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# SIXTH QUARTERLY PROGRESS REPORT

PREPARED UNDER
U. S. ARMY SIGNAL CORPS CONTRACT
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UNDER THE TECHNICAL SUPERVISION
OF THE ATOMICS BRANCH OF
THE APPLIED PHYSICS DIVISION
U. S. ARMY SIGNAL RESEARCH AND
DEVELOPMENT LABORATORIES
AT FORT MONMOUTH

by

M. N. HIRSH
P. N. EISNER

R-146-6 31 DECEMBER 1962

THE G. C. DEWEY CORPORATION

AN EXPERIMENTAL INVESTIGATION OF
THE EFFECTS OF RADIATION ON THE PROPOGATION
OF ELECTROMAGNETIC SIGNALS IN AIR

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# I. INTRODUCTION

The present report covers work performed during the period 1 October to 31 December 1962. It includes a description of the present status of the equipment, and an account of a series of oxygen ionization experiments performed during the period. An interpretation of these results as well as previous results is given. In the last chapter the plans for the next quarter are discussed.

A paper will be given at the New York Meeting of The American Physical Society in January, 1963, in which the experimental techniques used and preliminary results of oxygen measurements thus far obtained will be presented. The abstract of that paper is attached to the present report as Section V.

## II. EXPERIMENTAL EQUIPMENT

### A. INTRODUCTION

Once again the first half of the quarterly period was used to improve the experimental equipment, and the second half of the period was devoted to experiments using the newly refined apparatus. As indicated in the Fifth Quarterly Report a magnetic beam switching device was constructed, tested, and used during the present quarter. The vacuum system was repaired, a McLeod gauge was added to an enlarged gas handling system to provide for low pressure measurements, and more accurate frequency measuring equipment was added to the rf circuitry. Much time and effort were expended in an unsuccessful attempt to isolate the cavity electrically from the rest of the system to use it as a Faraday cup for measuring true beam current to the cavity. Direct beam current measurement is thus still not possible.

### B. VACUUM

The vacuum system was repaired and cleaned. The repair consisted of having a new flange made for the gold O-ring which seals the ultra-high vacuum pumping stack to the 6" clean valve leading into the experimental cavity. The new flange was made for us by F. J. Cooke, Incorporated and was welded onto the valve after the old, warped flange had been cut off. In addition the geometry of the foreline was altered to give more space for additional flasks of reagent grade gas on our gas handling system.

Heating tapes were wrapped around the cavity and its tubulations during the zeolite bakeout in order to help pump out water vapor more quickly. After one week of pumping the following pressures were recorded:

| | |
|---|---|
| Nude gauge in cavity - | $1.5 \times 10^{-6}$ Torr |
| Gauge on pump stack - | $3.3 \times 10^{-7}$ Torr |
| Gauge on pump stack, cavity closed to pump - | $1.9 \times 10^{-7}$ Torr |

A small leak was again found at the gold O-ring, which we feel is responsible for the high ultimate pressure in the pump stack itself ($1.9 \times 10^{-7}$ Torr). The cavity pressure, however, we believe is limited by wall desorption, primarily of water vapor. This will be remedied when the cavity is baked above 100$^{o}$C. Nevertheless, the cavity vacuum is adequate for the purity of gases currently used, which contain typically 200 parts per million of impurity. With the evacuated cavity shut off from the pump, the pressure rises about one decade per hour. Thus after one hour, the pressure inside the cavity would be equal to the partial pressure of impurities in oxygen at a total pressure of 0.1 Torr. Above 0.1 Torr, therefore, the cavity contributed impurities are no more than the impurities brought in with the gas.

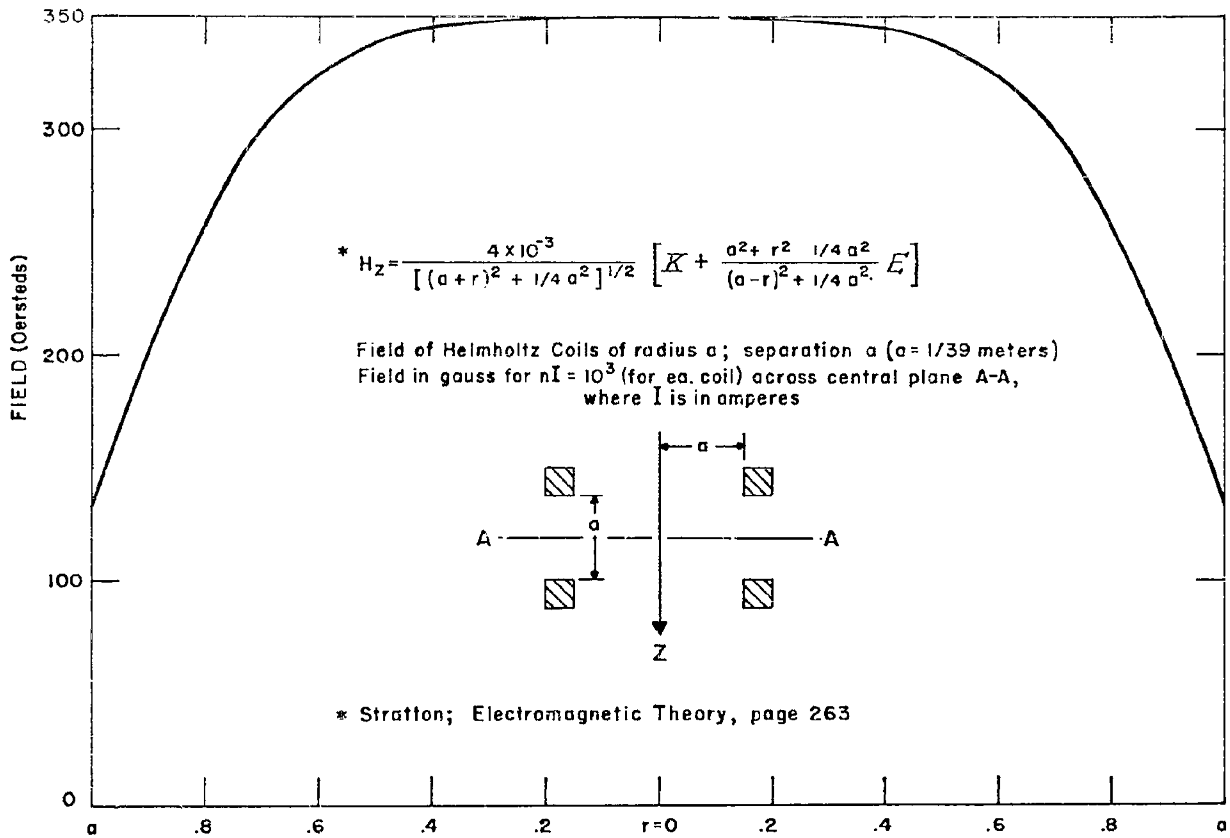
C. GAS HANDLING SYSTEM

The gas handling system has been enlarged to include six one-liter Pyrex Flasks each of Analyzed Reagent Grade oxygen and nitrogen. A small tilting McLeod gauge (Ace No. 8726) with a pressure range of 1 to $10^{-3}$ Torr has been added to the system. It is isolated from the clean gas by means of a liquid nitrogen-cooled trap.

D. MAGNETIC BEAM SWITCH

The magnetic beam switching unit pictured on page 27 of the Fifth Quarterly Report (figure 9 of that report) was constructed and tested during this quarter. Two coils, each having 50 turns of # 14 Teflon insulated copper wire, are placed in a Helmholtz coil arrangement (see figure 1) and driven in series by a

Figure 1. FIELD OF HELMHOLTZ COIL



Tabtron dc power supply which delivers up to 25 amperes. It was calculated that with ideal coils 20 amperes would deflect the 1.5 Mev electron beam 12 1/2$^{o}$. Experimentally, it has been found that 24 amperes are required, which reflects the departure of the coils from the ideal Helmholtz configuration. Figure 1 shows a calculation of the accelerating magnetic field, demonstrating the homogeneity characteristic of the Helmholtz configuration. This theoretical plot was used to calculate the electron trajectories.

All of the experiments performed during this quarter have used the beam switch in current measurements (see next section). The switched beam also permits us to measure the cavity resonant frequency in the absence of ionizing radiation quickly during the experimental run eliminating heating effects of the beam on the cavity and aluminum foil which, in the past, had limited the accuracy of frequency shift measurements to about 5 kcps at pressures greater than 5 Torrs. The technique of measurement utilizing the beam switch consists of switching the beam alternately between the cavity and a Faraday cup in sychronism with the swept-frequency oscillator in the rf circuit. This is illustrated in figure 2. The results of this technique will be described in later sections of this report.

## E. CURRENT MEASUREMENTS

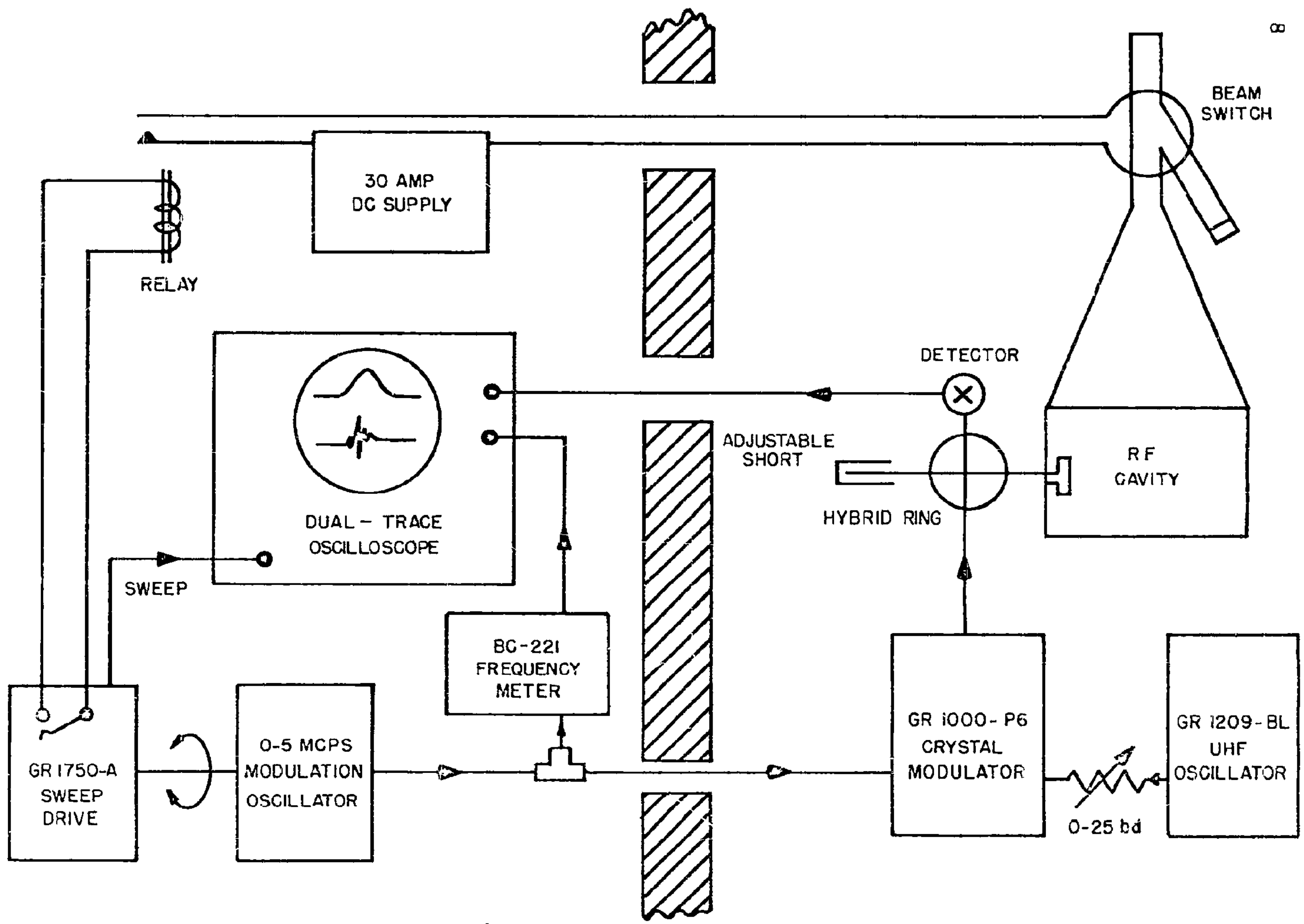
Van de Graaff electron beam currents are now measured by deflecting the beam into a side tube terminated by a Faraday cup. The beam actually entering the cavity is some fixed fraction of this current, the fraction depending on the mean scattering angle of the beryllium foil and the cavity-beam tube geometry. Much time and effort were expended to measure the cavity current directly, by electrically isolating the cavity from the beam tube and ground, and using it as a Faraday cup. The foreline leading to the cavity was insulated at a flanged joint, and the beam tube side of the 4-foot flange on the rf cavity was painted with several coats of glyptal to provide an insulating surface. The flange was then closed with insulated bolts. In the fastening process, however, some of the glyptal was apparently scraped off, and the cavity contacted the beam tube. Since considerable time had already been spent preparing the cavity for electrical isolation, and in fact the cavity had been taken off and put on the beam tube many times, it was decided to proceed to gas measurements without repairing the insulation break at this time. As a result, we are not yet able to measure the electron current to the cavity, but must rely on future calibrations and theoretical estimates.

F. RF CIRCUIT

Figure 2 is a block diagram of the rf circuit. It differs from the circuit used during the fifth quarter only in the use of the beam switch and consequent use of a frequency-swept display on the oscilloscope. A dual-trace oscilloscope displays the cavity resonance response on one trace and beat pattern from a BC-221 frequency meter on the other trace. As the frequency is swept to higher valves, the electron beam is on the cavity. At the end of this forward sweep, a switch in the sweep drive actuates a relay in the beam switch dc supply which switches the current into the Helmholtz coils, flipping the electron beam onto the Faraday cup. Meanwhile the modulation oscillator is sweeping down in frequency, enabling the experimenter to measure the resonant frequency of the gas filled cavity without ionization. The cycle then repeats itself.

The BC-221 frequency meter was calibrated against a Hewlett-Packard frequency counter and was found to be accurate and stable to better than 0.1 kilocycles per second. Frequency shifts with the BC-221 are measured to an accuracy of about 1 kilocycle per

Figure 2.
RF CIRCUIT DIAGRAM

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second by aligning the BC-221 marker on the scope with the top of the absorption curve. (Figure 2)

# III. OXYGEN EXPERIMENTS

## A. STEADY-STATE IONIZATION

We continued the measurements of steady-state ionization in oxygen as a function of pressure. In the fifth quarter we reported measurements (cf. figure 8, Fifth Quarterly Report) made over the pressure range 0.15-10 Torr using oxygen from Matheson cylinders, "Extra Dry Grade". However the impurities in the cavity due to the poor vacuum attained prior to filling the cavity exceeded the impurities in the cylinder gas.

The oxygen ionization experiments performed during this quarter were much less influenced by impurities. As indicated in Section II, Part B, impurity content is of the order of 200 parts per million of oxygen including cavity contributed impurities, because reagent grade oxygen was used and the cavity was evacuated to a pressure of $2 \times 10^{-6}$ Torr preliminary to filling. Table 1 lists the experiments and gives the experimental conditions prevailing for each run.

Notes to accompany Table I

1. All the runs grouped under one number are from the same flasks. Experiments started at low pressure and more gas was added to the cavity, thus increasing the pressure from experiment to experiment. The cavity was pumped out for at least 12 hours before another flask was opened.
2. "Oil", "Theory", and "McLeod" refer to the pressure measuring device used. The pressure in the 710 liter cavity due to a single flask (1 liter) is calculated to be 1.06 Torr and is denoted "theory" in the table.
3. The rf bridge was sometimes balanced to display dispersion, rather than absorption. A stable frequency counter (see page 7 ) was used to measure frequency in the first few experiments.

TABLE I - OXYGEN EXPERIMENTS

| GAS FLASK NUMBER | PRESSURE (TORR) | RF TECHNIQUE | LOW CURRENT SLOPE Kcps/$\mu$a |
|---|---|---|---|
| Cylinder | 1.75 $\pm$ 5% (oil) | Dispersion-counter | 0.875 |
| Cylinder | 1.6 $\pm$ 5% (oil) | Dispersion-counter | 0.97 |
| #1 | 1.06 $\pm$ 2% (theory) | Dispersion-counter | 1.23 |
| #2 | 1.06 $\pm$ 2% (theory) | Absorption-counter | 1.2 |
| #2 | 0.8 $\pm$ 5% (oil) | Absorption-counter | 1.44 |
| #2 | 0.65 $\pm$ 5% (oil) | Absorption-counter | 1.76 |
| #2 | 0.46 $\pm$ 10% (oil) | Absorption-counter | 2.2 |
| #2 | 0.31 $\pm$ 10% (oil) | Absorption-counter | 2.5 |
| #3 | 0.13 $\pm$ 5% (McLeod) | Absorption-BC-221 | 2.0 |
| #3 | 0.21 $\pm$ 5% (McLeod) | Absorption-BC-221 | 2.4 |
| #4 | .004 $\pm$ 15% (McLeod) | Absorption-BC-221 | $1.6 \times 10^{-2} \pm 100\%$ |
| #4 | .015 $\pm$ 10% (McLeod) | Absorption-BC-221 | .092 |
| #4 | .021 $\pm$ 10% (McLeod) | Absorption-BC-221 | 0.166 |
| #4 | .033 $\pm$ 10% (McLeod) | Absorption-BC-221 | 0.28 |
| #4 | .063 $\pm$ 5% (McLeod) | Absorption-BC-221 | 0.92 |
| #4 | 0.10 $\pm$ 5% (McLeod) | Absorption-BC-221 | 1.48 |
| #4 | 0.20 $\pm$ 5% (McLeod) | Abosrption-BC-221 | 2.04 |
| #4 | 0.41 $\pm$ 5% (McLeod) | Absorption-BC-221 | 2.2 |
| #4 | 0.59 $\pm$ 5% (McLeod) | Abosrption-BC-221 | 1.64 |
| #4 | 0.9 $\pm$ 5% (McLeod) | Absorption-BC-221 | 1.16 |
| #4 | 2.0 $\pm$ 5% (oil) | Absorption-BC-221 | 0.66 |

The measurements described in Table I yield linear plots of $\Delta f$ versus electron beam current. The slopes of these straight lines can then be related to ionization and charge removal through the steady-state equations described in our First Quarterly Report, and unfortunately never stated in these reports in a form explicitly relating to the slopes. For completeness, we restate the problem here.

We assume the gas to be ionized by beam electrons in binary collisions, such that

$$(1) \quad \left(\frac{dn}{dt}\right)_{gain} = Kpi$$

where p is the gas pressure in Torrs, i the beam current in microamperes. The coefficient K depends on beam geometry and energy loss per ion pair, and will be measured directly in the next report period. Since only linear processes are being studied in this report, the only loss mechanisms we need consider are 3-body electron attachment according to the reaction $O_2 + O_2 + e \longrightarrow O_2^- + O_2$, and diffusion, perhaps ambipolar. These losses can be written in a rate equation as

$$(2) \quad \left(\frac{dn}{dt}\right)_{loss} = \alpha p^2 n - \frac{c}{p} n.$$

In the steady-state, (1) and (2) can be equated, and after some algebra one can write

$$(3) \quad \frac{n}{I} = \frac{Kp}{\alpha p^2 + \frac{c}{p}}$$

The compilation of the slopes obtained from the measurements in Table 1 is shown in Figure 3. Included in the figure are data from the last quarterly period, measured in cylinder oxygen. New

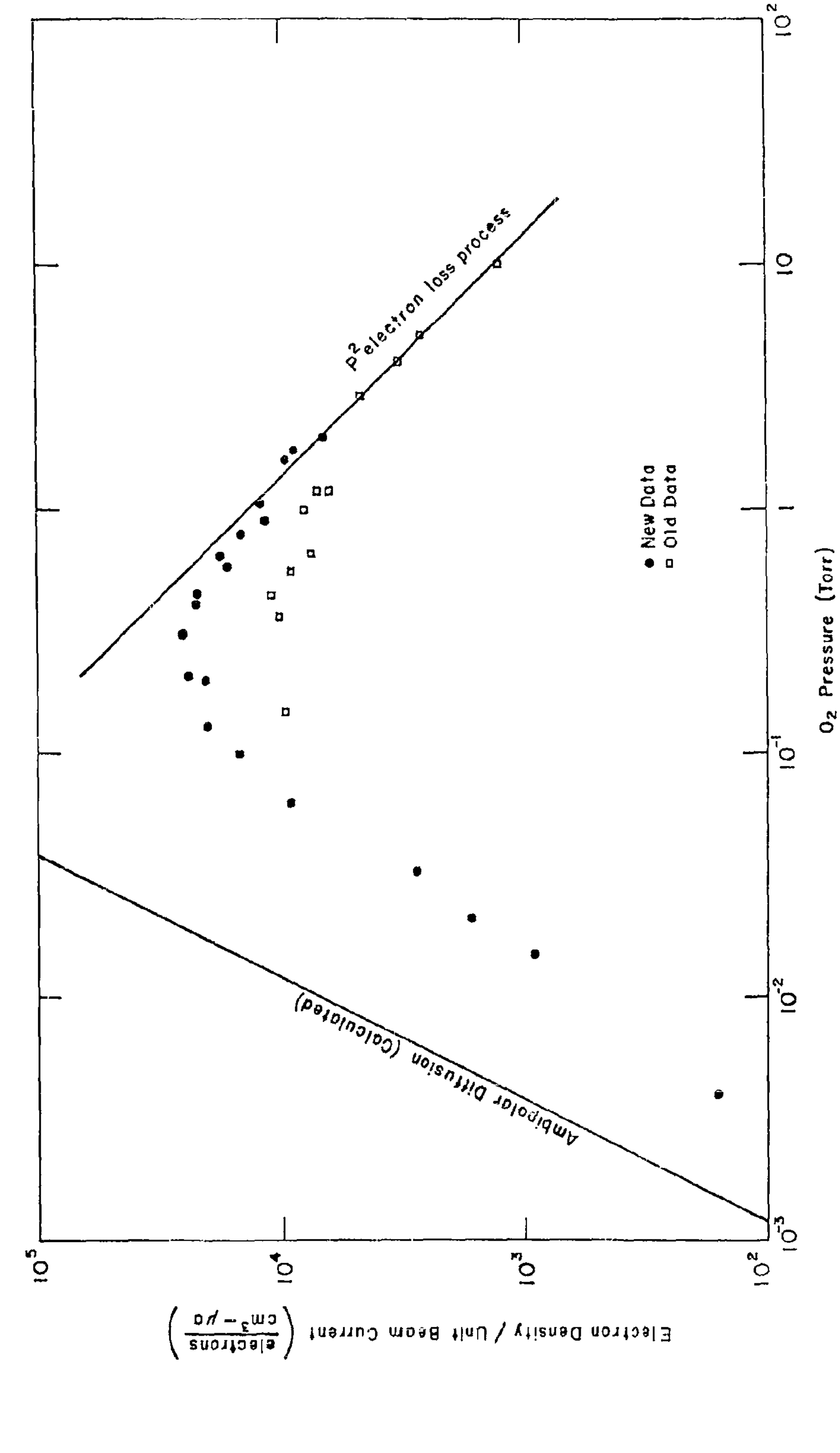



Figure 3. COMPILATION OF OXYGEN DATA

data are solid circles; old data are open squares. At pressures lower than 2 Torr the old data do not agree with the new measurements. This may be attributed to the lower purity of oxygen used in the early experiments. Notice that the high pressure slopes can be fitted by a $p^{-1}$ dependence, as required at high pressures from Equation 3, due to the $p^2$ dependence of the attachment term. This fit is significant for several reasons. It represents the lowest pressures at which three body attachment has been observed as the dominant electron removal mechanism. It also strengthens our belief that the pressure range above 1 Torr is characterized by secondary electrons which have completely thermalized, or the 1/p dependence would not be in evidence over a decade of pressure. The measurements of K during the next period should then permit a measurement of $\alpha$.

The behavior of the low pressure data cannot be understood at this time. Two features of the data should be mentioned, however. First, private communications from other workers studying oxygen indicate "unusual" behavior of the low-pressure data, all agreeing, however, that the electron loss is about 100 times too fast to be explained by simple diffusion. A calculated ambipolar diffusion loss is indicated in the figure for illustration. For this calculation, a value for $D_{ap}$ of 100 Torr-cm$^2$/sec was assumed, and the diffusion considered to proceed in fundamental mode. On the other hand, a recent publication(1) shows measurements similar to ours, but in a much smaller chamber. The pressures of the peaks of our respective curves of specific ionization *versus* pressure scale with diffusion frequency, that is, with $\Lambda^{-2}$ for our respective containers. This makes a diffusion explanation of the low pressure data at least plausible.

(1) J. A. Carruthers, Can. Jour. Phys. 40, 1528 (1962)

B. MEASUREMENT OF Q

Margenau[1] has shown that the ac conductivity of a weakly ionized gas may be written

$$(1) \quad \sigma_c = \frac{4\pi}{3} \frac{ne^2}{m\omega} \int_0^\infty \frac{(\nu_c/\omega - j)}{1 + \left(\nu_c/\omega\right)^2} v^3 \frac{\partial f_o}{\partial v} dv$$

Here e, m, and n are the charge, mass, and volume density of free electrons, $\nu_c$ is the elastic collision frequency of electrons of velocity v, and $f_o$ is the first term in the spherical harmonic expansion of the electron velocity distribution function. If $\nu_c$ were not a function of velocity, it is apparent that the ratio of real to imaginary part of $\sigma_c$ would be equal to $\nu_c/a$, from which $\nu_c$ could be found directly from a simple microwave measurement (cf 1st Quarterly Report):

$$(2) \quad \sigma_c/\sigma_l = \frac{\Delta(1/Q)}{2\Delta\nu/\nu_o} \longrightarrow \frac{\nu_c}{\omega} \left(\nu_c \neq (u)\right)$$

For oxygen, however, the electron collision frequency in the low energy range can be approximated by[2]

$$(3) \quad \nu_c = 2.9 \times 10^9 up, \text{ for } u < 0.1 \text{ ev}$$

where u is the electron energy in volts, p the gas pressure in Torrs. We assume that the electrons have a temperature $T_e$ corresponding to the mean energy $\bar{u}$. (We neglect electron heating in the ac probing field). To a good approximation we can write[3]

$$(4) \quad \sigma_r/\sigma_i \simeq A(\sigma) \quad \nu_c/\omega$$

(1) H. Margenau, Phys. Rev. 69, 508 (1946)
(2) A. V. Phelps, Jour. App. Phys. 31, 1724 (1960)
(3) Phelps, Fundingsland, and Brown. Phys. Rev. 84, 559 (1951)

where $A(\sigma)$ is given in the graph of Figure 4.

Therefore an expression may be found for $\upsilon_c$ using equation (2) and (4).

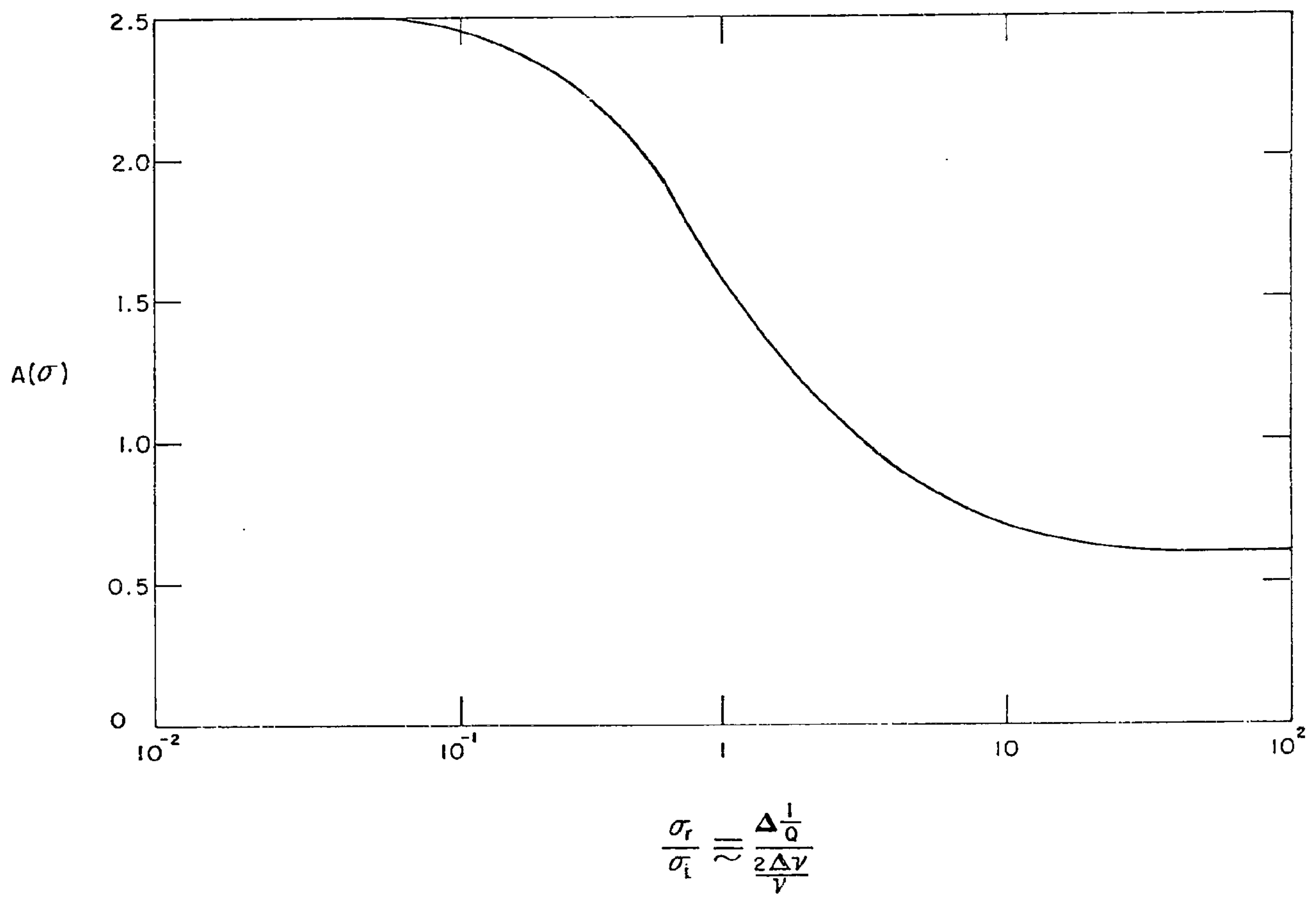
$$(5) \quad \upsilon_c = \left[\frac{\Delta \frac{1}{Q}}{2\Delta\nu/\nu_o}\right] \frac{\omega}{A(\sigma)} = \left[\frac{\Delta f_e - \Delta f_o}{2\Delta \nu}\right] \left[\frac{2.45\text{x}10^9}{A(\sigma)}\right]$$

This equation along with equation (3) yields the electron temperature in terms of the experimentally determined parameters: $\Delta\nu$ the frequency shift of the cavity $\Delta f_e$ the cavity "half" width with electrons, $\Delta f_o$ the cavity "half" width without electrons, and p the pressure of the gas.

Some very preliminary measurements of cavity Q were made during the quarter. They were made by balancing the rf bridge in the dispersion mode and measuring the bandwidth between extrema (inflection points of the absorption curve). The measurements proved to be difficult to make because of the inherent bridge noise in dispersion, making in-beam measurements almost a matter of guesswork. Also these measurements were made early in the quarter when the rf bridge had not been brought to its present state of accuracy. In fact these few preliminary measurements are consistent with electron temperatures $0.02 < T_e < 0.1$ev.

In the next quarter alternate experimental arrangements will be tried in order to reduce the noise which had obscured the Q changes in our early experiments. It is hoped that reducing the noise and using the new rf frequency measuring techniques described in this report will combine to yield reproducible and reliable Q measurements.

Figure 4. $A(\sigma)$ versus $\left(\frac{\sigma_r}{\sigma_i}\right)$



## IV. PLANS FOR NEXT QUARTER

The next quarter will be devoted entirely to experimental work. The experiments will include the following:

1) In Oxygen

   a. Q measurements
   b. Transient measurements

2) In Air

   a. Steady-state ionization _versus_ pressure
   b. Q measurements
   c. Transient measurements

3) Electron beam current calibration

## V. ABSTRACT OF APS PAPER N. Y. JANUARY 1963

Steady-State Ionization in Electron-Irradiated Oxygen*

Merle N. Hirsh and Philip N. Eisner, The G. C. Dewey Corporation, New York, New York

Abstract

A technique has been developed for measuring thermal electron processes in gases in a steady-state experiment obviating the need to make transient measurements in the afterglow. 1.5 MeV electrons from an accelerator irradiate the gas uniformly, producing ions and secondary electrons which are rapidly thermalized by gas collisions. The gas is contained in a 710 liter cylindrical rf cavity resonant in the $TE_{011}$ mode at 390 Mcps to permit microwave diangostics. The large cavity size minimizes wall effects, and ultra-high vacuum techniques safeguard gas purity. Preliminary measurements of steady-state ionization made in oxygen will be presented. The data yield an electron removal process linear in electron density, and varying with the square of the gas pressure with the rate coefficient $1.9 \times 10^{-30}$ $cm^6$/sec. This is identified as three-body attachment of electrons to $O_2$ in view of the agreement with published values for this rate coefficient. The technique holds particular promise in situations where several competing processes occur, because of the simplicity of the analysis, and in pressure regions where microwave discharges cannot be reliably maintained.

* Work supported by the Defense Atomic Support Agency through the Army Electronics Research Laboratory, Ft. Monmouth, New Jersey.

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