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Abstract

A pulsed Cs^+ beam has been developed for use on a polarized H^- source. Cesium ion production is by surface ionization using a porous tungsten ionizer. While satisfactory current pulses (5-10 mA $\gtrsim$ 0.5 ms) can be obtained, the pulse shapes are a sensitive function of the ionizer temperature and Cs surface coverage. The beam optical requirements are stringent, and the optics has been studied experimentally for both Cs^+ and Cs° beams. Computer calculations are in good agreement with the observed results. The present source has delivered 2.6 mA of Cs^+ through the interaction region of the polarized ion source, and as much as 2.0 particle mA of Cs°. A new source is being built which is designed to give 15 mA through the interaction region.

1. Introduction

A polarized H^- source is being developed at Brookhaven National Laboratory for use on the Alternating Gradient Synchrotron (AGS) around the end of 1983. Various portions of the design and construction of

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this source have been done by ANAC, Inc., Argonne National Laboratory, and Yale University.[1] This source, based on the colliding beam method for H— production, is similar to one operating at the University of Wisconsin.[2] Polarized hydrogen atoms are produced in a ground state atomic beam source, and subsequently pick up an electron in the "interaction region" by charge exchange with a 40-60 keV Cs° beam moving in the opposite direction. The emerging polarized H— ions are accelerated to 20 keV and removed from the source by a 90° electrostatic deflector.

One wants as high a Cs° beam intensity as possible in the interaction region, since the final polarized H— intensity is proportional to this Cs° current. The neutral Cs beam has to travel 1 meter to the center of the interaction region, where the overlap with the H° beam occurs across a region ~ 30 cm long and 1.6 cm in diameter. In addition to these beam optical requirements, reliable operation of the Cs source for long periods must be a major consideration.

The Cs source was first operated on a test stand, to study the Cs^+ optics and the pulsed operation of the porous tungsten surface ionizer. Next, a Cs vapor neutralizer was placed after the Cs source, to compare the Cs^+ and Cs° beam optics. Finally, the source and neutralizer were mounted on the polarized source.

2. Cesium Source and Test Stand

Figure 1 shows schematically the source and test stand. Cs ions are produced on a 1.9 cm diameter, 0.2 cm thick porous tungsten surface ionizer.* The Cs boiler, located in vacuum, could be either heated, or cooled by air or freon circulation. In order to make use of an existing pulsed power supply, four electrodes had to be used for pulsed extraction. The tungsten ionizer and beam-forming electrode were typically held at +40 kV. The extraction electrode was biased at +47 kV to suppress Cs ion emission between pulses, and pulsed to ground for beam extraction. The third electrode was held at -3 kV to prevent backstreaming electrons, and the fourth electrode was grounded. After the source, there is a ball joint/bellows arrangement which allows mechanical steering of the beam, followed by a Cs vapor neutralizer.

The test stand was pumped by a 1500 ℓ/sec turbopump, and pressures were typically 2 to 5 x 10^{-6} Torr while the source was in operation. The Faraday cup and beam profile monitor were both moveable along the beam axis, and the Faraday cup could be retracted to take profile measurements. The electronics of the profile monitor allowed one to vary the time during the beam pulse at which the profile was measured. The grid in front of the profile monitor was normally biased negative to suppress secondary electron emission, although when comparisons between the Cs^+ and Cs° profiles were made, the grid was biased positive to extract secondary electrons.

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*Spectra-Mat, Inc.

3. Cesium Beam Optics

Figure 2 shows the electrode geometry of the Cs source. The tungsten emitter dimensions and the extraction gap were chosen to be the same as on the Cs source used at the University of Wisconsin.[3] Although our electrodes were originally designed at ANL for a different configuration, computer calculations[4] using the SLAC Electron Trajectory Program,[5] showed that the differences in shapes compared to the Wisconsin electrodes were not significant. However, because an extra electrode was required in our case, in order to suppress backstreaming electrons, the extra length of the extraction sytem results in some degradation of the beam optics.

Since the beam profiles were typically measured at 1 meter from the source, it was important that the Cs^+ beam have a high degree of space charge neutralization after the last electrode. The negatively biased third electrode, preventing backstreaming electrons, was essential in this respect. When this electrode was grounded, the beam became very divergent due to the loss of space charge neutralization, and even the space charge blowup along the ~ 10 cm between the source and the neutralizer was significant. Figure 3 demonstrates how the Cs^+ profile improved during the beam pulse, due to this buildup of space charge neutralization. This sequence was taken with a 1.6 mA, 18.5 keV beam pulse. The background pressure, with some Argon being added, was 2×10^{-5} Torr. One could observe the decrease in the neutralization time with increased background pressure.

A mechanical flapper allowed pulsed operation of the Cs vapor neutralizer. Therefore, by changing the timing of the neutralizer pulse relative to the beam pulse, one could get a comparison of the Cs^+ and Cs° optics. The primary difference observed was that the Cs° optics was quite good even at the beginning of the pulse, not requiring space charge neutralization.

At the exit of the Cs source, the beam emittance must fit within the acceptance shown in Figure 4 in order to travel through the interaction region. This acceptance includes the influence of several limiting apertures. In principle, the optics from a source of this type can be made very good, because one has a well defined emitting surface. The dots in the acceptance Figure 4 are r, θ values at the exit of the source calculated for a 5 mA beam and 33.5 kV extraction voltage. Bars were put on the dots in the figure to represent the ~ ±2 mrad angular spread coming from the thermal energy of the beam. One can see the importance of thermal effects by calculating the beam emittance due to the emitter size and ion temperature, only. For a circular aperture, the normalized rms emittance, containing 91% of the beam, is given by[6,7]

$$\varepsilon_{N,rms} = 2R \left(kT/Mc^2\right)^{1/2} \pi \text{ m-rad}$$

where R is the aperture radius. M is the ion mass, and T is the ion temperature all in mks units. Assuming the ion temperature to be the same as the emitter temperature, then at 1273°K one gets $\varepsilon_{N,rms} = 1.8 \times 10^{-8} \pi$ m-rad, or, for a 40 keV beam, $\varepsilon_{rms} = 7$ cm-mrad. This is appropximately 45% of the total acceptance area.

We have also observed from computer calculations the importance of having the tungsten emitter properly aligned with respect to the beam-forming electrode. Slight misalignments (~ 0.1 mm) have a large influence on the optics of the outer portion of the beam.

Profiles measured 1 meter from the source typically had a full width of ~ 2.5 cm, and full width at half maximum of ~ 1.6 cm. Based on the measured profiles, we expected to get 3 mA of Cs at 40 keV through the interaction region. To date, as much as 2.6 mA has been measured. The calculations predicted well the optimum operating voltage for a given Cs current. There was good agreement, after including thermal effects, between measured and calculated beam profiles.

In order to improve further the beam intensity, a new Cs source is being built with modified electrode shapes and gaps, and only three electrodes (see Figure 5). The second and third electrodes will be, respectively, at -5 kV and ground, while the emitter and beam-forming electrode are at ~ -6 kV (to suppress Cs ion emission between pulses) and will be pulsed to as much as +60 kV. Figure 6 shows the calculated optics for a 15 mA, 39 keV beam. With some adjustment of the voltage, the total beam should go through the interaction region. The extraction gap will be adjustable from outside vacuum to allow optimization of the optics with the source in operation. In addition, we will have the ability to heat electrodes to try and prevent Cs buildup. The second electrode material will be aluminum, in order to be able to evaporate partial monolayer coverages of Cs at a reasonable temperature. Erosion of this electrode due to sputtering should not be a problem since the beam is pulsed.

4. Pulsed Operation

Operation of the polarized source with a pulsed (~ 0.1% duty factor) Cs beam rather than dc has advantages in terms of reliability. A 10 mA dc beam is injecting Cs into the system at a rate of 50 mg/hr. In pulsed operation, problems associated with Cs coating of electrodes and insulators, sputtering of surfaces hit by the Cs beam, and loading on power supplies, are reduced throughout the polarized source. However, due to the sensitivity of the beam optics to the extracted current, one needs a pulse having a relatively flat portion of at least 0.5 ms. While this has been realized for currents of up to 14 mA (4.7 mA/cm^2), maintaining the proper conditions for long periods is often difficult.

Cs ion production by surface ionization has been extensively studied, and sources in which Cs vapor is fed through hot, porous tungsten are widely used. These give a stable output current in dc operation, and the extracted current is primarily controlled by adjusting the temperature of the Cs boiler to change the supply rate of Cs to the porous tungsten. For pulsed operation, a backbias must be applied to the second electrode to prevent ion emission between pulses. This causes the Cs coverage on the tungsten to increase between pulses, thus allowing operation at much lower Cs boiler temperatures than in the dc mode. This is illustrated by the fact that the Cs current drops by at least a factor of 50 when switching from pulsed to dc operation with the same Cs supply conditions.

Figure 7 shows ion and atom evaporation rates for Cs on solid tungsten, as a function of the Cs coverage. These were calculated from expressions given by Taylor and Langmuir,[8] and are for zero field. The extracted ion current density is determined by the ion evaporation rate. Since the Cs supply rate is low, the surface coverage decreases during beam extraction, which in turn changes the evaporation rate. To obtain the flattest pulse, the coverage at the start of the pulse must be somewhat more than that giving maximum ion evaporation (~ 1.5% of a monolayer); and then during extraction, the coverage should pass through this optimum value. When operating in this way, the extracted ion current is controlled not by adjusting the Cs boiler temperature, but by changing the temperature of the tungsten emitter. The pulse shape is determined by the starting coverage and the extracted current. To a first approximation, one has a fixed number of Cs atoms on the surface which can be extracted, and higher beam currents (higher emitter temperatures) result in narrower pulses. Figure 8 shows typical pulses at two different beam currents.

Extracted current densities are often three to four times the calculated peak ion evaporation rate at a given temperature. For example, one can extract 2 mA/cm^2 at an emitter temperature of 1173° K, while from Figure 7 one sees that the peak ion evaporation rate is only $\sim 3.4 \times 10^{15}$ cm^{-2} sec^{-1}, corresponding to a current density of 0.54 mA/cm^2. Since the evaporation rates are zero field values, there is an increase in the ion emission due to the Schottky effect.[9] To determine the upper limit of this effect under normal operating conditions, the Cs current, I, was measured as a function of extractor voltage, V, over a range of voltages where beam optics was not effecting the results. By extrapolating a plot of ln I vs. $\sqrt{V}$ to zero voltage, it was determined that operation at 40 kV increased ion emission by a factor of two over zero field values. While this increase could be caused by a combination of processes it is in agreement with what one would calculate by assuming that the Schottky temperature is equal to the emitter temperature. The remaining difference between the measured and calculated ion emission rates can be accounted for by assuming that the effective surface area of the porous tungsten for ion emission is greater than that of solid tungsten. This may be due to ion emission from the pores.[10] In general, with this assumption, one can then explain the observed pulse heights and shapes reasonably well from curves such as those in Figure 7. It should be mentioned that since the emitter temperature was never high enough to remove foreign gases, and operating pressures were > 10^{-6} Torr, surface contamination effects are most likely present.

Estimates of the Cs supply rate needed to maintain the proper coverage when pulsing at 1 Hz give values $\lesssim 0.1$ mg/hr. Thus, the boiler temperature must remain low. One can, in fact, observe changes in the operation of the source due to Cs coming from the neutralizer. Experiments are planned to determine whether that Cs alone could be enough for the source operation.

Acknowledgements

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Figure Captions

Figure 1 Schematic of the Cs source, neutralizer, and test stand (not to scale).

Figure 2 Electrode geometry used for the present studies, with all dimensions given in cm. Typical operating voltages are indicated.

Figure 3 Beam profiles (1 meter from source) taken at various times during the beam pulse. The background pressure was 2 x 10^{-5} Torr (argon added), and the beam was 1.6 mA, 18.5 keV.

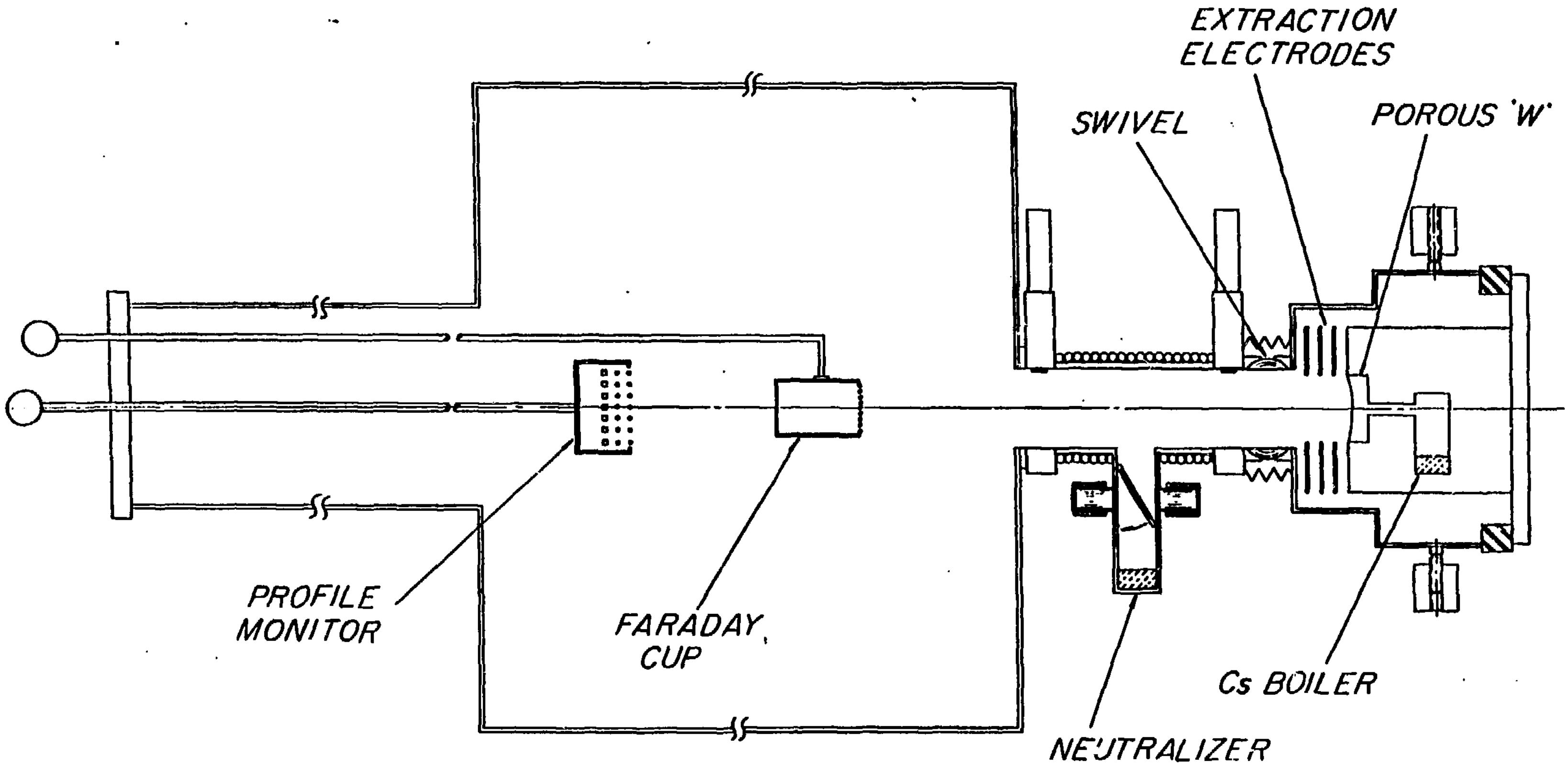
Figure 4 Cs beam acceptance of the polarized source. The dots are calculated r, θ values at the exit of the extractor for a 5 mA, 33.5 keV beam, with the electrode geometry as shown in Figure 2. Bars on the dots illustrate thermal effects.

Figure 5 Electrode geometry for an improved Cs source. All dimensions are in cm, and the voltage pulsing scheme is indicated.

Figure 6 Dots are the calculated r, θ values at the exit of the extractor shown in Figure 5, for a 15 mA, 39 keV beam. Also shown is the acceptance of the polarized source. The bars are shown to illustrate thermal effects.

Figure 7 Ion evaporation rates (ν_i) and atom evaporation rates (ν_a) shown as a function of the fractional coverage of Cs on tungsten, for two surface temperatures. These curves are calculated from expressions given by Taylor and Langmuir.[6]

Figure 8 Typical current pulses, taken at 38 keV, and with a 4 ms extractor voltage pulse. The 10 mA pulse was with an emitter temperature of 1223°K, and the 6 mA pulse was at 1173°K.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SWIVEL
POROUS 'W'
PROFILE MONITOR
FARADAY CUP
Cs BOILER
NEUTRALIZER

Figure 1

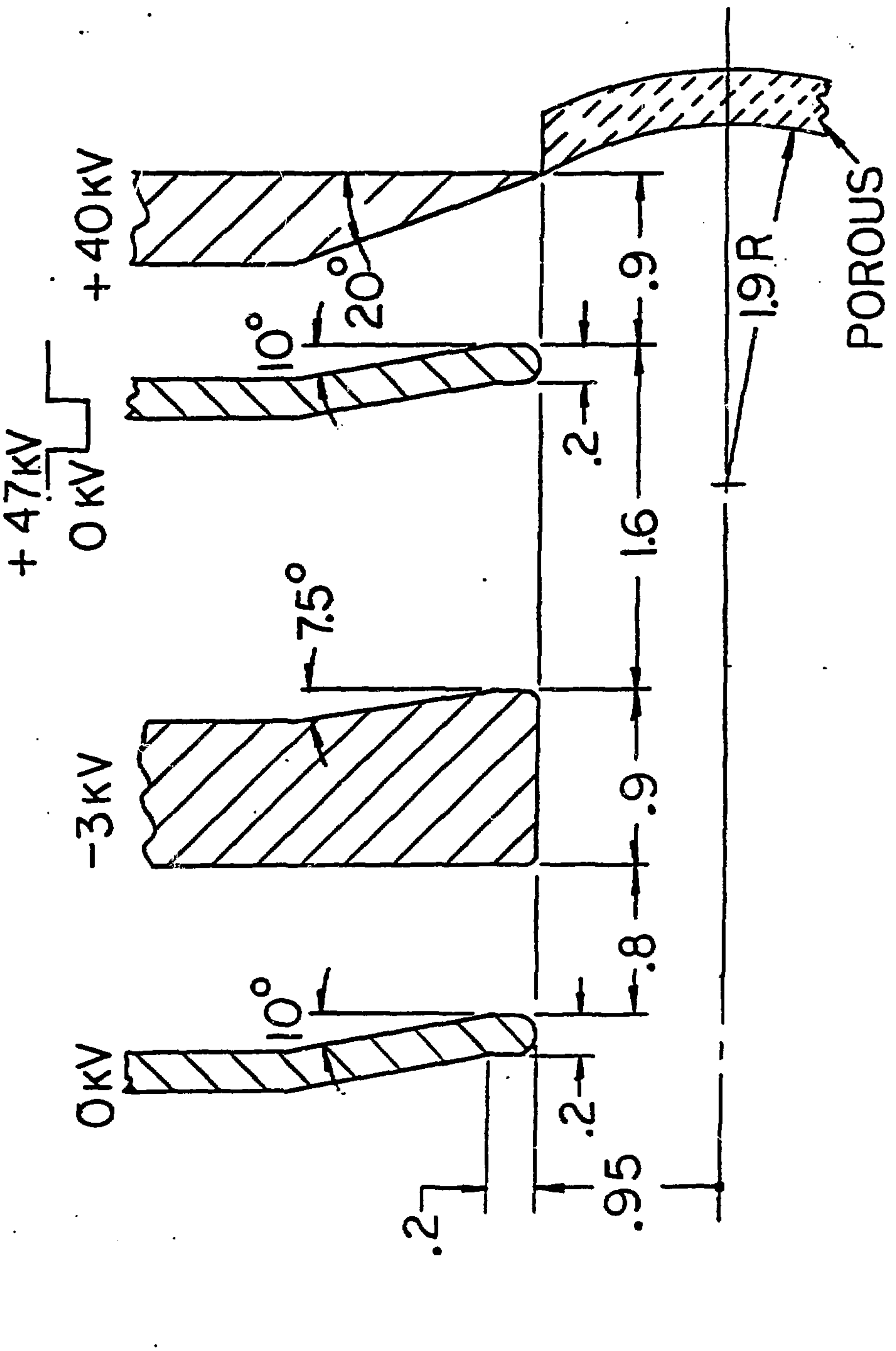


Figure 2

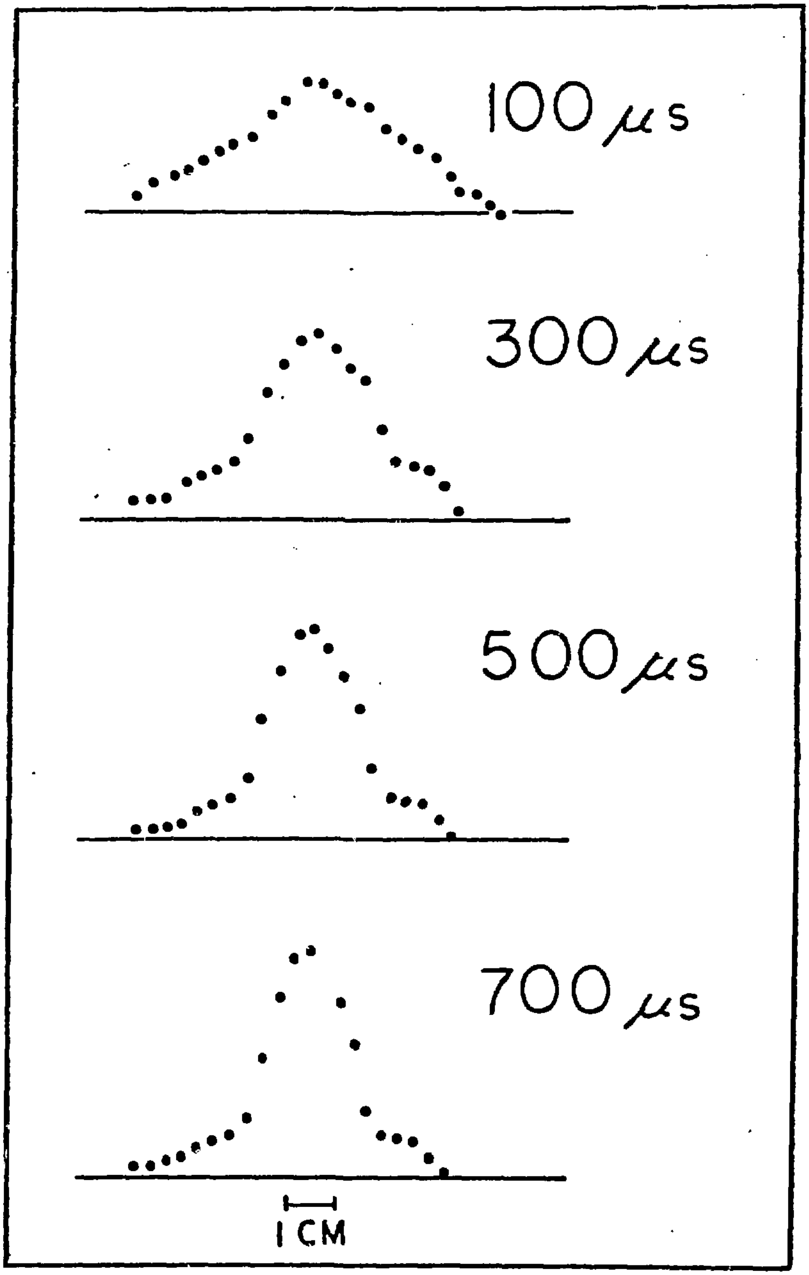


Figure 3

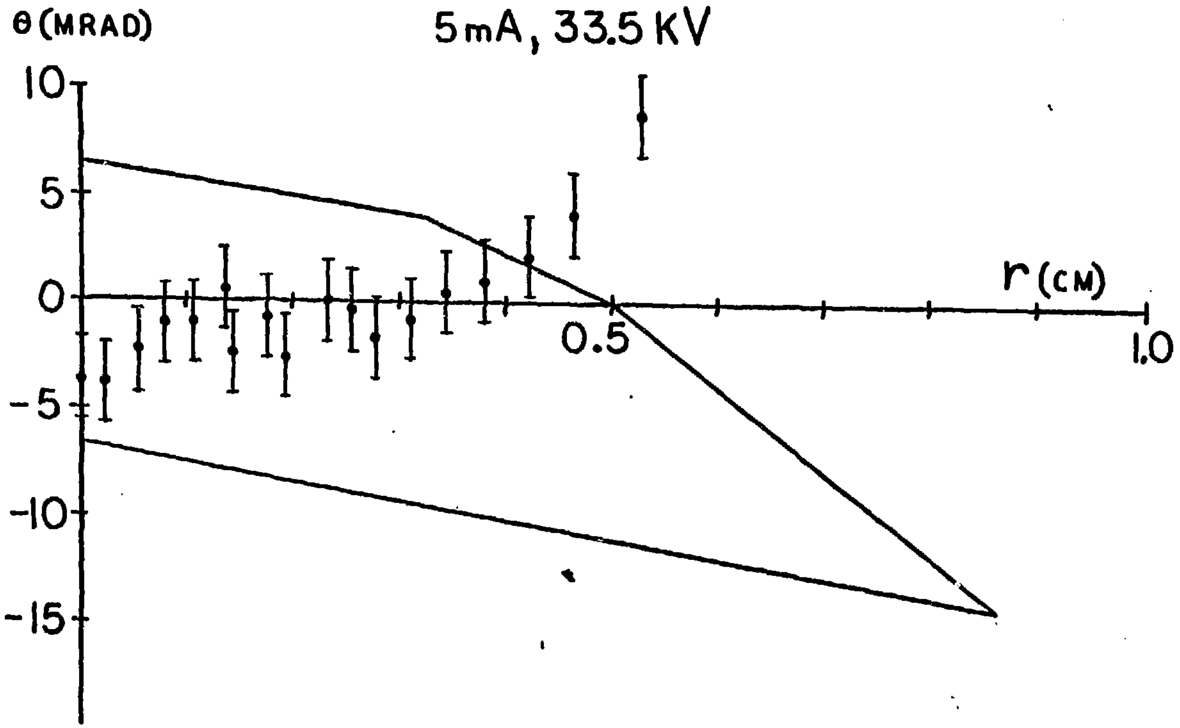


Figure 4

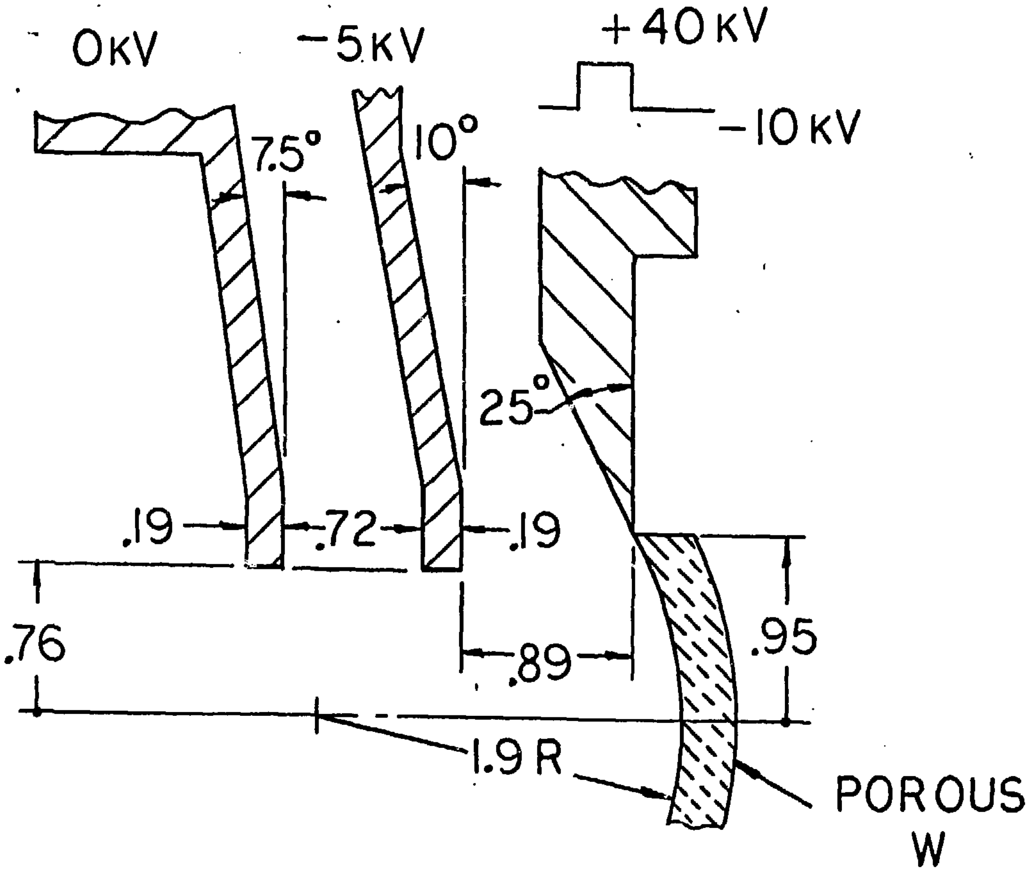


Figure 5

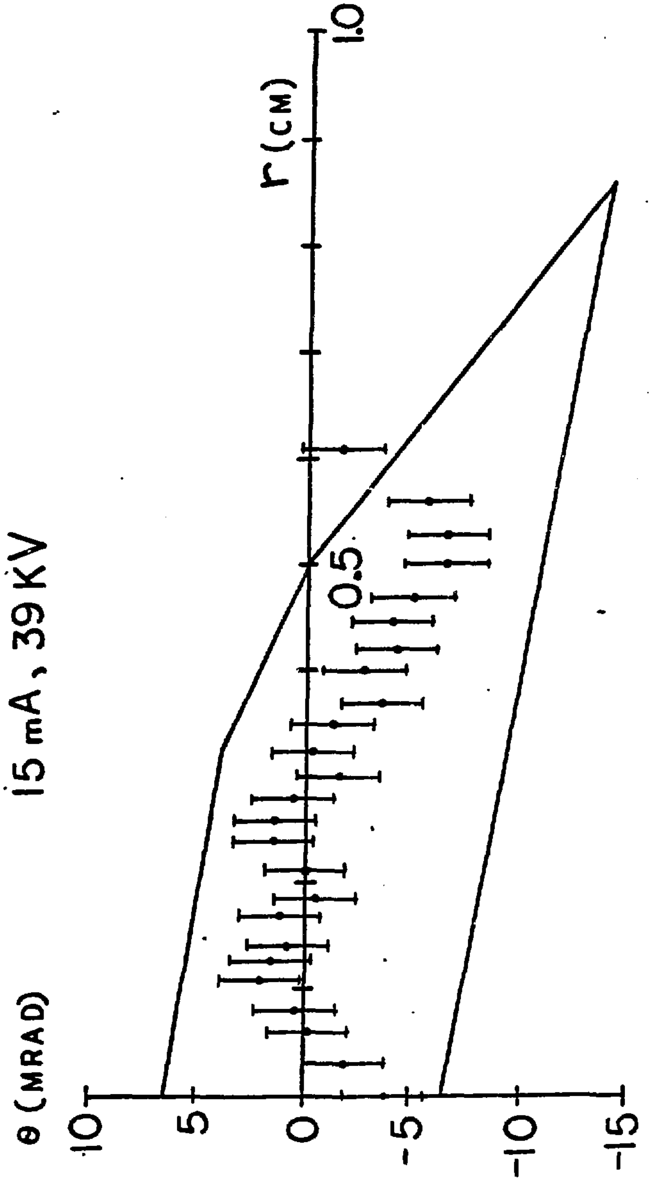


Figure 6

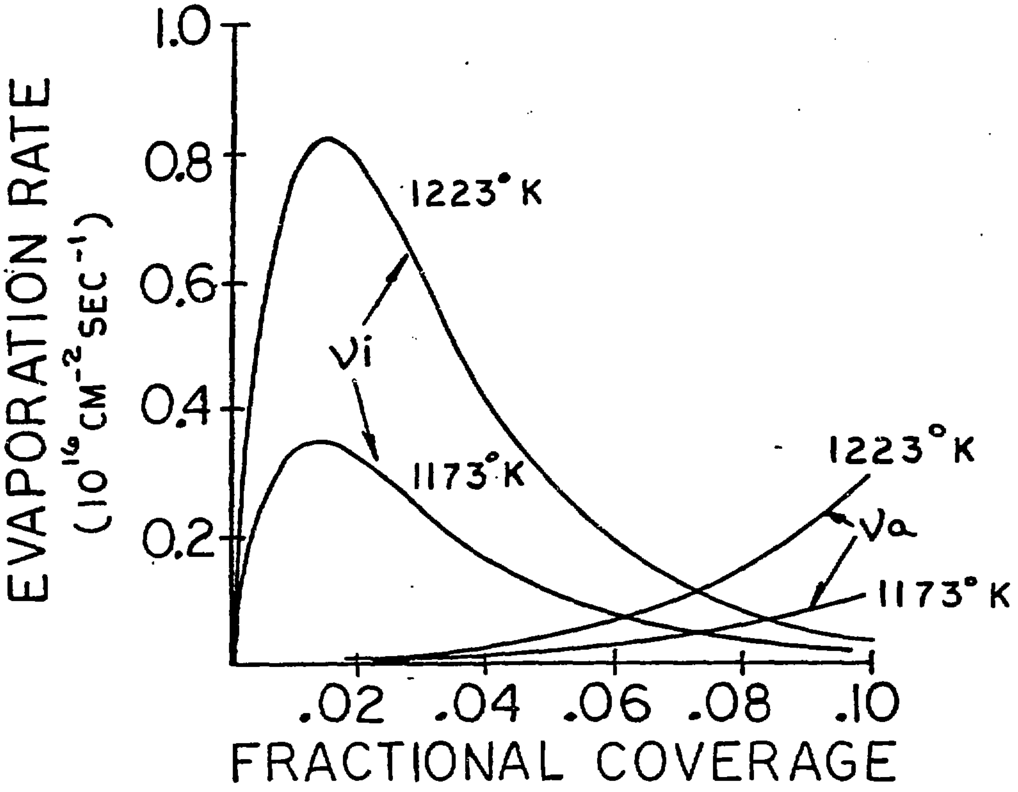
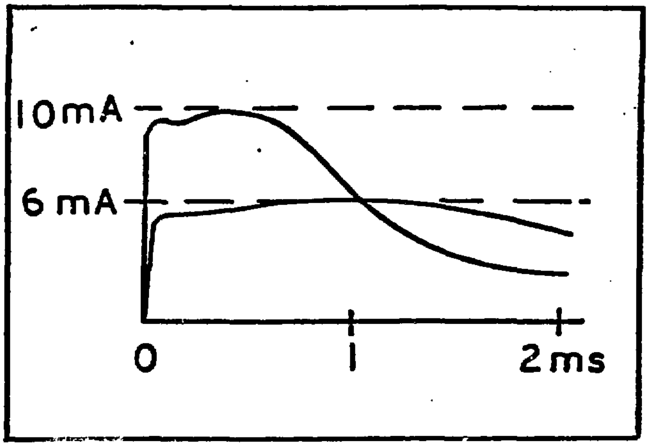

EVAPORATION RATE
(10^{16} CM^{-2} SEC^{-1})
1.0
0.8
0.6
0.4
0.2
.02
.04
.06
.08
.10
FRACTIONAL COVERAGE
1223° K
ν_i
1173° K
1223° K
ν_a
1173° K

Figure 7


10mA
6 mA
0
1
2ms