $Q$ is the total cross section. The data of Williams et al. do not go to energies lower than 2.5keV, however these data are typically 50% lower than those of Stebbings et al. and Rutherford and Vroom.
Table 2

<table>
<thead>
<tr>
<th>Collision</th>
<th>this work</th>
<th>H₂O corrected</th>
<th>Other Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>H⁺(250eV) + O</td>
<td>9.12</td>
<td>8.2</td>
<td>8.9</td>
</tr>
<tr>
<td>H⁺(500eV) + O</td>
<td>6.54</td>
<td>3.8</td>
<td>8.6</td>
</tr>
<tr>
<td>H⁺(1500eV) + O</td>
<td>12.65</td>
<td>7.3</td>
<td>8.0</td>
</tr>
<tr>
<td>H⁺(5000eV) + O</td>
<td>13.73</td>
<td>10.0</td>
<td>8.0</td>
</tr>
<tr>
<td>O⁺(1500eV) + O</td>
<td>18.07</td>
<td>N/A</td>
<td>15.6</td>
</tr>
<tr>
<td>O⁺(5000eV) + O</td>
<td>13.90</td>
<td>N/A</td>
<td>13.1</td>
</tr>
</tbody>
</table>

The error introduced by the presence of water in the target is such that our results at present are not capable of resolving this discrepancy. Further work on this project needs to be done to determine both the reason for the water presence and a suitable method to remove the water from the target.

We have found that there are several sources of the H₂O in the target cell. Water is sometimes introduced into the flow system from the high pressure O₂ cylinder. This water is now removed by placing a liquid nitrogen trap on the gas line between the adjustable leak valve and the microwave discharge. Water may also be present as an ambient gas in the target flow tube due to the technique used to coat the Pyrex and quartz flow tube with phosphoric acid. We apply hygroscopic P₂O₅ powder to the inside of the tube. The P₂O₅ reacts with water in the Houston air to form phosphoric acid. The tube is then wiped clean, however all of the water may not be removed. Whatever water is on the tube walls may then come off when the microwave discharge is turned on and the tube walls heated. Baking the flow tube by passing a current through Nickel-Chromium wire wrapped around the tube does removes the ambient water, however it also
seems to affect the tube in such a way as to cause complete recombination of atomic oxygen before the flowing gas mixture reaches the target cell. Baking is therefore not useful. In many tests performed since the water contamination was discovered, we have found that the best method for removing the water is by trapping the input gas with liquid nitrogen and carefully wiping out of the flow tube prior to insertion in the apparatus. Ongoing experiments are serving to determine the exact flow tube and target cell configuration which will result in the most atomic oxygen without introducing any other contaminant gasses.
CHAPTER IV
FUTURE IMPROVEMENTS

This thesis has reported the first attempts to use an apparatus designed to measure scattering cross sections with an atomic oxygen target. There is much work to be done in order to get reliable atomic oxygen scattering cross sections, and once this groundwork has been done, there are many interesting experiments which can be performed.

First and foremost, the water contamination must be effectively removed from the target cell without also removing the atomic oxygen. This is not believed to be a major problem, however it may require liquid nitrogen trapping of the target flow inside the vacuum chamber immediately before the flowing gas enters the target cell. The TOF-MS will allow complete determination of the water density in the target cell, as well as detect the presence of any other contaminants in the target such as mechanical pump oil or Teflon.

We have not yet fully understood the problem of excited states in the target gas. Although we have some information about the effect of any excited states on the DCS measurement, this information is all obtained in a negative, indirect manner. For example, we have changed the microwave conditions and detected no measurable difference in the DCS. This possibly means that there are no excited states in the target at all, or that the
cross section for charge transfer with the excited states is the same as for ground states, or perhaps that the changes in microwave conditions do not affect the excited state populations at all. The best method to determine the excited state population is to use the TOF-MS with threshold electrons. If the electron energy is above that required to ionize excited atoms or molecules, but below that required to ionize the ground state atoms or molecules, then the resulting ion signal in the corresponding mass peak must be due to ionization of metastable atoms or molecules. There are many problems associated with running the TOF-MS at electron energies around 10-30eV. First, the effect of any magnetic fields on the electron trajectory must be taken into account. The electron gun presently used has a magnetic cathode as well as several magnetic electrodes. A new electron gun is required. Second, the electron gun must be floated to a high positive voltage because the interaction region must be at high potential to accelerate the produced ions to high enough energy to be detected by the PSD. Third, the extraction potential applied in the ionization region must be pulsed. Low energy electrons will travel in straight lines during the zero field portion of the pulse, and the zero field will allow non-thermal ions formed through dissociative ionization collisions to leave the extraction region. The resulting TOF-MS spectrum would then not include dissociative ions except for those produced with very small initial kinetic energy or those produced with initial kinetic energy along the direction of the extraction potential. This technique will improve the signal to noise in the oxygen ion peak resulting in greater accuracy in determination of the atomic oxygen density.
A different technique employing a separate TOF measurement may result in more accurate determination of the O density. In this technique, Ne or Ar gas replaces O₂ in the TC, and the TOF-MS spectrum is obtained. The electron impact ionization cross sections for these noble gas atoms have been measured very accurately. The TOF-MS spectrum along with the previously measured cross sections allow determination of the target parameter κ₁ from equation 12a. This parameter can then be used with the discharge off measurement to get a value for the O₂ direct ionization cross section. This cross sections value is then used, rather than the Rapp et al value, in equation 22 to determine the atomic oxygen density. While we have not yet tried this approach, it would reduce the overall uncertainty in the measurement atomic oxygen density by improving the accuracy of the cross section ratio used in equation 20.
APPENDIX I
THE POSITION SENSITIVE DETECTOR

The position-sensitive detector (PSD) is used to determine the location of particles which strike its surface. This appendix describes this detector in detail. These detectors have been used in experiments to measure DCS's for several years in this laboratory, and therefore much of the following description has been previously reported.\textsuperscript{11,12,18,25,29}

The PSD consists of two micro-channel plates mounted in a chevron configuration, followed by a specially-designed resistive anode. Figure A-1 shows the detector along with the voltage biasing network. A single particle impacts in one of the channels of the front plate as shown schematically in figure A-2 causing the ejection of one or more electrons from the channel surface. The bias voltage along the channels serves to accelerate these electrons down the channel whereupon more wall collisions occur, ejecting more electrons, resulting in an electron cascade. These electrons (typically $10^3$ per impacting particle) exit the first plate and enter several channels in the second plate. More cascades in the channels of the second plate result in a charge cloud of about $10^7$ electrons that strike the resistive anode. The leads at the four corners of the anode convey the electron charge pulse to the detector electronics. The specially designed anode allows for a simple calculation of the centroid position of the charge distribution. The detector
electronics takes approximately 16 µsec to output two 8 bit digital numbers proportional to the X and Y impact position of the original particle. The electronics also puts out a strobe signal indicating valid data. The front plate of the PSD is biased negative with respect to ground in order to reject low energy electrons and reduce the background noise.

The detector must have uniform detection efficiency over its entire active area. This uniformity is tested by sweeping a small diameter ion beam across the PSD surface and counting the number of events at each position. These tests indicate that the PSD does have uniform efficiency within ± 5% with some variation from plate to plate.

Due to MCP saturation effects, the PSD has different absolute detection efficiency for different intensity beams. Saturation curves similar to those reported by Newman, Schafer, and Gao are taken to insure that the detection efficiency for the relatively low intensity neutral charge transfer products is the same as that for the relatively high intensity primary ions. The primary ions are spread across a 5x5mm square by an AC voltage applied to the deflection plates DP. This voltage has no effect on the neutral charge transfer products. This spreading reduces the intensity of the ion beam by increasing the surface area of the PSD which is struck, simplifying absolute efficiency matching.

Absolute position calibration of the PSD is obtained by placing a grid with known mesh spacing directly in front of the PSD. The shadow of this grid can be seen in the 256x256 data array. The absolute calibration depends upon the characteristics of the resistive anode as well as the particular analog to digital converter used. The PSD and electronics
combination used in this experiment have been calibrated. Each bin in the array corresponds to 98 ± 2 microns.

The PSD can also be used as a particle detector for timing. An RC network connected to the rear plate of the PSD picks up the signal due to the electron cloud leaving the rear plate. This signal is sent to the input of an fast amplifier discriminator (Lecroy MVL100). The absolute resolution of the timing pulse is limited by the depth of the microchannel plates and the corresponding time difference between ions impacting the channel walls at the entrance of the channel or impacting further down the channel.
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