

## II. MICROWAVE GASEOUS DISCHARGES

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### A. 100-MEGACYCLE BREAKDOWN

A large reentrant cavity, resonant at 100 Mc, has been constructed to extend the measurements of high-frequency gas-discharge breakdown in hydrogen and to check the theory in the region of high electric fields. This particular frequency was chosen as a compromise between the ease of obtaining high r-f power and the physical limitation of the size of the cavity involved.

From the equation (1)

$$E^2 = \frac{d\lambda}{dv} \frac{Q_U P}{\pi} \sqrt{\frac{\mu_0}{\epsilon_0}}$$

we find that the electric field at the center of the cavity can be found if we know the tuning rate,  $d\lambda/dv$ , the unloaded  $Q$ ,  $Q_U$ , and the power absorbed,  $P$ . The method of obtaining  $d\lambda/dv$  has been described in a previous report (1) and the value was checked by assuming the cavity to be a capacitance-loaded resonant transmission line and calculating  $d\lambda/dv$  directly. The power absorbed by the cavity was measured by a Micromatch Model M252 wattmeter, capable of measuring both incident and reflected power and, indirectly, the absorbed power. By means of this wattmeter the cavity was matched at resonance by adjusting the coupling to the cavity for practically zero reflected power. The unloaded  $Q$  of the cavity can be found if the susceptance  $B$  of the cavity is known at a frequency slightly off resonance as well as the conductance  $G$  of the cavity, known from the condition of match at resonance. A measurement of the power incident on and reflected from the cavity slightly off resonance suffices to determine a circle of constant reflection coefficient on an admittance chart from which  $B$  can be determined. The unloaded  $Q$  will then be given by the expression

$$Q_U = \frac{B f_0}{2G \Delta f}$$

where  $f_0$  is the resonant frequency and  $\Delta f$  the small change in frequency made to measure  $B$ .

From a knowledge of the tuning rate and the unloaded  $Q$ , which are properties of the cavity, and the power required to initiate breakdown, the electric field for breakdown was calculated and compared to existing data

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obtained at microwave frequencies and by Thompson (2) and Githens (3) at lower frequencies. This comparison is shown in Fig. II-1. It is possible to obtain a wide range of values for  $E\lambda$  in this experiment and these values will be extended further in the near future. It is also intended to measure breakdown in helium contaminated with a little mercury vapor for which a simple theory may be used.

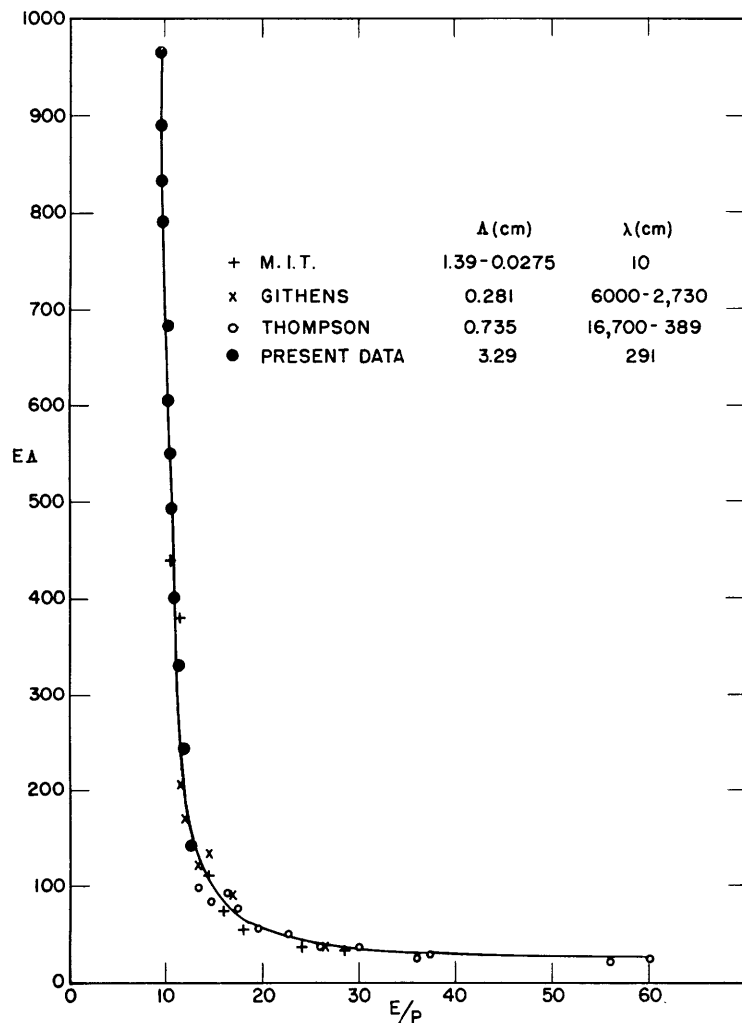


Fig. II-1 Effective breakdown voltages as a function of  $E/p$  calculated from breakdown measurements of numerous workers.

### References

- (1) S. C. Brown, M. A. Biondi, M. A. Herlin, E. Everhart, D. E. Kerr, R.L.E. Technical Report No. 66, M.I.T. (1948).
- (2) J. Thompson, *Phil. Mag.* 23, 1 (1937).
- (3) S. Githens, *Phys. Rev.* 57, 822 (1940).

## B. MEASUREMENT OF THE PROPERTIES OF LOW-DENSITY MICROWAVE GAS DISCHARGES

A cavity method has been developed for measuring the properties of low-density discharges. The method is applicable as long as the absolute magnitude of the electron current density is much less than the displacement current density.

Analysis shows (4) (5) that, in the region of the cavity resonance involved, one may replace the cavity and discharge by a lumped constant circuit. Such a circuit for a cavity with single output is shown in Fig. II-2, where  $g_s$  is the series conductance of the line, loops, etc;

$$j\beta\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$$

is the susceptance of the empty cavity;  $\omega$  is the radian frequency;  $\omega_0$  is the cavity resonant frequency;  $g$  is the conductance due to all internal losses except the discharge;  $g_d + jb_d$  is the discharge admittance. The discharge admittance can be expressed as

$$g_d + jb_d = \frac{\beta}{\epsilon_0 \omega_0} \frac{\int \sigma E^2 dv}{\int E^2 dv}$$

where  $\sigma$  is the complex conductivity of the discharge.

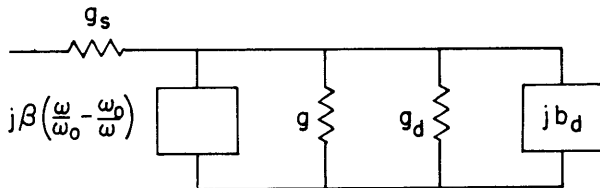


Fig. II-2 Equivalent circuit of cavity with discharge.

Since all the parameters of the circuit except the discharge admittance can be determined (5) from measurement on the empty cavity, two measurements on the loaded cavity will suffice to determine  $g_d$  and  $b_d$ . These might be the db standing-wave ratio  $R$  at the empty resonant frequency  $\omega_0$ ,  $R$  at  $\omega \neq \omega_0$ , or  $\frac{dR}{d\omega}$  at  $\omega_0$ . The discharge admittance is then found by straightforward analysis. These three methods are useful if the loaded resonant frequency  $\omega'_0$  is so far removed that the oscillator cannot reach it, but the accuracy of the measurements is not great. If possible, the new resonant frequency  $\omega'_0$  and the db standing-wave ratio  $R'_0$  at  $\omega'_0$  should be measured. The former determines  $b_d$  directly, for the shift of the resonance is given by  $\omega'_0 - \omega_0 = -b_d \omega_0 / \beta$ ; the latter measurement determines  $g_d$ .

Most accurate results are obtained by plotting a resonance curve for the loaded cavity. If this is done the maintaining field can be calculated at once. In addition, various checks can be made, such as the constancy of  $\beta$ .

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For any of the measurements it is necessary that frequency excursions be made at constant electron density. A simple method of monitoring the density consists of measuring the light intensity of the discharge. As the frequency is varied over the range of interest, the input power is adjusted so that the intensity is kept constant. Since the spatial and velocity distributions of the electrons do not change appreciably over the small range of frequency, the method is quite reliable.

If power measurements on the loaded cavity are made at frequencies other than the loaded resonant frequency, the power absorbed must be corrected to that absorbed at resonance, in order to use standard formulas involving the  $Q_U$  of the cavity. At constant electron density

$$P = P_0 \left[ 1 + \frac{\beta \left( \frac{\omega}{\omega_0'} - \frac{\omega_0'}{\omega} \right)^2}{g' g_s \left( 1 + \frac{g'}{g_s} \right)} \right]$$

where  $P$  is the power absorbed at  $\omega$ ,  $P_0$  is the power absorbed at  $\omega_0'$ , and  $g' = g + g_d$ .

If the maintaining field is independent of density, the discharge is stable in the cavity only as long as  $dP_d/d\bar{n} (\bar{n}/P_d) < 1$ , where  $P_d$  is the power absorbed in the discharge, and  $\bar{n}$  is the average density. If the series loss is neglected, analysis shows that the discharge is stable if

$$A(1 + g + A\beta\bar{n}) + B\beta \left( \frac{\omega}{\omega_0'} - \frac{\omega_0'}{\omega} \right) > 0$$

where  $g_d = A\beta\bar{n}$ ,  $b_d = B\beta\bar{n}$ . The constants  $A$  and  $B$  are functions of the field and electronic modes, and are independent of the cavity size and electron density. Since  $A > 0$ ,  $B < 0$ , it may be seen that the discharge is always stable for  $\omega = \omega_0'$ . The frequency of extinction above  $\omega_0'$  can be estimated by noting that  $\beta(\omega/\omega_0' - \omega_0'/\omega) = g + A\beta\bar{n}$  at the half-power points of the loaded resonance curve.

The cavity will tend to undercouple with increasing discharge power. The db standing-wave ratio decreases from  $R_0$ , its value at the empty resonance, to  $R'_0$ , the value at the loaded resonance. It can be shown that

$$R_0 - R'_0 = 20 \log (1 + A\bar{n}Q_U)$$

where  $Q_U$  is the unloaded  $Q$  of the empty cavity.

These techniques are being applied to the study of maintaining electric fields of microwave gas discharges. Preliminary measurements of gas

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discharges in hydrogen at densities of the order of  $10^8$  electrons/cc indicate that the method is practicable.

References

- (4) J. C. Slater, Rev. Mod. Phys. 18, 441 (1946).
- (5) D. J. Rose, D. E. Kerr, M. A. Biondi, E. Everhart, S. C. Brown, R.L.E. Technical Report No. 140, M.I.T. (1949).

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