General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

NASA CR- 159446

Investigations of Negative and Positive

Cesium Ion Species

L. M. Chanin

Department of Electrical Engineering

University of Minnesota

Minneapolis, Minnesota

September 1978

Final Report

Prepared for

National Aeronautics and Space Administration

NASA Lewis Research Center

Contract NSG-3094

Table of Contents

Foreword

Foreword

The work reported in this document was performed by
L. M. Chanin, Professor, Department of Electrical Engineering,
University of Minnesota. A number of graduate students and
research technicians have contributed to the studies - in
particular, David E. Sutliff and D. G. Kuehn.

The encouragement and guidance of James F. Morris,
Head of the Thermionics and Heat Pipe Section of the
NASA Lewis Research Center, are gratefully acknowledged.

I. Summary

The cesium thermionic converter has been the subject of considerable discussion and extensive studies since its introduction in the late 1950's. Interest in developing practical converters has led to the need for basic information on various aspects of cesium discharges or plasmas. In 1969 N. S. Rasor summarized "a phenomenological description" of basic converter operation in which he identified a number of possible effects which could restrict converter efficiency. One of these related to the possibility in the unignited mode of operation of negative ion effects at the collector which might dominate the conditions in that region. In particular, the possible emission of negative cesium ions from the collector was suggested.

The present studies were undertaken to provide a direct test of the hypothesis of negative ion creation at the anode or collector of a diode operating under conditions simulating a cesium thermionic converter. The experimental technique involves using direct ion sampling through the collector electrode with mass analysis using a quadrupole mass analyzer. Similar measurements are undertaken on positive ions extracted through the emitter electrode.

Measurements have been made on a variety of gases including pure cesium, helium-cesium mixtures and cesium-hydrogen as well as cesium-xenon mixtures. The gas additive was used primarily to aid in understanding the negative ion formation processes. Measurements were conducted using emitter (cathode) temperatures up to $\simeq 1000°F$.

The major negative ion identified through the collector was Cs^- with minor negative ion peaks tentatively identified as H^-, H_2^-, H_3^-, He^- and a mass 66. Positive ions detected were believed to be Cs^+, Cs_2^+ and Cs_3^+.

The observation of Cs^- is believed to be associated with a "threshold" cesium pressure which is interpreted to indicate a gas phase origin rather than a surface process as previously suggested. Under all experimental conditions studied thus far the negative ion currents are generally small ($< 10^{-2}$) compared to the corresponding positive ion current signals.

II. Introduction

Negative Ion Hypothesis

A remarkable result of collector work function ϕ_c studies noted by Rasor is that the measured ϕ_c seems to be nearly independent of the composition of the collector surface[1]. Values of ϕ_c, inferred from converter output characteristics by many investigators using a variety of materials and preparation techniques, are reported in the range of $1.4 \leq e\phi_c \leq 1.6$ eV[2]. Specially prepared surfaces with work functions as low as 1 eV in vacuum have given work functions in the "typical" range when used as converter collectors. This lack of dependence on surface composition leads to the suspicion that the measured ϕ_c is controlled by some fundamental property associated with cesium.

Two other anomalous results obtained from collector work function measurements are significant[1]. First, the collector work function measured in some regions of the J-V curve has been found by independent observers to have a rather strong dependence on emitter temperature[3,4,5]. Second, the output potential of the converter has been observed to vary with collector temperature at a rate consistent with the existence of a virtual collector due to back-emission from the collector[6]. These results led Rasor[1] to suggest that collector emission currents of not more than a few milliamperes/cm^2 could produce significant effects in a plasma delivering on the order of 10 amperes/cm^2 to the collector.

Negative Ion Formation Processes

Volume Formation Reactions

.   Table 1 lists some general volume production reactions for negative ions. Reactions (1) - (4) each involve the capture of a free electron. In these reactions, the kinetic energy of the electron prior to its capture plus the electron affinity of the atom or molecule is released by the capture process and must be dissipated in some way. For the radiative capture process (1) the required energy is released by the emission of a photon. In reactions (2) the third body carries away the energy to be dissipated. Of these, reactions (2B) and (2C), where the third body is an atom or molecule, are the most probable, especially when the third body is a molecule with several internal degrees of freedom. Reaction (2A) has a small probability of occurrence due to the small electron-electron collision cross section. In reactions (3) and (4) the excess energy is carried off by the dissociated molecule and the excited molecule, respectively. The dissociation of the K_2 molecule into a negative ion and an atom, as in (3), is responsible for the production of negative potassium ions[7].

Reactions (5) and (6) do not involve electron capture. In process (5) the colliding electron supplies energy to excite the molecule, which then dissociates into a positive and a negative ion. Process (6) occurs only for collisions between energetic atoms, or when the electron affinity of X is greater than the ionization potential of Y.

Table 1 - Negative ion volume formation processes

1. $X + e \rightarrow X^- + h\nu$

2A. $X + 2e \rightarrow X^- + e$

2B. $X + e + M \rightarrow X^- + M$

2C. $X + e + M \rightarrow X^- + M^*$

3. $XY + e \rightarrow X^- + Y$

4. $XY + e \rightarrow (XY^-)^*$

5. $XY + e \rightarrow X^- + Y^+ + e$

6. $X \cdot Y \rightarrow X^- + Y^+$

Table 2 - Negative ion surface formation processes

7. $X + e(s) \rightarrow X^-$

8. $X^* + e(s) \rightarrow X^-$

9. $X^+ + 2e(s) \rightarrow X^-$

10. $Y + X(s) \rightarrow X^- + Y$

11. $Y^+ + X(s) \rightarrow X^- + Y^+$

12. Direct evaporation of X^- from a hot surface

Note: e(s) and X(s) denote electrons and atoms
      originating in the surface, respectively.

Surface Formation Processes

Table 2 shows some of the more probable negative ion production mechanisms involving collisions with surfaces. Reactions '$^-$) - (9) involve a colliding particle coming off the surface as a negative ion, whereas in reactions (10) and (11) the colliding particle causes the emission of a second particle as a negative ion. Process (7) is the mechanism postulated by Rasor[8] for the production of Cs^- ions at the collector of the cesium thermionic converter. This reaction is possible when the electron affinity of the negative ion is greater than the work function of the surface. Similarly, reaction (8) is possible when the excitation energy of the arriving atom plus the electron affinity of the negative ion is greater than the work function of the surface. Generally, reactions (9) - (11) are more efficient for the faster, more energetic, incident atoms or ions. The direct evaporation of negative ions from hot surfaces (12), has been observed but the mechanism is not clearly understood.

III.   Experimental Apparatus

High Vacuum System

A block diagram of the system is shown in Fig. 1.   An
Edwards rotary pump and an air cooled oil diffusion pump were
used to obtain the necessary vacuum.   A thermoelectrically
cooled baffle was mounted on top of the diffusion pump to
minimize backstreaming of oil vapor into the vacuum system.
The section of Fig. 1 enclosed by dashed lines was capable
of being baked at a temperature of 350°C.   A background pressure
of less than 10^{-8} Torr was obtained after baking.   The vacuum
system was generally constructed with Pyrex glass and stainless
steel (SS 304).   All metal connections were sealed with either
heliarc welds or copper gasket flanges.   The high vacuum bakeable
valves were Granville-Phillips 1/2 inch type C valves.

The gas handling portion of the vacuum station consisted
of a gas supply and pressure control system.   The gas supply
consisted of one liter pyrex flasks of research grade gas and
cataphoresis tubes for impurity control.   The gas pressure control
involved the use of a capacitance manometer whose output drove
a servo-controlled leak valve.   The gas lost through the sampling
orifice in the discharge tube was continuously replaced by the
leak valve thus maintaining a constant pressure in the discharge
tube.

The cesium handling portion of the system was primarily
constructed of stainless steel.   The cesium which was supplied
in evacuated pyrex ampoules was introduced into the discharge tube
through a still which for high pressure cesium studies enabled
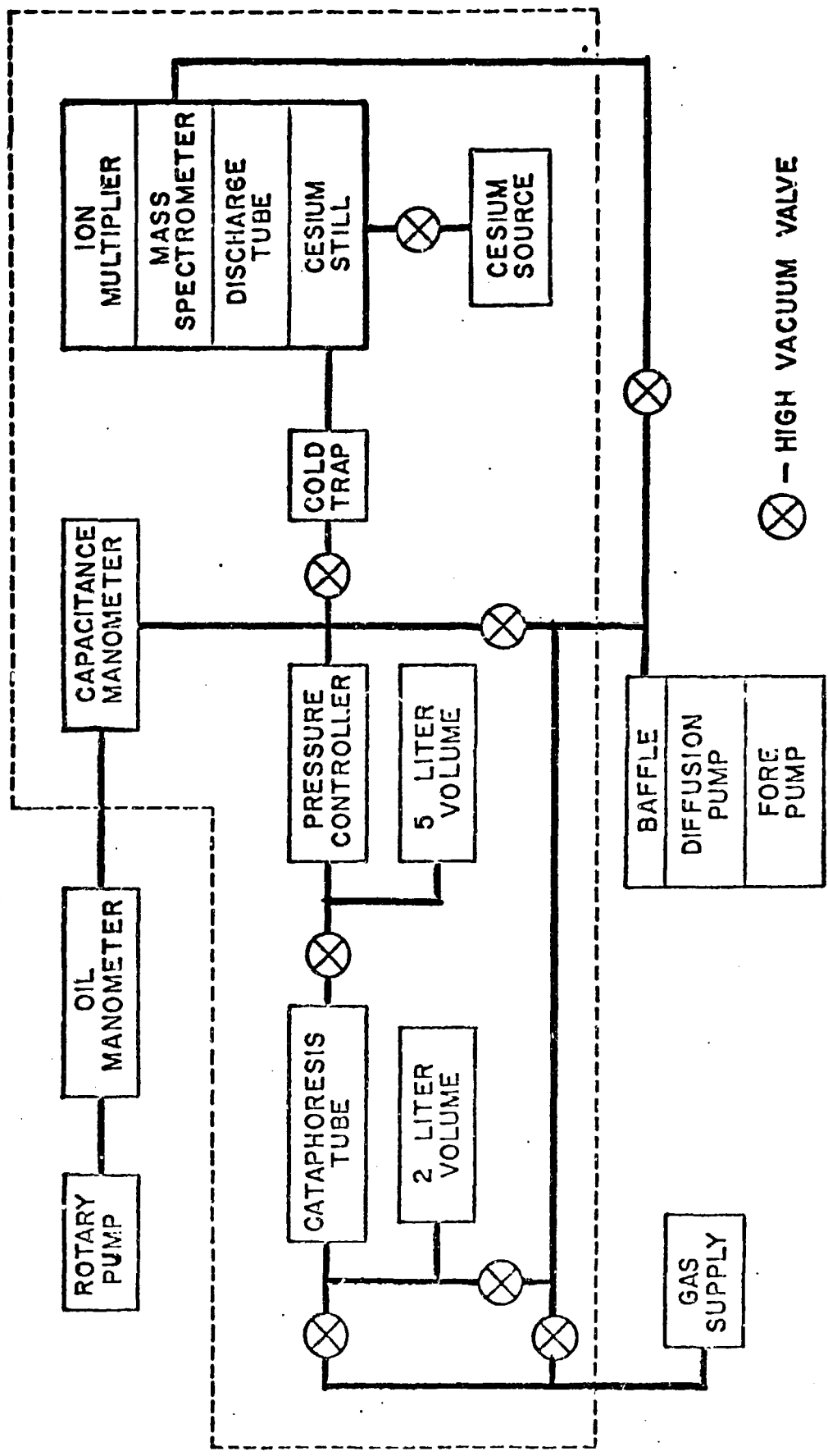evacuation of desorbed gases due to the high temperature operation.

FIGURE 1 - BLOCK DIAGRAM OF HIGH VACUUM SYSTEM

The entire cesium handling section, except for the cold trap and the cool side of the still, was heated by either ovens or heating tapes. The cesium vapor pressure was controlled by heating the boiler region of the still in an air oven. The data of Taylor and Langmuir[9], confirmed by more recent investigations[10,11], was used to calculate the cesium vapor pressure from the boiler region temperature.

A schematic diagram of the discharge tube is shown in Fig. 2. The basic vacuum container was constructed with stainless steel (SS 304). The sampling orifice assembly served as a grounded electrode and formed a high vacuum seal between the discharge tube and the mass spectrometer region. The sampling orifice assembly consisted of a nickel gasket and a thin nickel foil. The gasket was used to form the high vacuum knife edge seal and also served as a backing plate for the 25 µm thick foil. A 100 µm diameter orifice was used for most measurements. The sampling orifice was used as both a cathode and an anode in a DC discharge. With the orifice grounded, the polarity of the discharge was determined by the polarity of the applied voltage.

For many measurements the moveable emitter shown in Fig. 2 was replaced by one which was indirectly heated using tungsten filaments. The design of the heated emitter which used macor ceramic as an insulator prevented the direct passage of gas particles, radiation etc. from the filament area into the discharge region of the tube. The heated emitter was capable of operation up to ~ 1000°F.
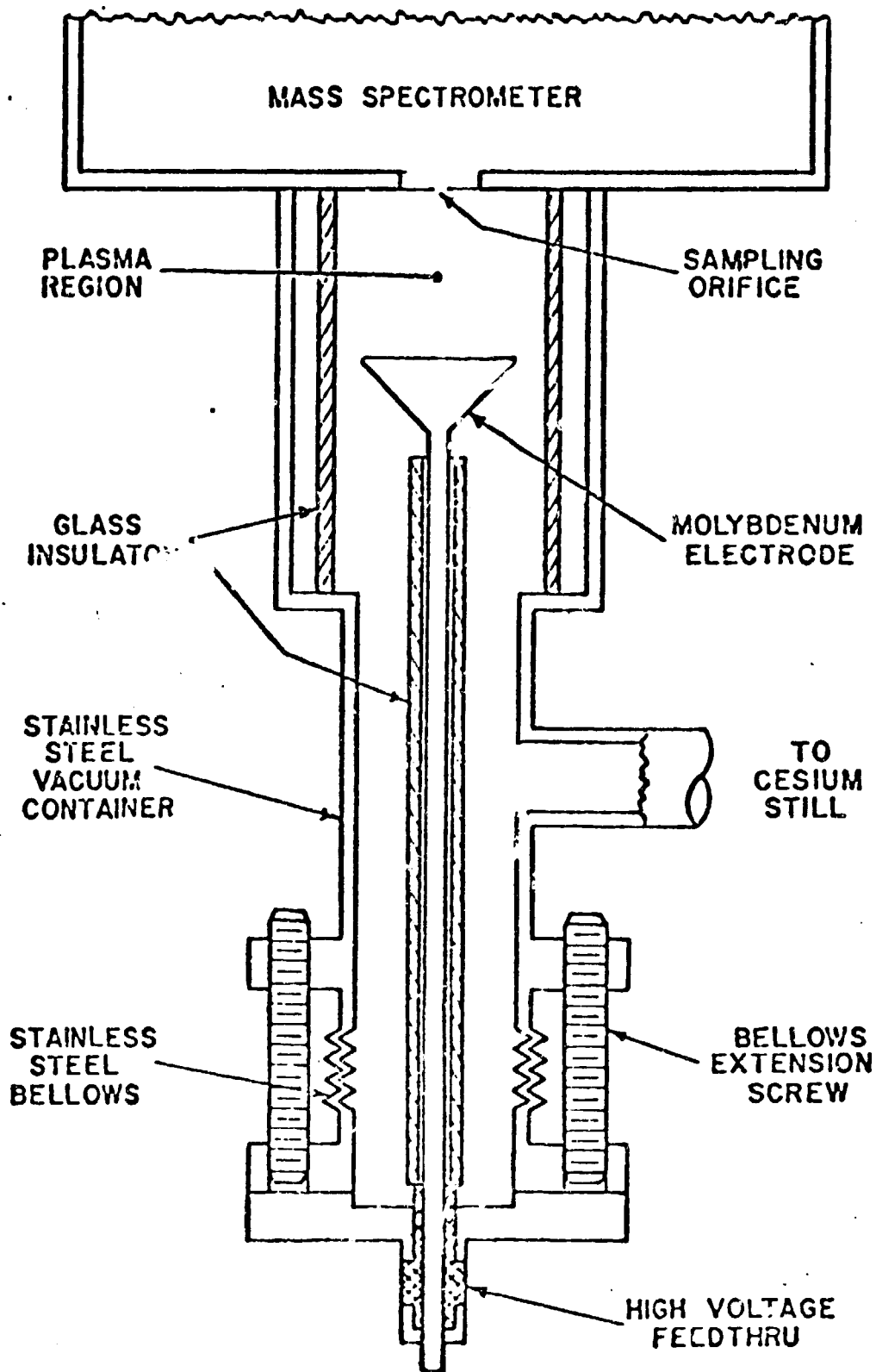
FIGURE 2 – SCHEMATIC DIAGRAM OF THE DISCHARGE TUBE

There are considerations involved in the design of the sampling orifice. The object is to extract charged particles from the plasma in sufficient quantities to obtain a detectable signal without disturbing the plasma. To minimize the disturbance of the plasma, particles must travel through the sampling orifice under effusive flow conditions. This requires that the orifice diameter be less than (and preferably much less than) the mean free path of the particles in the discharge tube. Also, charged particles emerging from the sampling orifice under effusive flow conditions are most probably formed in the discharge tube, since collisions within the orifice are unlikely. To minimize collisions with the walls of the orifice, it is important that the orifice appear as a hole rather than a tunnel. This requires that the orifice diameter be larger than the metal foil thickness. The mean free path of cesium at one Torr is a few hundred microns. For a foil thickness of 25 μm, the optimal orifice diameter lies in the 25 - 100 μm range. Within this range, smaller holes are more desirable because effusion of cesium (particularly the neutral cesium) through the orifice is smaller thus reducing the problem of cesium condensation on the insulators in the mass spectrometer and ion multiplier regions. Changes in sampling orifice dimensions due to cesium condensation in or near the orifice can affect the relative transmission of the various ion species. For this reason regular hole cleaning procedures, consisting of heating and positive ion bombardment, were performed.

The process of sampling ionic species from a plasma involves several considerations. Reactions occurring within and behind the sampling orifice can lead to the accumulation of data not

representative of the processes occurring in the plasma.
Collisional reactions occurring within the orifice channel
may change the relative magnitudes of the ion signals
transmitted. Ions transmitted through the sampling orifice
may also be subject to mass discrimination. Gas polymerization
(or clustering) reactions can occur as a result of the expansion
of the gas from the high pressure region in the discharge tube
to the low pressure of the mass spectrometer region. This type
of reaction is especially favorable in alkali vapors and
molecular gases.

Electronic Detection System

Two different detection systems were used in these studies.
The primary detection system was an ion counting system using
a multi-channel sc ler which is schematically shown in Fig. 3.
The other detection system directly measured electron and ion
currents. The heart of the ion counting system, the primary
detection system, was a multi-channel scaler (MCS) used in
conjunction with a mini-computer. The pulses from the Be-Cu
ion multiplier anode were transmitted through a pulse transformer
and fed into a series of two or three (depending on signal
magnitude) EG&G Model AN101 wide band amplifiers, each with a
gain of 4.0. The amplifier output entered an EG&G Model T101
discriminator that had a variable threshold voltage. The logic
signal output of the discriminator was fed to the count input of
the multi-channel scaler.

The multi-channel scaler controlled the entire data
acquisition process. A voltage ramp output from the MCS was
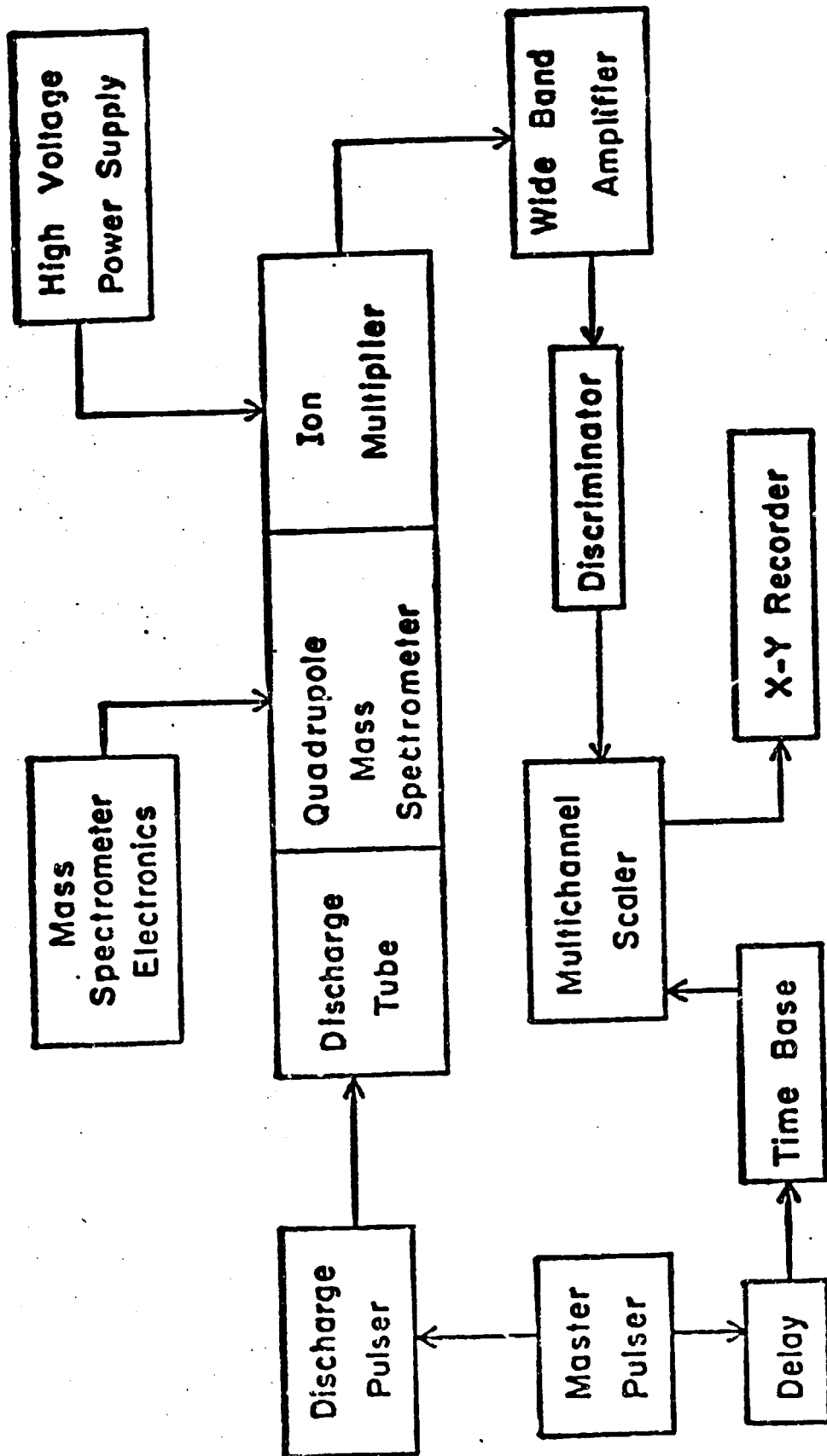used to drive the mass spectrometer electronics. The MCS would

13

FIGURE 3 – BLOCK DIAGRAM OF MEASURING SYSTEM

receive counts corresponding to a specific particle charge-to-mass ratio range as determined by the ramp voltage output level. The counts received during a preset dwell time were then stored by the computer and displayed on an oscilloscope screen. The ion counting system was capable of storing 10^6 counts in each of 1024 channels. The data was displayed as counts as a function of charge-to-mass ratio. The number of counts could be displayed on any of 24 linear ranges or as the logarithm of the number of counts. The data was then plotted as displayed on a Hewlett Packard 7004B X-Y plotter.

IV. Results

Mass Analysis of Negative Ions from Discharges

Relatively few reports appear in the literature concerning negative ion sampling from active discharges. Careful examination of the problems involved in such studies reveals many reasons for the lack of reliable data on this subject. As previously noted, the extraction of ions from an active discharge and subsequent mass analysis poses many problems. The most severe problem for negative ion analysis involves the possibility of collisional detachment reactions within the orifice or at the entrance to the quadrupole mass spectrometer. Most negative ion species are weakly bound hence detachment reactions can significantly falsify data. Many negative ion processes are very strongly electron energy dependent hence discharge conditions can strongly affect the relative concentration and also the type of negative ion species detected.

Initial Tests

A series of initial tests were performed to determine the feasibility of negative ion sampling from the anode of an active discharge. The apparatus used for this test, was used previously by Kamin and Chanin[12]. Mass scans were performed on active oxygen discharges. For pressures in the 1 to 5 Torr range, O^-, O_2^-, and O_3^- were all observed effusing from the anode, while O^+ was observed through the cathode. When this test proved successful, the apparatus was dismantled and modified for use with cesium as described in section III. Oxygen was again used to test the cesium apparatus to ensure the ability to sample negative ions.

After the oxygen tests were completed, the remaining oxygen was pumped out of the system and the apparatus was baked to remove any remaining impurities.

Helium was also used as a test gas to evaluate the overall performance of the system. The primary purpose of the helium, however, was to act as a buffer gas with cesium when the cesium pressure alone was insufficient to maintain a discharge.

A mixture of hydrogen in helium was also used in the experiment at one point. In some of the negative ion mass scans obtained from helium-cesium discharges it was suspected that a negative hydrogen ion mass peak had been detected. However, due to the difficulty in resolving very low mass peaks (1 or 2 amu) from an electron peak (at essentially mass zero) when scanning over several hundred atomic mass units and due to a failure of the sampling orifice, the detection of a negative hydrogen ion mass peak was not verified during that trial. After the 50 μm diam. sampling orifice assembly had been replaced with a larger 100 μm diam. sampling orifice, the helium-hydrogen mixture was studied. The object was to determine whether or not a mass peak at mass one (H^-) or two (H_2^-) could be resolved from the electron mass peak. By increasing the mass spectrometer quadrupole field frequency (to about 750 kHz) to scan a mass range up to about 150 amu, the observed H^- mass peak was easily resolved from the electron peak. Again, after these studies were completed, the remaining gas was pumped out and the apparatus was baked.

Initial studies using cesium were made using an emitter which operated at the "ambient" temperature necessary to achieve the

desired cesium vapor pressure corresponding to essentially glow discharge conditions. An example of these measurements is shown in Fig. 4 which shows results of sampling negatively charged particles through the anode (collector) electrode. In addition to observing ions identified as H^- and Cs^-, it will be noted that the all ion electron peak is detected at mass zero. We believe that the origin of H^- is primarily the result of contamination due to the gas handling system rather than desorption from the metallic surfaces in contact with the plasma.

The typical negative ion mass spectra shown in Fig. 4 is for $p_o(Cs) = 8.5 \times 10^{-2}$ and a discharge current of 5 mA. As molecular positive ions have been observed previously[13], the mass spectrometer was operated at a frequency of 426 kHz to cover as broad a mass range as possible for the maximum filtering voltages. Unfortunately, this resulted in a resolution at low masses which was inadequate to determine any contribution from He or H_2 to the hydrogen-ion peaks. The structure apparent in the Cs^- peak was much more strongly dependent upon variations in QMS voltage settings than in the actual discharge parameters. A similar structure is inherent in the positive ion spectrum and has also been observed elsewhere where mechanical alignment of QMS rods was not exact[14]. Due to different ion velocities and secondary emission coefficients at the Be-Cu dynode, exact estimates of the relative concentrations of positive and negative ions present in the plasma region cannot be made by simply comparing the ion signals. However, the Cs^-/Cs^+ ion signal ratio was generally between 10^{-2} and 10^{-1} for glow discharge conditions.

p_o (He) = 3.4 Torr ± 3%
p_o (Cs) = 8.5 × 10^{-2} Torr ± 15%
Discharge Voltage = 185 V
Discharge Current = 5 mA
Electrode Spacing = 2.0 cm
QMS Frequency 426 kHz

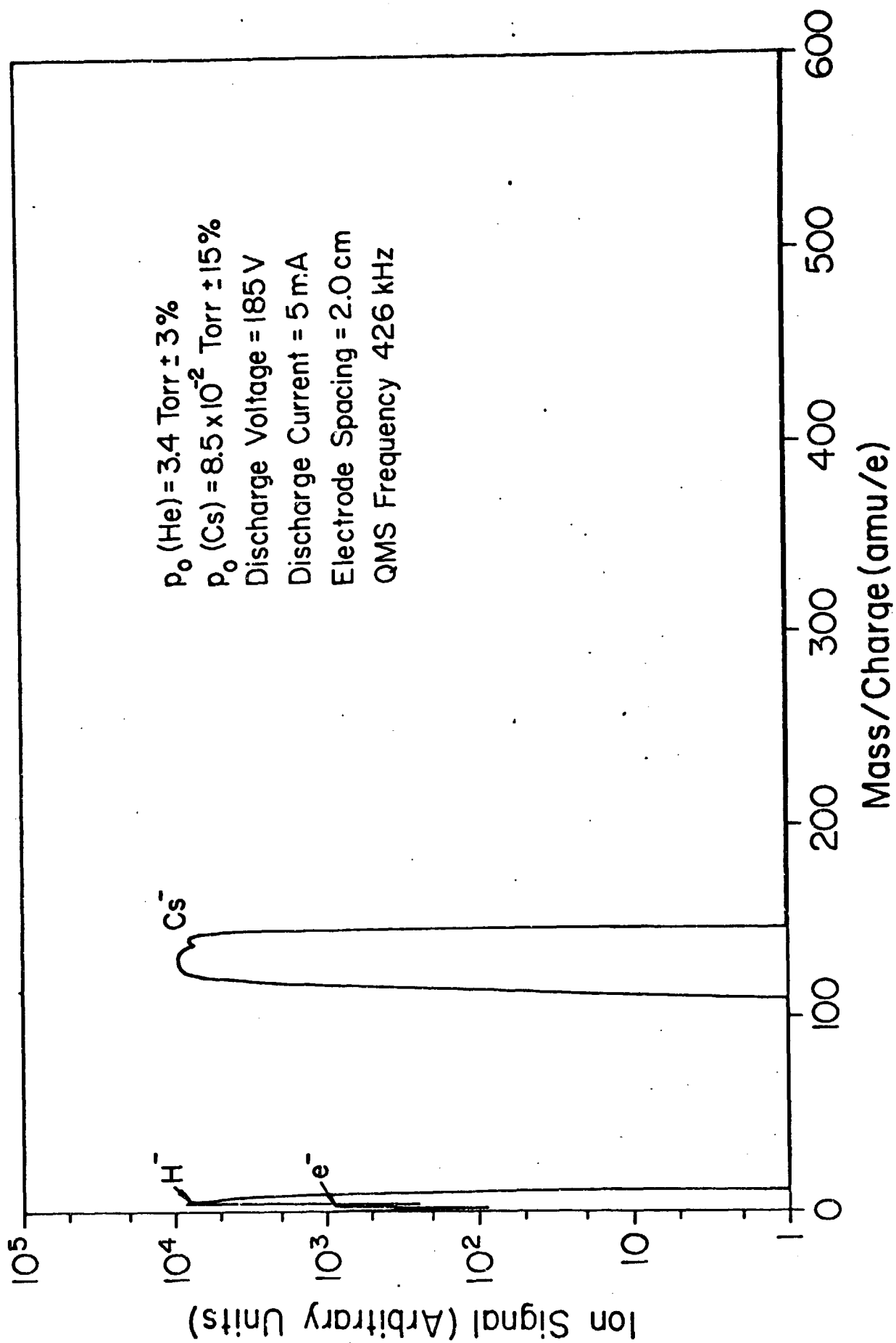Mass/Charge (amu/e)

Ion Signal (Arbitrary Units)

FIGURE 4 – NEGATIVE ION MASS SCAN. ION SAMPLING WAS PERFORMED THROUGH THE COLLECTOR. THE EMITTER WAS OPERATED AT AMBIENT TEMPERATURE.

To illustrate the complex nature of a low mass negative ion spectrum Fig. 5 shows an amplified scan of low masses observed using a He-0.05% H_2-Cs mixture. In addition to the electron component, structure seems apparent corresponding possibly to masses 1-4. As previously noted, H^- has been known to exist for many years; also the detection of H_2^-, H_3^- and He^- has been reported some time ago. The data shown in Fig. 5 were obtained by changing the ratio of the dc and rf power applied to the quadrupole rods. The emitter was operating at approximately 900°F.

For the second phase of the investigations, thermionic converter conditions were more closely approximated by decreasing the electrode spacing D to 0.5 cm and using the filament to heat the lower electrode when used as the cathode (or emitter, in converter technology). Helium addition was no longer required for measurable discharge currents as had been the case for the larger D. Since low-mass positive and negative ions had been apparent, the operating frequency of the QMS was increased to 640 kHz to give better resolution in this region.

A positive ion spectrum is illustrated in Fig. 6 with identifications for the observed species. Of these, Cs^+ and Cs_2^+ are well known[13], and Cs^{++} was tentatively identified as a doubly-charged species based upon: (1) a discharge current dependence much stronger than that of the singly-charged ions and (2) the fact that a rather high "appearance potential" voltage drop across the electrodes (e.g., 65 V at p_0(Cs) = 10^{-3} Torr) was required. The peak near the mass/charge of 35 is believed due to minor impurities in the vacuum system and the Cs. The addition of

ORIGINAL PAGE IS
OF POOR QUALITY

He – 0.5% H$_2$–Cs, P$_O$(He) = 0.16 TORR
P$_O$(Cs) = 7.6x10^{-2} TORR, I = 5 mA
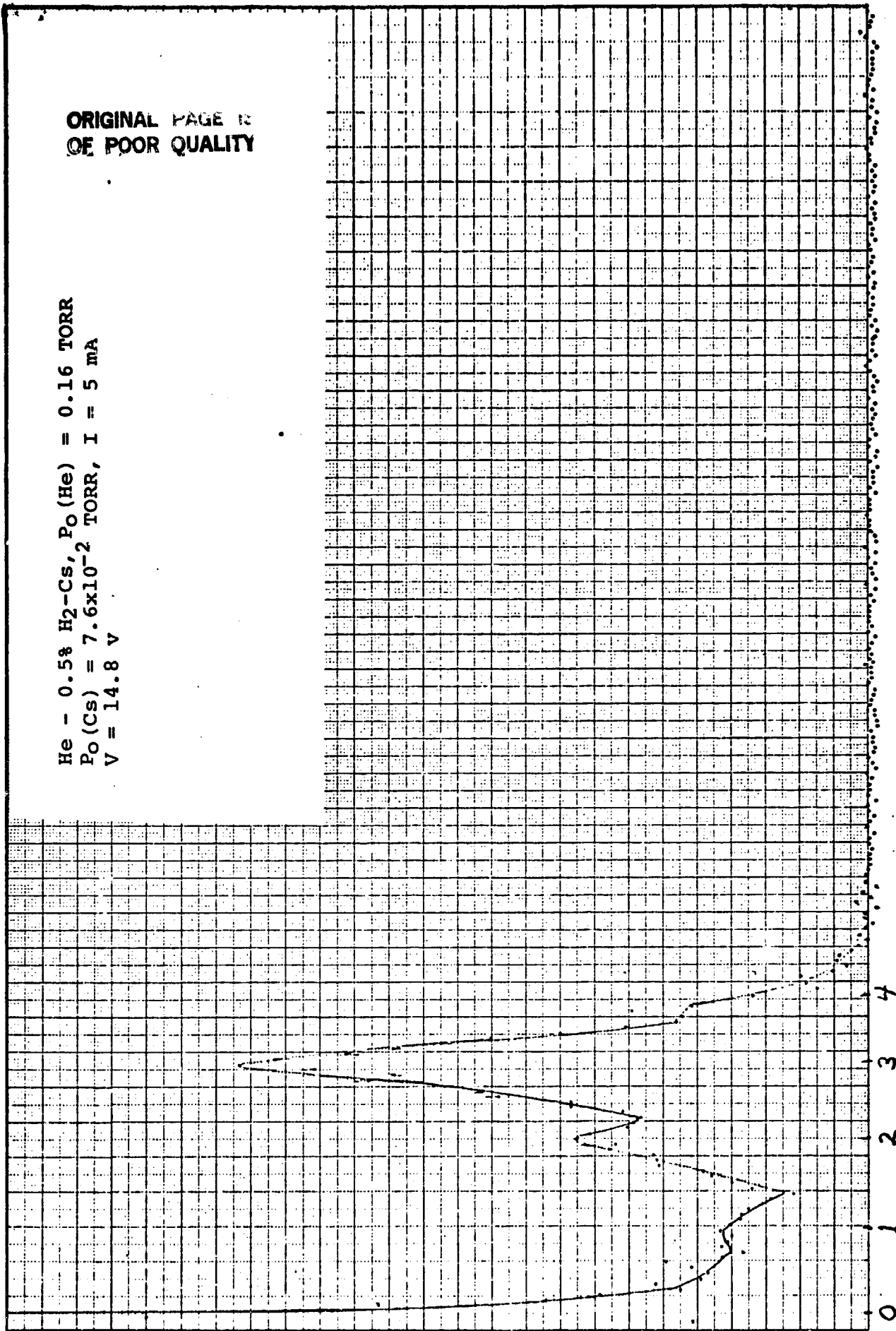V = 14.8 v

m/e =   0   1   2   3   4

FIGURE 5 – NEGATIVE ION MASS SCAN AT LOW MASSES FOR A
He – H2 – Cs MIXTURE. THE SAMPLING WAS PERFORMED
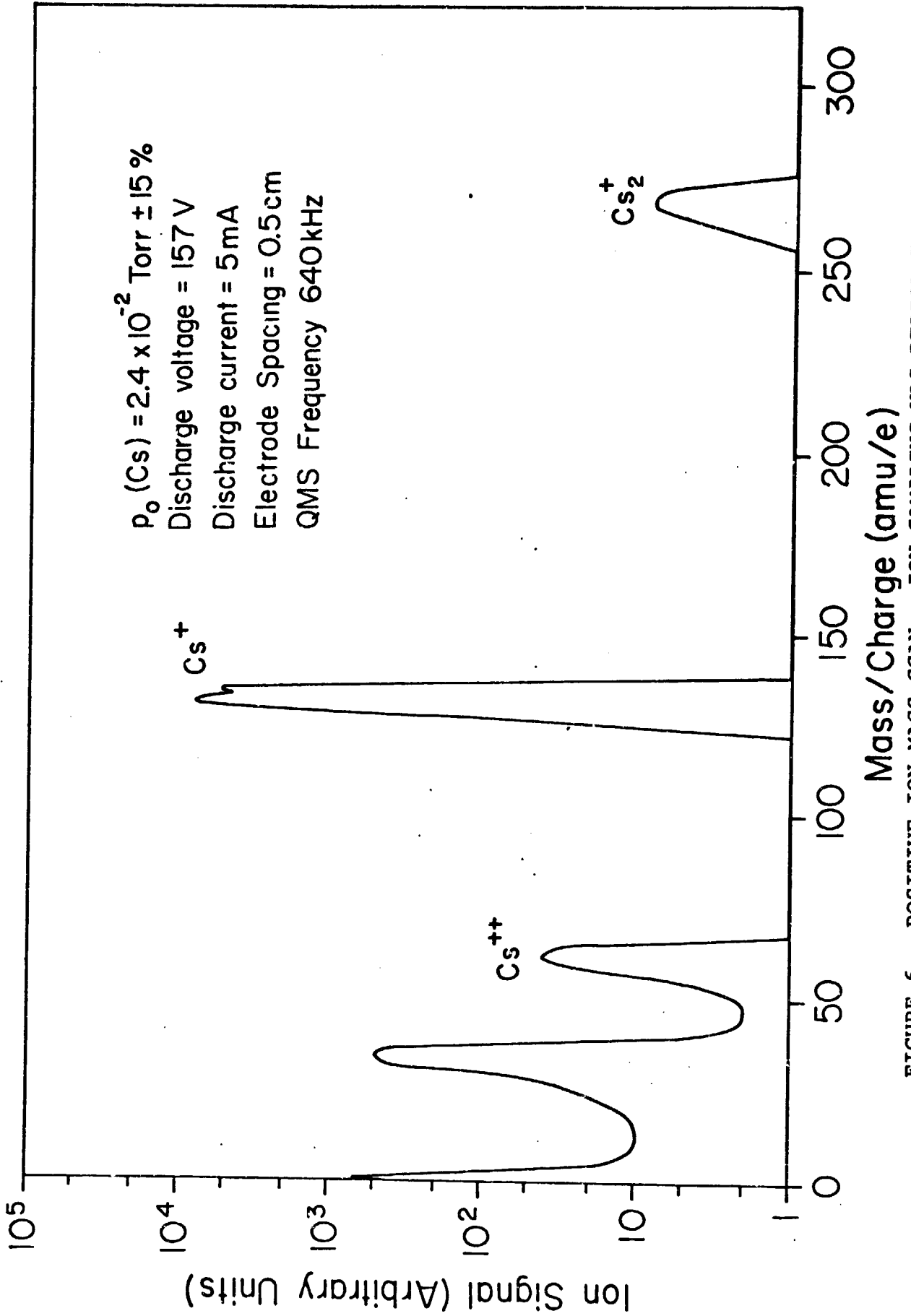THROUGH A HEATED COLLECTOR ELECTRODE.

FIGURE 6 – POSITIVE ION MASS SCAN. ION SAMPLING WAS PERFORMED THROUGH THE EMITTER. THE COLLECTOR WAS OPERATED AT AMBIENT TEMPERATURE.

He in pressures from 0.1 to 1.0 Torr resulted in the appearance of an He^+ peak. Atomic and molecular hydrogen positive ions were observed only with the addition of a mixture of He plus 0.5% H_2.

For negative ion studies, the emitter electrode was heated to approximately 950°K as measured with a thermocouple in close proximity to the electrode. Increased electron emission was definitely apparent, as the applied voltage across the electrodes was only 1/10 that necessary to produce the same current at ambient temperatures. Furthermore, a very large electron peak was apparent at all cesium vapor pressures. The "threshold" for Cs^- observation was $p_o(Cs) \approx 3 \times 10^{-2}$ Torr - at which point the electron-neutral mean free path is of the order of 10^{-1} cm [15]. This is believed indicative of the existence of volume formation processes for the negative cesium ions. Coincident with the appearance of Cs^- was a second negative species at one-half the mass/charge. These are shown in Fig. 7, which represents the negative ion spectrum present at $p_o(Cs) = 8.9 \times 10^{-2}$ Torr. The very large peak at m/e ~ 0 was entirely due to electrons; this was confirmed by operating the QMS at a frequency of 1.33 MHz where the mass/charge resolution was less than one amu/e. When Cs was present alone in the discharge region, the only other negative species was at m/e ~ 40 and was believed due to minor impurities in the Cs (e.g., potassium). Under all conditions, increasing $p_o(Cs)$ resulted in increased negative-ion signals.

Addition of either He or $He-H_2$ resulted in several low mass negative species even at low $p_o(Cs)$ where the negative
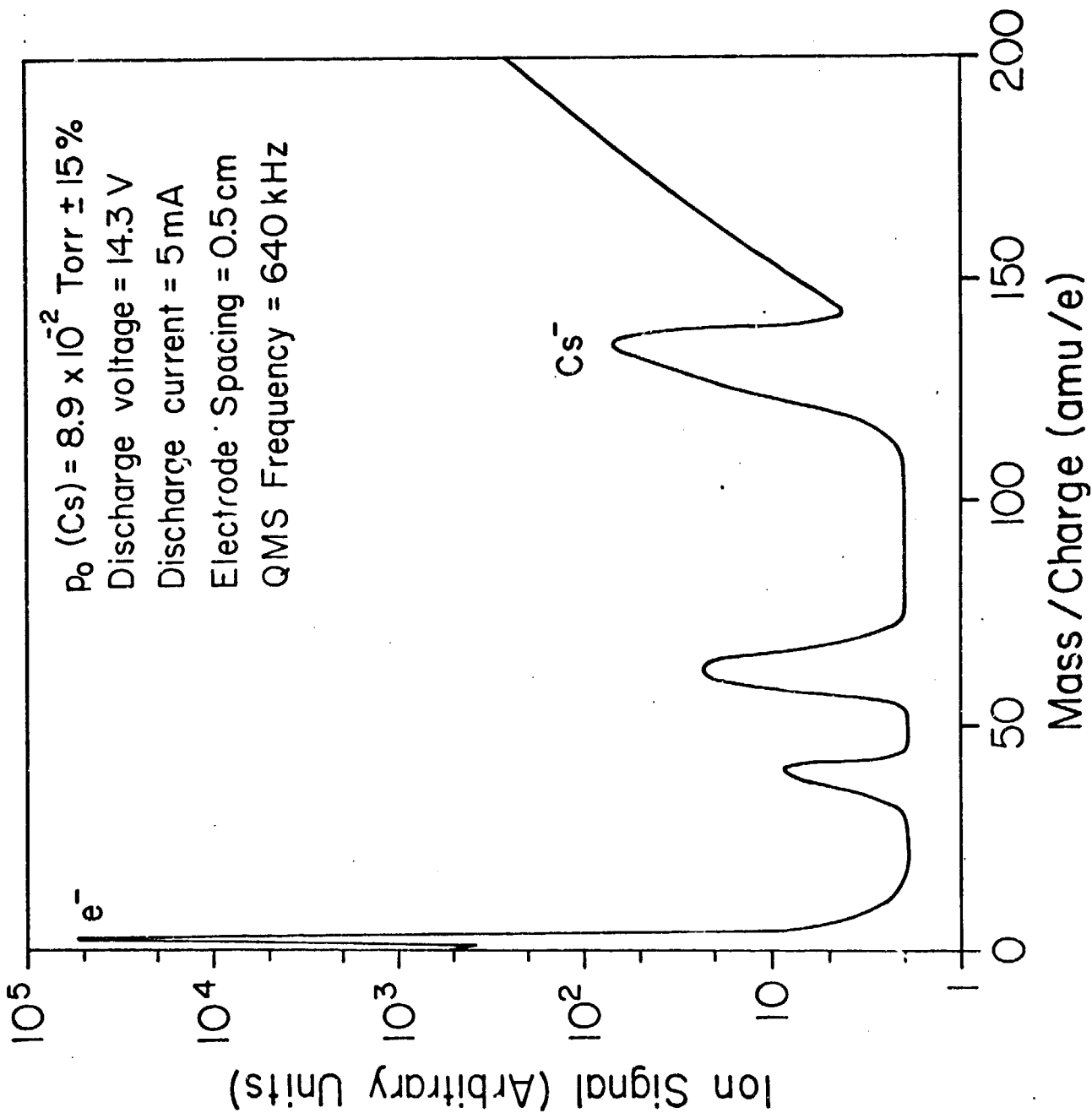
FIGURE 7 – NEGATIVE ION MASS SCAN. ION SAMPLING WAS PERFORMED THROUGH THE COLLECTOR. THE EMITTER WAS OPERATED AT APPROXIMATELY 9500 K.

Cs ions were not apparent. At the increased QMS frequency, the low-masses were resolved into atomic and molecular hydrogen plus what was believed to be He^-. The production of negative hydrogen ions in an H_2-Cs system was not unexpected[16]. The data indicate that the observed hydrogen species (when H_2 addition was not intentional) were primarily a result of contamination due to the gas-handling system rather than desorption from the volume of metallic surfaces in contact with the plasma. The presence of the He or He-H_2 mixture had the additional effect of enhancing the Cs^- and $[m/e \approx 66]^-$ peaks, presumably because of a decrease in average electron energy due to collisional effects.

The negative ion at $m/e = 66$ was only present in conjunction with the Cs^- and seemed to have essentially the same dependence on both p_o(Cs) and the applied electrode potentials. No known impurity in the Cs had even approximately this particular mass. Furthermore, this particular ion peak precisely overlapped the Cs^{++} peak in the positive spectrum. A possible explanation would involve the production of positive ions within the QMS itself, and these in turn could produce electrons at the spectrometer's (cesiated) exit grid by secondary emission. (The multiplier was biased at such a potential that only negative particles would be collected.) To test this hypothesis, high energy (≈ 100 V) positive ions created in the discharge region were sent through the QMS; no signal above background level was detected. Although numerous authors have discussed the unlikely possibility for formation of doubly-charged negative ions[17,18], in light of the present experimental evidence, it is tempting to ask if this species could not indeed be Cs^{--}? Additional studies should be conducted to further investigate this possibility.

Table 3 gives an example of representative peak height values of the more important negative and positive ions relative to conditions which tended to enhance the production of negative cesium ions, namely, a small current (2.5 mA) with a small potential drop (< 10 V) across the electrodes. Helium and He + 0.5% H_2 were added in small quantities so as to act as a small perturbation to the pure Cs case. The peak height values are all normalized values relative to the Cs^+ peak observed in the He-Cs case (i.e., the largest peak of the entire set). Approximately ten times the applied potential was required to maintain the same current for the positive ion (cold cathode) studies as for the negative-ion (hot cathode) data. It is important to note that the relative electron energies differ significantly for the 5 sets of ion data shown in Table 3.

TABLE 3 - REPRESENTATIVE PEAK HEIGHT VALUES

GAS	POSITIVE IONS				NEGATIVE IONS				COMMENT
	He^+	Cs^+	Cs^{++}	Cs_2^+	$[MASS2]^-$	$[MASS3]^-$	Cs^-	Cs^{--}	
Cs	0	0.26	1.3×10^{-3}	7×10^{-4}	$<10^{-4}$	$<10^{-4}$	1.2×10^{-2}	4×10^{-3}	
He+Cs	6×10^{-4}	1.00 ②	5×10^{-3}	7×10^{-4}	$<10^{-4}$	$<10^{-4}$	1.5×10^{-2}	5×10^{-3}	$P_{He} = 0.13$ Torr
He+Cs+H$_2$	—	—	—	—	4.6×10^{-2}	9.2×10^{-2}	1.6×10^{-2}	5×10^{-3}	$P_{He+H_2} = 0.16$ Torr 0.5% H$_2$

$T_{COLLECTOR} \approx$ AMBIENT

$T_{EMITTER} \approx 1000°F$

$P_{Cs} = 6 \times 10^{-2}$ Torr

$P_{Cs} = 6 \times 10^{-2}$ Torr

1   DISCHARGE CURRENT = 2.5 mA, EXCEPT Cs^{++} AT 5 mA

2   Cs^+ PEAK IN HE+Cs USED AS REF. VALUE

V. Conclusions

We believe that the original objectives of the investigation supported by NSG-3094 have been achieved - Cs⁻ does exist under conditions approximating those encountered in the cesium thermionic converter. Independent measurements conducted by personnel at Rasor Associates have confirmed the presence of Cs⁻.

It is obvious that there are many questions to be answered concerning the role of negative ions in cesium plasmas. Not only are the answers to these questions important to the basic understanding of cesium plasmas, they can also have very significant effects on the development of the cesium thermionic converter. The existence of a negative ion space charge barrier near the collector of the converter could place a lower limit on the effective collector work function. This could have the effect of limiting the maximum output voltage and power density of the converter, and raise serious questions concerning further development of the cesium converter.

One important question which we believe merits further study is the origin of Cs⁻. How are the negative cesium ions formed? Are they formed at the collector (anode) surface as proposed by Rasor[8], or in the volume as suspected from the results of this study? As previously noted, evidence from the observed "threshold" pressure for the appearance of Cs⁻ based on both the "cold" cathode and simulated converter conditions implies a volume creation process. Perhaps both volume and surface phase reactions contribute. Clearly further studies could easily resolve this point.

Other important questions remain unanswered concerning basic collision processes in cesium plasmas which are important to the

future development of cesium thermionic converters and also
find application in areas such as controlled thermonuclear
fusion. We believe that the basic physics and chemistry of
cesium plasmas is still relatively poorly understood; moreover,
this lack of understanding will continue to handicap substantial
progress in the area of thermionic energy conversion as it has
in previous years.

References

1. N. S. Rasor, Final Technical Report, Office of Naval Research, Contract No. N00014-69-C-0279 (1969).

2. N. S. Rasor, Advanced Thermionic Energy Conversion, Rasor Associates, Inc., Sunnyvale, California (1975).

3. J. D. Dunlop II, Proc. IEEE Thermionic Conv. Spec. Conf., Cleveland, Ohio (1964).

4. J. M. Houston, Proc. IEEE Thermionic Conv. Spec. Conf., Gatlinburg, Tennessee (1963).

5. R. Breitwieser, Proc. IEEE Thermionic Conv. Spec. Conf., Gatlinburg, Tennessee (1963).

6. N. S. Rasor and S. Kitrilakis, Proc. IEEE Thermionic Conv. Spec. Conf., Cleveland, Ohio (1964).

7. D. Ya. Dudko, Yu. P. Korchevoy, and V. N. Makarchuk, Proc. 12th International Conference on Phenomena in Ionized Gases, Eindhoven, The Netherlands, 1975.

8. N. S. Rasor, Practical Aspects of Fundamental Research in Thermionic Conversion, Final Technical Report, Office of Naval Research, Contract No. N00014-69-C-0279 (1969).

9. J. B. Taylor and I. Langmuir, Phys. Rev. $\underline{51}$, 753 (1937).

10. M. Rozwadowski and E. Lipworth, J. Chem. Phys. $\underline{43}$, 2347 (1965).

11. K. J. Nygaard, J. Chem. Phys. $\underline{49}$, 1995 (1968).

12. M. Kamin and L. M. Chanin, Appl. Phys. Letters $\underline{29}$, 756 (1976).

13. R. S. Bergman and L. M. Chanin, J. Appl. Phys. $\underline{42}$, 4208 (1971).

14. Peter H. Dawson (ed.), Quadrupole Mass Spectrometry (Elsevier Scientific Publishing Co., N.Y., 1976) pp. 125-127.

15. J. M. Houston and H. F. Webster, Advances in Electronics and Electron Physics, Academic Press $\underline{17}$, 125 (1962).

16. J. R. Hiskes, A. Karo, and M. Gardner, J. Appl. Phys. <u>47</u>, 3888 (1976).

17. H. S. W. Massey, <u>Negative Ions</u> (Cambridge University Press, Cambridge, Eng., 1950).

18. Earl W. McDaniel, <u>Collision Phenomena in Ionized Gases</u> (John Wiley & Sons, Inc., N.Y., 1964).

Papers Presented

"Cesium Thermionic Converter Ion Species"

D. E. Sutliff and L. M. Chanin, IEEE 1977

International Conference on Plasma Science, Troy, New York

"Negative Ion Species in Cesium Discharges"

D. E. Sutliff, D. G. Kuehn and L. M. Chanin

1978 IEEE International Conference on Plasma Science,

Monterey, California

Paper to be Published

"Negative and Positive Cesium Ion Species"

D. G. Kuehn, D. E. Sutliff and L. M. Chanin

(To be published Appl. Phys. Letters Dec. 1, 1978)