II. MICROWAVE GASEOUS DISCHARGES

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A. INTRODUCTION

The general aim of this research is to study the fundamentals of gas discharges by microwave techniques. All the research done by this group has been related to this general theme.

<div align="right">S. C. Brown</div>

B. HIGH-DENSITY MICROWAVE GASEOUS DISCHARGES

Initial experiments with high-density microwave gaseous discharges were performed with a quarter-wavelength re-entrant 100 Mc/sec cavity. It was pointed out in an earlier report (Quarterly Progress Report, July 15, 1953, pp. 10-11) that the higher the power in the discharge, the more difficult it was to match the cavity to the line, and the higher the standing-wave ratio became. The reason for this can readily be understood by reference to Fig. II-1. In the range of these experiments the impedance of the discharge decreases with increasing power (and electron density) and, in fact, becomes less than the characteristic impedance of the line. Under this condition a shorted quarter-wave line is not a satisfactory circuit for producing the discharge.

This problem can be solved either by changing the frequency sufficiently or by changing the dimensions of the cavity. The first method was found to be impracticable because it was not satisfactory to tune an oscillator over the wide range of frequency required. Thus, the second method was chosen and a special tunable cavity was designed. The details of this cavity are shown in Fig. II-2. It consists essentially of a re-entrant
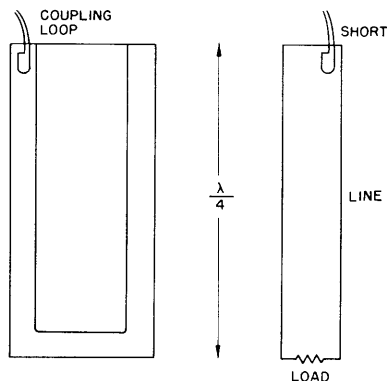

Fig. II-1

Fixed frequency quarter-wave re-entrant
cavity and equivalent circuit.

A ← → A
STANDARD 7/8" COAXIAL LINE

76.2 CM

SECTION A-A

SLIDING ANNULUS FITTED ON EITHER SIDE WITH COPPER BERYLLIUM FINGERS

114.5 CM

5.7 CM COUPLING LOOP

TUBE TO TAKE MOVABLE PROBE ASSEMBLY

OUTLET FOR PUMPING LEAD

106.9 CM

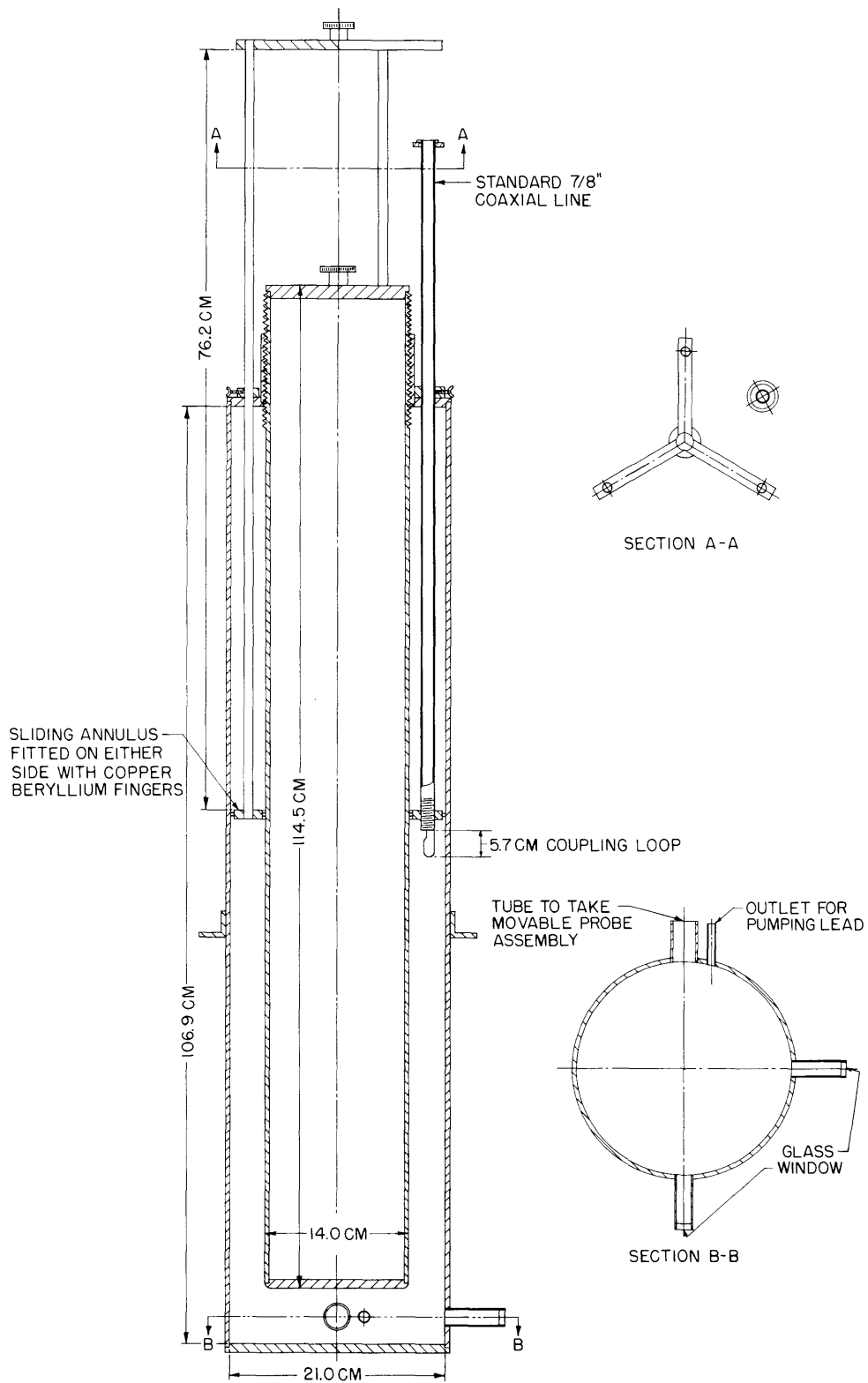14.0 CM

GLASS WINDOW

SECTION B-B

B ← → B

21.0 CM

Fig. II-2

Re-entrant cavity, tunable to resonate at frequencies between 70 Mc/sec and 170 Mc/sec. The cavity gap is adjustable from 1.25 cm to 7.6 cm.

cavity and a tuning stub, incorporated into a single unit. The range of the resonant frequency of the empty cavity is from 70 Mc/sec to 170 Mc/sec. It is possible to tune the cavity accurately to any frequency within this range. The Q varied a little with the position of the tuning plunger, but when set to resonate at 100 Mc/sec the Q was 2500. It was found that this cavity could be considerably better matched with a high-density discharge than the fixed-frequency cavity.

One important advantage of improved matching is that more power can be obtained in the discharge. Thus it was possible to obtain low-pressure discharges above plasma resonance in a large gap. A cylindrical quartz bottle 5 cm high was used. It was found that discharges like those shown in Fig. II-3 could be obtained. This was not expected from the existing theory. (See W. P. Allis, S. C. Brown, E. Everhart: Phys. Rev. 84, 519, 1951.) However, this theory is deduced for the case of infinite plane plates. In the present experiment the lateral dimensions are about the same as the separation. For this reason, the theory is not applicable and it is hoped to deduce a theory appropriate to this case. The dark region is probably due to the principal mode (E field perpendicular to the plates) being strongly attenuated since, in this case, the discharge is above phase resonance. The dark region did not occur at higher pressures when conditions were such that the discharge was above impedance resonance but below phase resonance.
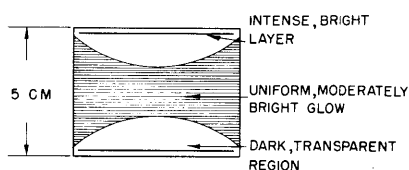

Fig. II-3

Typical high-power discharge in hydrogen at 1.5 mm pressure in tunable 100 Mc/sec cavity.

Certain experiments are also being performed with discharges in the 3 Mc/sec band. An LC circuit is used as the load of a power oscillator, the discharge being produced in the space between the capacitor plates. Under certain conditions an unexpected form of discharge has been observed. This discharge contains, near its center and parallel to the bright layers at the top and bottom of the discharge, two (and sometimes four, six, or even eight) bright layers or striations. A tentative theory is that these are caused by plasma ion oscillations. If this theory proves to be correct, the phenomenon will be of considerable interest, since Cousins and Ware observed such oscillations in their pinch-effect studies with toroidal discharges (S. W. Cousins, A. A. Ware: Proc. Phys. Soc. (London) 64, 164, 1951.

CORRECTION: In Fig. II-4, page 9, Quarterly Progress Report of October 15, 1953, the abscissa notation should read $n_o \lambda^2 cm^{-1}$.

K. S. W. Champion

C. PROBE STUDIES

The experiment in the microwave cavity shown in Fig. II-5 of the Quarterly Progress Report, October 15, 1953, was continued. The density distribution as a function of position in the cavity was measured by the positive ion saturation of the probe. A typical result is shown in Fig. II-4. For comparison, the machine solution obtained by Allis and Rose (W. P. Allis, D. J. Rose: The Transition from Free to Ambipolar Diffusion, to be published in The Physical Review) for the density distribution in a steady-state discharge in hydrogen is also shown in Fig. II-4. This solution was obtained for a parallel plate geometry, assuming that the frequency of ionization is independent of position and that the diffusion is close to ambipolar. At the ambipolar limit, the density distribution would be cosinusoidal. The machine solutions of Allis and Rose show that the diffusion in the steady-state microwave discharge, as used in the present experiment, is below the ambipolar limit.

In order to study the possibility of measuring charge densities by means of probes in the pressure range from 2 mm Hg up, the following equation was derived, assuming that the flow of positive ions is controlled by mobility:

$$i = \frac{2\pi\mu\epsilon_o \ell V_s^2}{\left(r_o^2 - r_s^2\right)^{1/2} - r_o \ln\left[\dfrac{r_o}{r_s} + \left(r_o^2 - r_s^2\right)^{1/2}/r_s\right]} \tag{1}$$

where i is the current to the probe, μ is the mobility of positive ions, ϵ_o is the permittivity, ℓ is the length of the probe, V_s is the probe-to-plasma potential, r_o is the sheath radius, and r_s is the probe radius.
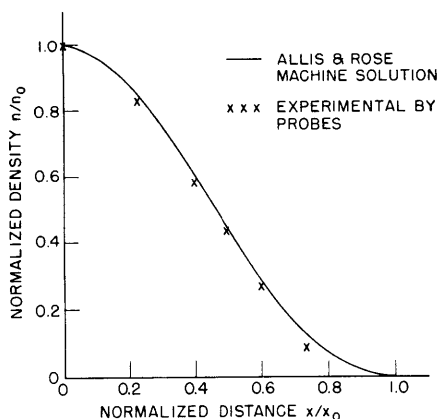

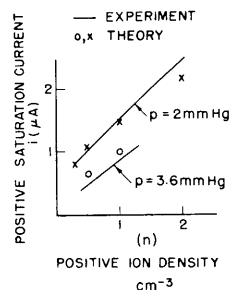Fig. II-4

Density as a function of position.

Fig. II-5

Ion current to probe
vs ion density.

It is assumed that at the sheath radius r_o the random current $[(nv)/4]$ is collected, so that the second equation is

$$i = 2\pi r_s \ell \frac{nv}{4} \frac{r_o}{r_s} \tag{2}$$

By solving Eq. 1 and Eq. 2 simultaneously we can obtain an expression for r_o/r_s. Substituting this into Eq. 2 gives the current. A plot of (i vs n) obtained by this theory is compared to the experimental result in Fig. II-5. The experimental value for positive ion density was obtained from the frequency shift of the microwave measuring signal by assuming that the positive ion density and the electron density are the same.

G. J. Schulz