II. MICROWAVE GASEOUS DISCHARGES

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A. ELECTRON COLLISION CROSS SECTIONS

Measurements on the determination of collision cross sections (1) have been continued. Preliminary data were obtained in mercury. The results were unsatisfactory because of scattering of data at low values of the measuring field. However, there was an indication that the electrons did not reach thermal equilibrium with the mercury atoms. It is believed that the presence of the mercury metastable in the afterglow produces collisions of the second kind with the electrons, thus raising the average electron energy above thermal energy. Plans are being made to study the effect of the metastables by photometric techniques.

An attempt was made to measure the collision cross section in sodium vapor. Inasmuch as the data must be taken at a temperature of 450 °C, considerable investigation was performed to obtain a glass container that would not react with sodium at these temperatures. The effect of the reaction is a change in the dielectric constant of glass which is undesirable during the progress of the measurements. Glass bottles coated with a glaze similar to that used in sodium vapor lamps were unsuccessful at the operating temperatures. The use of a glass bottle was abandoned and a steel microwave cavity is being constructed. It will be nickel-plated and have ceramic seals, eliminating the necessity for glass in the cavity. It is believed that both the nickel and ceramic will be unaffected by the hot sodium vapor.

After small changes were made in improving the microwave detecting system, measurements were retaken in helium. The results differed by about 25 percent from the previous data. This discrepancy was due to the improvement in the measuring technique; hence, in order to further improve the accuracy of the data and remove the defects which handicapped the previous measurements, the following changes are being made. The breakdown pulse is being isolated from the measuring system by utilizing a rectangular cavity excited in two different modes. This will permit greater breakdown field strengths and eliminate any perturbation of the measuring system by the breakdown power. S-band waveguide and a precision waveguide attenuator are being used to increase the accuracy of impedance measurements. A waveguide balanced mixer is being constructed to increase the sensitivity of the microwave receiver. Preliminary measurements show that minimum signal powers of about 0.1 μw can be measured, an improvement of 10 db over the previous receiver system.

B. BREAKDOWN IN PURE HELIUM

These are the results of 12 breakdown runs with microwave cavities of different sizes:

1. Measurements in cavities of lengths $L_1 = 1/16$ inch, $L_2 = 1/8$ inch, and $L_3 = 1/4$ inch yield a universal curve $E_e\Lambda$ as a function of E_e/p in the range $8 \leqslant E_e/p \leqslant 70$, if we use the simple breakdown condition $\overline{D} = \Lambda^2\overline{\nu_i}$. This condition assumes diffusion as the only loss mechanism for the electrons.

2. Outside of the range $8 \leqslant E_e/p \leqslant 70$ the results are hardly reproducible (Fig. II-1) and it seems necessary to take into account other processes such as secondary ones at the walls.

   a. $E_e/p > 70$: New cavities, especially cavities of very small L values (1/16 inch) show the tendency to yield, at first, very low $E_e\Lambda$ values for $E_e/p > 20$. They give higher values after every new baking until a stable curve is reached which agrees for $8 < E_e/p < 70$ with the curve from other cavities. However, at $E_e/p \approx 70$ it begins to run below the universal curve. This last behavior may be explained by the fact that at $E_e/p = 70$ the mean free path becomes comparable with L; the diffusion theory can therefore no longer be valid. The irreproducible behavior of new cavities of extremely small L values is probably due to secondary processes at the walls, since the volume becomes larger as L gets smaller and wall processes become more important. Changes in the surface conditions from baking to baking could be responsible for the unstable behavior.

   b. $E_e/p < 8$: In this range the sensitivity for the indication of impurities is large, and it was not possible to get reproducible results with the present experimental setup. Improvements may be reached by using an all-metal system which can be baked at higher temperatures; or the impurities may be inherent in the gas.

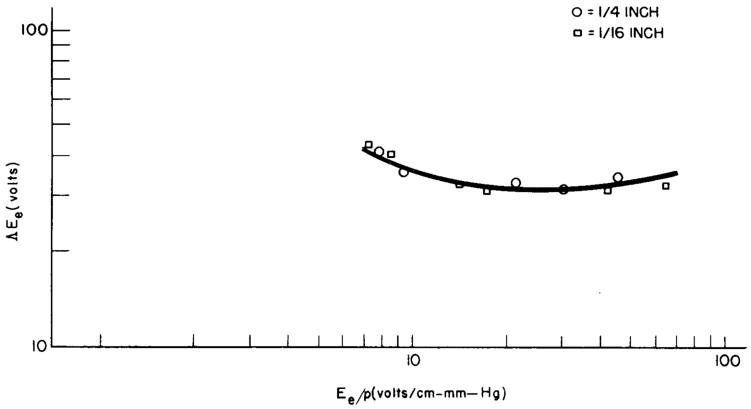

Fig. II-1
Breakdown data in pure Helium gas.

This question has to be cleared up by further experiments.

3. The use of a bypass liquid helium trap seems to have little influence on the purity conditions. Since through-traps have many disadvantages (large amount of liquid helium, sometimes unstable pressure reading due to gas oscillations) it is hoped that an improvement in the getter construction will yield more stable results.

4. It has been found that two technical facts were the main sources of error in previous measurements:

   a. The flux used for the soldering of the loops can only be removed completely by boiling the loop assembly in water for about an hour after its first chemical cleaning. It then has to be cleaned chemically again.

   b. The VSWR of the thermistor mount changes with the power level. In the pressure range of interest the thermistor mount of the experimental setup had, for instance, a VSWR of 3 db at the minimum level and nearly 8 db at the maximum level. This inconvenient behavior can be appreciably improved by using the conventional directional coupler of 33.5 db together with a pad of 5-8 db. But the VSWR has to be checked for all used power levels after each run. Use of the 49-db directional coupler is not possible since the bridge is then not sensitive enough over the whole range of interest.

5. Finally, it may be mentioned that the last run was carried out with two cavities of $L_1 = 1/4$ inch and $L_2 = 1/16$ inch at the same time. The purpose was to find out if Λ is really the correct scaling factor (existence of a universal plot $\Lambda E_e = f(E_e/p)$) under exactly the same purity conditions. It also reduces the number of time-taking bakings from two to one. The breakdown data of both cavities were indeed in excellent agreement with each other, even in the low E_e/p range.

C. OSCILLATIONS IN D-C DISCHARGES

A study of the high frequency oscillations occurring in a previously described mercury arc discharge tube (2) was carried out. Two methods of detection were tried: the first utilized a coaxial resonant line; the second, a radar receiver, AN-SPR-2, with a range of 1000-3000 Mc/sec. A crystal, a probe, or a coupling loop could be placed in the coaxial resonator for signal detection but all three pick-ups were broadbanded and fairly insensitive. The output of an AN-SPR-2 receiver, operating on a heterodyne principle, was observed visually on an oscilloscope. This permitted an accurate determination of the frequency of the oscillation and showed the general character of the oscillation. This receiver was used to pick up oscillations with the movable probe. The discharge may be divided into two regions in searching for oscillations: the region between the cathode and the scattering layer; and the region between the scattering layer and the anode. No oscillations were picked up in the first region at any time. The high frequency noise level was lower in this region than in the second region. All oscillations were found beyond the scattering layer and thus indicated the necessity of the scattering layer to generate the oscillations. The probe usually disturbed the arc and a strong low frequency noise was generated by the arc while the probe picked up a high frequency signal. However, the high frequency oscillations could be picked up in some regions when the arc was not being disturbed by the probe.

The plasma frequency may be related to the electron density by the Langmuir formula

$$\omega_p^2 = \frac{ne^2}{m\epsilon_0} \quad \text{mks}$$

$$f_p \approx 9000\sqrt{n} \quad \text{n in electrons/cc.}$$

The frequencies predicted by this formula would lie in the range 1000-3000 Mc/sec. The only signal which verified this relation appeared as an increased noise level. While very strong oscillations which had an amplitude envelope synchronized with a 60-cycle frequency were usually observed, these oscillations were not at the plasma frequency. The results of this study indicated that high frequency oscillations are present in the discharge, but that the general nature of the oscillations is much more complicated than previously reported.

D. NONUNIFORM FIELD BREAKDOWN IN HEG

The theory for uniform electric field breakdown in helium with a small amount of mercury (Heg) in microwave cavities indicates that the effective high frequency ionization coefficient ζ_e is a function of E_e/p alone, and, hence, is independent of the diffusion length Λ of the cavity. By definition, $\zeta_e = (1/E_e\Lambda)^2$ and for TM_{010}-mode cylindrical cavities, whose height L is small compared to the radius R, therefore approximating the condition of infinite parallel plates, Λ is equal to L/π. Under these conditions the electric field in the cavity is essentially constant over the region of the discharge. The theoretical curve for ζ_e as a function of E_e/p, calculated from the formulas of reference 3, is drawn in Fig. II-2. As already shown in this reference, this theoretical curve predicts breakdown electric fields over the range of container size for which the electric field is uniform. When the dimensions of the cylindrical cavity are such that the height is comparable to the radius, the electric field is no longer constant over the region of the discharge and its spatial variation must be accounted for in the theory.

A theory had been developed (4) in which, by defining a ζ_e^* for nonuniform fields, the curve of ζ_e as a function of E_e/p becomes a universal curve valid for uniform as well as for nonuniform breakdown data. ζ_e^* is defined as

$$\zeta_e^* = \left(\frac{1}{E_e\Lambda_e}\right)^2$$

where Λ_e is an effective diffusion length for nonuniform fields. Λ_e may be regarded as an equivalent parallel plate separation to give the same breakdown field as that of the actual cavity. The solution of the characteristic breakdown equation, with the proper boundary conditions imposed and with the nonuniformity of the field included, leads to a method of calculating Λ_e. In the characteristic breakdown equation

$$\nabla^2(Dn) + \zeta_e^* E_e^2(Dn) = 0$$

where D is the diffusion coefficient and n the electron density. ζ_e^* is approximated by

$$\zeta_e^* = \left(\frac{1}{E_{oe}\Lambda_e}\right)^2 \left(\frac{E_e}{E_{oe}}\right)^{\beta-2}$$

where $(1/E_{oe}\Lambda_e)^2$ is the value of the ionization coefficient at the maximum field point. The quantity $\beta-2$ is obtained as the slope of ζ_e vs E_e/p plot on a logarithmic scale at the point E_{oe}/p. Since $\beta-2$ is a function of E_e/p, Λ_e will also be a function of E_e/p.

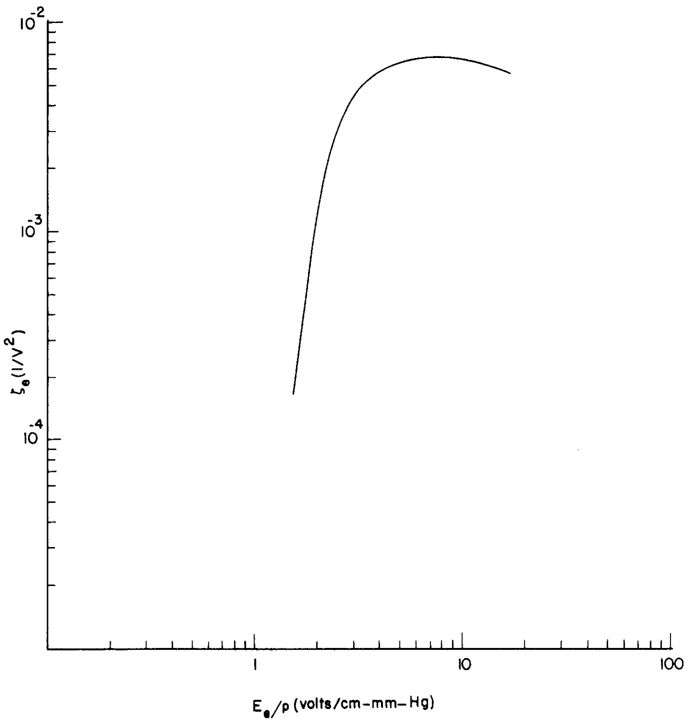

Fig. II-2

Theoretical ζ_e curve for Mercury.

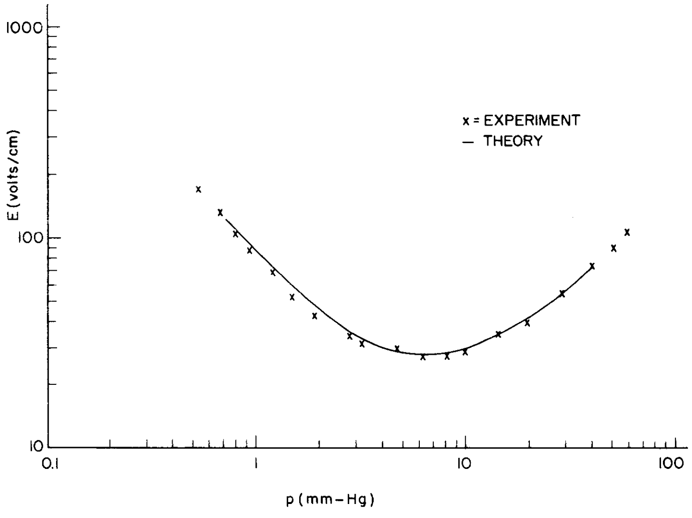

Fig. II-3

Comparison of experimental electric field and values predicted from theory for the cylindrical 3-inch cavity.

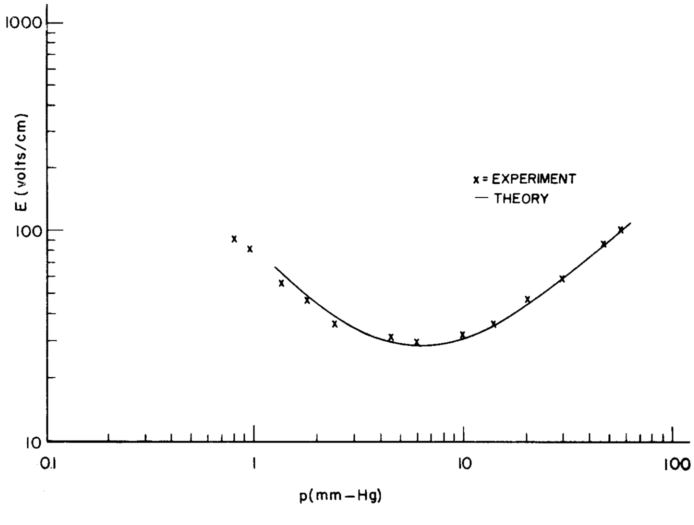

Fig. II-4

Comparison of experimental electric field and values predicted from theory for the spherical cavity.

By means of the above theory for determining Λ_e and the ζ_e vs E_e/p plot, one can predict the breakdown data, E_e vs p for a given nonuniform field cavity. An analogous theory has also been developed (5) for spherical cavities excited in the lowest electric field modes.

Breakdown data were obtained in Heg for a cylindrical cavity with R = 1.6 inches and L = 3 inches, and for a spherical cavity with a radius of 4.69 cm. The experimental data are plotted in Figs. II-3 and II-4. It is believed that the above theories for nonuniform fields cannot be used immediately to determine theoretical data of E vs p because they do not take into account the effect of the diffusion of metastables through the cavity before ionizing a mercury atom. In spite of this fact, data have been calculated tentatively with the theories given above. These theoretical data are plotted on the same Figs. II-3 and II-4. Regardless of the different geometry, the agreement with the experimental data is seen to be good in both cases, well within the limits of accuracy. Thus, at least descriptively, it is believed that uniform and nonuniform data in Heg may all be plotted on one single curve of ζ_e vs E_e/p, where the ordinate is ζ_e for uniform fields and ζ_e^* (calculated with the above theories) for nonuniform fields.

The method was also attempted for nonuniform data in H_2, but the experimental data were higher than the theoretical predictions, well beyond the limits of accuracy. One reason for the discrepancy may be the presence of excitation in H_2, whereas excitation is absent in Heg. This point and the accuracy of the approximations used in the theories are being investigated.

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