Absorption and Dispersion of Microwaves in Flames*

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The dependence of the high-frequency electric conductivity and the optical constants of a weakly ionized gas on the microwave frequency, the electron-molecule collision frequency, the electron concentration, and an external magnetic field are discussed. Measurements of the electric conductivity between 23.10 and 92.96 kMc/sec indicate that the effective electron-molecule collision frequency in an acetylene-air flame is independent of the electron velocity within the limits of error. Cyclotron resonance of free electrons has been found in low-pressure flames at 24 kMc/sec. This effect can be used to determine both the concentration of free electrons and the electron collision frequency.

INTRODUCTION

MEASUREMENTS of the absorption of microwaves by flames have been successfully used to investigate chemical reactions involving ionized components.[1,2] On the other hand, flames may be used to study the electromagnetic properties of ionized gases on a moderate scale. One advantage of this method arises from the fact that the electron concentration, N, and the electron collision frequency, ν, two fundamental quantities of an ionized gas, can be varied independently over a wide range. When sprays of alkali salt solutions are introduced into the flame, partial thermal ionization of the alkali atoms occurs, and the electron concentration N is a function of the salt concentration in the solutions. If the free electrons are in thermal equilibrium with the flame gases, their energy distribution will be Maxwellian. Furthermore, the electron collision frequency ν can be varied by burning the flame in a closed vessel under variable pressure.

A general theory of the electric conductivity of an ionized gas at high frequencies has first been given by Margenau.[3] More recently, this theory has been extended to the case where the ionized gas is placed in a constant, homogeneous magnetic field.[4] Such quantities as the complex refractive index and the reflection coefficient can easily be derived from the complex electric conductivity, which seems most suitable to describe the electromagnetic properties of ionized gases. In this work, only the electronic part of the conductivity will be considered, since the contribution of the heavy ions is negligible on account of their mass. The concentration of charged particles in the flames investigated in this work is very low compared with the number of neutral gas molecules. Therefore electron-electron and electron-ion collisions may be neglected and only encounters between electrons and neutral gas molecules need be considered. Furthermore, it will be assumed that these collisions are elastic.

In the presence of a magnetic field the electric conductivity is described by an antisymmetric tensor. In order to obtain its components, it is customary to determine the electron velocity distribution function under the influence of a weak, alternating electric field by solving the Boltzmann transport equation.[4] Taking the magnetic field H parallel to the z axis, the result is

$$\sigma_{xx}=\sigma_{yy}=-\frac{4\pi}{3}\frac{e^2}{m}\int_0^\infty \frac{\nu+i\omega}{(\nu+i\omega)^2+\omega_c^2}v^3\frac{\partial f_0}{\partial v}dv,$$
$$\sigma_{xy}=-\sigma_{yx}=+\frac{4\pi}{3}\frac{e^2}{m}\int_0^\infty \frac{\omega_c}{(\nu+i\omega)^2+\omega_c^2}v^3\frac{\partial f_0}{\partial v}dv, \quad (1)$$

where e and m are the electronic charge and mass, respectively, ν is the electron-molecule collision frequency, ω the circular frequency of the electric field, and $\omega_c=eH/mc$ is the cyclotron frequency. The distribution function in the absence of the electric field, f_0, is assumed to be isotropic, i.e., to depend only on the magnitude v of the electron velocity. In the absence of a magnetic field, i.e., for $\omega_c=0$, the electric conductivity is a scalar:

$$\sigma=-\frac{4\pi}{3}\frac{e^2}{m}\int_0^\infty \frac{1}{\nu+i\omega}v^3\frac{\partial f_0}{\partial v}dv. \quad (2)$$

For the special case that the electron-molecule collision frequency is independent of the electron velocity v,

* This research was supported in part by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command and by the California Research Corporation; and in part by the Office of Naval Research.
[1] T. M. Sugden, Discussions Faraday Soc. **19**, 68 (1955). (Further references are given in this and the two subsequent papers and in the discussions in the same volume.)
[2] K. E. Shuler and J. Weber, J. Chem. Phys. **22**, 491 (1954).
[3] H. Margenau, Phys. Rev. **69**, 508 (1946).
[4] L. G. H. Huxley, Proc. Phys. Soc. (London) **B64**, 844 (1951); R. Jancel and T. Kahan, J. phys. radium **14**, 533 (1953); W. P. Allis, "Motions of ions and electrons" in *Handbuch der Physik* (Springer-Verlag, Berlin, 1956), Vol. 21; Kelly, Margenau, and Brown, Phys. Rev. **108**, 1367 (1957). See also: L. Mower and R. F. Whitmer, Sylvania Electric Products, Inc., Mountain View, California, Technical Reports No. MPL-1, No. MPL-4, No. MPL-M1 (unpublished); J. Schneider and F. W. Hofmann, Duke Microwave Report No. 25 (unpublished).

Eqs. (1) and (2) simplify to

$$\sigma_{xx}=\frac{Ne^2}{m}\frac{\nu+i\omega}{(\nu+i\omega)^2+\omega_c^2},$$
$$\sigma_{xy}=-\frac{Ne^2}{m}\frac{\omega_c}{(\nu+i\omega)^2+\omega_c^2}, \tag{3}$$

$$\sigma=\frac{Ne^2}{m}\frac{1}{\nu+i\omega}, \tag{4}$$

since $\int_0^\infty v^2 f_0 dv=N/4\pi$, where N is the number of free electrons per cc.

DISCUSSION

Case A: $H=0$

In the following, the velocity distribution function f_0 is assumed to be Maxwellian:

$$f_0(v)=N(m/2\pi kT)^{\frac{3}{2}}\exp(-mv^2/2kT), \tag{5}$$

where k is Boltzmann's constant and T the absolute temperature of the electron gas. Now the electric conductivity in the absence of a magnetic field, as given by Eq. (2), may be written in the form

$$\sigma=\frac{8}{3\sqrt{\pi}}\frac{Ne^2}{m}\int_0^\infty\frac{1}{\nu(u)+i\omega}u^4\exp(-u^2)du, \tag{6}$$

where u is dimensionless and equal to $(m/2kT)^{\frac{1}{2}}v$. The main difficulty in evaluating the integral in Eq. (6) arises from the velocity dependence of the electron collision frequency ν. If N_1, $N_2\cdots$ are the numbers per cc of neutral particles of type 1, $2\cdots$ and Q_1, $Q_2\cdots$ their cross sections for collisions with the electrons and v the root mean square (rms) of the electron velocity, ν is given by

$$\nu=v(N_1Q_1+N_2Q_2+\cdots). \tag{7}$$

The collision frequency ν is related to the mean free path λ of the electron by $\nu=v/\lambda$. For flame temperatures of 1000° to 3000° the mean electron energy is 0.13 ev to 0.39 ev. Unfortunately the present knowledge of electron-molecule cross sections is rather incomplete in this energy range.[5,6]

For a rough estimation of the electron cross section, one can assume that the electron will be appreciably scattered if its kinetic energy $mv^2/2$ is of the order of the interaction energy W between the electron and the molecule, i.e., for $W\simeq mv^2/2$. If $W(r)$ is known as a function of the distance r between the two colliding particles, the distance r_0 which fulfills the above condition can be calculated, giving the cross section $Q=\pi r_0^2$.

[5] R. Kollath, in *Handbuch der Physik* (Springer-Verlag, Berlin, 1958), Vol. 34, Fig. 7, p. 10.

[6] H. H. Landolt and R. Börnstein, *Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie* (Springer-Verlag, Berlin, 1950), sixth edition, Vol. I, Part I, p. 374.

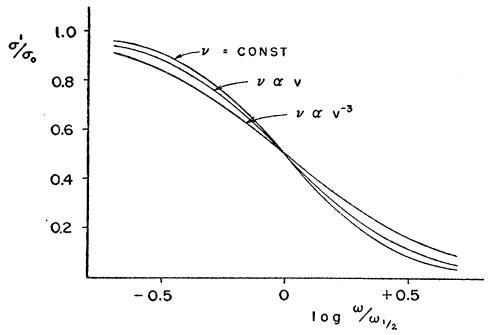

FIG. 1. Dispersion of the real part of the electric conductivity for velocity-dependent electron collision frequencies ν.

The effect of the velocity dependence of the cross section Q on the high-frequency conductivity will be investigated by calculating the real part σ' of the conductivity for the three cases: (i) $Q=$const, (ii) $Q\propto 1/v$, and (iii) $Q\propto 1/v^4$. The first case has been treated by Margenau.[3] Since $1/\lambda=NQ$, the mean free path of the electron is constant, i.e., $\nu\propto v$. The second case, $Q\propto 1/v$, yields a constant collision frequency, and the conductivity reduces to the simple expressions given by Eqs. (3) and (4). This case corresponds to an electron-molecule interaction energy $W(r)\propto 1/r^4$, which holds for the electrostatic energy between an electron and a neutral, nonpolar molecule. Finally, the case $Q\propto 1/v^4$, i.e., $\nu\propto 1/v^3$ corresponds to collisions between electrons and ions, where $W(r)\propto 1/r$.

Figure 1 shows the high-frequency behavior of the real part σ' of the electronic conductivity for the three cases discussed above. The quantity σ'/σ_0 is plotted against the logarithm of $\omega/\omega_{\frac{1}{2}}$, where $\omega_{\frac{1}{2}}$ is the frequency at which σ' has dropped to one half of its static value σ_0. The curve corresponding to $Q\propto 1/v^4$, i.e., $\nu\propto 1/v^3$, was obtained from Eq. (6) by graphical integration. If ν is constant, the dispersion of σ' corresponds to a Debye relaxation process with a relaxation time $1/\nu$. If, however, ν is a function of the electron velocity, the dispersion of σ' can be interpreted as a superposition of Debye terms with a continuous distribution of relaxation times. As shown by the general theory of relaxation processes[7] this results always in dispersion curves with smaller slopes. The relative deviation of the other conductivity dispersion curves from the Debye curve is small as long as $\omega/\nu<1$, but becomes significant for higher frequencies.

Optical Constants

The complex index of refraction $n=n'+in''$ is related to the complex electric conductivity $\sigma=\sigma'+i\sigma''$ by

$$n=(1-i4\pi\sigma/\omega)^{\frac{1}{2}}. \tag{8}$$

The contribution of the neutral gas molecules to the refractive index is very small and has been neglected.

[7] H. Fröhlich, *Theory of Dielectrics* (Clarendon Press, Oxford, 1949).

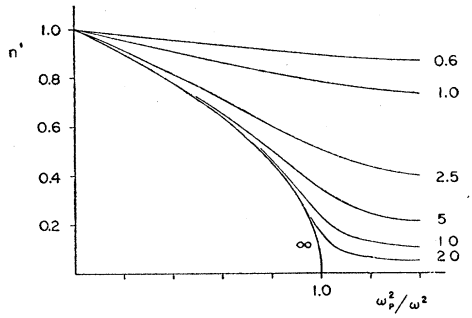

FIG. 2. Refractive index n' of an ionized gas as a function of the electron density in units ω_p^2/ω^2 at 24 kMc/sec. The parameter is the inverse collision frequency in units ω/ν, assuming ν to be independent of the electron velocity.

The real and the imaginary components of n are

$$n'=(1/\sqrt{2})\{[(1+\beta)^2+\alpha^2]^{\frac{1}{2}}+1+\beta\}^{\frac{1}{2}},$$
$$n''=(1/\sqrt{2})\{[(1+\beta)^2+\alpha^2]^{\frac{1}{2}}-1-\beta\}^{\frac{1}{2}}, \tag{9}$$

where $\alpha=4\pi\sigma'/\omega$ and $\beta=4\pi\sigma''/\omega$. If the collision frequency is much smaller than the microwave frequency, n'' approaches zero and n' simplifies to the well-known expression

$$n'=[1-(4\pi e^2N/m\omega^2)]^{\frac{1}{2}}. \tag{10}$$

At fixed frequency ω, the refractive index decreases with increasing electron concentration N and becomes zero for the plasma frequency $\omega_p=(4\pi e^2N/m)^{\frac{1}{2}}$. At even higher concentrations N, the refractive index is imaginary, i.e., an electromagnetic wave undergoes total reflection. Figure 2 shows how this behavior is modified by taking into account the collisions of the electrons. In this case, n' never reaches zero. Figure 3 gives the dependence of the absolute value R of the reflection coefficient on the electron concentration for normal incidence on a boundary between two semi-infinite media. R is related to n' and n'' by

$$R=\frac{(n'-1)^2+n''^2}{(n'+1)^2+n''^2}. \tag{11}$$

Neglecting the electron collisions, i.e., for $\omega/\nu=\infty$, the wave undergoes total reflection for electron concentrations exceeding the critical value ω_p. For small values of ω/ν and $(\omega_p/\omega)^2$ the reflection coefficient becomes negligibly small. A layer of ionized gas whose thickness greatly exceeds the wavelength is then capable of absorbing the incident wave almost completely. It approaches the properties of a black body for this frequency.

The attenuation β, in db, of the intensity of an electromagnetic wave is related to the imaginary part n'' of the refractive index by

$$\beta=10(\log_{10}e)(2\omega/c)n''d, \tag{12}$$

where d is the path length. For sufficiently small electron concentrations N, i.e., for small σ' and σ'', Eq. (9) yields in first order

$$n''=\frac{2\pi\sigma'}{\omega}=\frac{2\pi}{\omega}\frac{Ne^2}{m}\frac{\nu}{\nu^2+\omega^2}, \tag{13}$$

and the attenuation β is a linear function of the electron concentration.

Case B: $H\neq 0$

For the following it will be assumed that the electron-molecule collision frequency is independent of the electron velocity. In this case, separation of the electric conductivity σ_{xx}, as given by Eq. (3), into its real and imaginary parts yields

$$\sigma_{xx}'=\frac{Ne^2}{2m}\left(\frac{\nu}{\nu^2+(\omega+\omega_c)^2}+\frac{\nu}{\nu^2+(\omega-\omega_c)^2}\right),$$
$$\sigma_{xx}''=-\frac{Ne^2}{2m}\left(\frac{\omega+\omega_c}{\nu^2+(\omega+\omega_c)^2}+\frac{\omega-\omega_c}{\nu^2+(\omega-\omega_c)^2}\right). \tag{14}$$

It should be noted that these equations show a close similarity to formulas given by Van Vleck and Weisskopf[8] and by Fröhlich,[7] which describe the transition between relaxation absorption and resonance absorption. In the absence of a magnetic field, Eqs. (14) represent a relaxation-type dispersion of the electric conductivity with a single relaxation time $1/\nu$, corresponding to a continuous decrease of the real part σ' with increasing frequency. In the presence of a magnetic field, however, the absorption may have resonance character. Cyclotron resonance will occur near $\omega=\omega_c=eH/mc$ if an electron is able to make at least one revolution in the magnetic field before colliding with another particle, i.e., for $\omega/\nu>1$. As the collision frequency is further decreased, the cyclotron line becomes rapidly sharper (Fig. 4).

Taking the magnetic field as the independent variable,

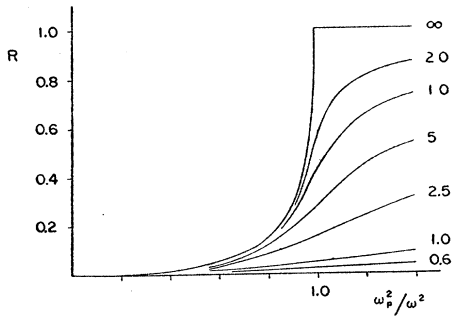

FIG. 3. Reflection coefficient R of an ionized gas as a function of the electron density in units ω_p^2/ω^2 at 24 kMc/sec. The parameter is the inverse collision frequency in units ω/ν, assuming ν to be independent of the electron velocity.

[8] J. H. Van Vleck and V. F. Weisskopf, Revs. Modern Phys. 17, 227 (1945).

one obtains from Eq. (14)

$$\int_0^\infty \sigma_{xx}' dH = \tfrac{1}{2}\pi ecN. \tag{15}$$

The integral absorption, i.e., the area under any curve in Fig. 4, is therefore a function of the electron concentration alone. Equation (15) is also valid if the collision frequency ν is dependent on the electron velocity since the order of integration over v and H may be interchanged. The collision frequency ν may be obtained from the shape of the absorption line. For sufficiently sharp lines the relative half-width can be derived from Eq. (14) as

$$\Delta H/H_0 = 2\nu/\omega, \tag{16}$$

where $H_0 \pm \Delta H/2$ are the values of the magnetic field at which the conductivity σ_{xx}' has dropped to one half of its maximum value. This simple method of obtaining ν from the shape of the resonance curve only holds exactly if ν is velocity independent. However, Kelly, Margenau, and Brown[4] found that the resonance lines for the cases $\nu \propto v$ and $\nu \propto v^2$ almost coincide with the line for which ν is constant.

EXPERIMENTS AND RESULTS

Case A: $H=0$

Experimental evidence for the theoretical conclusions concerning the velocity dependence of the electron-molecule collision frequency ν was obtained from microwave attenuation measurements on an acetylene-air flame containing alkali vapors as electron source. These measurements form part of a broader research project[9] dealing with the intensity-density relationship of the spectral lines which are emitted by alkali vapors added to a flame. Attenuation data were obtained at seven wavelengths ranging from 12 mm to 3 mm, permitting the construction of a dispersion curve of the real part σ' of the electric conductivity.

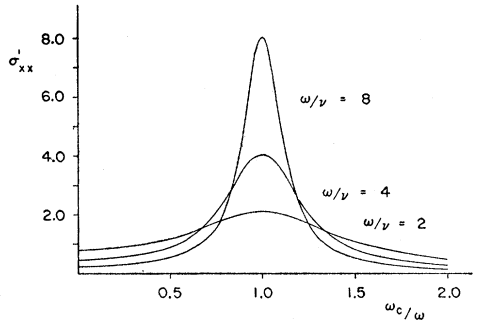

FIG. 4. Cyclotron resonance for various collision frequencies in units ω/ν. The real part σ_{xx}' of the conductivity in arbitrary units is plotted against the magnetic field in units ω_c/ω. The frequency ω and the electron concentration N are constant.

[9] This investigation, by Dr. Hedwig Kohn and the authors, will be published elsewhere.

TABLE I. Dispersion of the electric conductivity of an acetylene air flame.[a]

Frequency (kMc/sec)	Attenuation β (db)	Conductivity σ' (10^8 sec^{-1})
23.10	1.44	9.9
29.51	1.23	8.5
36.76	1.08	7.4
43.50	0.91	6.3
61.16	0.64	4.4
69.88	0.46	3.2
92.96	0.33	2.3

[a] The σ' values were calculated from Eqs. (12) and (13).

A Lundegårdh-type acetylene-air burner producing a homogeneous sheet of flame gases of about 8 mm thickness was used. The blue zone of primary reaction was 2.5 mm high. Free electrons were produced by thermal ionization of alkalis which were added to the flame as fine sprays of aqueous salt solutions. A description of the burner and the atomizer system was given by Hinnov and Kohn.[10] Microwave radiation for measurements at 12-mm, 10-mm, and 8-mm wavelength was generated by the Raytheon klystrons 2K33, QK290, and QK291, respectively. For shorter wavelengths these tubes were used with frequency multipliers and detectors of the type described by King and Gordy.[11] The flame was placed between two K-band wave-guide horns, 30 mm apart, one leading to the detector, the other from the klystron or the frequency multiplier. The direction of microwave propagation was perpendicular to the burner slot, with the wave-guide axis located 8 mm above the top of the burner.

After the salt spray was introduced into the flame the power received by the detector dropped from the value P_0, corresponding to the "clean" flame, to P. The attenuation in db is $\beta = 10 \log_{10}(P_0/P)$. Equations (12) and (13) indicate that the attenuation β and the real part σ' of the electric conductivity are proportional if the electron concentration N is sufficiently low.

Measurements of β were carried out with widely varied concentrations of alkalis. The results obtained with a 0.25-molar NaCl solution are given in Table I.

Assuming that the electron collision frequency ν is independent of the electron velocity, σ' is obtained from Eq. (4)

$$\sigma' = \sigma_0 \Big/ \left(1 + \frac{\omega^2}{\nu^2}\right), \tag{17}$$

where $\sigma_0 = Ne^2/m\nu$. The values of σ_0 and ν which give the best fit to the experimental data are

$$\sigma_0 = 13.1 \times 10^8 \text{ sec}^{-1},$$
$$\nu = 26 \times 10^{10} \text{ sec}^{-1}.$$

Figure 5 shows that a Debye curve, as obtained with

[10] E. Hinnov and H. Kohn, J. Opt. Soc. Am. **47**, 156 (1957).
[11] W. C. King and W. Gordy, Phys. Rev. **93**, 407 (1954).

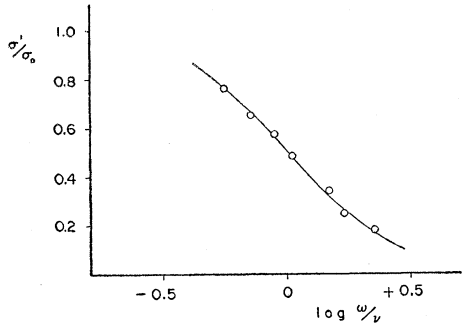

FIG. 5. Dispersion of the real part of the electric conductivity of an acetylene-air flame. σ'/σ_0 is plotted against $\log(\omega/\nu)$.

these parameters from Eq. (17), is in fair agreement with the experimental points.

The electron-molecule cross section Q is related to the collision frequency ν by Eq. (7): $Q=\nu/vN_0$ where $v=(3kT/m)^{\frac{1}{2}}$ is the mean (rms) electron velocity and N_0 the number of neutral gas molecules per cc. The temperature of the flame, as obtained by Hinnov and Kohn[10] from photoelectric line reversal measurements, was 2480°K. Thus

$$Q=\pi r_0^2=26\times10^{-16}\ \text{cm}^2,$$
$$r_0=2.9\times10^{-8}\ \text{cm}.$$

The composition of the flame gases at 2480°K has been calculated by Hinnov and Kohn,[10] the principal constituents and their partial pressures being N_2, 0.72; CO_2, 0.12; H_2O, 0.10; and CO, 0.05. The experimentally determined electron-molecule cross section must be interpreted as a weighted average of these molecular constituents and possibly of minor constituents with large cross sections. The experimental average collision radius r_0 is considerably larger than the van der Waals radii of the above molecules, defined for molecule-molecule collisions, which are of the order of 1.5×10^{-8} cm. Such a result can be expected in view of the directly measured electron-molecule cross sections at electron energies below 1 ev.[5,6]

From microwave measurements at wavelengths in the range 10 cm to 0.8 cm, Belcher and Sugden[12] obtained an electron collision frequency of 8.8×10^{10} sec^{-1} for a coalgas-air flame at 2200°K. Subsequent investigations by Sugden and coworkers[1] and by Shuler and Weber[2] with different flames (hydrogen-air, hydrogen-oxygen, acetylene-air) make use of this value. No satisfactory explanation can be offered for the discrepancy between the collision frequencies obtained by Belcher and Sugden and in this work.

Case B: $H\neq0$

Ingram[1] suggested that cyclotron resonance could be used as a sensitive method of measuring electron concentrations. It was noted by Sugden[1] that such a resonance cannot be observed at atmospheric pressure and at 8-mm wavelength but that the method is promising for low-pressure flames, due to the lowered collision frequency. Cyclotron resonance in such a flame has been detected by the authors.[13]

The design of a low-pressure burner for premixed acetylene and air, or oxygen, was facilitated by the work of Wolfhard[14] who investigated the stability conditions for flames under reduced pressure. The low-pressure vessel used in the present experiments was a Pyrex cylinder of 41-mm inner diameter, fitting between the pole faces of the electromagnet. It was cooled outside by jets of compressed air. Acetylene-air mixtures burning on Pyrex tubes of 8-mm inner diameter yielded stable flames at pressures ranging from about 200 mm Hg to 30 mm Hg. At lower pressures, stable flames can only be maintained on still wider burner tubes. The geometrical conditions imposed by the magnet, however, limited the diameter of the tubes. Therefore, a gas mixture of higher burning

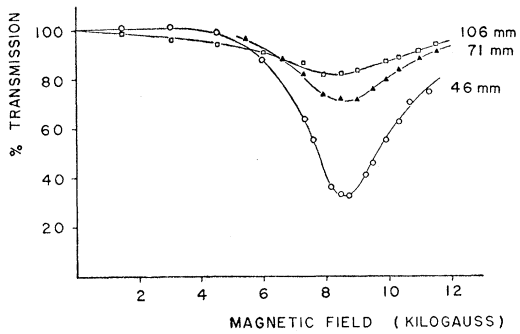

FIG. 6. Cyclotron resonance observed in an acetylene-air flame at a frequency of 24.2 kMc/sec under various pressures.

velocity, acetylene-oxygen, was used to obtain stable flames in the range from 25 mm Hg to 6 mm Hg, with burner tubes of 13-mm and 19-mm inner diameter. The pumping speed available precluded flames under pressures lower than 6 mm Hg.

Acetylene was introduced into the burner from the side after passing a needle valve. A small orifice in the bottom end of the burner tube admitted the air or oxygen. The usual method of adding alkali to a flame by operating an atomizer with one of the gases which form the combustible mixture fails at low pressure. This difficulty was overcome by atomizing the salt solution with air or oxygen into a flask at atmospheric pressure, trapping out all except the smallest droplets. The remaining fine mist was passed through a wide, open ended tube with a side branch connected to the air orifice of the burner tube. The diameter of the orifice was so chosen that the pressure drop from

[12] H. Belcher and T. M. Sugden, Proc. Roy. Soc. (London) **A201**, 480 (1950).

[13] J. Schneider and F. W. Hofmann, Phys. Rev. Letters **1**, 408 (1958).

[14] H. G. Wolfhard, Z. tech. Physik **24**, 206 (1943).

atmospheric to the desired flame gas pressure admitted just the amount of air or oxygen required to give stable flame conditions. By this design, only a small part of the mist from the atomizer entered the burner tube with the air or oxygen. For salt concentrations higher than 0.1 molar this technique was not entirely satisfactory due to frequent clogging of the suction hole. The flame was ignited by a discharge between two steel wire points connected to a Tesla coil.

The rectangular waveguide horns were lined up with their axes perpendicular to the static magnetic field. The microwave was polarized in the vertical direction, i.e., perpendicular to the static magnetic field and to the direction of propagation. The microwave had to pass through the air-cooled Pyrex wall of the vessel before and after traversing the flame gases. The magnetic field could be electronically swept over a range of 3000 gauss in about 20 seconds.

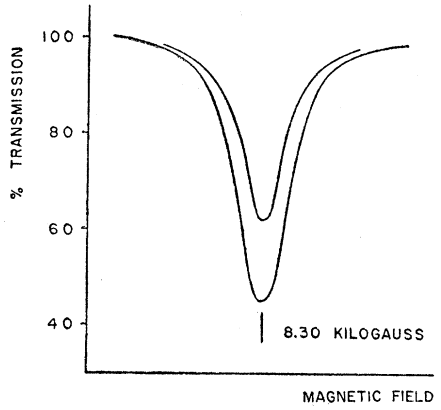

FIG. 7. Copy of recorder traces of cyclotron resonance observed in an acetylene-oxygen flame at 23.2 kMc/sec under a pressure of 7.5 mm Hg. The total field sweep is 2600 gauss, the line width 460 gauss. The weaker line was obtained from a clean flame without added alkali.

As Fig. 6 shows, the first indication of a cyclotron resonance appears at a pressure near 100 mm Hg. The resonance line becomes rapidly sharper as the pressure is further decreased. The free electrons originated from a 1-molar KCl solution; no resonance was observed from the "clean" flame. The geometrical limitations mentioned above required the use of oxygen instead of air in order to work at still lower pressures. The two lines shown in Fig. 7 were obtained at a pressure of 7.5 mm Hg, the weaker one without added alkali, the stronger with a 1-molar KCl solution. At this low pressure the reaction zone was very extended and came close to the level of the microwave beam. Since the recombination rate is small at low pressures, free electrons originating from the reaction zone can be expected in a concentration sufficiently high to be detected by their cyclotron resonance.

The microwave frequency was 23.2 kMc/sec and the resonance lines have their common center at the magnetic field H given by the cyclotron resonance condition $\omega_c = eH/mc$. Both lines have very nearly the same half-width, *viz.*, 460 gauss. The recorder traces give the transmission, i.e., the ratio P/P_0 of the incident to the transmitted microwave power. In order to calculate the electron collision frequency ν and the electron concentration N from the line width and the total absorption corresponding to Eqs. (16) and (15), the ordinate scale in Fig. 7 has to be taken in units of $10 \log_{10}(P_0/P)$, i.e., in db, since this quantity is proportional to N. Assuming a velocity-independent collision frequency and using Eq. (16), the value $\nu = 0.37 \times 10^{10}$ sec^{-1} results. The collision frequency deduced from the dispersion of the electric conductivity in the acetylene-air flame was 26×10^{10} sec^{-1}. Considering the pressure ratio of 760 mm to 7.5 mm, the collision frequency obtained for the low-pressure flame appears reasonable. Using graphical integration, Eqs. (12), (13), and (15) gave for the electron concentration N of the "clean" flame 0.7×10^{10} cm^{-3} and for the flame with added alkali vapor 1.2×10^{10} cm^{-3}. The layer of flame gases traversed by the microwave was about 35 mm thick. The sharpest cyclotron resonance line was obtained at a pressure of 6.0 mm Hg and at a frequency of 30.2 kMc/sec. The line had its center at 10 700 gauss and had a half-width of 400 gauss.

ACKNOWLEDGMENTS

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