II. MICROWAVE GASEOUS DISCHARGES

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A. BREAKDOWN IN HYDROGEN AT 100 MEGACYCLES

A new cavity was constructed to extend the experimental range of data for breakdown of hydrogen at 100 Mc and to test further the validity of the simpler theory for hydrogen. The cavity is a capacitance-loaded, quarter-wave transmission line, as was the earlier model, but of somewhat different relative dimensions and construction. This cavity is constructed of copper-plated brass and is water-cooled to prevent excessive temperature rise during operation. The whole cavity is vacuum-tight and more rigidly constructed than the earlier model. Figures II-1 and II-2 show the pertinent dimensions of both cavities.

The new cavity has a measured unloaded Q of 3500 and a calculated average electric field at the center of the cavity of 7000 volts/cm with an input power of 1000 watts. This electric field is about six times as great as that obtainable in the first cavity. However, the diffusion length Λ is about 0.7 cm, or approximately one-fifth that of the first cavity, so that theoretically we can cover the same range of parameters $E\Lambda$, and p/E as was possible in the first cavity. We are able to extend considerably the range of electric field and pressure used, and to compare two cavities of different size.

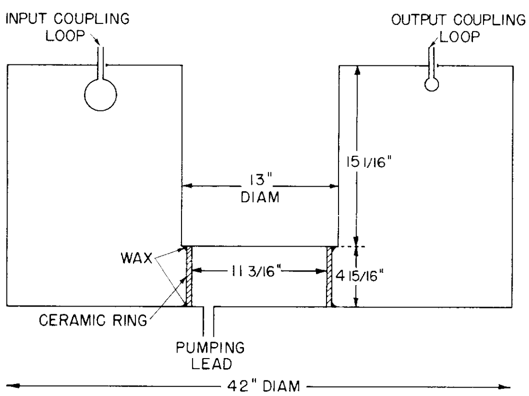

Fig. II-1 First 100-Mc resonant cavity.

The experiment was, however, not too successful. At low pressures the discharge was concentrated at the center of the cavity where the electric field is known. But at high pressures, the breakdown occurs at the outer edge of the axial reentrant post where the voltage gradient is higher than in the center because of the relatively sharp corner. In this pressure region a plot of average electric field and pressure is undoubtedly meaningless because the actual breakdown electric field is somewhat higher than the measured value.

The plot of data shown in Fig. II-3 shows that at low pressure there is relatively good agreement with theory and earlier experiments but at high pressures the breakdown electric field is much smaller than theory or previous experimental results. Further work was started to obtain a design of a reentrant post that would ensure breakdown taking place only at the center of the cavity.

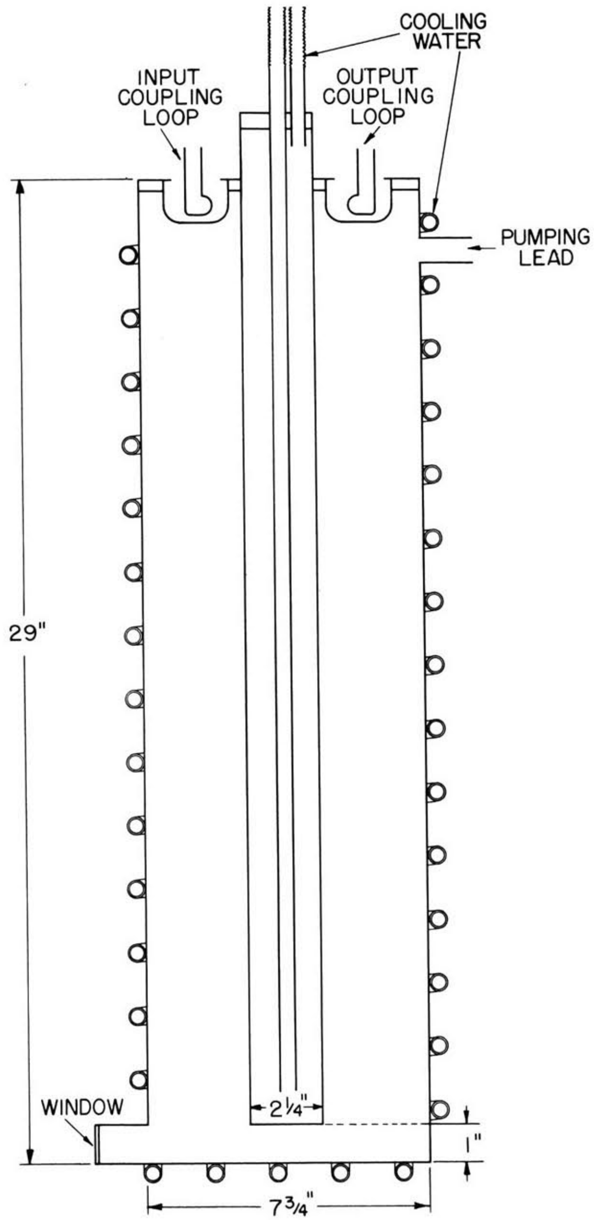

Fig. II-2 Second 100-Mc resonant cavity.

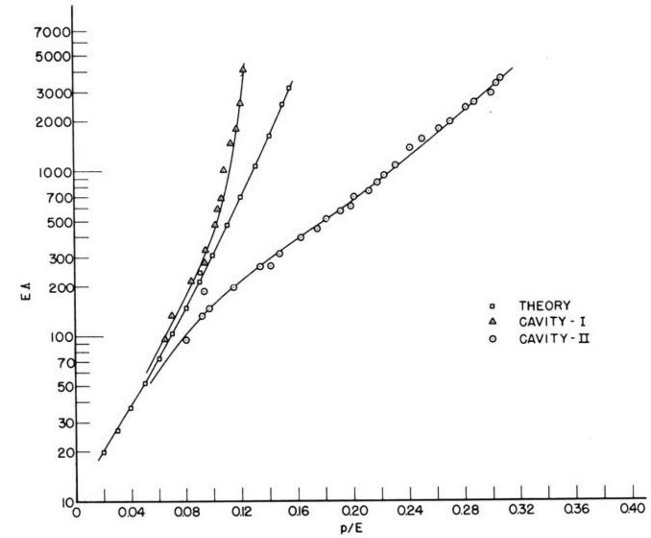

Fig. II-3 100-Mc breakdown data and theory.

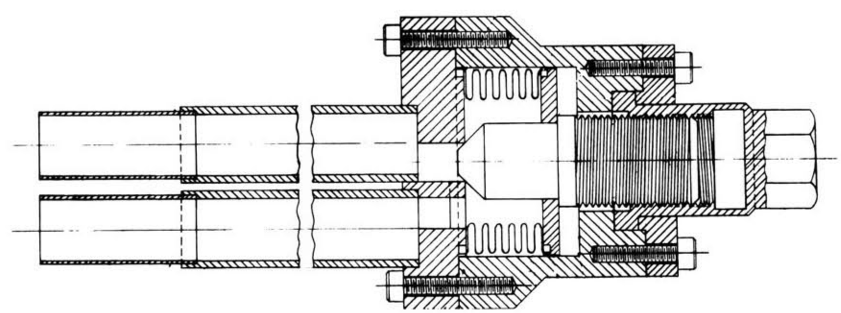

Fig. II-4 Vacuum valve.

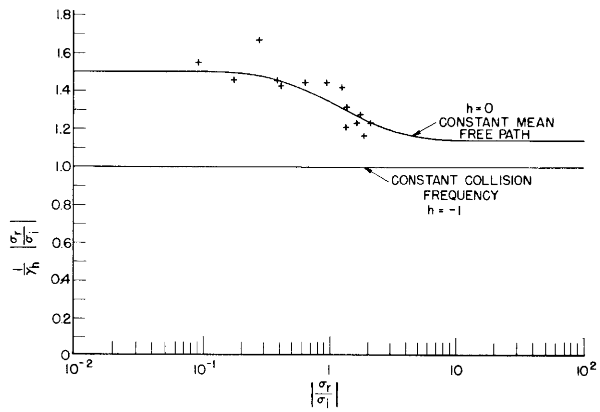

Fig. II-5 Curve for $\frac{1}{\gamma_h}|\sigma_r/\sigma_i|$ vs γ_h for ℓ = constant and ν_c = constant. Experimental points plotted for $\gamma_o/p = 113$ $\left[P_c = 18.7\ \text{cm}^{-1} \text{ at } 1\ \text{mm}\ (^\circ\text{C})\right]$.

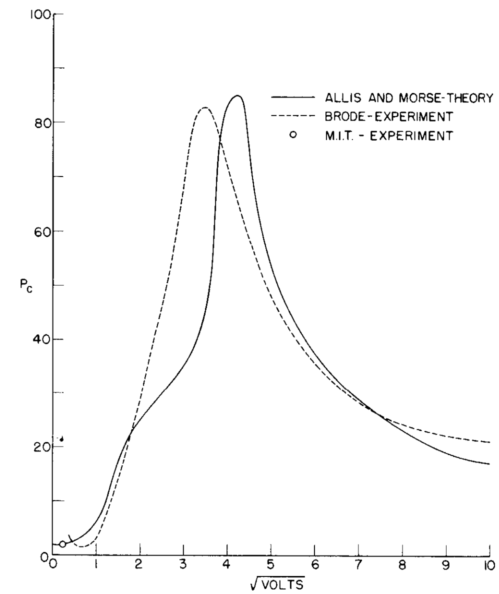

Fig. II-6 Collision probability for electrons in argon.

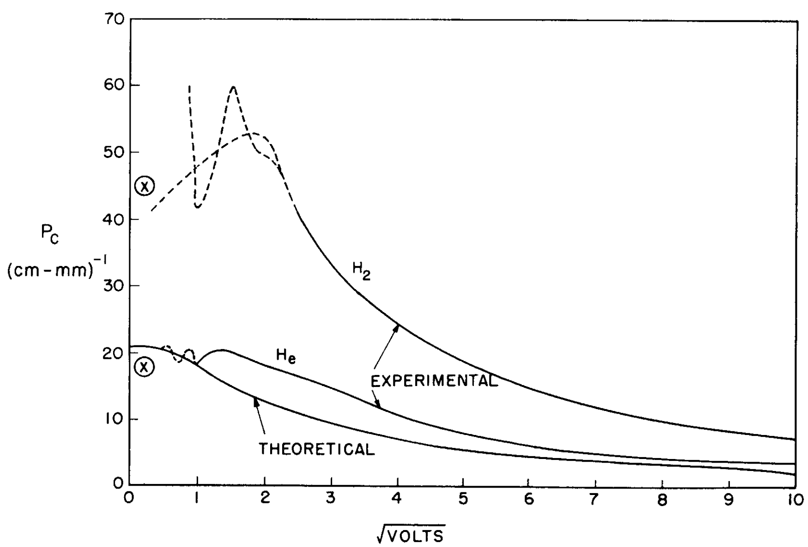

Fig. II-7 Collision probability for electrons in helium and hydrogen.

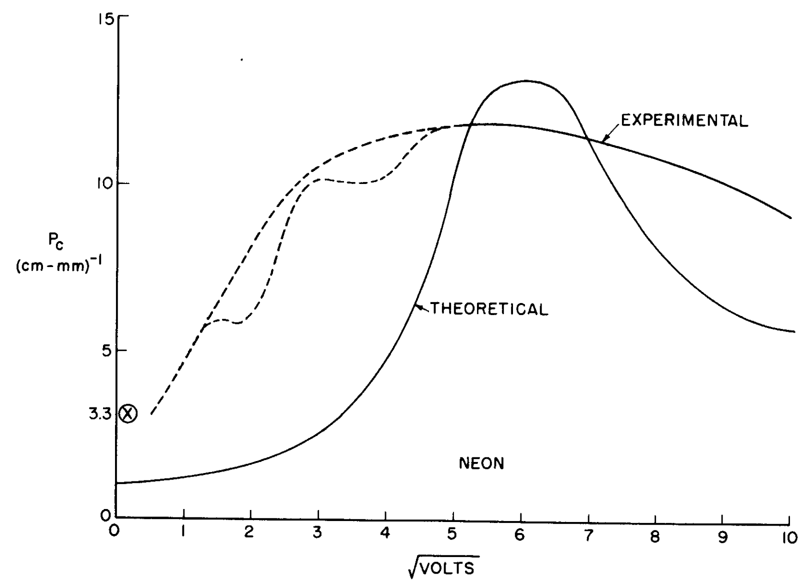

Fig. II-8 Collision probability for electrons in neon.

B. VACUUM VALVE

D. Alpert and R. T. Bayard (1) have reported a successful all-metal valve for vacuum systems. We have simplified their design and constructed a successful model which has been used on a vacuum system pumping to 10^{-9} mm Hg. The construction is illustrated in Fig. II-4. The body is made of OFHC copper, with a Monel metal bellows and a Kovar nose. The valve may be baked for outgassing at 400°C.

C. COLLISION PROBABILITY MEASUREMENTS

The values of the collision probability for electrons with gas atoms reported previously (2) were calculated from the measurements of the complex conductivity on the assumption that the mean free path for the electrons was independent of the electron energy. The quantum mechanical calculations by Allis and Morse (3) show that this assumption is reasonable for sufficiently low electron energies. The present work applies Margenau's theory for the conductivity of electrons in thermal equilibrium with a gas (4) to the determination of the effective value of the exponent h in the approximation to the collision probability, $P_c = av^h$. In this equation a is a constant and v is the electron velocity.

Theory shows that the ratio σ_r/σ_i is a function of the parameters

$$\gamma_h = \frac{ap}{\omega}\left[(2kT/m)^{(h+1)/2}\right]$$

and h; where p is the pressure normalized to 0°C, ω is the applied radian frequency, k is the Boltzmann constant, m is the electron mass and T is the absolute gas temperature. One method for determining h is to vary p at constant ω and T and compare the measured values of $\frac{1}{p}|\sigma_r/\sigma_i|$ with the theoretical values of $\frac{1}{\gamma_h}|\sigma_r/\sigma_i|$. Figure II-5 shows that the measured values for electrons in helium at 300°K can be made to fit the theoretical curve for h = 0 to within the experimental error by a choice of the scale factor

$$\frac{\gamma_o}{p} = \frac{a}{\omega}\left(\frac{2kT}{m}\right)^{1/2} .$$

The data cannot be made to fit the h = -1 curve. The theoretical curve for h = + 1 has not been calculated for σ_r/σ_i near unity but should be much steeper than the curve for h = 0, since as

$$(\sigma_r/\sigma_i) \to 0, \ \frac{1}{\gamma_1}(\sigma_r/\sigma_i) \to 2.5$$

and as

$$(\sigma_r/\sigma_i) \to \infty, \ \frac{1}{\gamma_1}(\sigma_r/\sigma_i) \to 0.5 .$$

A second method for determining h is to vary the temperature T of the gas. Thus a change in the temperature of argon from 300°K to 545°K caused σ_r/σ_i to decrease by a factor of 1.3 at constant pressure. Since σ_r/σ_i is nearly a linear function of γ for h = 0 and $\gamma_o < 0.3$, it is possible to check for consistency with the assumption of h = 0 by noting that for h = 0, σ_r/σ_i varies as $(T^{0+1/2})/T$ and so decreases by 1.35 in this case. The 1/T factor is required to correct for the change in gas density with temperature at constant pressure and the $T^{1/2}$ to take into account the change in the electron temperature.

Further evidence that h > -1 in helium, neon and argon was obtained by noting that when the strength of the r-f field was increased to values appreciably greater than those used for the measurements discussed above, the value of σ_r/σ_i began to increase. Since small increases in the electron energy as a result of the applied field are equivalent to an increase of the electron temperature at constant gas temperature, this observation shows that $\frac{h+1}{2} > 0$ or h > -1. Quantitative measurements of the change in conductivity with the applied r-f field will be made in the course of future work.

The preliminary value of P_c for argon is $P_c = 1.7\ \text{cm}^{-1}$ at 1 mm pressure normalized to 0°C and is in excellent agreement with the theoretical calculation of Allis and Morse (3) as shown in Fig. II-6. Figures II-7 and II-8 show the experimental and theoretical values for P_c for hydrogen, helium and neon. The values of P_c determined from conductivity measurements (2) are seen to agree well with extrapolation of previous experiments and in the case of helium, the value agrees with theory (3).

References

1. D. Alpert, R. T. Bayard: Tenth Annual Conference on Physical Electronics, M.I.T., April 1, 1950.
2. Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., October 15, 1950.
3. W. P. Allis, P. M. Morse: Zeit. f. Phys. 70, 567 (1931).
4. H. Margenau: Phys. Rev. 64, 508 (1946). The results of this theory are reformulated in a convenient form in the Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., July 15, 1950.