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RESEARCH ON PLASMA SHEATHS AND BOUNDARY

LAYERS AROUND STAGNATION POINT ELECTRODES

Semi-Annual Progress Report

(July 1, 1966 - December 31, 1967)

Grant NSG724

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1. Introduction

This report covers the work performed during the period July 1, 1966 - December 31, 1967 under the research grant NSG-724 entitled "Research on Plasma Sheaths and Boundary Layers Around Stagnation Point Electrodes" sponsored by the National Aeronautics and Space Administration. The technical monitor is Mr. Howard Stine of Ames Research Center.

2. Theoretical Program

Theoretical effort during the period described herein have progressed in three directions. Firstly, a detailed examination of the atomic processes responsible for cathode operation has been undertaken. While the study is not yet complete, the early results indicated that previous concepts of cathode operation may be incorrect, particularly w.r.t. the role of line radiation. They also permitted the formulation of a simple predictative theory capable of predicting qualitative and semi-quantitative cathode characteristics using a minimum of unwarranted assumptions. This theory formed a basis of an oral paper recently presented at the American Physical Society Meeting[1]. Since the theory is still being refined, a full report will not be presented at this time. The major arguments and conclusions, however, will be submitted concurrently as an informal report[1].

Some of the derivations of reference 1 are, unfortunately, heuristic. It is not presently possible to improve them due to the overwhelming theoretical difficulties involved. To supplement this, a separate study which

1. Chen, M. M., "A boundary layer theory of cathodes operation in a dense gas", American Physical Society Fluid Dynamics Divisional Meeting, Stanford, California, Nov. 1966. Also Informal Report, Grant NSG-724, March 15, 1967.

2. Wyner, E., "The role of ultra-violet radiation on cathode operation", Informal Report, Grant NSG-724, March 16, 1967.

is not intended to be predictative but is based as much as possible on a previously reported experimental observation was also undertaken. A report on this is being submitted concurrently.[2] In view of the fact that this study, as reference 1, was obliged to contend with some assumptions which could not easily be proved, and in view of some questionable conclusions of the experimental observations quoted, it is not surprising that there are some differences in the conclusions of these two studies. The differences dramatically point out the need for coordinated theoretical and experimental investigations.

The investigations on physical mechanisms made it possible to recast the stability theory of thermionic cathodes, which have been described in a previous report. The revised stability theory is currently being prepared as a special technical report, and is expected to be issued in the near future.

Since our investigations[1,2] pointed out conclusively that radiation is an important cathode process, an effort has been initiated to examine methods of treating the radiative transfer equation, particularly in the presence of radiating cathode wall and excitation non-equilibrium. This has led to the discovery of a novel technique capable to yielding both approximate and exact solutions of the radiative transfer equation. A special technical report[3] on this technique will be submitted concurrently with the present progress report.

3. Experimental Program

3A. Reconstruction of Mason Laboratory

During the summer of 1966, a major reconstruction of Mason Laboratory

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3. Chen, M. M., "Half-space Expansions for Non-Equilibrium Radiative Transfer Equation", March 15, 1967.

was initiated by the University in an effort to update the educational and research facilities of the building. The plan calls for the relocation of the cathode studies under the present program from first floor to a more spacious, enclosed laboratory in the second floor, where air conditioning and light-tight shades will be provided to facilitate spectroscopic studies. The completion of this new laboratory, originally scheduled for December, has now been postponed to February. It is realistically anticipated that by mid-March the investigations can be expected to resume in this new location.

While the plan of construction called for minimum interference with activities in progress at the old location, in reality the constant shaking of the air hammers, the ever present dust, and the frequent power interruptions make serious spectroscopic study impossible. As a consequence, it was decided to postpone such studies till the move to the second floor is accomplished. In the meantime, a new measurement concept involving time dependent measurements of the cathode current was tried out in the old laboratory. Due to the preliminary nature of the experiment, it was not seriously affected by the reconstruction. Preliminary results nevertheless appeared successful, as will be described below.

3B. Time Dependent Measurement

The most important unknown quantities on cathode operation are the fractions of the currents carried by ions, by field emission, secondary emission, and thermionic emission. It was suggested that some discrimination may be possible if one takes advantage of the different decay rates of these processes. This could best be explained by writing the current as

$$j = j_{+} + e \sum_i \gamma_i^* r_i^* + e \sum_{\nu i} \gamma_{\nu i} r \frac{I_{\nu i}}{h_{\nu i}} + \gamma_{+} j_{+} + e \Sigma \gamma_i^m r_i^m$$

$$+ AT^2 e^{-\frac{e\phi - cE^{1/2}}{kT}}$$

$$= [e \sum_i \gamma_i^* r_i^* + e \sum_i \gamma_{\nu i} \frac{I_{\nu i}}{h_{\nu i}}]$$

$$+[j_{+} + \gamma_{+} j_{+} + AT^2 (e^{\frac{-cE^{1/2}}{T}} -1) e^{\frac{-e\phi}{kT}} + e \sum_i \gamma_i^m r_i^m]$$

$$+ [AT^2 e^{\frac{-e\phi}{kT}}]$$

where γ^m Metastable State Auger Coefficients

γ^* excited state auger coefficients

$\gamma_{\nu i}$ photoemission coefficients

$\gamma +$ ion Auger coefficients

r metastable flux

c Schottky field correction coefficient = 4.4 $^oK\ cm^{1/2}\ v^{-1/2}$

γ^* excited atom flux

Note that

$$E \approx j_{+}^{1/2}$$

If one assumes that the particles are produced primarily by fast electron bombardments and that once produced, they diffuse to the wall faster than they can be destroyed by collisions, then as soon as the cathode voltage is removed, the particle flux will decay rapidly. The contribution of the first bracket, with a time constant of the order of $A \approx 10^{-8} - 10^{-7}$ sec, would decay first. The contribution of the second bracket would decay according to the diffusion time, of the order of $10^{-4} - 10^{-2}$ sec. Finally, if space charge can be prevented, the third bracket would decay according to the thermal time constant, of the order of $10^{0} - 10^{2}$ sec. Thus, there are at least two orders of magnitude difference between the decay time of the three brackets. Properly displayed on oscilloscopes, the relative contribution of the three groups should not be difficult to obtain, as shown in Figure 1.

A preliminary set of such data are shown in Figure 2. Unfortunately, there are no electronic switches capable of operating at such high speed with a large current and low voltage drop. Consequently, a mechanical switch was used for this set of data. This made it impossible to capture the earliest portion of the transient. The results were, therefore, not entirely conclusive.

To overcome this difficulty, a special switch was designed with a triggering contact to permit better synchronization of the oscilloscope. This switch is shown in Figure 3. Timing tests of this switch indicate that it was capable of synchronizing with a reproducibility of 5 μs, which was marginal for the purposes intended. It is planned to carry out a set of measurements with this switch in early April when the move to the new laboratory will have been completed.

Concurrently, a second switch is also being designed to eliminate or reduce the contact bounce which are present in all mechanical switches.

3C. Spectroscopic Studies

Due to the large number of data points required for each set of data, previous attempts of spectroscopic measurements have been significantly hampered by the lack of automatic recording and data reduction equipment. Consequently, it was decided to couple the voltmeter directly to an IBM card punch. A rented card punch has been delivered in December. A Hewlett-Packard coupler is on order and expected to be delivered in March. In view of the forthcoming operation of this system and in view of the laboratory reconstruction, it was decided to postpone all spectroscopic investigations until spring.

In recent years, the advantages of Fabry-Perot interferometers as high resolution, inexpensive spectroscopic tool has become well known. Due to its obvious usefulness in determining the neutral and ion temperatures via Doppler line broadening measurements, for which no other instrument is capable, serious consideration is being given to constructing such an instrument. The members of the lazer group at Yale have considerable experience in its use and operation, and they are expected to render valuable assistance in the evaluation and design of such an apparatus. While a design has not yet evolved, it has been estimated that the construction would cost about $1500.00.

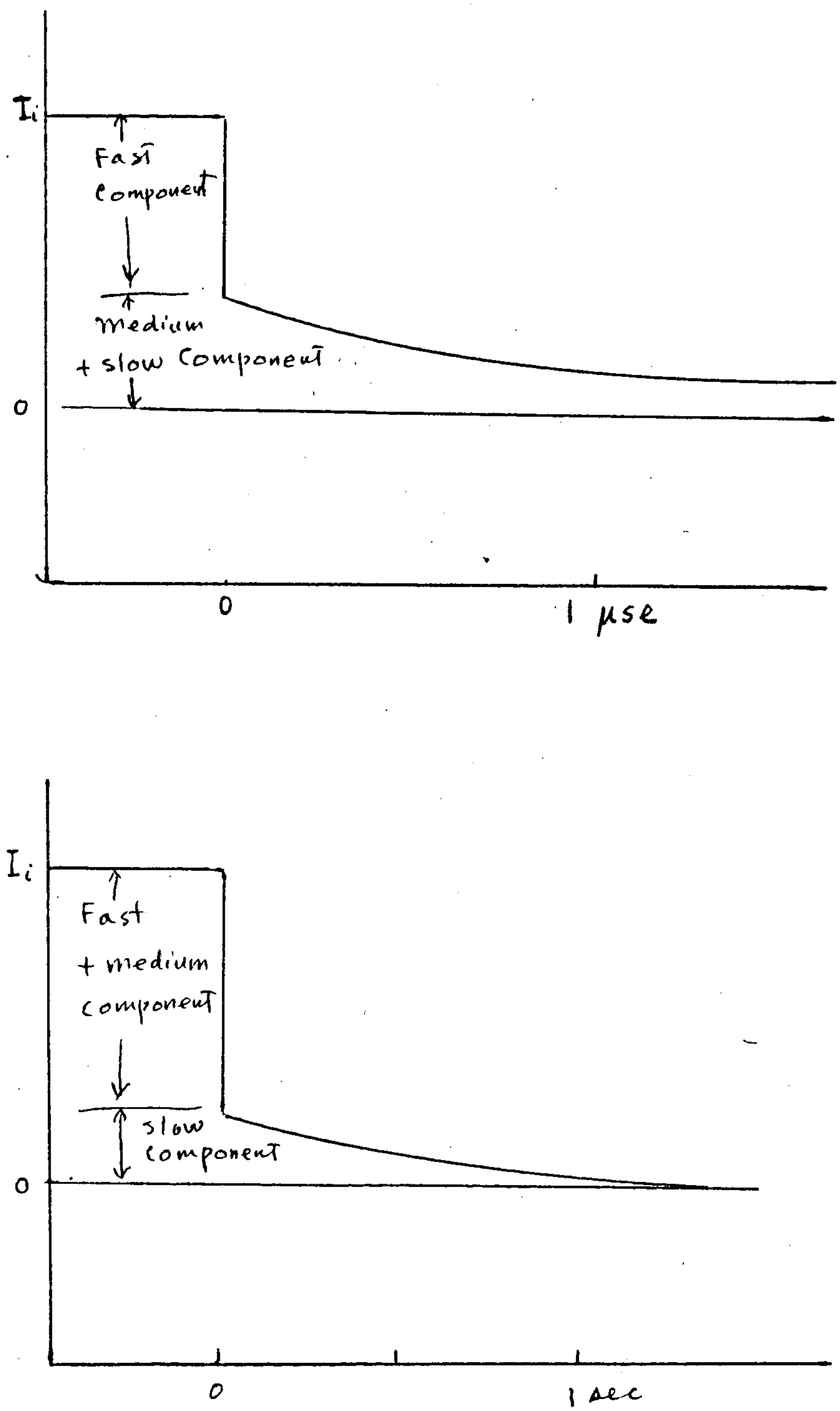


Fig. 1 Expected current decay curves for shorted cathode illustrating the technique of determining the three components of cathode current.

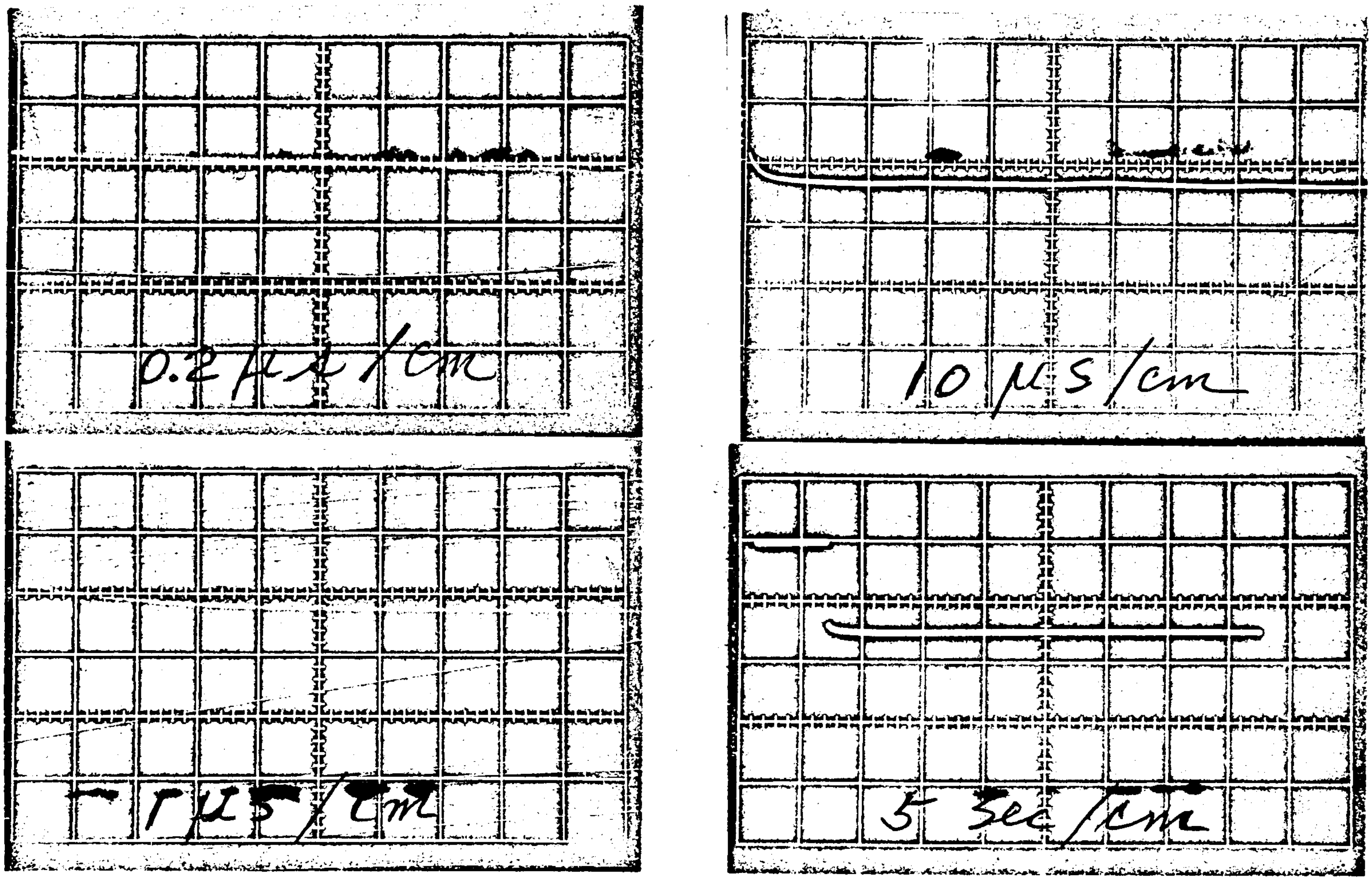
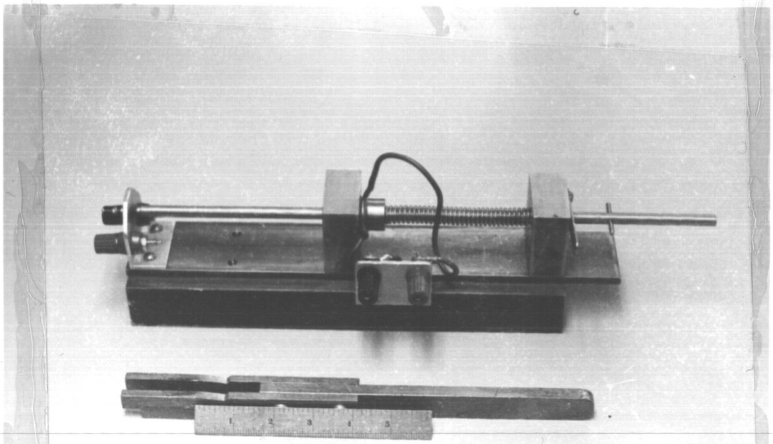


Fig. 2 Current decay records for test cathode with mechanical switch. I_i (initial current) = 16.5A $V_i \approx 30V$. All oscillograms with vertical scale 11.0 A/cm. This preliminary set of data indicated that the fast component of the current constituted about 50%, the medium component 30%, and the slow (thermionic) component about 20% of the total current.



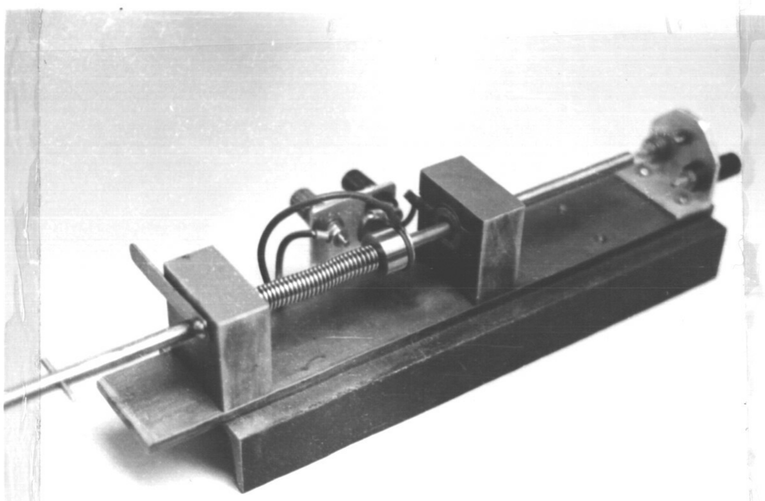


FIG. 3