SATELLITE MEASUREMENTS OF NEUTRAL COMPOSITION WITH A VELOCITY MASS SPECTROMETER

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This contributed paper has been prepared for presentation at the Fifteenth COSPAR Meeting, 10-24 May 1972 in Madrid, Spain
Paper f.49

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ABSTRACT

A new instrument has been designed and successfully flown which is capable of measuring the atmospheric composition by energy analysis of an incoming stream of gas at satellite velocity. At satellite velocity the energies of several species are approximately H(0.3 ev), He(1.3 ev), O(5.3 ev), and N_2(9.3 ev). The operating principle is based simply on the fact that electron bombardment ionization does not impart significant energy to the ion formed in the majority of the interactions and retarding energy analysis can be used to separate the ionized stream by mass. The ion source is a modification of the Pierce type which provides a uniform sheet of electrons through a field free ionization region. The instrument was flown on the OV1-21 satellite which was launched into an 780 x 920 km polar orbit on 7 August 1971. Real time data were obtained from the experiment for a period of one month. Sample spectra obtained from the instrument are shown and some of the details of the experiment are discussed. Preliminary results from the experiment which obtained measurements of He and O are presented.

1. Introduction

An almost obvious approach to the problem of measuring the composition of a uniform high velocity stream of particles such as that encountered by a satellite, is to perform an energy analysis to separate the components by mass. An instrument, referred to as a Velocity Mass Spectrometer (VMS), has been designed, developed, and successfully flown on a satellite which can measure the atmospheric composition by an energy analysis. The technique of using a retarding potential analyzer (RPA) for satellite measurements of electron and ion energies has been accomplished by several investigators (c.f. [1,2]). Apparently, there have been no previous attempts to perform an energy analysis of the neutral species of the upper atmosphere. The VMS uses an electron impact ionization source to ionize the neutral gas flux which is then analyzed by retardation in an electric field. The major requirement of this relatively simple instrument is to perform the ionization in a region free of electric fields with a well defined electron beam. At satellite velocities the energies of the atmospheric species are sufficiently large, compared to the mean thermal energy, that mass analysis by energy separation of the species is practical. Gravitational separation of species in the upper atmosphere results generally in smaller concentrations of the heavier masses. This distribution allows retarding energy analysis that separates the larger concentration of lighter masses and still measures the lesser constituents because of their appearance at a greater retarding energy.

The technique of energy separation offers several advantages over the more conventional type of mass spectrometer. One of the chief concerns with conventional techniques is the question of chemical changes to the ambient composition caused by the instrument surfaces and the hot filament of the ion source. Measurements of O, O_2, and H suffer to some degree due to chemical adsorption (recombination) on the instrument surfaces. It is generally agreed that to a greater or lesser degree all measurements to date show smaller O concentrations and larger O_2 concentrations than exist in the ambient atmosphere due to the surface recombination process. The detailed processes involved with surface reactions are not completely understood. However, it is likely that when a high velocity particle (8 km/sec) undergoes chemical adsorption on an instrument surface, it will not leave the surface with an appreciable fraction of its initial velocity. Thus, those atoms which recombine would not contribute to the composition measured by an energy analysis. In fact, most of the atoms or molecules which strike any instrument surfaces would not contribute to the measurement, thus eliminating or at least minimizing effects associated with both chemical and physical adsorption. A second advantage is that the sampling characteristics of the instrument can be chosen by the design of the limiting aperture. Concern over the question of thermal accommodation is minimized because the reflected particles should not be detected in the VMS, whereas, the reflected particles provide most of the measured signal in conventional open and semi-open ion source mass spectrometers. The experiment uses an electron impact source to ionize the neutral gas flux. The ion which results from stripping an electron from an atom or molecule by electron collision, does not receive significant kinetic energy. Since the neutral species are ionized in an enclosed region where electric fields are negligible, the measurement in the retarding field is not influenced by the satellite potential. The simplicity of this experiment makes it attractive for satellite measurements since no rf or magnetic fields are required to obtain a mass analysis. A density analysis is relatively straight forward since the main factors which are needed are the ionization cross section of the species, the instrument geometry, grid transmission, and a detection system for which the efficiency is known.

2. Experiment Description

The instrument shown in Figure 1 was developed and flown on the

OV1-21 satellite on 7 August 1971. The orbit was 780 x 920 km with an inclination of 88°. Data were collected on an average of 6 to 10 real time passes per day over a period of four weeks. The instrument was mounted with its axis perpendicular to the spin axis and the spin axis was normal to the orbit plane. Thus, once each spin period the instrument axis pointed along the velocity vector.

The operation of the instrument is shown in an idealized case in Figure 2. The important part of the instrument is the ion source which has been patterned after the Pierce-type [3] source which is especially suited to provide a well-defined electron sheet through the field-free ionizing region. For example, as much as 80% of the electron current entering a slit on one side of the box was found to exit a slit of the same size on the other side of the region 4 cm away. Figure 2 indicates the geometry of the source used in the VMS and shows an idealized mass spectrum that would be obtained from the retarding energy analysis. The instrument is also capable of providing temperature information from an analysis of the step occurring at the energy corresponding to a particular species. Several factors contribute to a background which will tend to distort this idealized representation. If appreciable numbers of molecular species are present, some energetic ions will be formed through dissociative processes with a spectrum of energies decreasing as a function of energy [4,5,6]. Another factor which may provide some background contribution at low retarding voltages is the fact that the thermal accommodation coefficient is not unity and some fraction of the reflected species will have sufficient energy to penetrate the retarding field.

The ion source configuration is shown in Figure 3. Two filaments were included for redundancy and were mounted opposite one another (the left side is actually a duplicate of the right). The focusing electrodes on the side of the box opposite from the emitting filament were used to collect and regulate the electron current. The electron current could be switched by ground command between levels of 10 µ amps or 100 µ amps. The 100 u amp electron beam current allowed a large increase in sensitivity and the 10µ amp level caused a smaller distortion of the electric field in the source. The electrons were produced by heating a 0.076 mm diameter tungsten wire. The electron energy in the ionization region was 150 ev. The grid above the ionization region was used to repel ambient positive ions. A grid below the ionization region was used to isolate the high electric field of the secondary emission multiplier. The ion current was detected by a secondary emission multiplier and pulse counting techniques were used to measure the outputs. Two threshold levels were available in the pulse amplifier to allow determination of possible changes in detection system sensitivity. The retarding voltage was stepped through 48 levels each second. An alternative mode of operation was a repetition of four steps with each of the four levels sampled twelve times per second to provide a higher angular resolution. The spin period of the satellite was approximately 50 seconds and the geometry of the ion source allowed particles to enter the instrument without reflection when the instrument axis was within ±20° of the velocity vector. Since the instrument program of operation was based on a 1 second period, a series of 4 retarding energy spectra were obtained during each spin cycle where atmospheric species could be measured. When the angle of attack is sufficiently small that the particles of the direct flux are not shadowed by the defining aperture, the particle flux will not change with angle of attack. The retarding energy associated with a particular mass will change as $\cos^2\alpha$ (where α is the angle of attack between the velocity vector and the instrument axis).

The energy step resolution of this experiment was limited to about 0.34 volts which does not provide a very well defined retarding spectrum. The results from this experiment do show that the instrument performs as expected and has provided a limited amount of data in the vicinity of 800 km. During the first two weeks of operation, the instrument did not provide useable information on the atmospheric species because the background pressure of the outgassing molecular constituents was high. The background was produced by dissociative ionization of species such as H_2O and CO. Dissociative ionization of these outgassing constituents can provide particles with energies up to tens of electrons volts [4,5,6]. Since the atmospheric density near 900 km is typically on the order of $10^5/cm^3$ to $10^6/cm^3$, the outgassing background signal can swamp the signal from the atmospheric species for a considerable period. The electron multiplier was mounted off-axis in order that effects associated with solar illumination of the multiplier and the effects of energetic particles would be minimized.

In Fig. 4, a sample spectrum is shown. The retarding voltage was stepped from -5 volts to +10 volts in increments of about 340 millivolts. The pulse count output from a secondary emission multiplier is shown as a function of retarding voltage for a spectrum near minimum angle of attack and for a spectrum in the vehicle wake. The difference between the ram and the wake, plotted at the right-hand side of the figure, is caused by the flux of gas intercepted by the satellite. The wake spectrum exhibits a gradual drop as a function of increased retarding voltage and is due to energy carried off by products of dissociative ionization processes in the ion source. Distinct drops are seen at energies corresponding to helium, and atomic oxygen. Converting the count measured by making use of the entrance geometry, grid transmission factors, ionizing electron current, and ionization cross-sections, He and O densities are roughly $3 \times 10^5/cm^3$ and $2 \times 10^6/cm^3$, respectively near 780 km. Preparation and analysis of the data are in preliminary stages. Approximately 130 satellite passes of about 10 minutes duration were obtained.

3. Discussion of Results

Although the data from the experiment are limited, several very interesting points can be realized from the preliminary examination of the results. First, the results have shown that this technique can provide measurements of the neutral species on a high velocity vehicle such as a satellite. In addition, charged particle fluxes have been detected in the polar regions moving both up and down the magnetic field lines. The two factors that most adversely affect the measurements were the contribution from the dissociative-ionization of outgassing products and solar ultraviolet reflections on the secondary emission multiplier. The effect of the solar UV radiation was to provide a spurious signal when the instrument axis pointed in the general direction of the sun.

An instrument is presently being designed and constructed which will take advantage of the idea of energy separation used in the Velocity Mass Spectrometer combined with the resolving power of a quadrupole mass spectrometer. The result of combining the two instruments is that the advantages of the velocity mass spectrometer can be maintained and the background contribution of dissociative ionization can be eliminated by tuning the quadrupole to a particular mass of interest and then performing a retarding energy analysis. The new combined instrument will be launched during the latter part of 1973.

4. Acknowledgements

The authors appreciate the efforts of Mr. Robert McInerney in providing the vehicle attitude information. The contributions of Mr. R. A. Wlodyka and Mr. R.B.E. Moren to the development of the electronics and Mr. G. S. Federico to the mechanical design are gratefully acknowledged.

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Illustrations

Figure 1	The VMS instrument shown in flight condition with the blow-off cap sealed.
Figure 2	A schematic drawing of the velocity mass spectrometer with an idealized representation of the retarding energy analysis spectrum together with a picture of the instrument with its vacuum housing removed.
Figure 3	Detail drawing of top and side views of the ion source used in the instrument.
Figure 4	A sample spectrum from orbit 296 on 27 August 1971. The conditions at minimum and maximum angle of attack are shown together with the difference between these two cases.

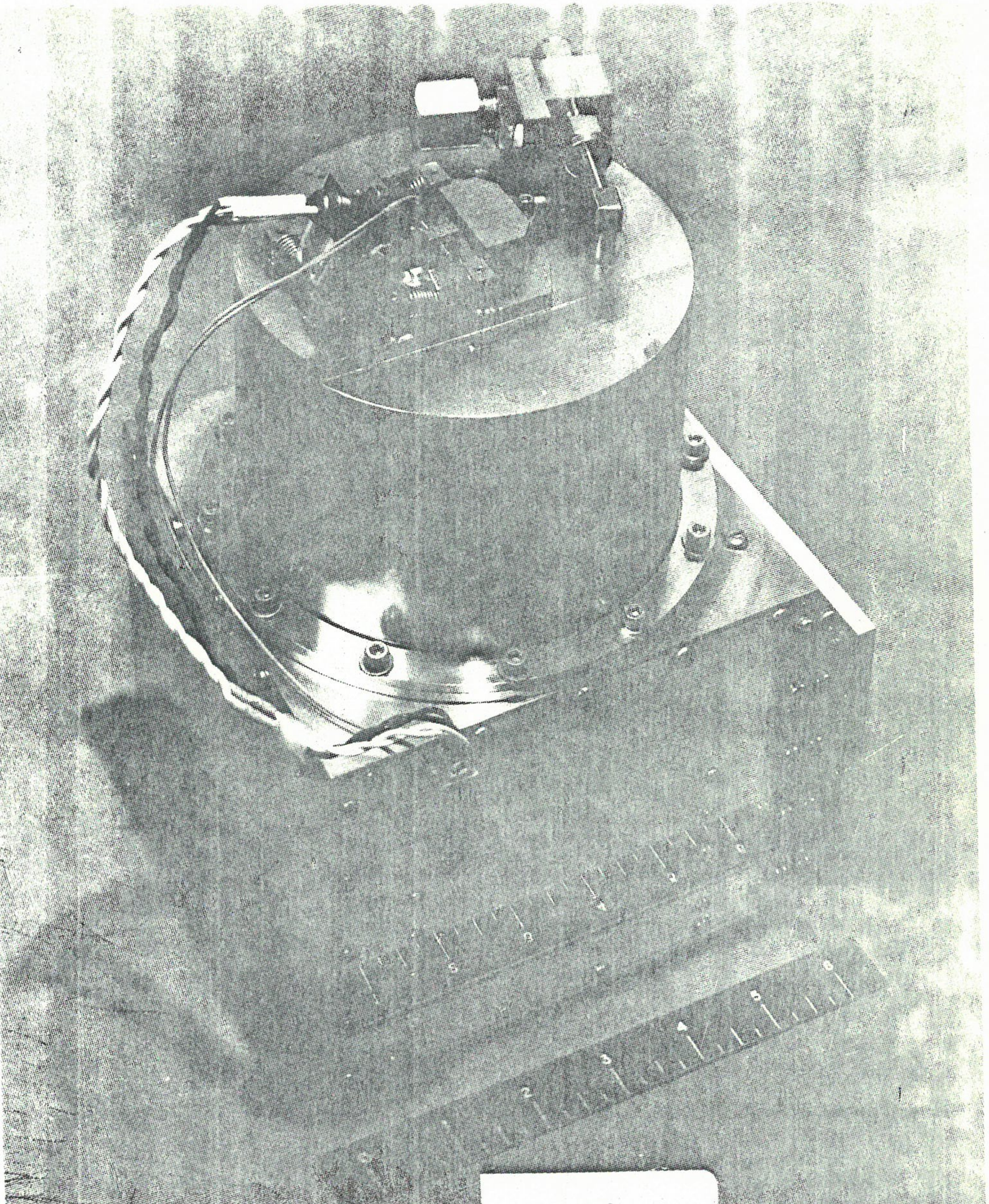

FIGURE 1

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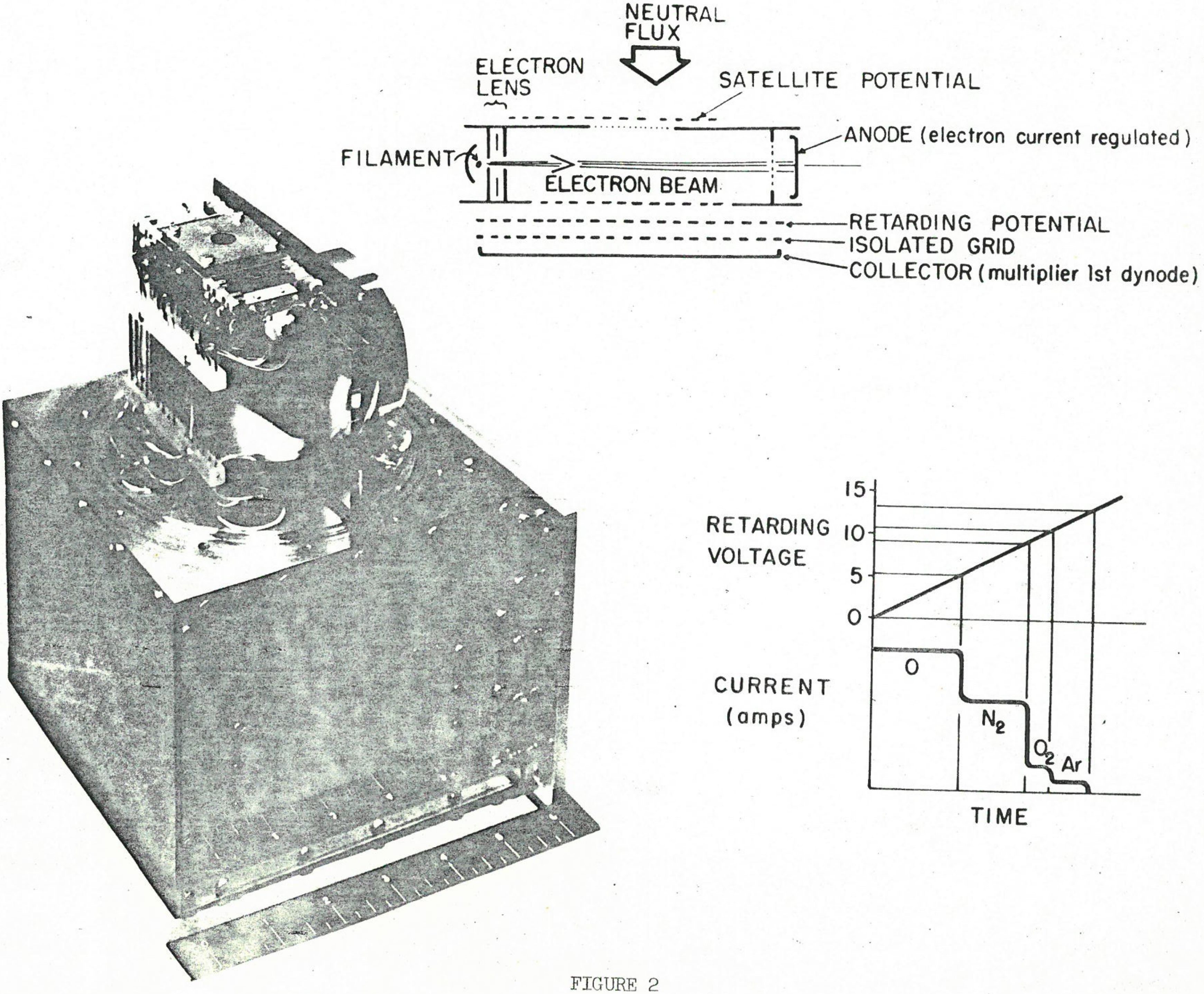
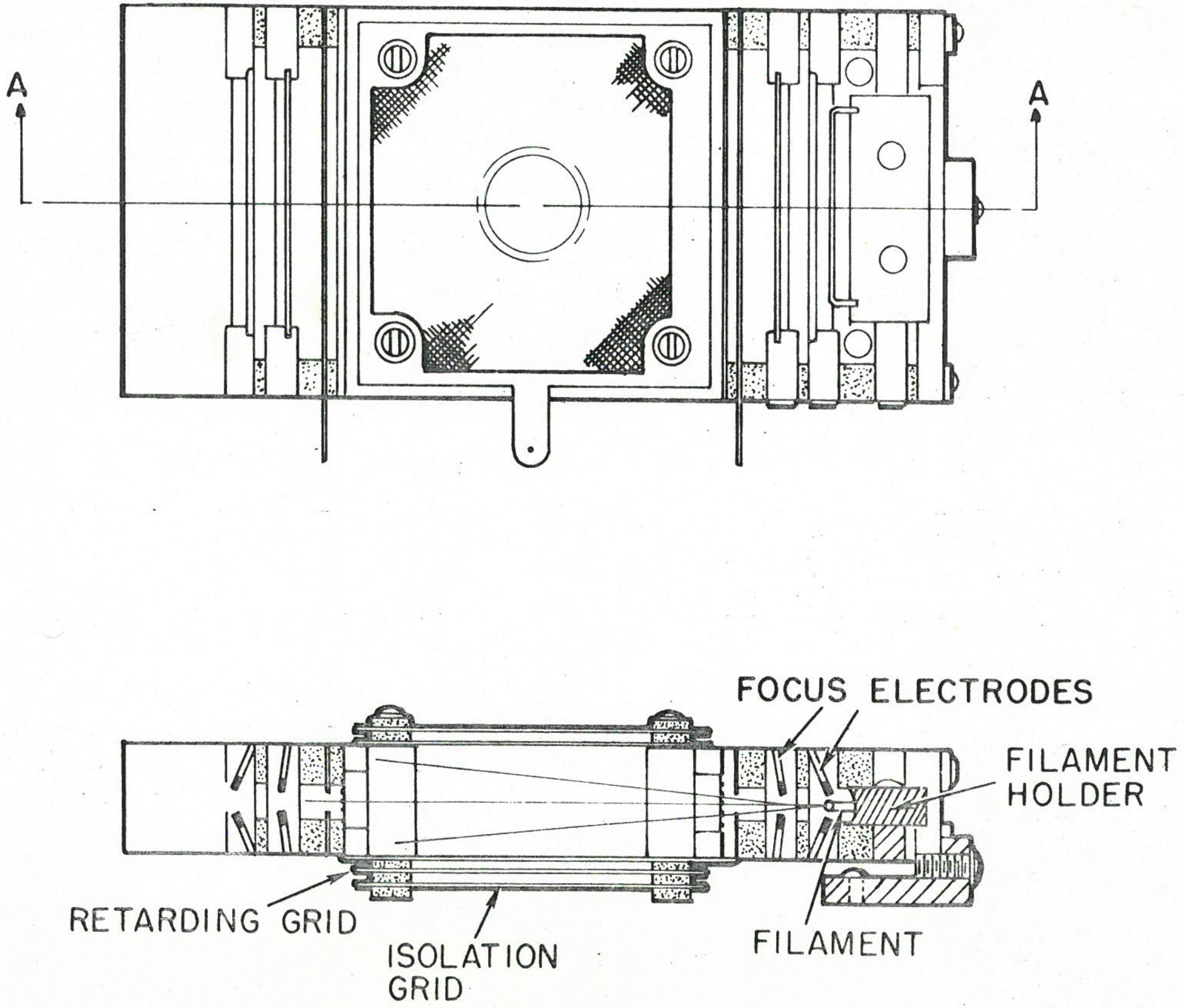


FIGURE 2

AFCRL PHOTO 11-570

ION SOURCE ASSEMBLY



VIEW A-A

FIGURE 3

AFCRL PHOTO 11-98

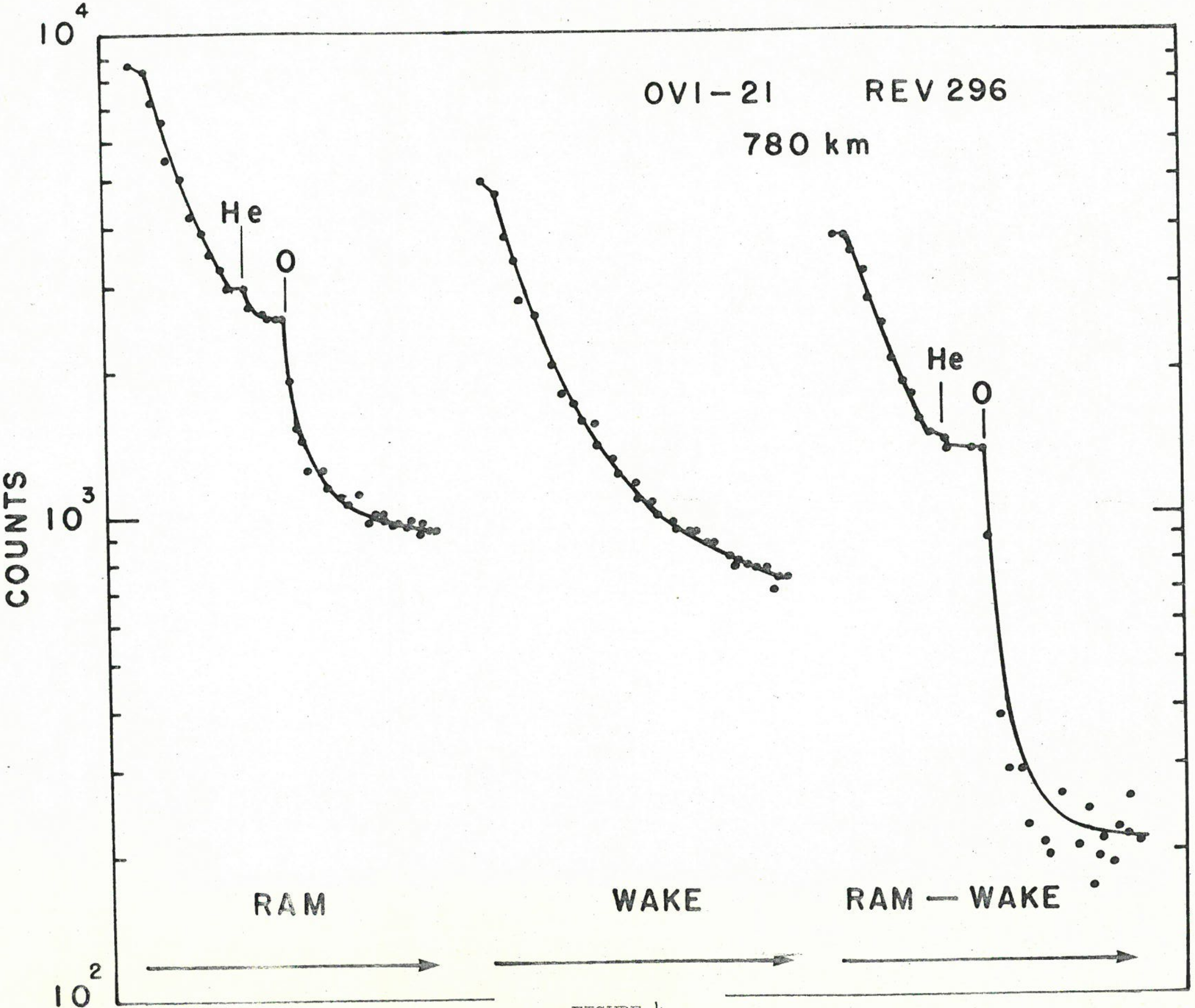


FIGURE 4

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