R Geballe

CONFERENCE ON GASEOUS ELECTRONICS

SPONSORED BY THE
AMERICAN PHYSICAL SOCIETY,
DIVISION OF ELECTRON PHYSICS

PROGRAM AND ABSTRACTS OF PAPERS

GENERAL ELECTRIC RESEARCH LABORATORY
THE KNOLLS
SCHENECTADY, NEW YORK
OCTOBER 4, 5, 6, 1951

1951 CONFERENCE ON GASEOUS ELECTRONICS

Technical Program

A. FUNDAMENTAL PROCESSES
Chairman: O. Oldenberg, Harvard University

Thursday October 4 10:00 A. M.

A 1. Ionization by Electron Impact on CO, N_2, NO, and O_2. H. D. Hagstrum, Bell Telephone Laboratories

A 2. Attachment of Thermal Electrons in Oxygen. Manfred A. Biondi, Westinghouse Research Laboratories

A 3. Ionization and Attachment in Oxygen. Melvin A. Harrison and Ronald Geballe, University of Washington

A 4. Probability of the Formation of He_2^+, N_2^+, and A_2^+ from Excited Atoms. J. A. Hornbeck, Bell Telephone Laboratories.

Intermission

A5. Positive Ions in the After Glow of a Low-pressure Helium Discharge. Arthur V. Phelps, Massachusetts Institute of Technology

A 6. The Formation and Decay of Metastable Mercury Molecules. A. O. McCoubrey, Westinghouse Research Laboratories

B. FUNDAMENTAL PROCESSES (Cont.); HOT CATHODE ARCS
Chairman: L. Malter, R. C. A. Laboratories

Thursday October 4 2:45 P. M.

B1. Preliminaries on Photoionization in N_2 and O_2 in the Vacuum Ultraviolet. G. L. Weissler and Nathan Wainfan, University of Southern California

B 2. Dissociative Attachment of Electrons to Diatomic Molecules. T. Holstein, Westinghouse Research Laboratories.

Intermission

B 3. Some Problems of the Cesium Rectifier. A. W. Hull, General Electric Research Laboratory

B 4. Clean-up of Helium in an Arc Discharge. M. J. Reddan and G. F. Rouse, National Bureau of Standards

B5. Tritium Tracer Experiment for Investigating Gas Clean-up in Hydrogen Thyratrons. Sol Schneider, Signal Corps Engineering Laboratories

B 6. New Investigations of the Plasma. D. Gabor, Imperial College, London.

C. PLASMAS AND PROBES
Chairman: W. P. Allis, Massachusetts Inst. of Tech.

Friday
October 5
9:30 A. M.

C1. Ambipolar Diffusion of Electrons and Ions into a Cylinder. Joseph Slepian and L. S. Frost, Westinghouse Research Laboratories

C2. Energies of Positive Ions in a Cold-cathode Discharge in a Magnetic Field. John Backus and Norman E. Huston, University of Southern California

C3. On the Discharge Mechanism in Hot-cathode Rare-gas Diodes, Especially with Negative Arc Drop. G. Medicus and G. Wehner, Wright Field

C4. Plasma Density Distributions in the Anode Glow Mode of an Externally-heated Hot-cathode Arc. E. O. Johnson and W. M. Webster, R. C. A. Laboratories

Intermission

C5. Reliability of Probe Measurements in Hot-cathode Gas-diodes. Gottfried Wehner and Gustav Medicus, Wright Field

C6. Probe-plasma Interaction. W. M. Webster, R. C. A. Laboratories

C7. Magneto-ionic Resonance in Microwave Cavities. Benjamin Lax, Air Force, Cambridge Research Center

D. MICROWAVES: ARCS
Chairman: W. F. Huxford, Northwestern University

Friday
October 5
2:00 P. M.

D1. Invited Paper
Growth (Build-up) of an Electrodeless High-frequency Discharge. A. von Engel, Oxford University

D2. High-frequency Discharge at Low Pressures, Characterized by Secondary Electron Resonance. Albert J. Hatch and H. Bartel Williams, New Mexico College of A. and M. A.

D3. An Anisotropic Gas Discharge Plasma As a Medium for Guided Microwave Propagation. L. Goldstein, M. Lampert, and J. Heney, Federal Telecommunication Laboratories, Inc.

D4. Electron Distribution Functions in Combined D-C Space Charge and A-C Fields. Ira B. Bernstein and T. Holstein, Westinghouse Research Laboratories

Intermission

D5. Further Results of Studies of Microwave Oscillations in Gaseous Discharges. Roger P. Wellinger, Joseph A. Saloom, and James E. Etter, University of Illinois

D6. Retrograde Arc Motion of Supersonic Speed. Charles G. Smith, Raytheon Manufacturing Company

D7. The Tungsten Arc in Mixtures of Argon and Helium. T. B. Jones and Merrill Skolnik, Johns Hopkins University

D8. Electrical Phenomena in the Hissing Arc. T. B. Jones and B. H. List, Johns Hopkins University

E. SPARK, GLOW, AND CORONA
Chairman: D. Alpert, Westinghouse Research Labs.

Saturday
October 6
9:30 A. M.

E1. Luminous Fronts Resulting from Constrained Low-pressure Spark Expansion. Richard G. Fowler and Walter D. Compton, University of Oklahoma

E2. Band Spectra in Pulsed Nitrogen Discharges. C. F. Hendee, Northwestern University

E3. Electrical Fields in the Crooke's Dark Space of Low-pressure Glow Discharges by Electron Beam Probes. Robert P. Stein, University of California (Presented by L. B. Loeb)

E4. Positive Point-to-plane Corona Studies in Air. M. Menes and L. H. Fisher, New York University

E5. Mechanisms of Positive and Negative Corona in Hydrogen and Argon Between Coaxial Cylindrical Electrodes over an Extended Area. Eugene J. Lauer, University of California (Presented by L. B. Loeb)

E6. Hollow Cathodes for VR-tubes with Extended Current Range. F. C. Todd and J. E. Drennan, Battelle Memorial Institute

A1. IONIZATION BY ELECTRON IMPACT IN CO, N_2, NO, and O_2.

H. D. Hagstrum, Bell Telephone Laboratories, Murray Hill, New Jersey

All the ionization processes which occur on electron impact in CO, N_2, NO, and O_2 have been restudied with a special mass spectrometer in which mass, appearance potential, and initial kinetic energy (by retarding potentials after mass analysis[1]) can be determined simultaneously. Results agree well with kinetic energy determinations based on velocity dispersion in the analyzer[2], on transverse deflection in the analyzer and discrimination at the exit slit[3], and on retarding potential measurements without mass analysis[4,5]. Appearance potential measurements generally agree very well with previous measurements[2,4,5]. In oxygen the present work reveals structure in the appearance potential data missed before[2] and brings agreement with the accepted values of $D(O_2)$ and EA(O). The new measurements in CO, N_2, and NO appear to strengthen the "electron impact position" regarding controversial energetic quantities related to these molecules[6], indicating again that D(CO) = 9.61 ev, L(C) = 136 kcal., $D(N_2)$ = 7.38 ev, D(NO) = 5.30 ev, EA(O) = 2.2 ev, and that the O^- ion has an excited state very near the positive energy continuum.

---

1. R. E. Fox and J. A. Hipple, Rev. Sci. Inst. 19, 462 (1948).
2. H. D. Hagstrum and J. T. Tate, Phys. Rev. 59, 354 (1941).
3. C. E. Berry, Phys. Rev. 78, 597 (1950).
4. W. W. Lozier, Phys. Rev. 44, 575 (1933); ibid. 45, 850 (1934); ibid. 46, 268 (1934).
5. E. E. Hanson, Phys. Rev. 51, 86 (1937).
6. H. D. Hagstrum, Phys. Rev. 72, 947 (1947); J. Chem. Phys. 16, 848 (1948).

A2. ATTACHMENT OF THERMAL ELECTRONS IN OXYGEN.
Manfred A. Biondi, Westinghouse Research Laboratories

Microwave techniques(1) are used to measure the removal of electrons in oxygen. At sufficiently high gas pressures and low electron densities, attachment of electrons to oxygen molecules becomes the dominant removal process. The cross section for attachment of thermal electrons (.04 ev average energy) is found to be $Q_a = 1.2 \times 10^{-22}$ cm^2, independent of pressure over the range 8 - 25 mm Hg. This value agrees with the calculated cross section for radiative capture of electrons. On the other hand, it disagrees with the Bloch-Bradbury theory of electron capture by excitation of molecular vibration(2) which predicts a cross section of 10^{-19} cm^2 for thermal electrons in O_2. It is hoped that future studies of the attachment in O_2 as a function of electron energy will resolve this discrepancy.

---

1. M. Biondi, Rev. Sci. Instr. 22, 500 (1951).
2. F. Bloch and N. Bradbury, Phys. Rev. 48, 689 (1935).

A3. IONIZATION AND ATTACHMENT IN OXYGEN.

Melvin A. Harrison and Ronald Geballe, Department of Physics, University of Washington

Ionization currents have been measured in oxygen using plane-parallel electrodes separated as far as four centimeters. The curves thus obtained cannot be fitted by assuming that ionization alone takes place. If the effects of attachment are also considered, good fits are possible. Values for the coefficients of both of these processes have been determined for E/p in the range from 30 to 75 volts/cm/mm. The first Townsend coefficient behaves normally and does not exhibit the sudden dropping-off found by K. Masch[1] for $E/p < 40$, which probably was due to the increasing importance of attachment. Furthermore, an appreciable attachment probability persists to considerably larger E/p (> 60) than indicated by previous results[2,3], which may have been obscured by ionization. An explanation of the process now becomes possible in terms of atomic rather than molecular ions.

---

1. K. Masch, Arch. f. Elektrotechnik, 26, 587 (1932).
2. N. Bradbury, Phys. Rev. 44, 883 (1933).
3. R. H. Healey and J. W. Reed, "The Behavior of Slow Electrons in Gases," Amalgamated Wireless Limited, Sydney, 1941.

A4. PROBABILITY OF THE FORMATION OF He_2^+, Ne_2^+, and A_2^+ FROM EXCITED ATOMS. J. A. Hornbeck, Bell Telephone Laboratories, Murray Hill, New Jersey

Rough measurements of the probability of forming molecular ions in the noble gases have been obtained from studies[1] of the pulsed Townsend discharge in which the pressure is varied at constant E/p_o, the ratio of electric field to gas pressure. Equations based on the established formation process[2] when fitted to the data give values of two parameters; first, the ratio η_{exc}/η_i, where η_{exc} and η_i are first Townsend coefficients, i.e., the number of excitations (of the proper kind) and ionizations/volt/electron, and second, the product $\tau\sigma$, where τ is a mean lifetime before decay by radiation of the several excited atomic states involved and σ is a mean cross section for the process. The results are: $\tau\sigma \times 10^{22}$ cm^2 sec = 0.5 in helium, 0.5 in neon, and 0.9 in argon; the order of magnitude of η_{exc}/η_i is 0.2 in helium at E/p_o = 14 volts/cm x mm Hg, 0.2 in neon at E/p_o = 15, and 1 in argon at E/p_o = 30. These results indicate that molecular ions should cause observable deviations from the Paschen breakdown (similitude) law; also d-c measurements of η as usually defined should show a pressure dependence at low E/p_o.

---

1. J. A. Hornbeck, Phys. Rev. 83, 374 (1951).
2. J. A. Hornbeck and J. P. Molnar, Phys. Rev. (in press).

A5. POSITIVE IONS IN THE AFTERGLOW OF A LOW-PRESSURE HELIUM DISCHARGE*. Arthur V. Phelps**, Research Laboratory of Electronics, Massachusetts Institute of Technology

The positive ions responsible for the ambipolar diffusion coefficient for helium reported by Biondi and Brown[1] have been identified as He^+ ions. The positive ions which diffuse to the walls were studied with a mass spectrometer. The average electron density was determined from the shift in the resonant frequency of the microwave cavity. As the pressure of the helium was increased, the dominant ion in the afterglow was found to change from He^+ to He_2^+. The rate of conversion of He^+ ions to He_2^+ ions was estimated from the electron density decay data to be about one-third the value predicted by Bates[2].

These experiments show that there is good agreement between the theoretical predictions and recent experimental determinations of the mobility of the He^+ ion in helium. The dominance of the He_2^+ ion at the higher pressures lends support to the proposal[2] that the He_2^+ ion is responsible for the large electron-positive ion recombination coefficients observed by Biondi and Brown[1].

---

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and O. N. R.
** Now at Westinghouse Research Laboratories, East Pittsburgh, Penn.
1. M. A. Biondi and S. C. Brown, Phys. Rev. 75, 1700 (1949).
2. D. R. Bates, Phys. Rev. 77, 718 (1950).

A6. THE FORMATION AND DECAY OF METASTABLE MERCURY MOLECULES. A. O. McCoubrey, Westinghouse Research Laboratories

The program on the persistent band fluorescence of mercury vapor[1] has now achieved the point where the observations can be classified in a physically interpretable manner. The following results have been obtained: (a) The ratio of intensity of the visible band (4850 Å) to that of the ultraviolet band (3350 Å) is essentially proportional to the square of the vapor density N. (b) Both bands decay according to a curve which is characterized by two time constants. The longer of these has been studied quite extensively; it is found to obey a relationship of the type $1/\tau = A/N + B + C N^2$. (c) By the use of two different enclosure geometries the diffusion contribution has been separately evaluated; the collision radius obtained therefrom is 7 Å. These results may be interpreted according to the following picture. Incident 2537 Å radiation creates $^3P_1$ atoms which upon collision are converted to the $^3P_0$ metastable state. The metastable atoms then combine chemically with normal mercury atoms to form the $^3O_u^-$ state of Hg_2. This state decays both spontaneously by the emission of the ultraviolet band and by collision-induced radiation of the visible band.

---

1. Phys. Rev. 82, 567 (1951); 76, 1259 (1949).

B1. PRELIMINARIES ON PHOTOIONIZATION IN N_2 AND O_2 IN THE VACUUM ULTRAVIOLET*. G. L. Weissler and Nathan Wainfan, Physics Department, The University of Southern California

Using a normal incidence vacuum spectrograph as a monochromator, radiation from a constant intensity light source is passed through an exit slit into a chamber which contains at low pressures either N_2 or O_2. Photoionization produced in these gases is measured as a function of wave length with a low-voltage ionization chamber. Energy measurements of the radiation passing through the exit slit are made with a sensitive thermocouple, and the number of photons per second entering the ionization chamber is determined. From this and the ions collected the photoionization cross sections can be obtained. A detailed description of the apparatus will be given together with preliminary results.

* The aid of the O.N.R. is gratefully acknowledged.

B2. DISSOCIATIVE ATTACHMENT ON ELECTRONS TO DIATOMIC MOLECULES. T. Holstein, Westinghouse Research Laboratories

According to the Franck-Condon Principle, the reaction $XY + e \rightarrow X + Y^-$ proceeds in two stages. The electron is first captured by the neutral molecule without alteration of the positions and velocities of the nuclei; the resultant XY^- complex then dissociates into the final products. Now, in the region where the potential curve of XY^- lies above that of XY, the molecular ion is unstable towards autodetachment. Hence, the cross section Q for the reaction is equal to the cross section Q_C, for the formation of XY^-, multiplied by the probability e^{-T_S/τ_A} that XY^- dissociate without autodetachment. (Here, τ_A is the autodetachment lifetime and T_S the "stabilization" time required for the nuclei to reach the crossing point of the XY and XY^- potential curves.) Q_C itself is readily obtained in terms of τ_A from the "one-level dispersion" formula often employed in the theory of nuclear reactions. The final expression for Q contains τ_A which, for the present, we treat as a phenomenological constant. Values of τ_A required to effect agreement with experiment, e.g., for the case of O_2, are $\sim 10^{-15}$ sec, which, though somewhat smaller, is still of the order of magnitude of auto-ionization times computed for light atoms(1).

---

1. Ta-You Wu, Phys. Rev. 66, 291 (1944).

B4. CLEAN-UP OF HELIUM IN AN ARC DISCHARGE. M. J. Reddan and G. F. Rouse, National Bureau of Standards

The results of an investigation of the clean-up of helium gas in an arc discharge by a negatively-charged tantalum wire probe were reported earlier. More recent studies have been made with a tube in which the probe is a nickel cylinder. A particularly important feature of the tube design is that the amount of gas recoverable from the probe can be clearly distinguished from that which is recoverably from parts of the tube near the probe. The following statements apply to a nickel probe: 1. Severe sputtering of nickel onto the glass wall of the tube occurs at probe potentials as low as 100 volts. 2. Over-all recovery of gas has averaged about 85 per cent. 3. Heating the sputtered layer to 325°C for three hours drives off gas to about 70 per cent of the total recovered. 4. Heating the probe to 825°C for 1.5 hours yields gas to about 30 per cent of the total recovered. 5. Using the number of atoms recovered from the probe as a measure of the number trapped in the probe, one finds that the rate of clean-up increases with probe voltage in a manner quite like that reported previously for tantalum. At a probe potential of about 100 volts, three out of every ten thousand ions which strike will stick in the probe.

B5. TRITIUM TRACER EXPERIMENT FOR INVESTIGATING GAS CLEAN-UP IN HYDROGEN THYRATRONS. Sol Schneider, Signal Corps Engineering Laboratories

As a means of studying the clean-up of hydrogen in pulse-operated thyratrons, standard hydrogen thyratrons are filled with a 1 per cent tritium (H^3_2), 99 per cent hydrogen (H^1_2) mixture to normal pressure (600 microns). These tubes are then operated in a line-type pulse modulator circuit. At various stages during the life of the tube, from initial filling to destruction, the tubes are disassembled and the parts are checked for activity using an "inside" beta counter and autoradiographs. The "inside" beta counter is calibrated against standard beta sources, and the activity can be interpreted in terms of quantities of tritium.

The activity on the surfaces of the parts of the tube as indicated by the "inside" beta counter neglects the variations in distribution of the tritium over the surface of the parts. The autoradiographs, however, give detailed pictures of the distribution of tritium on any surface. Examination of autoradiographs has indicated considerable tritium on those surfaces which are covered with evaporated materials, subjected to heavy ion bombardment, or are in a strained state.

Examination of the distribution of tritium with respect to depth for both the glass and metal parts is now being made.

B6. NEW INVESTIGATIONS ON THE PLASMA. D. Gabor, Imperial College, London

The interaction of electrons in highly ionized gases has remained a very obscure subject, until recently. The classical experiments of I. Langmuir and H. Mott-Smith indicated very strong energy- and momentum exchange between electrons, which could not be accounted for by binary collisions. Recent experiments, carried out by Mr. A. E. Ash in the Imperial College, London, have conclusively shown that the binary collision formulae of Langmuir, Thomas and of other authors give a substantially correct value for the diffusion of a very weak electron beam in a plasma which is in thermal equilibrium. Such a plasma is produced very easily by heating a tubular barium-strontium oxide cathode, which is coated inside. The oxide coating is capable of emitting a very weak positive ion current, which is drawn out by the electron space charge, and substantially neutralizes it, forming a plasma very nearly in equilibrium at the temperature of the coating.

These experiments prove that the momentum and energy interchange due to the collective action of large numbers of electrons and ions is in fact very weak, weaker than the effect of binary collisions. This disproves a paper by the author, 1933, in which the collective action was strongly overestimated. A new attack on the problem, already outlined by I. Langmuir in 1928 was more successful. The collective interaction is treated as the interaction of the beam electron with random plasma waves, and is found to be only a fraction of the binary interaction, which is itself very weak.

It now becomes necessary to give a new interpretation to the experimental results of Langmuir and Mott-Smith obtained in mercury arcs at extremely low pressures. These arcs cannot have been in a steady state, even if no strong oscillations could be picked up outside. Theoretical work on such apparently steady, but in fact violently turbulent arcs has already made some progress.

C1. AMBIPOLAR DIFFUSION OF ELECTRONS AND IONS INTO A CYLINDER. Joseph Slepian and L. S. Frost, Westinghouse Research Laboratories

Previously reported experiments in ambipolar diffusion done under the direction of the senior author gave results at variance with the behavior expected from Schottky's theory of ambipolar diffusion. This paper extends the study and shows how experimental data and theoretical predictions are brought into agreement in the absence of a magnetic field and under suitable experimental conditions. The causes of the previous disagreement are shown to be (1) operation of the arc at a voltage above normal, resulting in reduced rates of decay of ion density; (2) the presence of probe currents due to electron emission from the probe; (3) insufficient ion current densities in the early experiments to assure equal ion and electron densities, as required by the theory; and (4) an extension to the theory necessary because of the appreciable size of the ionic mean free path relative to the tube radius. New experimental data is presented illustrating all these considerations, and equations are derived governing causes (3) and (4).

C2. ENERGIES OF POSITIVE IONS IN A COLD-CATHODE DISCHARGE IN A MAGNETIC FIELD*. John Backus and Norman E. Huston, Physics Department, The University of Southern California

Studies are being made of the energy distribution of positive ions in a cold-cathode discharge in a strong magnetic field. The discharge is of the Philips Ionization gauge type previously described(1) operating at about 0.3 amp at 800 volts in a magnetic field of 2000 gauss; using copper cathodes in argon gas at about 1-3 microns pressure. The discharge is shut off periodically for approximately 50 microseconds by means of a pulsing unit to be described, and the ion current to the cathode during the off period is observed on an oscilloscope. Analysis of this current shows that the ions flowing to the cathode after the discharge is extinguished have an approximately Maxwellian distribution with a temperature equivalent of 0.8 to 1.3 volts, depending on the discharge current.

---

* Supported by the Research Corporation and the O.N.R.

1. A. Guthrie and R.K. Wakerling, Electrical Discharges in Magnetic Fields, Chapter 11, McGraw-Hill Book Co., New York (1949).

C3. ON THE DISCHARGE MECHANISM IN HOT-CATHODE RARE-GAS DIODES, ESPECIALLY WITH NEGATIVE ARC DROP. G. Medicus and G. Wehner, WCESD, Wright Field

By decreasing the work function of the anode (evaporation of Ba) and at the same time increasing the work function of the cathode (indirectly heated Ta cathode), the voltage-current characteristic is shifted so that regions of negative d-c voltage drop appear. EMF's of 0.8 volts at amperages in the order of 0.5 amp were obtained in Xe of about 200 μ Hg pressure. In this case about 0.3 per cent of the cathode heating power was directly transformed into electrical energy. The effect is brought about by the electrostatic field existing between the high work function cathode and the low work function anode short circuited outside, which is superimposed to the space charge field of the discharge. The electrons emitted from the cathode have a potential energy with respect to the anode that is roughly equal to the work-function difference between cathode and anode. Otherwise such an EMF discharge in essence behaves like a normal low-voltage arc discharge with the characteristic potential maximum between the electrodes.

C4. PLASMA DENSITY DISTRIBUTIONS IN THE ANODE GLOW MODE OF AN EXTERNALLY-HEATED HOT-CATHODE ARC. E. O. Johnson and W. M. Webster, RCA Laboratories Division, Radio Corporation of America

The plasma associated with the anode glow mode(1) of an externally-heated hot-cathode arc is a particularly convenient one to study since the balance and behavior of the particles can be accounted for with a good degree of certainty. Because of the peculiar potential distribution of the discharge, electrons enter the plasma from the cathode against a small retarding field and so retain a temperature close to that of the cathode. Ions are generated in the electron sheath at the anode by electrons which travel from the plasma to the anode. These ions fall into the plasma and maintain its density against diffusion losses of the ions to the end plates. Since ions cannot be lost either at the cathode or anode, the total ion current arriving at the end plates is a direct measure of the total ion current entering the plasma, in cases where the conditions are such that the volume recombination losses are negligible.

Plasma density distributions have been derived in terms of the tube geometry, gas parameters, and the anode current subject to the assumption of quasi-neutrality. The theoretical distributions are in fair agreement with experiments that do not depend upon the usual probe density measurements. Analysis of the density distributions leads to the criterion for the transition of the discharge out of the anode glow mode.

---

1. Described by L. Malter at the 1950 Conference on Gaseous Electronics.

C5. RELIABILITY OF PROBE MEASUREMENTS IN HOT-CATHODE GAS DIODES. Gottfried Wehner and Gustav Medicus, WCESD, Wright Field

Probe measurements in gas discharges can give quite erroneous results owing to changes in the work function Φ of the probe that may be in the same order of magnitude as the plasma electron velocities or as the plasma potentials to be measured. The different influences which determine the Φ-change (oxidation, contamination with barium compounds, sputtering and evaporation from the probe) were separated by studying several diodes with different kinds of cathodes. The probe characteristics were recorded by an X-Y plotter which reduced the recording time to some seconds per run.

In oxide or barium cathode tubes the work function of a tungsten probe near the cathode decreases so fast that reliable results can only be obtained if the time between measuring and cleaning procedure is less than some seconds. In the anode region the influence of oxygen released from an oxide cathode predominates (Φ-increase) because most of the barium compounds return to the cathode after becoming ionized.

With the proper probe cleaning procedure no deviation from the Maxwellian velocity distribution of the plasma electrons could be found, even in oxide cathode tubes (pressure 150 μ) with the probe only ten mm away from the cathode and over a range of four powers of ten in probe current.

C6. PROBE--PLASMA INTERACTION. W. M. Webster, RCA Laboratories

The presence of a bounding surface--such as a probe--alters the density distribution of a gas discharge plasma to a degree that depends on such parameters as electrode geometry and gas pressure. As a result, probes measure a plasma density which may be markedly different from the plasma density that would exist in the same place in their absence. A simple analysis leads to an analogy method for computing actual plasma density distribution for certain cases.

C7. MAGNETO-IONIC RESONANCE IN MICROWAVE CAVITIES.

Benjamin Lax, Air Force Cambridge Research Center

The complex resonant frequency ω of a cavity containing a non-uniform plasma in a magnetic field can be calculated exactly from

$$\omega^2 - \omega_\mu^2 = j \frac{\omega}{\epsilon_o} \frac{\int \vec{J} \cdot \vec{E}_\mu^* \, dv}{\int \vec{E} \cdot E_\mu^* \, dv}$$

if $\vec{E}$, the perturbed electric field, and $\vec{J}$, the current density in the magneto-ionic gas given by the product of the conductivity matrix and $\vec{E}$, are known. The subscript μ indicates unperturbed quantities.

For the first order effect of the plasma take $\vec{E} \approx \vec{E}_\mu$. Applying this to a cylindrical cavity in an axial magnetic field gives for the TE_{111} mode a split resonance. The frequency shifts $\Delta\omega_o \sim 1/(\omega_\mu + \omega_b)$ and $\Delta\omega_e \sim 1/(\omega_\mu - \omega_b)$ are respectively those of the ordinary and extraordinary modes of the cavity, each with the same proportionality factor, for a given plasma density and gyromagnetic frequency ω_b. Experimental verification of the theoretical results will be presented.

D2. HIGH-FREQUENCY DISCHARGE AT LOW PRESSURES CHARACTERIZED BY SECONDARY ELECTRON RESONANCE*. Albert J. Hatch and H. Bartel Williams, Physical Science Laboratory, New Mexico College of A. and M. A.

Gas discharge characteristics have been studied at frequencies from 30 to 90 mc/s using flat electrodes of aluminum, copper, and silver-plated copper at separations of one to four cm inside a bell jar. Pressures have been held at one micron Hg or less. For each spacing a cutoff frequency is observed below which it is impossible to obtain breakdown with field strengths of several hundred volts/cm. Double values of breakdown field strength are observed above cutoff, with lower values of 15 to 20 volts/cm being observed in certain cases. The cutoff and double breakdown values define a breakdown region not previously reported.

This type of breakdown observed first by Gutton[1] in 1924 appears to be initiated by multiplication of secondary electrons at the electrode surfaces, these electrons oscillating between the electrodes in approximate resonance with the applied high-frequency potential.

Theories reported by Alfven and Cohn-Peters[2] and Gill and von Engel[3] to describe this type of discharge have not been very successful. A new approach to the theory has been developed which gives promising correlation with observations.

---

* Supported by the Navy Bureau of Ordnance.

1. C. Gutton, Comptes Rendus, 178, 467-470 (1924).
2. H. Alfven and H. J. Cohn-Peters, Arkiv fur Matematik, Astronomi och Fysik, 31, 1 (1944).
3. E. W. B. Gill and A. von Engel, Proceedings of the Royal Society, A192, 446-463 (1948).

D3. AN ANISOTROPIC GAS DISCHARGE PLASMA AS A MEDIUM FOR GUIDED MICROWAVE PROPAGATION. L. Goldstein, M. Lampert, and J. Heney, Federal Telecommunication Laboratories, Inc.

When a uniform d-c magnetic field is applied across a free-electron medium, that medium acquires thereby a proper frequency, namely the gyrofrequency of electrons for the particular value of magnetic field. The presence of this proper frequency will affect electromagnetic wave propagation through the medium. In our experiments the free-electron medium is provided by the plasma of a d-c gas discharge, either pulsed or continuous. Propagation at microwave frequencies through such a medium has been studied in both circular and rectangular wave-guide, the magnetic field being parallel to the direction of propagation in all cases.

In circular waveguide, at low magnetic fields, a very large Faraday effect is observed. In both types of waveguide, at magnetic fields near the electron gyroresonant field, effects typical of anomalous dispersion are observed. These effects may be used to investigate the state of discharge, in that the electron density and collision frequency determine their magnitudes. The theory has been worked out for the case of unbounded propagation.

D4. ELECTRON DISTRIBUTION FUNCTIONS IN COMBINED D-C SPACE CHARGE AND A-C FIELDS.

Ira B. Bernstein and T. Holstein, Westinghouse Research Laboratories

Most previous treatments of this problem have assumed the effect of d-c space-charge fields, such as ambipolar fields, to be small. Here it is considered dominant. This implies that the electron can be considered as moving with constant energy w (equal to the kinetic energy u plus the electrostatic potential energy ψ) in the space-charge well. The effects of collisions and the a-c field are regarded as perturbations. In particular it is assumed that on the average the electron executes many oscillations in the well before suffering appreciable energy change due to collisions and the a-c field. This indicates the desirability of introducing the variable w into the Boltzmann equation instead of u. The mathematical elaboration of these ideas leads to a difference-differential equation which can be solved under certain simplifying assumptions regarding the cross sections. The distribution function and specific ionization rate thus derived are compared with the corresponding quantities for the case of no space-charge field.

D5. FURTHER RESULTS OF STUDIES OF MICROWAVE OSCILLATIONS IN GASEOUS DISCHARGES. Roger P. Wellinger, Joseph A. Saloom and James E. Etter, University of Illinois

In the process of investigating the causes of microwave oscillations in gaseous discharges, a new series of measurements has been made on the Wehner oscillator, using improved microwave circuitry and a more stable discharge. It was found that under certain conditions the bandwidth of the oscillator spectrum was as broad as seven per cent, but by proper adjustment of the discharge parameters the bandwidth could be made to be as narrow as approximately 0.3 per cent. Measurements have shown that the broad bandwidth was associated with the presence of several simultaneous oscillations at different frequencies. Only when the oscillator operated in one dominant mode was it possible to obtain accurate quantitative measurements on the wavelength characteristics of the oscillations. The r-f power distribution in the discharge was measured using biased probes, which indicated the presence of bunched electrons in the discharge. By using small r-f probes, the phase difference between r-f signals present at any two points in the discharge was measured. By changing various elements of the Wehner oscillator a correspondence between this oscillator and the gas discharge diode oscillators investigated by previous workers is shown. The envelope of the diode oscillator is equivalent to one of the elements of the Wehner structure.

D6. RETROGRADE ARC MOTION OF SUPERSONIC SPEED. Charles G. Smith, Raytheon Manufacturing Company

A mercury arc in a vertical magnetic field was raced around a carboloy cylinder projecting about three mm above the mercury. Arc current and field were parallel except at the carboloy anchor. Revolutions per second were observed by probe methods. The motion was retrograde (contrary to amperes law) for all fields. The speed curve rose rapidly between 1000 and 3000 oersteds and leveled off at 120 meters per sec (approximately sonic speed in the Hg vapor.) At about 9000 oersteds the curve rose rapidly to about twice the plateau value and continued a less rate of rise to the highest field, 16,500 oersteds. Studies could be made of an arc running around in a shallow groove cut in the carboloy near its top. This arc was above the junction of liquid and carboloy. Its speed curve showed a short plateau but with speeds about three times those noted above. Ultimate speeds about six times sonic were found. These and other observations seem to leave us without a satisfactory theory of the retrograde motion.

D7. THE TUNGSTEN ARC IN MIXTURES OF ARGON AND HELIUM*.

T. B. Jones and Merrill Skolnik, Johns Hopkins University

An experimental study was made of the properties of the electric arc with one-fourth-inch diameter tungsten-rod electrodes in mixtures of argon and helium at atmospheric pressure. The current range was from 10 to 100 amperes. Measurements were obtained of the plasma gradients and of the variations of the arc voltage as a function of the composition of the mixture for constant current. The change in arc appearance with the mixture was also observed. It was found that the properties of the arc in mixtures were a cross between the properties observed in the pure gases. With mixtures ranging from pure argon to argon containing 85 per cent helium, the properties of the argon arc were more dominant, while the influence of the helium was more pronounced for concentrations of helium greater than this amount. When the properties of the argon arc were more dominant, the chief effect of the helium was observed at the cathode region. In general, small amounts of argon in helium have greater effect on the arc characteristics than small amounts of helium in argon. However, the dependence of the arc properties on the presence of the lower ionization potential gas is considerably less than that observed in glow discharges.

---

* This work was supported by the Office of Naval Research.

D8. ELECTRICAL PHENOMENA IN THE HISSING ARC*. T. B. Jones and B. H. List, Johns Hopkins University

When the carbon arc begins to hiss in air, several phenomena occur simultaneously: (1) there is an abrupt drop in arc voltage of about ten volts; (2) the anode spot begins to move in a rapid random manner; (3) audio-frequency and radio-frequency oscillations are produced by the arc; and (4) there is a darking of the anode, indicating a lower anode temperature. A study of the hissing arc at atmospheric pressure in air, nitrogen, oxygen, argon, helium, and carbon dioxide showed that these characteristic changes occurred only in air, nitrogen, and oxygen. The abrupt drop in voltage was shown to be related to the mechanism of supplying positive ions in the vicinity of the anode. The magnitude of the voltage drop is believed to be dependent upon the ionization potential of the chemical products formed in the arc.

Both types of oscillations were independent of circuit parameters. The low-frequency random oscillations of voltage, current, and sound were produced by the rapid motion of the anode spot. The radio-frequency oscillations occurred in narrow bands at 1, 2, 4, 8, 16, 32, and 64 megacycles per second. It was shown that these oscillations might be caused by motions of positive ions in the arc plasma.

---

*This work was sponsored by the Office of Naval Research.

E1. LUMINOUS FRONTS RESULTING FROM CONSTRAINED LOW-PRESSURE SPARK EXPANSION.* Richard G. Fowler and Walter D. Compton, University of Oklahoma

Abrupt, high-energy, low-pressure discharges expand in an organized manner into side avenues. The expanding gas is luminous but is not an afterglow. It is an actively exciting front to luminosity. Velocity of propagation measurements show the motion to be of a quasi-acoustical nature. Measurements of Stark broadening show a high level of ion concentration. The relation between spectral intensity and ion concentration is quadratic, suggesting radiative recombination. The ion concentration increases as the front progresses, and is more appropriately expressed as a function of time than space. Spark currents approach 10,000 ampere values and decay in synchronism with the duration of luminosity.

The luminous fronts are believed to be preceded by a shock wave. When an obstacle is placed in the course of the fronts they can be made to reflect before reaching the obstacle. The velocities of the reflected fronts and the initial front are governed by quite different laws.

---

* Supported by the Office of Naval Research.

E2. BAND SPECTRA IN PULSED NITROGEN DISCHARGES* C. F. Hendee**, Department of Physics, Northwestern University

When the high-voltage trigger pulse is applied to the external electrode of a condenser discharge flash tube, a short duration light flash is emitted that procedes the main light flash associated with the discharge of the condenser. This light flash has been studied oscillographically and has a duration generally between 10^{-6} sec and 10^{-7} sec. Using this technique to produce a discharge in nitrogen, the light pulse shapes of the First and Second Positive bands have been studied. The First Positive band pulse has a decay time about ten times that of the Second Positive band, and decreases with increasing pressure. The decay time vs pressure curve is of the form expected when a metastable level is involved. This may be due to a slight metastability in the upper $B^3\pi g$ level of the First Positive band system or to metastability of the $a^1\pi$ level[1] from which the $B^3\pi g$ level may be populated by the process suggested by Nicholls[2].

---

* This work has been supported by the Bureau of Ships under contract NObs-28373, Dr. W.S. Huxford, Director.
** Now at Philips Laboratories, Inc., Irvington-on-Hudson, N.Y.
1. G. Herzberg, Phys. Rev., 69, 362 (1946).
2. R.W. Nicholls, Nature, 162, 231 (1948).

E3. ELECTRICAL FIELDS IN THE CROOKE'S DARK SPACE OF LOW-PRESSURE GLOW DISCHARGES BY ELECTRON BEAM PROBES.
Robert P. Stein, Department of Physics, University of California
(Presented by L. B. Loeb)

An electron beam probe was made to traverse the Crooke's dark space of glow discharges in air at from 10^{-4} to 5×10^{-3} mm pressure, both at various distances from the cathode in the dark space as well as at other points in the glow discharge. The deflections of the beam were calibrated by known fields and thus registered the fields existing. Fields ranging from 400 volts/cm down to 2 volts/cm could be measured. The curves obtained as functions of pressure and current were reproducible and clean cut. While superficially the curves were of the form observed once by Aston, the potential fall was not actually linear. The data obtained and their interpretation will be presented.

E4. POSITIVE POINT TO PLANE CORONA STUDIES IN AIR*. M. Menes and L. H. Fisher, New York University

Measurements were made of formative time lags of the positive point-to-plane corona in dry air, using points of radii 0.07, 0.2 and 0.3 mm, gaps of 5, 10 and 15 mm, and steady ultraviolet illumination. Pressures ranged from 700 to 30 mm Hg. Pre-onset current-voltage measurements with illumination were made for these geometries.

The formative time lags at a given pressure and gap geometry increase with decreasing overvoltage, showing a limiting upper value at onset. These threshold lags range from less than 0.1μs near atmospheric pressure to 1μs at 30 mm Hg and show a slight but not marked dependence on point radius, gap length, or illumination level.

The steady state current curves are continuous and reversible up to onset, and unless breakdown occurs, remain so through and beyond onset. Space charge effects are noticeable below onset. The steady state corona manifests itself as a burst pulse glow in all but one point-gap combination where pre-onset streamers occur. Moisture was found to favor streamer formation.

The short threshold lags together with their slight dependence on geometry indicate that the positive corona onset in air is gas dependent.

---

* Supported by the ONR and the Research Corporation.

E5. MECHANISMS OF POSITIVE AND NEGATIVE CORONA IN HYDROGEN AND ARGON BETWEEN COAXIAL CYLINDRICAL ELECTRODES OVER AN EXTENDED AREA. Eugene J. Lauer, Department of Physics, University of California, (Presented by L. B. Loeb)

Mechanisms in the corona discharge from a fine platinum wire at a positive potential along the axis of a hollow nickel cylinder have been investigated by using the oscilloscope to analyze the pulses caused by α particles passed through the low field region parallel to the wire. The secondary coefficient γ_p for the photoelectric effect at the cathode in hydrogen had values from 69×10^{-5} at 100 mm to 4.9×10^{-5} at 650 mm pressure. For the hydrogen ions, γ_i at the cathode was less than 10^{-6}. The mobility of the positive ions (presumably H_2^+) was 13.4 (±0.4) cm^2/volt x sec at 760 mm and 20°C. Adding 0.1 to 1.0 per cent of oxygen to hydrogen resulted in the formation of O_2^- ions and also increased the photon absorption in the gas. For the argon positive ions, γ_i was about 8.5×10^{-4} extrapolated to zero pressure and decreased with increasing pressure and was less than 1/10 γ_p. Most of the ions were A_2^+ with a mobility of the 1.94 (±0.08) cm^2/volt x sec. The pressure dependence of the secondary coefficients is ascribed to back diffusion. Positive wire d-c current voltage data were taken in hydrogen and argon at several pressures. Sparks occurred with the positive wire in argon at relatively lower gap voltages than in hydrogen.

E6. HOLLOW CATHODES FOR VR-TUBES WITH EXTENDED CURRENT RANGE. F.C. Todd and J.E. Drennan, Battelle Memorial Institute

Penning and his associates at Philips have shown that very stable voltage-regulator tubes are obtained when the noble gases contain less than one part per million of impurities and when the internal surface of the glass envelope is covered with sputtered metal. To further improve VR-tubes, the origin and elimination of hysteresis in tubes with these very pure noble gases was presented to this conference last year. As another improvement, the current range of VR-tubes can be extended to 600 milliamperes, or more, by the use of hollow cathodes.

Satisfactory tubes show spectral lines of the cathode metal in the hollow-cathode glow. The voltage response to superimposed pulses of current through those tubes indicates a variation in the relative importance of the different V-processes for different cathode metals. Although the metal is important, the mechanism of the hollow-cathode glow depends on the kinetic theory properties of the gas, which have been discussed in the literature(1). This is demonstrated for molybdenum plates in argon and neon by the smooth curves that are obtained for plots of the regulation of the tube in volts against the product of the gas pressure on the tube by the separation of the plates of the hollow cathode.

---

1. L. B. Loeb, Fundamental Processes of Electrical Discharges in Gases, p. 601.