

II. MICROWAVE GASEOUS DISCHARGES

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Microwave Breakdown in Air. Breakdown has been measured in TM_{010} -mode cavities which are long enough to require the non-uniform field theory reported in the last progress report. These results extend the measurements of the high-frequency ionization coefficient to nearly the full range available without increasing the magnetron power. The final complete set of curves for air is shown in Fig. II-1. A technical report on this subject is being prepared.

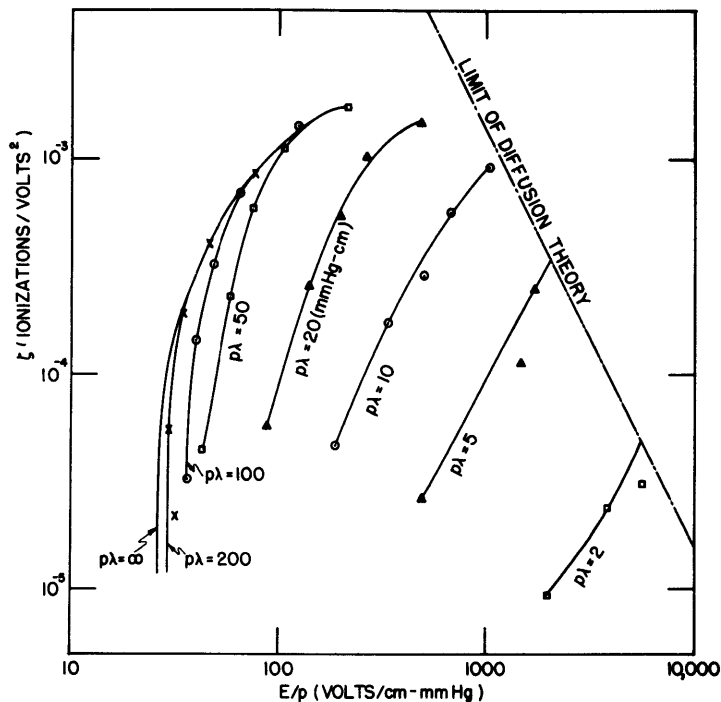


Fig. II-1. High frequency ionization coefficient ζ in (ionization/volts²) as a function of E/p (volts/cm-mm Hg) and $p\lambda$ (mm-cm).

Microwave Breakdown in Helium. The ionization coefficient ζ has been derived for helium treated with mercury, from the Boltzmann transport equation on the basis of kinetic theory. The derivation gives $\zeta = \nu/DE^2$, where ν is the ionization rate per electron, D is the

diffusion coefficient of electrons in the gas, and E is the r.m.s. value of the electric field.

For the case where the probability of collision is inversely proportional to the electron velocity, v, kinetic theory gives

$$nv = \frac{4\pi\tau\mu b}{3\Lambda^2} v_c^3 \frac{d}{dz} \left\{ e^{-\frac{1}{2}(1+\frac{1}{b})z} M(\alpha, \frac{3}{2}, z) + \frac{C}{z^{\frac{1}{2}}} M(\alpha - \frac{1}{2}, \frac{1}{2}, z) \right\}_{z=z_a} \quad (1)$$

where

$$\tau = \frac{1}{2.3710^9 p} ,$$

$$\mu = \frac{3m\Lambda^2}{M^2} ,$$

$$b = \left\{ 1 + \frac{6.74 \left(\frac{E}{p}\right)^2}{(p\Lambda)^2 \left\{ 5.62 + \left(\frac{60\pi}{p\lambda}\right)^2 \right\}} \right\}^{\frac{1}{2}}$$

$$z = 9.20 b \cdot \left(\frac{p}{E}\right)^2 \left\{ 5.62 + \left(\frac{60\pi}{p\lambda}\right)^2 \right\} ,$$

$$\alpha = .75 \left(1 - \frac{1}{b}\right) ;$$

p is the pressure in mm of mercury, m is the mass of the electron, M the mass of the atom, n the electron density, Λ^2 is a factor which depends on the geometry of the cavity, and λ is the free-space wavelength of the electric field; z_c and v_c refer to the values of these quantities for electronic energies equal to the excitation energy. $M(\alpha, \gamma, z)$ is the confluent hypergeometric function in α and γ , and C is a constant depending on boundary conditions. One also obtains

$$nD = \frac{2\pi\tau}{3(ab)^{\frac{3}{2}}} \int_0^{z_c} z^{\frac{1}{2}} e^{-\frac{1}{2}(1+\frac{1}{b})z} \left\{ M(\alpha, \frac{3}{2}, z) + \frac{C}{z^{\frac{1}{2}}} M(\alpha - \frac{1}{2}, \frac{1}{2}, z) \right\} dz .$$

Dividing the ratio of (1) and (2) by E^2 , one obtains

$$\zeta = \frac{1}{(\Delta E)^2} \frac{1}{\left(\frac{M(\alpha, \frac{3}{2}, Z_c)}{e^{\frac{2}{3}\alpha Z_c}} - 1 \right)}$$

The expression so obtained is not strictly accurate, however, since the probability of collision is not hyperbolic for all energies but is as shown in Fig. II-2.

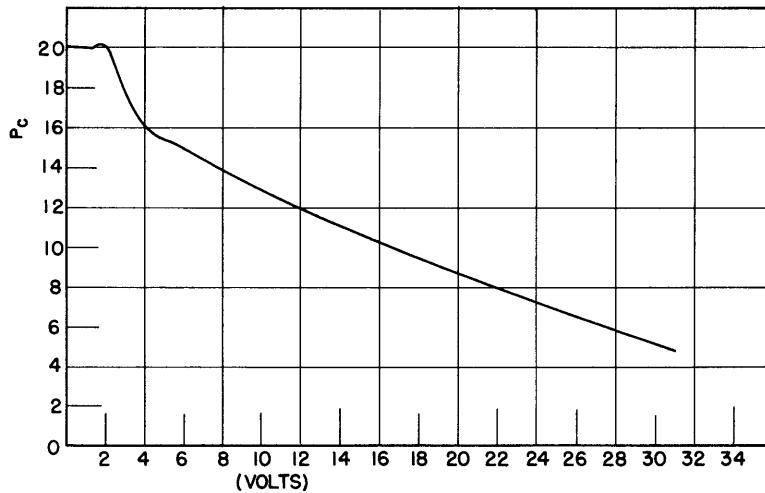


Fig. II-2. Probability of collision in helium as a function of energy, at 1 mm pressure.

The effect of the slower electrons will be noticeable at the higher pressure ranges, so that a correction may be made in this case. Since nD is an integral over the distribution function from zero energy to the excitation energy, we may use the distribution function obtained for constant collision probability (see last progress report) for the integral from zero to two volts and that of Eq. (2) for the remainder. This has been done, and an expression for ζ obtained. The breakdown condition as obtained from the diffusion equation is that $\zeta = 1/\Lambda^2$. Thus ζ may be predicted for a given cavity and given frequency as a function of E/p .

Experimental. The breakdown of pure helium treated with mercury has been measured at 3000 Mc. Reproducible results were obtained after considerable care was taken with the vacuum system - the cavities being made of O.F.H.C. copper with glass-kovar coupling leads. The whole vacuum system was outgassed over a period of several days and distilled mercury was used to

introduce a small amount of mercury vapor into the helium. The cavity was a short cylinder operating in the TM_{010} -mode, the power being supplied by an S-band c-w magnetron. A radioactive source was placed near the cavity to provide electrons. The electric field was slowly increased until breakdown was indicated on a transmission meter showing a mismatch.

Figure II-3 shows the experimental points along with the theoretical values of ζ . The work is continuing with more cavities and other gases.

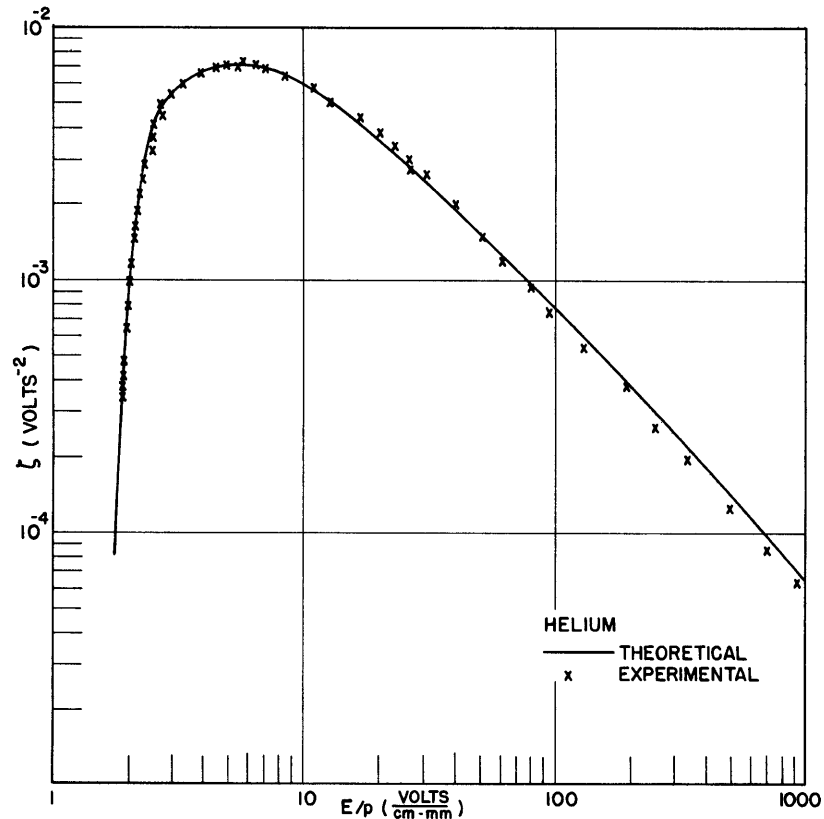


Fig. II-3. Ionization coefficient in helium.

Measurements of the Ambipolar Diffusion Coefficient in Helium. In the last progress report calculations to show the necessary gas purity for accurate data were given. A vacuum system capable of maintaining the desired purity has been built. The system holds at between 10^{-7} and 10^{-6} mm Hg pressure indefinitely when isolated from the pumps so that no appreciable contamination of the helium occurs during the several hours required to take data. Several runs have been made; the data from a typical run are plotted in Fig. II-4. The data resemble quite closely

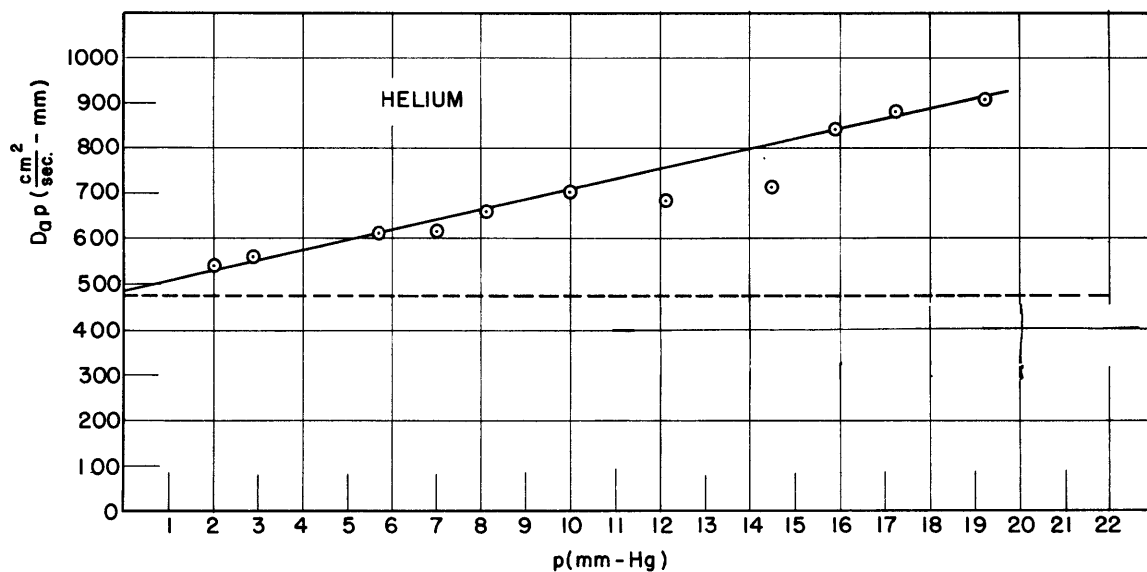


Fig. II-4. Extrapolated value of D_p from theoretical μ_+ at 760 mm pressure.

the curve given in the October 1947 Progress Report. The additional purity obtained seems to have resulted in a lowered diffusion rate as predicted.

Comparison of these data with other measurements can be achieved from the relation between D_a and the positive ion mobility, μ_+ :

$$D_a = \frac{D_+\mu_- + D_-\mu_+}{\mu_+ + \mu_-}$$

$$\simeq (D_+/\mu_+ + D_-/\mu_-)\mu_+ .$$

Since both positive ions and electrons are at room-temperature energy in this experiment; we have the result from kinetic theory

$$\frac{D_+}{\mu_+} = \frac{D_-}{\mu_-} = \frac{kT}{e}$$

$$D_a \simeq \frac{2kT}{e} \mu_+ .$$

Comparison of the measured value of D_a with the mobility measurements of Tyndall and Powell¹ in helium at 760 mm pressure indicates a difference of a factor of two between the two measurements. However, the comparison of D_a with Massey and Mohr's² theoretical calculation of μ_+ in helium at 760 mm pressure gives good agreement in the limit of zero pressure (cf. Fig. II-4). The departure of the experimental data from theory may be due to the action of a removal process other than ambipolar diffusion.

Some preliminary studies on neon have been made. Since diffusion in neon should be slower than in helium other removal processes should show up more clearly in the data. Analysis of the data indicates that a low-energy recombination between electrons and positive ions is taking place in addition to the usual diffusion. Observation of recombination light for at least 300 μ sec after the discharge is terminated supports this hypothesis. As yet insufficient time has been available to correlate the variation in recombination light intensity with the electron density measured in the microwave experiment.

It is planned to study the low-energy recombination in neon in more detail. The resulting information should enable us to predict the importance of this recombination in helium and to correct the data to achieve better agreement with the theoretical value of D_a .

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1. A. M. Tyndall and C. F. Powell, Proc. Roy. Soc., A134, 125 (1931).
 2. H. S. W. Massey and C. Mohr, Proc. Roy. Soc. A144, 199 (1934).