ELECTRON ENERGY RELAXATION IN OXYGEN

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Laboratory studies of the cross-modulation effect in important atmospheric gases are much needed in order to evaluate and interpret phenomena associated with ionospheric cross modulation (Luxemberg effect). It is also possible, under certain conditions, to evaluate the cross section for rotational excitation of the atmospheric molecules by slow electrons from the measured electron-energy relaxation time constants. We report here results showing that cross sections thus computed differ markedly from those predicted by theory,[1] and possible reasons for the discrepancy are discussed. For a number of years it has been known that the experimentally determined average fractional energy loss, the G factor, in nitrogen and dry air far exceeded the value $2m/M$ deduced from classical elastic collision theory. A decade ago Gerjouy and Stein[2] were able to account for the large G factor in nitrogen by considering rotational excitation caused by the quadrupole interaction. Their theoretical results agree well with the experimental results obtained by Mentzoni and Row,[3] who calculated explicitly the G factor and its temperature dependence. Electron-energy relaxation in oxygen has been studied in recent years[4-6]; however, the various efforts were more or less of a preliminary nature. Narasinga Rao,[7] using the gyroresonance perturbation technique in an oxygen magnetoplasma, has shown that to heat the electron gas efficiently, high amplitudes of resonant microwave signals are needed to overcome the barrier of inelastic collisions. The need for narrow, high-power disturbing signal pulses with sharp leading and trailing edges was soon realized. A narrow pulse is needed to avoid altering the electron density during heating, and the sharp trailing edge is necessary for measuring the fast relaxation times. The relaxation of the sensing signal after the cessation of the heating signal is assumed to be caused only by the cooling of the electron gas and not due to any significant changes in the number density of the electrons.

The results reported here pertain to the interaction taking place in an oxygen plasma (afterglow) created in a cylindrical wave guide. The gas could be heated to any desired temperature up to about 1000°K, thus yielding controllable electron temperature under isothermal conditions. Radiation temperature measurements indicated[8] that isothermal conditions exist prior to the incidence of microwave pulses for cross modulation.[9] The detailed description of the experimental arrangements can be found elsewhere.[3] An example of the cathode-ray oscilloscope display of the cross modulation is illustrated in Fig. 1. In Fig. 2 are shown the composite results of these and earlier measurements. It is seen that all the recent micro-

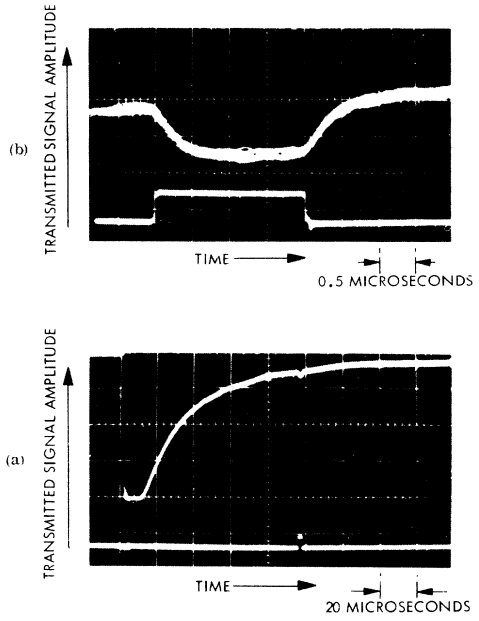

FIG. 1. (a) Transmission trace of sensing wave with cross modulation, and (b) cross modulation expanded, at $p_0 = 3.9$ Torr and $T_{gas} = 974$°K.

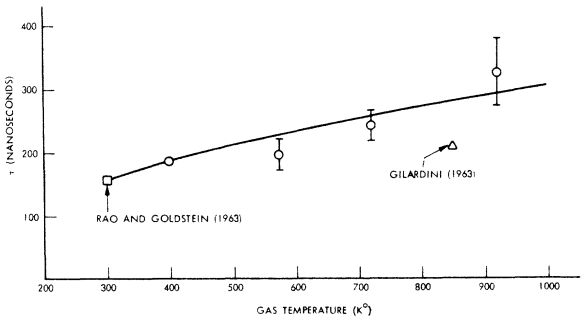

FIG. 2. Measurements of the electron-energy relaxation time, τ, as a function of gas temperature (= equilibrium electron temperature) in oxygen. The earlier data are normalized to $N(O_2) = 0.96 \times 10^{17}$ molecules/cm^3 ($p_0 = 3.0$ Torr). τ at 850°K is obtained from Gilardini's experimental data of $G = (4.8 \pm 1) \otimes 10^{-3}$ for T_e between 850 and 1900°K and collision probability

$$P_m = 12(850/350)^{1/2} \text{ (cm Torr)}^{-1}$$

extrapolated from his value $P_m = 12$ (cm Torr)$^{-1}$ between 300 and 400°K.

wave laboratory measurements of τ agree fairly well within the accuracy of the measurements. The solid curve in the figure follows a $T_e^{1/2}$ dependence normalized to the value $\tau = 160$ nsec at $T_e = 300$°K and at a gas pressure $p = 3.0$ Torr. Such a temperature dependence is predicted from theoretical considerations.[2]

The evaluation of the G factor from τ depends upon a knowledge of ν_{em} which has recently been measured[8] as $\langle \nu_{em} \rangle = 3p_0 T_e 10^5$ (sec^{-1}). Adopting this value, one obtains $G = 2.3 \times 10^{-2}$ at room temperature, which is an order of magnitude larger than in nitrogen for the same temperature.[2] The G factor in oxygen would be more than seven times the nitrogen value, even if one were to assume a somewhat larger value of collision frequency derived from the probability of collision, P_c, reported by others.[10]

If one takes the Maxwellian average of the Gerjuoy-Stein cross sections for rotational excitation, one obtains for the relaxation time constant[3]

$$\tau = \frac{3}{16}\left(\frac{\pi}{2}\right)^2 \frac{m^{1/2}}{qBN}(kT_e)^{1/2},$$

where m = electron mass, k = Boltzmann's constant, N = molecular number density, B = rotational constant, and $q = (8/15)Q^2 \pi a_0^2$, with Q equal to the quadrupole moment of the molecule and πa_0^2 being the Bohr cross section. Microwave laboratory determinations of τ shown in Fig. 2 would indicate that the effective quadrupole moment of oxygen is 2.8 in units of ea_0^2. This value is in complete disagreement with the small value, $Q < 0.33$, previously reported[11] for oxygen.

The reasons for the discrepancy are not clear. Some of the uncertainties of the measurements are as follows. It could be that the electron velocity distribution is not Maxwellian; this would yield a change on the average. Then there is the possibility that a large portion of the oxygen molecules are vibrationally or even electronically excited. If this is so, the theoretical bases do not apply to the experiment. The problem of nonvanishing spin of the ground state ($X\,^3\Sigma_g^-$) does not, according to Takayanagi,[12] yield significant changes. He, however, points out the possibility of short-range interactions being important.

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[9]The time decay of the electron energy after the removal of the ionization pulse [see Fig. 2(a) of reference 8] is not exponential, since the criterion $T_e - T_0 / T_0 \ll 1$ is not satisfied in this case. T_e = electron temperature, T_0 = gas temperature.
[10]Comprehensive list of references is given in reference 8.
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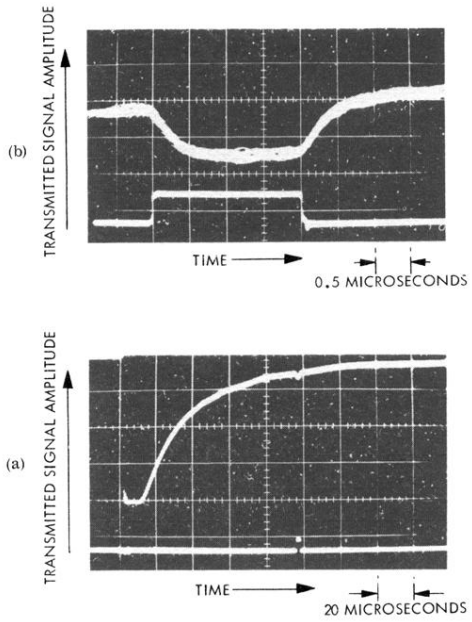

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