# Measurement of Absolute Cross Sections for the $2s^2\ ^1S – 2s2p\ ^1P^o$ Transition in $O^{4+}$

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Experimental electron excitation cross sections are reported for the $2s^{2\,1}S – 2s2p^1P^o$ transitions in $O^{4+}$ located at 19.689 eV. The JPL electron-cyclotron resonance ion source is utilized [1], along with the energy loss method, in a merged electron-ion beams geometry [2]. The center-of-mass interaction energies for the measurements are in the range of 18 eV (below threshold) to 30 eV. Data are compared with results of a 26 term ***R***-matrix calculation that includes fine structure explicitly via the Breit-Pauli Hamiltonian [3]. There is good agreement with theoretical results and with previous electron energy-loss measurements [3]. Clear resonance enhancement is observed in both experiment and theoretical results near threshold for this $^1S$-$^1P^o$ transition. J. Lozano and N. djuric acknowledge support through the NASA-NRC program. This work was carried out at JPL/Caltech and supported by NASA. [1] J. B. Greenwood, S.J. Smith, A. Chutjian, and E. Pollack, Phys. Rev. A **59** 1348 (1999). [2] A. Chutjian, Physica Scripta **T110**, 203 (2004). [3] M. Bannister et al., Int. J. Mass Spectrometry **192,** 39 (1999). .

## Experimental Description

A detailed description of the experimental setup has_ been given by Smith et al. [1]. A general overview and recent developments are presented here.

Highly charged ions are generated in a Caprice type ECR ion source [2], extracted anc directed into a double focusing 90° bending magnet, where the desired ion is selected. The beam is deflected and focused through several regions of differential pumpir..g before reaching the interaction chamber, which possesses a base pressure of about 5x 1 $0^{-10}$ mbar. The whole region is immersed in a uniform magnetic field of :25-5G gauss.

A narrow electron beam is aligned with the ion beam through a trochoidal (ExB) deflection in the merging plates and the beams interact over a distance of 20cm. They are subsequently separated and directed into their respective Faraday cups where the currents are monitored.

Energy loss electrons resulting from excitation of the ions (Eqn.1), are confined to the merging axis by the magnetic field. The electrons spiral with a Larmor radius R given by

$$R = \frac{m v_{LAB} \sin ?}{eB}$$

where $V_{LAB}$ is the laboratory velocity of the scattered electrons and e is their scattered angle. B is the magnetic field strength.

On entering the analyzing plates the energy loss electrons suffer a larger deflection than primary electron beam as they have a smaller axial velocity, the deflection D being

$$D = \frac{El}{Bv_{axial}}$$

where E is the electric field, 1 the length of the plates and $V_{axial}$ the velocity electrons along the axis inside the plates. This directs the electrons onto a set microchannel plates used for position sensitive detection. The electrons scattered at more than 90° in the lab frame, are reflected by an electrostatic mirror [3], sending them towards the detector also. In this way we obtain 100% collection of the electrons inelastically scattered from the excitation process.

Contamination of these "signal" electrons can occur from electrons elastically scattered from the ion beam. Although the elastic electrons are scattered with a larger energy, the analyzing plates can only separate electrons with different axial velocities. Therefore elastic electrons scattered at angles close to 90° are overlapped with the inelastic electrons on the channel plate detector. However as these electrons have large Larmor radii they can be filtered out using a novel "electronic aperture" recently installed.

The "electronic aperture" is a 16 rod multipole array with opposite polarity voltages on adjacent poles. Due to the symmetry of the rods, the potential and electric field at the central region of the array are zero. However close to the poles the electric field increases sharply. As a result electrons with small Larmor radii travel through the array unaffected. Larger spirals send the electrons periodically into a strong electric field causing the electron to be deflected away from the axis. By increasing the voltages on the multipoles the effective diameter can be changed making the "electronic aperture" more versatile than fixed physical apertures.

Due to the diffuse nature of ion beams, even at the ultra high vacuum of our chamber the ion density is less than the background gas density. More electrons will be generated from collisions of the beams with background gas than from excitation of ions. Therefore we use a double beams modulation technique to extract the signal from the noise. The electron and ion beams are switched on and off with a 90° phase shift between them, generating 4 possible channels from which the signal can be extracted.

Channel A = electron beam off, ion beam off Channel B = electron beam on, ion beam on
Channel C = electron beam on, ion beam off Channel D = electron beam off, ion beam on

Signal = Channel A + Channel B - Channel C - Channel D

These chopping and channel gating pulse lines are realized using a National Instruments digital input-output board operated in a pattern generation mode to produce periodic waveforms. The chopping pulses are used to drive a high voltage pulser with output lines directed to deflectors in the electron and ion beam lines. The 4 gating pulse lines representing channels A, B, C, D are used to gate the input pulses coming from the micro-channel plates.

The incoming positional information from the channel plates is analyzed by a Quantar 2401 position computer. A fast "Rate" output is generated which indicates the real count rate hitting the detector. This line is directed to four 32 bit counters on a counter timer board each of which are gated with pulses representing channels A,B,C,D respectively. In this way the count rates in the 4 channels can be accurately determined. These values need to be known to apply a dead-time correction. The position computer also converts the pulse information into 8 bit words representing the X and Y positions at which the electron has impinged upon the channel plate surface. These digital lines, along with the channel gating lines, are directed to a second digital input-output board which can read the data at rates much faster than the dead-time associated with the position computer (3.5 μs). The data is sent directly to RAM and operates in a double buffering mode.

This data can be analyzed to produce a two dimensional representation of the signal which is falling on the detector. Provided elastic scattering at angles close to 90° has been eliminated there should be a clear separation of the inelastic and elastic signal in the 2 dimensional mapping.

As mentioned earlier we obtain 100% collection of the inelastically scattered electrons. This allows us to measure total cross sections for the excitation process and we have the ability to make these measurements absolute, by measuring all the parameters of the collision process directly. The cross section 0 is calculated from the following equation

where R is the signal rate, q the charge state of the ion, ε is the detector efficiency, Ii , Ie , Vi and Ve are ion and electron beam currents and velocities, L is the interaction length and F is the form factor given by

$$F_k = \frac{\int\int i_e(x,y,z_k)dxdy \int\int i_i(x,y,z_k)dxdy}{\int\int i_e(x,y,z_k) i_i(x,y,z_k)dxdy}$$

$$\frac{1}{F} = \frac{1}{4}\sum_{k=1}\frac{1}{F_k}$$

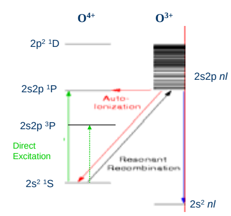
which is measured at 4 different positions along the beam axis. The beam densities i(x,y,z) are determined by measuring the current in the Faraday cups while vanes with small holes (0.07mm2) are rotated through the beams. An XY array of density points with a spacial separation ofO.3mm is obtained, allowing the profile of the beams to displayed and the form factor to be calculated.

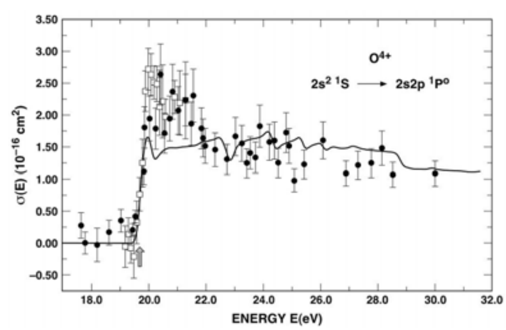
## JPL Results for $O^{+4}$

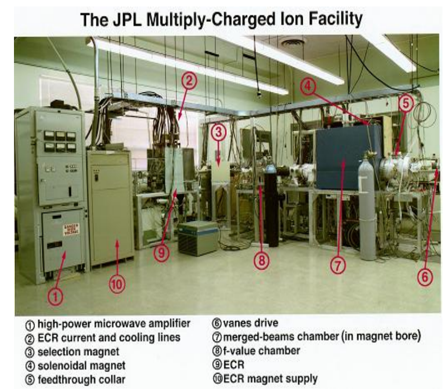
### Electron-Impact Excitation of HCIs

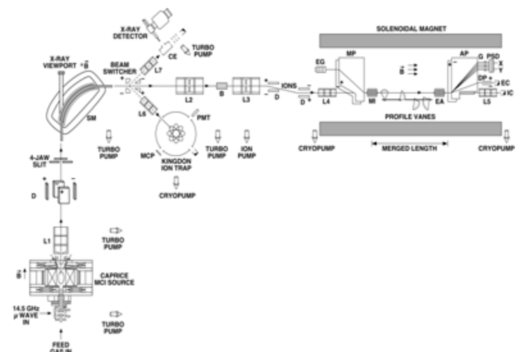
*Direct Excitation:* $e + O^{4+}(2s^2) \rightarrow O^{4+}(2s2p) + e$

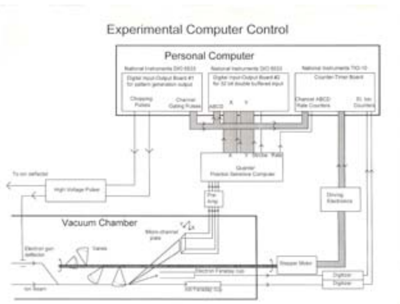
*Indirect – Resonant Excitation:* $e + O^{4+}(2s^2) \rightarrow O^{3+}(2spn'l')$
$\rightarrow O^{4+}(2sp) + e$



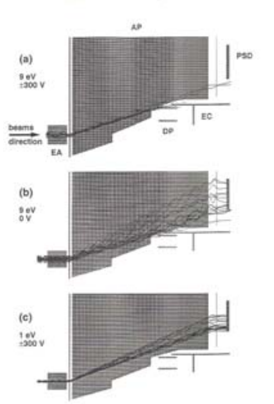



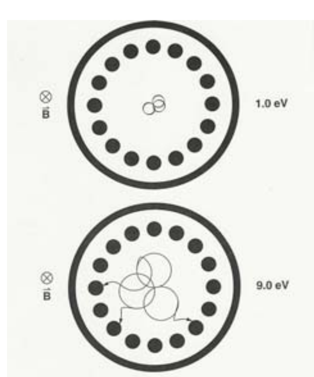



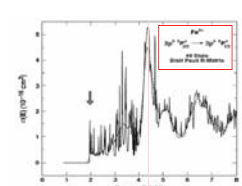




Photograph of merged beams apparatus




Action of Trochoidal Plates and electronic aperture on inelastic and Elastic electrons

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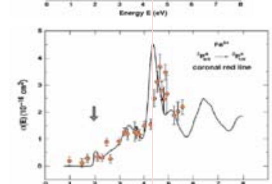


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