THE INTERACTION OF OXYGEN ATOMS WITH SOLID SURFACES AT eV ENERGIES

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I. INTRODUCTION

This report covers the first year of work performed under NASA Grant NGR-47-005-077 during the period June 1, 1967 through May 31, 1968.

In order to understand in detail the behavior of space vehicles in rarefied atmospheres it is necessary to have specific knowledge concerning the interaction of the atoms and molecules of the atmosphere with surfaces of the vehicle, particularly for particle energies corresponding to space vehicle orbital and escape velocities. The goal of the present research program is to investigate the mass spectrum resulting when oxygen atoms, moving with satellite velocities, strike a solid surface. In addition to adding to the small amount of information presently available concerning particle-surface interactions at energies corresponding to satellite velocities, the results will be of particular value in providing information that will aid in the interpretation of mass spectrometric studies of the neutral constituents of the earth's upper atmosphere. Although the principal concern of the research reported here is with monatomic oxygen the technique described in this report can be used for studies of other components of the atmosphere and interstellar space.

In the study of the interactions of neutral atomic oxygen with solid surfaces one must consider the possibility that the oxygen atoms spend a relatively long time on the surface and as a consequence the character of the particles leaving the surface does not depend to an appreciable extent on the energy of the incident atoms. In this event one could study the interaction of O atoms with surfaces using the more conventional thermal techniques. However, the few measurements that have been made on particle-surface interactions in the 1-10 eV range indicate that the molecules leaving the surface are far from fully accommodated to the temperature of the surface and hence have probably

suffered only a few collisions with surface atoms before leaving the surface. There are, unfortunately, no such measurements for oxygen atoms, but one should probably be hesitant about applying results obtained from studies of the interaction of thermal oxygen atoms with surfaces to situations where the relative velocity between atom and surface is in the range of satellite velocities, particularly since the kinetic energy of these atoms is close to the dissociation energy for the O_2 molecule.

SECTION II

BACKGROUND

The principal objective of the research reported here is an investigation of the distribution of masses that result when oxygen atoms strike a solid surface. The interest is concentrated on oxygen atoms having a kinetic energy in the range 4-10 eV, corresponding to velocities in the satellite range.

Several recent studies [1],[2] have been made of the recombination of atoms with surface atoms to form various species of molecules. These measurements have been conducted under conditions where the incident particles have thermal energies. If one is to use the results of such studies for application to practical situations where the atoms striking the surface have velocities in the satellite range, then it must be demonstrated that the results are essentially independent of the incident particle's energy in the range from thermal up to several eV.

Even though the development of the space program has generated great interest in particle-surface interactions in the eV energy range, very little experimental information is currently available. This is due to the rather awkward experimental techniques that must be used to perform measurements at these energies. However, within the past two years several measurements of the momentum transfer to surfaces by atoms, molecules, and ions in the energy range 1-200 eV give some indication of the character of the particle-surface interaction at these energies. A study of the dependence of normal momentum transfer to surfaces by argon and helium atoms [3] with energies up to 4 eV indicate that at the higher energies investigated the momentum of the atoms leaving the surface is roughly 30 percent of the incident momentum. Work at the University of Virginia [4] indicates that for 10 eV N_2 molecules the momentum of the particles leaving the surface is about 15 percent of the incident momentum. Similar measurements using N_2^+ ions [5] in the

energy range 5-100 eV show that the reflected momentum is 30-100 percent of that of the incident ions. While these studies were carried out under conditions where the character of the surfaces was not well controlled, they all indicate that when atoms, molecules, or ions moving with energies of several eV strike a solid surface a large number of the particles leaving the surface have velocities comparable to the velocity of the incident particles. This suggests that at these energies many of the incident particles collide with only a few of the surface atoms and that they do not spend an appreciable amount of time on the surface. Although no similar studies have been carried out for monatomic oxygen, in light of the results for other particles one should not anticipate that O atoms striking a surface at satellite velocities will accommodate sufficiently to the temperature of the surface to cause processes such as adsorption and recombination to proceed at a rate that is independent of the energy of the O atoms. Current theories on the thermal accommodation coefficient [6] also indicate that at high energies (in the eV range) one expects the particles striking the surface to experience only a few collisions with surface atoms and that the energy of the reflected particles will be comparable to the incident energy.

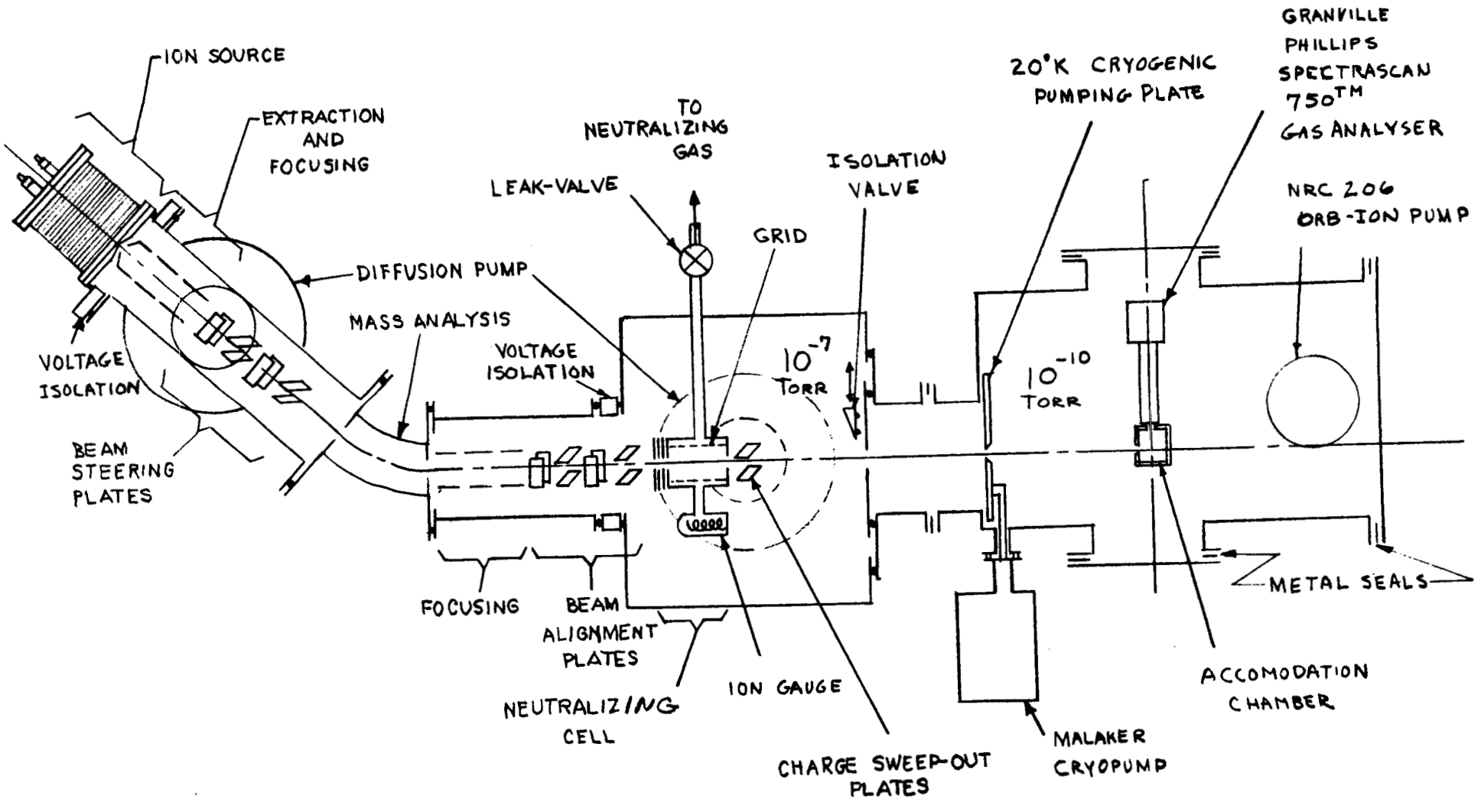

FIGURE 1

SURFACE RECOMBINATION APPARATUS

SECTION III

EXPERIMENTAL APPARATUS

The atomic oxygen beam for these experiments is produced by forming O^- ions in an ion source, accelerating the ions electrostatically to the desired energy, and then removing the excess electron by collisional detachment, resulting in a fast, neutral atomic oxygen beam.

Efforts during this initial year have been devoted to the design and construction of the all stainless steel atomic oxygen beam system, and to the procurement of the requisite apparatus and instrumentation.

A schematic of the beam system is shown in Fig. 1. The system consists of an ion source, mass analysis chamber, neutralization chamber, and an ultra-high vacuum target chamber. These components will be described in more detail in the following paragraphs.

The ion source is a magnetically confined, oscillating electron bombardment source capable of generating intense beams of positive or negative ions [7]. For the generation of O^- ion beams we have used both O_2 and CO_2 as source gases, both of which give about the same total current of O^- ions. Using O_2 however, as the source gas results in a filament lifetime of only about 6 to 8 hours. Since this is inconveniently short we are presently using CO_2 which results in a quite satisfactory filament lifetime of about 50 hours.

The negative ions are extracted from the source and focused by a three element einzel lens system. Immediately downstream of the einzel lens are mounted four pairs of vertical and horizontal steering plates to direct the beam into the entrance slit of the magnet. The source chamber is pumped by a 4 in. oil diffusion pump with a rated pumping speed of 750 ℓ/sec. Between the pump and the chamber are located a water cooled baffle, liquid nitrogen trap, and a 4 in. gate valve. Thus the pumping speed at the source chamber is reduced to

about 170 ℓ/sec. The background pressure in the source chamber is about 5×10^{-7} Torr (no source gas) and normally rises to a pressure of about 1×10^{-5} Torr with the source in operation.

In the magnet section the ions are deflected through an angle of 30° for mass selection. The average radius of the ion path is 23.5 cm. The entrance and exit slits of the magnet are of equal size, 0.635 cm in width and 1.25 cm high.

After exiting from the magnet section the ions are focused by another three element einzel lens and directed by means of a second set of steering plates into the neutralizing cell mounted in the neutralization chamber. See Fig. 1. The neutralization chamber is 14 in. in diameter and 12 in. long. This chamber is pumped by a 6 in. oil diffusion pump with a rated pumping speed of 1440 ℓ/sec, with a water cooled baffle, liquid nitrogen trap, and 6 in. gate valve between the pump and chamber. The pumping speed at the chamber is thus reduced to about 350 ℓ/sec. Normal background pressure in the neutralization chamber is 3×10^{-7} Torr. This pressure rises to about 5×10^{-7} Torr operating only the source, and to about 8×10^{-6} Torr with the source operating and neutralizing gas in the neutralizing cell.

The neutralizing cell is an aluminum cylinder oriented so that the beam traverses along the longitudinal axis of the cylinder. The cell has an inside diameter of about 3.18 cm and is about 7.62 cm long. The cell contains a cylindrical wire grid mounted concentrically with the cell axis. This grid can be used to measure the electrons detached in the collision process. An ion gage, mounted directly on the neutralizing cell, is used to monitor the neutralizing gas pressure. The pressure in the cell when evacuated is about 8×10^{-6} Torr, whereas the cell pressure when neutralizing the O^- beam is about 5×10^{-4} to 10^{-3} Torr.

The target chamber employs only metal-to-metal seals. It has an inside diameter of 17 in. and is 20 in. long. The chamber is

pumped by a NRC-206 6 in. Orb-Ion pump with a rated pumping speed for air of 900 ℓ/sec. In addition to the Orb-Ion pump the target chamber also employs a disk, cooled to about 22°K by a Malaker Corporation "Cryomite" cryopump, to condense those molecules entering from the neutralization chamber. Thus, the target chamber is entirely free of organic materials except for that small amount entering from the neutralization chamber. The ultimate vacuum of the target chamber has not yet been determined but should be in the 10^{-10} Torr range. The initial pump-down for leak detection using only the Orb-Ion pump and rubber gasket seals resulted in a pressure of 8×10^{-8} Torr with no detectable leaks.

The mass determinations will be performed using a Granville-Phillips Spectrascan 750 quadrupole gas analyzer. This analyzer has a rated sensitivity of about 10^{-15} Torr for N_2 and should be adequate for our purposes. The analyzer has been received and will be checked thoroughly and put into operation within the next two weeks.

SECTION IV

FUTURE WORK

We have now completed the construction phase of the research program, as planned. The first experiment to be performed in the coming year is simply to observe the mass components in a cubical accommodation chamber into which our fast, neutral atomic oxygen beam is admitted. The accommodation chamber is constructed of two pieces of copper, easily taken apart by removal of several small screws. The desired surface material can thus be electroplated on the copper chamber quite easily. Mounting of the accommodation chamber and gas analyzer is now proceeding, and we should be able to make our first preliminary measurements within the next few weeks.

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