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CONFERENCE ON GASEOUS ELECTRONICS

SPONSORED BY THE
AMERICAN PHYSICAL SOCIETY,
DIVISION OF ELECTRON PHYSICS

PROGRAM AND ABSTRACTS OF PAPERS

BARBIZON-PLAZA HOTEL, NEW YORK, N.Y.
OCTOBER 19, 20, 21, 1950.

1950 Conference on Gaseous Electronics

Program

A. FUNDAMENTAL PROCESSES

Chairman: H. Margenau, Yale University

Thursday
October 19
10:00 A.M.

A1. Electron Removal Processes in H_2, A and Kr. R. B. Holt, John M. Richardson, and A. Redfield, Harvard University

A2. Recombination Phenomena in Nitrogen. R.B.Bryan, Dartmouth College

A3. Ionization by Metastable Atoms in Pure Helium and in Neon. Manfred A. Biondi, Westinghouse Research Laboratories

A4. Studies of Lifetimes of Metastable Atoms in Rare Gases. Arthur V. Phelps, Bell Telephone Laboratories

A5. Origine de la Phosphorescence des Gaz Excites par une Decharge Electrique. L. Herman, Sorbonne, Paris, France

B. FUNDAMENTAL PROCESSES

Chairman: W. P. Allis, Massachusetts Institute of Technology

Thursday
October 19
1:30 P.M.

Invited Paper

B1. Reproducibility of Gas Discharges. F. M. Penning, Philips Research Laboratories, Eindhoven, Netherlands

B2. Mass Spectrometric Studies of Molecular Ions in the Rare Gases. Julius P. Molnar and John A. Hornbeck, Bell Telephone Laboratories

B3. Mobilities of Rare Gas Atomic and Molecular Ions. John A. Hornbeck, Bell Telephone Laboratories

B4. Mobilities of Positive Ions in Gases. T. Holstein, Westinghouse Research Laboratories

Intermission

Chairman: H. D. Hagstrum, Bell Telephone Laboratories

B5. Diffusion of Ions in a Strong Electric Field. Gregory H. Wannier, Bell Telephone Laboratories

B6. Further Studies in Mercury Band Fluorescence. A. O. McCoubrey, D. Alpert and T. Holstein, Westinghouse Research Laboratories

B7. Isotope Effect in the Imprisonment of Resonance Radiation. D. Alpert, A. O. McCoubrey and T. Holstein, Westinghouse Research Laboratories

B8. Progress in Excitation of Mercury Vapor by Positive Alkali Ions. Robert N. Varney, Washington University

C. HIGH FREQUENCY DISCHARGES

Chairman: L. Tonks, General Electric Company

Friday
October 20
9:00 A.M.

C1. The Energy Distribution of Electrons in Electrodeless Discharges. W. P. Allis, Massachusetts Institute of Technology

C2. Breakdown in Hydrogen at 100 MC Frequency. Sandborn C. Brown, Massachusetts Institute of Technology

C3. Maintaining Electric Fields in a Steady-State Microwave Discharge. David J. Rose, Massachusetts Institute of Technology

C4. Electron Recombination and Cross-Section Measurements in Decaying Hydrogen Plasma. Lawrence J. Varnerin, Jr., Sylvania Electric Products Inc., Boston, Massachusetts

C5. A Microwave Method for Measuring P_c at Thermal Energies. O. T. Fundingsland, Air Materiel Command, Cambridge, Massachusetts

Intermission

C6. Dielectric Coefficient of Ionized Gases. Donald E. Kerr, Johns Hopkins University

C7. Polyresonance in Bounded Magneto-Ionic Gases. Benjamin Lax, Air Force Research Laboratory, Cambridge, Massachusetts

C8. High Frequency Discharge in Helium-Argon Mixtures. C. S. Clay and J. G. Winans, University of Wisconsin

D. SPARK AND CORONA DISCHARGES

Chairman: D. Alpert, Westinghouse Research Laboratories

Friday
October 20
1:45 P.M.

D1. Formative Time Lags of Spark Breakdown in Nitrogen and Argon. G. A. Kachickas and L. H. Fisher, New York University

D2. Ion Pulses in the Positive Ion Space Charge Detector. Nathan Wainfan and G. L. Weissler, University of Southern California

D3. Further Results on Absorption Coefficients in N_2 in the Vacuum Ultra-violet. Po Lee and G. L. Weissler, University of Southern California

D4. Progress Report of the Gaseous Electronics Research Group. L. B. Loeb, University of California, Berkeley.

Intermission

Chairman: O. S. Duffendack, Philips Laboratories

D5. Time Studies in Positive Point-to-Plane Corona. M. Menes, New York University

D6. Corona Studies in Electron-Attaching Gases by Means of Concentric Cylindrical Systems. Charles G. Miller and David L. Fayman, University of California, Santa Barbara, California

D7. Experiments upon the Initiation of an Electric Arc. L. H. Germer, Bell Telephone Laboratories

D8. On the Production of Extreme Temperatures by Electrical Discharges. Louis Gold, Watertown, Massachusetts

E. ARC DISCHARGES

Chairman: G. L. Weissler, University of Southern California

Saturday
October 21
9:00 A.M.

E1. Motion of an "Anchored" Arc Impelled by a Magnetic Field. C. G. Smith, Raytheon Manufacturing Company

E2. Studies in Stationary Hot-Cathode Arcs (with demonstration). L. Malter and E. O. Johnson, RCA Laboratories, Princeton, New Jersey

E3. Afterglow Studies in Hot-Cathode Arcs. E. O. Johnson, RCA Laboratories, Princeton, New Jersey

E4. Exceptionally Low Voltage Drops in Hot-Cathode Gas Discharges. G. Medicus and G. Wehner, Dayton, Ohio

E5. Experimental Techniques for the Measurement of Thyratron Breakdown. Hanns J. Wetzstein, Cambridge, Massachusetts

Intermission

Chairman: R. M. Bowie, Sylvania Electric Products, Inc.

E6. The Use of an Arc Cathode as a Source of Emission for High Power Tubes. P. H. Kafitz, D. H. Goodman, and D. H. Sloan, University of California, Berkeley, California

E7. The Reignition of Short Arcs at High Pressures. Lauriston P. Winsor, Rensselaer Polytechnic Institute

E8. Improved Potential-Probe Measurements in Carbon Arcs. W. Finkelnburg, Engineering Research and Development Laboratories, Ft. Belvoir, Virginia

E9. Oscillations in Direct Current Arcs. T. B. Jones and B. H. List, Johns Hopkins University

E10. Characteristics of the Helium-Tungsten Arc with High Currents. T. B. Jones and Merrill Skolnik, Johns Hopkins University

F. GLOW DISCHARGES

Chairman: W. B. Nottingham, Massachusetts Insitute of Technology

Saturday October 21

F1. Probe Technique for the Measurement of Electron Temperature. M. A. Easley, General Electric Company, Nela Park

F2. Gas Temperatures and Elastic Losses in a Low-Pressure Mercury-Argon Discharge. C. Kenty, M. A. Easley and B. T. Barnes, General Electric Company, Nela Park

F3. Characteristics of Moving Striations in a Mercury-Krypton Mixture. H. L. Steele, Jr., Westinghouse Electric Corporation, Bloomfield, N.J.

F4. Moving Striations in H_2 and D_2 Glow Discharges. Thomas M. Donahue, Johns Hopkins University

F5. Electrode Reactions in the Glow Discharge. F. E. Haworth, Bell Telephone Laboratories

Intermission

Chairman: L. H. Fisher, New York University

F6. Dynamic Characteristics of Glow Discharges in the Rare Gases at Ultrasonic Frequencies. W. D. Parkinson, Johns Hopkins University

F7. Decimeter Plasma Oscillations: Experiments and Considerations. L. Brennan, J. Saloom and R. Wellinger, University of Illinois

F8. Glow Discharge Tubes as High Voltage Voltage-Regulator Tubes. David L. Fayman and Charles G. Miller, University of California, Santa Barbara, California

F9. Momentary Intensification of the Electron Beam Obtained from a High-Voltage Cold-Cathode Discharge. John H. Park, National Bureau of Standards, Washington, D.C.

F10. Some Characteristics of Low Pressure Discharges in Pure Noble Gases. F. C. Todd and J. E. Drennan, Battelle Memorial Institute

A1. ELECTRON REMOVAL PROCESSES IN HYDROGEN, ARGON, AND KRYPTON.* R. B. Holt, John M. Richardson, and A. Redfield, Harvard University

Previously described techniques[1] for the measurement of electron densities in and light emission from pulsed discharge afterglows have been applied to hydrogen, argon, and krypton. Electron densities were measured by observing the shift in resonant frequency of a microwave cavity containing the discharge. The spectrum of the light emitted was observed as a function of time by means of pulsed photomultipliers and by means of a spectrograph and high-speed mechanical shutter. In argon, recombination-type electron removal was observed in the moderate pressure range (1-30 mm) with a coefficient which depends on pressure and to some extent on the degree of excitation of the ions produced in the discharge. The total amount of light emitted indicated that the electron removal process was partially radiative and partially non-radiative. In hydrogen non-radiative (in the optical region, at least) recombination accounts for the removal of the majority of the electrons in the modorate pressure range. The recombination coefficient was a function of pressure. Recombination-type electron removal was also observed in krypton, with the amount of light emitted in the process strongly dependent on minute amounts of impurities (particularly xenon). These results have been used in a detailed analysis of the mechanism of electron removal in the above gases.

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[1] Phys. Rev. <u>77</u>, 239 (1950).

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

A2. ELECTRON RECOMBINATION IN NITROGEN. R. B. Bryan, Harvard University*

Electron-density measurements have been made using the method of microwave cavity resonant shift. Two values of α are observed at high power, only one at low power, where α is defined by the equation $\frac{du}{dt} = - \alpha n^2$. The low power α seems to be equal to the highest value at high power. Photomultiplier studies show that most of the light is not a result of electron-recombination, but is due presumably to association of atoms to form neutral molecules. By measuring the absolute light intensity, the rate of association of atoms is determined. At 6 mm, electron-recombination gives for low power a value of α of 2×10^{-6} cm^3 sec^{-1} ; for high power, 2×10^{-6} cm^3 sec^{-1} and 9×10^{-7} cm^3 sec^{-1}. The rate of association of atoms is 3×10^{-8} cm^3 sec^{-1}. In bottles contaminated with CN, the lower value of α did not appear.

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*Now at Dartmouth College.

A3. IONIZATION BY METASTABLE ATOMS IN PURE HELIUM AND IN NEON. Manfred A. Biondi, Westinghouse Research Laboratories

Microwave techniques have been used to study the electron density variation in He and Ne afterglows. An initial increase in density is observed lasting for approximately one millisecond after the maintaining field is removed from the discharge. This delayed ionization evidently results from the collision of pairs of metastable atoms. Analysis of the initial rise permits an evaluation of the diffusion and volume loss of the metastable atoms. The results are given in the following table:

Gas	$D_m p$ $(cm^2/sec)(mmHg)$	Volume Destruction Cross-Section, σ_v $cm^2 \times 10^{21}$
Airco Reagent He	530± 30	5.8±0.5
Purified He	565±30	2.9±0.6
Airco Reagent Ne	200±20	30±3

The volume loss of Ne metastables can be explained by collisions with normal Ne atoms which raise the metatable to a radiating stage. This explanation fails for He where the nearest radiating level is 0.7 volt above the metastable level. To assure that impurities were not the cause of this volume loss, reagent He was liquefied and re-evaporated into special flasks. From the table it is seen that the volume loss is reduced but not eliminated.

A4. STUDIES OF THE LIFETIMES OF METASTABLE ATOMS IN THE AFTERGLOW OF RARE GAS DISCHARGES*. Arthur V. Phelps, Bell Telephone Laboratories

The lifetimes of the lower metastable states of Ne, He, and A in the afterglow of a pulsed discharge have been measured as a function of pressure, p, at 300°K and 77°K. The lifetimes were determined by passing light of an appropriate wavelength through the gas and measuring the time constant of decay of the absorption at low percentage absorption. In neon at 300°K and high p the probabilities of decay of the lower metastable state and the nearby radiating state are equal and directly proportional to p. Thus the metastable destruction process appears to be one of excitation to the radiating state by collision with normal atoms. At 77°K the volume destruction is much lower and is proportional to p^2. In helium at high p the destruction is proportional to p^2 and about 60 times as probable at 300°K as at 77°K. In argon the volume loss approaches a p^2 law at 300°K and 77°K and is roughly independent of temperature. The variation in the metastable diffusion coefficients is between $T^{1/2}$ and T at constant gas density.

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*The method and apparatus were developed by Dr. J. P. Molnar of the Bell Telephone Laboratories and used by the author at the Laboratories during the summer of 1950 while on leave from the Research Laboratory of Electronics, Massachusetts Institute of Technology.

B2. MASS SPECTROMETRIC STUDIES OF MOLECULAR IONS IN THE RARE GASES. J. P. Molnar and John A. Hornbeck, Bell Telephone Laboratories

Molecular ions of the rare gases (He_2^+, Ne_2^+, A_2^+, Kr_2^+, and Xe_2^+) produced by electron impact at gas pressures from 10^{-4} to 10^{-2} mm Hg were detected with a small mass spectrometer. The ion intensity increased linearly with electron current and with the square of the gas pressure. The form of the ionization vs electron energy curves resembles closely curves of excitation probability. The onset (appearance) voltages for the molecular ions were less than those for the atomic ions by 1.4 (+0.7,-0.2) volts for He, 0.7 (+0.7,-0.3) volt for Ne, 0.7 (+0.7,-0.2) volt for A, 0.7 (+0.7,-0.3) volt for Kr. These results can be interpreted, we believe, only by assuming that the method of formation of the molecular ions observed in this experiment is, using helium as an example, first by electron impact $He + e + K.E. \rightarrow He^* + e$ followed by the collision process $He^* + He \rightarrow He_2^+ + e$, where He^* stands for a helium atom raised to a high-lying excited state. Arnot and M'Ewen[1] proposed a similar interpretation of their mass spectrometric studies of helium, except that they reported onset voltages low enough to permit metastable atoms to form molecular ions.

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[1] F. L. Arnot and M. B. M'Ewen, Proc. Roy. Soc. A171, 106 (1939).

B3. MOBILITIES OF RARE GAS ATOMIC AND MOLECULAR IONS.

John A. Hornbeck, Bell Telephone Laboratories

Tyndall and Powell[1] observed an ion mobility μ_o in He at room temperature and zero field of 19.9 cm^2/volt-sec.* which they assigned to He$^+$. Theory[2] based on scattering by the polarization force and gas kinetic repulsion gives μ_o = 22.4 for He$^+$ and therefore $\mu_o \simeq 19$ for He$_2^+$. But Massey and Mohr[2] have shown further that symmetry effects involving only He$^+$ should reduce the mobility of He$^+$ to 11. We have measured simultaneously by a pulse technique the mobilities of molecular and atomic ions in He as a function of E/p_o. At slightly above zero-field conditions, our measurements confirm the theory by yielding $\mu_o(\text{He}^+) = 9.4$ and $\mu_o(\text{He}_2^+) = 18$. Similarly our measurements of Ne$_2^+$ and A$_2^+$ agree within experimental error with those of Munson and Tyndall[3] which they ascribe to Ne$^+$ and A$^+$ respectively. The mobilities of the molecular ions exceed those of the atomic ions by approximately the factors 1.5 in argon, 1.8 in neon and 1.9 in helium.

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[1] A.M.Tyndall and C.F.Powell, Proc. Roy. Soc. A134, 125(1931).

* Mobilities are quoted in these units for gas density at 0°C, 760 mm pressure.

[2] H.S.W.Massey and C.B.O.Mohr, Proc. Roy. Soc. A144, 188(1934).

[3] R.J.Munson and A.M.Tyndall, Proc. Roy. Soc. A177, 187(1941).

B4. MOBILITIES OF POSITIVE IONS IN GASES. T. Holstein, Westinghouse Research Laboratories

The mobilities of Ne^+ and A^+ in their parent gases have been calculated by a procedure similar to that employed by Massey and Mohr[1] for He^+ and He. The results are 4.2 and 1.64 cm/sec per volt/cm, respectively, under conditions of standard gas density (2.69×10^{19}/c.c.) and $T = 293°K$. A crucial step in the procedure is the computation of the "resonance" or charge-exchange component of the total ion-atom interaction. In the present paper, this step is achieved by a new method whose sole requirement is a knowledge of the Hartree-Fock wave-function of the outermost atomic shell. The resonance interaction curves so obtained differ somewhat from those given by Massey and Mohr's perturbation treatment. The mobility theory in its present form is strictly valid only for ions whose electronic angular momentum is zero. However, preliminary estimates show that the error incurred in its application to Ne^+ and A^+ (whose ground states are either $^2P_{1/2}$ or $^2P_{3/2}$) is $\lesssim 10\%$.

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[1] H.S.W. Massey and C.B.O. Mohr, Proc. Roy. Soc. <u>A144,</u> 188 (1934).

B5. DIFFUSION OF IONS IN A STRONG ELECTRIC FIELD.

Gregory H. Wannier, Bell Telephone Laboratories

When gaseous ions move with appreciable drift velocity in a strong electric field, the diffusion concept can be salvaged: there exists a diffusion tensor in the frame of reference moving with the ion drift velocity. The tensor has two components D_{zz} and D_{xx}, which are, respectively, diffusion coefficients longitudinal and transverse to the field. They depend on the field strength E; for high field, $D \sim E^{1/2}$ for constant mean-free-path and $D \sim E^2$ for constant mean-free-time. In the latter case explicit expressions for the coefficients can be derived: $D_{xx} = (M+m)\tau\langle c_x^2\rangle_{av}[M\langle 1-\cos\chi\rangle_{av}]^{-1}$; $D_{zz} = (M+m)\tau[\langle c_z^2\rangle_{av}-\langle c_z\rangle^2_{av}]\,[M\langle 1-\cos\chi\rangle_{av}]^{-1}$; where M and m are the masses of the gas molecules and ions, respectively, χ the angle of scattering, and $\langle c_x^2\rangle_{av}, \langle c_z^2\rangle_{av}, \langle c_z\rangle_{av}$ are velocity averages communicated earlier.[1] Einstein's relation can be generalized to read $eD_{nn} = 2$ (ion mobility)(random energy in the direction n). Since this relation contains no model parameters and holds dimensionally in the high-field range, it may apply more generally than just to the mean-free-time case for which it was derived.

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[1] M.I.T. Conference Report on Physical Electronics, March 30, 1950, p.65.

B6. FURTHER STUDIES IN MERCURY BAND FLUORESCENCE.

A. O. McCoubrey, D. Alpert and T. Holstein,
Westinghouse Research Laboratories

Previous researches on the persistence of band fluorescence in mercury vapor[1,2] have been continued. Shot fluctuations, which limited the accuracy of earlier measurements, have been greatly reduced by time sampling techniques involving the use of a gated photomultiplier tube. Improved measurements of the time decay of band fluorescence as a function of temperature and vapor density have been carried out down to densities as low as 6×10^{15}/cc. At this limit, and with a fluorescence tube of radius 0.65 cm, diffusion of the metastable entities to the walls is found to be the predominant removal mechanism. With a second tube of radius 2.3 cm, in which the diffusion was cut down by a factor of 12.5, and at T = 200°C, a decay time of seven milliseconds is observed. This time constant is essentially independent of density over the range 0.9×10^{16}/cc to 2×10^{16}/cc. The density independence indicates that the decay process is radiative and hence suggests that the metastable entity is molecular. At higher densities (4×10^{16}/cc) a composite decay curve, indicative of the presence of a second metastable "reservoir", is observed.

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1. T. Holstein, D. Alpert, and A. O. McCoubrey, Phys. Rev. 76, 1259(1949).

2. A. O. McCoubrey, D. Alpert, and T. Holstein, Report on Conference on Gaseous Electronics, November 3, 4 and 5, 1949, Paper D1.

B7. ISOTOPE EFFECT IN THE IMPRISONMENT OF RESONANCE RADIATION.

D. Alpert, A. O. McCoubrey, T. Holstein,
Westinghouse Research Laboratories

On theoretical grounds[1] it is expected that the decay time of imprisoned resonance radiation in the vapor of a single even isotope of mercury should be from five to six times larger than that observed with the natural samples of mixed isotopic constitution. To investigate this effect experimentally, decay measurements[2] were carried out with a sample of Hg_{198} (3.1% contamination of Hg_{199}) kindly loaned to us by the Bureau of Standards. For vapor densities below 3×10^{15} atoms/cc. the predicted effect was verified; e.g. at $N = 2 \times 10^{15}$/cc., the decay time T_{198} is equal to sixteen microseconds whereas T_{mixed} is three microseconds. For N greater than 3×10^{15}/cc. the ratio T_{198}/T_{mixed} diminishes; this secondary effect can be interpreted in terms of a transfer of excitation from Hg_{198} to Hg_{199} by collisions of the second kind. A rough estimate of the cross-section for this process gives a value of $5 \times 10^{-14} cm^2$, ten times the gas kinetic cross-section and in order-of-magnitude agreement with theoretical expectations.

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1. T. Holstein, Phys. Rev. 72, 1212(1947), and subsequent unpublished calculations.

2. D. Alpert, A. O. McCoubrey, T. Holstein, Phys. Rev. 76, 1257(1949).

C1. THE ENERGY DISTRIBUTION OF ELECTRONS IN ELECTRODELESS DISCHARGES.* William P. Allis, Massachusetts Institute of Technology

The distribution function for electrons is expanded in spherical harmonics in velocity space and Fourier series in time. Substituted in the Boltzmann Equation, the zeroth order function obeys an equation which can be separated into space and energy functions, n(x) and f(v). The spatial part leads to the condition $\upsilon_i = D_s/\Lambda^2$, where υ_i is the ionization frequency per electron, Λ the diffusion length of the tube, and D_s a diffusion coefficient which varies from that for free electrons to the ambipolar coefficient according to the space charge in the tube. The energy part obeys the equation

$$\frac{d}{dv}\left(\frac{eE_e v}{m}\right)^2 \upsilon_c \frac{df}{dv} + \frac{3m}{M}\frac{d}{dv}(v^3\upsilon_c f) = \frac{v^4 f}{\upsilon_c\Lambda^2} - \frac{3e}{m}\frac{u_s v^3}{\upsilon_c\Lambda^2}\frac{df}{dv} + 3v^2(\upsilon_q - q)f$$

whose terms represent, in order, energy transfers through the applied field, recoil, diffusion, space charge, and inelastic processes. The effective electric field is

$$E_e^2 = E_o^2 + \frac{\upsilon_c^2}{\upsilon_c^2+\omega^2}\frac{E_1^2}{2} .$$

The solution of this equation is given in terms of quadratures and an asymptotic series. Its application to breakdown and to steady discharges at not too low pressures is discussed.

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*This work has been supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.

C2. BREAKDOWN IN HYDROGEN AT 100 MC FREQUENCY.*

Sanborn C. Brown, Massachusetts Institute of Technology

Previous studies of microwave breakdown in hydrogen have led to a very successful theoretical explanation for the behavior of the phenomenon of a.c. breakdown. The theory was applied not only to the microwave region but also to longer wavelength measurements. The 100 mc experiment was designed to extend the range of experimental observations beyond the range of the previous theory in the direction of higher pressure. A new theory has been developed for the radio frequency breakdown in hydrogen which is applicable to higher pressure phenomena. At higher pressures the energy per mean-free-path which the electrons gain in the field is low, and the electrons make very few ionizing collisions compared to elastic and exciting collisions. A much simpler theory has been developed for this case which is applicable also to high pressure breakdown at lower frequencies calculated by the previous theory, so that the two theories can be shown to overlap. The experimental methods of observation will be outlined and good agreement will be shown between theory and experiment.

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*This work has been supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.

C3. MAINTAINING ELECTRIC FIELDS IN A STEADY-STATE MICROWAVE DISCHARGE.* David J. Rose, Massachusetts Institute of Technology

The microwave field required to maintain a discharge at various electron densities in hydrogen has been measured. The experimental methods are summarized. The electron velocity distribution in the hydrogen plasma is derived from the Boltzmann transport equation, taking account of the d.c. space charge field. From this distribution, the ionization rate per electron, the diffusion coefficient, and the mobility are calculated by standard formulae. In the steady state, a relation exists between these three quantities and the space charge field. The resulting equation is solved to yield the rate of electron flow out of the discharge and the average electron energy, in terms of the applied microwave field, its frequency, the cavity size, and gas pressure. The spatial distributions of ions and electrons in the plasma also yield an equation for the rate of flow in terms of the diffusion and mobility coefficients of the charged particles and the electron density. The electric field required to maintain the discharge is calculated as a function of electron density, cavity size, and frequency, using the fundamental properties of the gas. Theory and experiment are compared.

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*This work has been supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.

C4. ELECTRON RECOMBINATION AND CROSS-SECTION MEASUREMENTS IN DECAYING HYDROGEN PLASMA*.

Lawrence J. Varnerin, Jr., Sylvania Electric Products Inc., Boston, Massachusetts

A method is described by which the impedance of a decaying plasma in a section of waveguide may be determined as a function of time by use of transient standing wave detection equipment. From the impedance, both real and imaginary components of the complex dielectric constant of the plasma may be obtained. The density can then be determined and, as a result, the mode of decay of electron density established. In addition, the resistive component is related to the collision cross-section of electrons. This measurement affords a means of determining the energy dependence of the mean-free-path of electrons. Data for hydrogen are presented.

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*This work was made possible by S. C. Proj. No. 27-3238-2.

C5. A MICROWAVE METHOD FOR MEASURING P_c AT THERMAL ENERGIES.*

O. T. Fundingsland, AF Cambridge Research Laboratories

The ratio σ_r/σ_i of the real to the imaginary part of the complex conductivity of an ionized gas in a microwave resonant cavity can be measured during the post-discharge plasma decay by transient standing wave techniques. The solutions for constant collision frequency ($P_c \propto v^{-1}$) and for constant P_c differ in that σ_r/σ_i is inversely proportional to the pressure p in the first case, but not strictly so in the latter. This distinction is small but it implies that an experimental plot of $\frac{1}{p}(\sigma_r/\sigma_i)$ versus either p or σ_r/σ_i should give some indication of the velocity dependence of P_c. Further evidence concerning $P_c(v)$ can be obtained by noting how the measurements are affected when the average electron energy is raised slightly by increasing the intensity of the probing signal. Measurements at room temperature will be reported for helium, hydrogen and neon. The values calculated by assuming constant P_c agree satisfactorily with extrapolations of Brode's collision probability curves.

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*Performed at M.I.T., R.L.E., supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.

C6. DIELECTRIC COEFFICIENT OF IONIZED GASES. Donald E. Kerr, The Johns Hopkins University

The formula for the conductivity or dielectric constant of an ionized gas has been a subject of some controversy, chiefly because of the possible existence of a Lorentz polarization term. Using the single-electron approach in a manner due essentially to Darwin, it is found that Lorentz polarization and positive-ion collision forces just cancel in an electrically neutral plasma, but local differences in electron and positive-ion densities introduce a correction and also modify the local plasma-resonance frequency. The effects of mixed a-c and d-c fields and of diffusion are best expressed through the electron energy distribution function and the Boltzmann transport equation. The spherically symmetrical part of the distribution function, F_o, is customarily considered to be independent of time. This is not true, however, when both a-c and d-c electric fields are present, and the electron current depends upon both the steady and alternating components of F_o as well as those of the electric field. This fact, coupled with the effects of diffusion in a bounded discharge, renders quantitative measurements difficult. A discussion will be given of the theoretical and experimental problems that are encountered.

C7. POLYRESONANCE IN BOUNDED MAGNETO-IONIC GASES.

Benjamin Lax, AF Cambridge Research Laboratories

The change in the resonant frequency of a cavity produced by the presence of an ionized gas assumes a more complex character when an external magnetic field is superimposed on the system. The resultant anisotropy of the medium, as expressed by a non-symmetrical matrix, together with the dispersive nature of the conductivity components give rise to a polyresonant phenomenon. This polyresonance manifests itself in elliptically polarized fields having "ordinary" and "extraordinary" multiple resonant frequencies corresponding to each vacuum mode. Explicit theoretical solutions are obtained for uniform electron densities in a parallel plate geometry, with several orientations of the magnetic field. Degeneracies of higher modes under certain conditions of electron density and magnetic field are also discussed.

C8. THE HIGH FREQUENCY DISCHARGE IN HELIUM-ARGON MIXTURES.

C. S. Clay and J. G. Winans, University of Wisconsin

High frequency breakdown and extinction field strengths were measured for argon, helium and helium-argon mixtures. The excitation frequency was 527 mc. The discharge chamber was a cylinder 13 mm diameter and 110 mm long. With increase in pressure the breakdown and extinction field strengths passed through a minimum. The pressure for minimum breakdown field strength was less for argon and argon-helium mixtures than for pure helium. The pressure at which the extinction field strength was minimum was less than the pressure at which breakdown field strength was minimum. In mixtures of argon and helium the spectra of argon was more strongly excited, relative to helium, by high frequency than by low frequency excitation. Under high frequency excitation the source was brightest when the gas pressure was that for minimum extinction field strength. The spectrum of mercury was photographed under pulsed and continuous wave excitation at a carrier frequency of 527 mc. Pulsed excitation gave spectral lines of Hg I, Hg II as well as Hg_2^+ bands. Continuous wave excitation gave Hg I lines only. The theory of Brown, Herlin, and MacDonald described all observations[1].

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1. Brown, Herlin, and MacDonald, Phys. Rev. <u>75</u>, 411 (1948).

D1. FORMATIVE TIME LAGS OF SPARK BREAKDOWN IN NITROGEN AND ARGON.* G. A. Kachickas and L. H. Fisher, New York University

Formative time lag measurements of spark breakdown in air[1] and oxygen[2] have been extended to nitrogen and argon. The results in nitrogen and air are almost identical, the time lags in both gases being independent of pressure and increasing with increasing gap separation. In argon, the formative time lags at overvoltages above a few percent are many orders of magnitude longer than the corresponding times in nitrogen and air. The time lag vs. per cent overvoltage (O.V.) curve varies much more slowly in argon than in nitrogen. For example, at atmospheric pressure and a gap separation of 1 cm, the time lags are 100 µs at 10 per cent O.V. and decrease to 1 µs at 100 per cent O.V. In argon, the time lag vs. per cent O.V. curve is not independent of pressure, the curves for low pressures lying below those for high pressures. The time lags for argon increase with increasing gap separation. Interpretation of the results will be given.

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2. G. A. Kachickas and L. H. Fisher, Phys. Rev. 79, 232 (1950).

*Supported by the Office of Naval Research and the Research Corporation.

D2. ION PULSES IN THE POSITIVE ION SPACE CHARGE DETECTOR.*

Nathan Wainfan and G. L. Weissler, University of Southern California

Using a Kingdon Cage Space Charge Detector[1], pulses were observed due to individual positive ions generated in the residual gas by emission electrons. The pulse shape was essentially independent of the number of pulses; they disappeared when operating the detector in the saturation region. The average pulse duration was of the same order as ion life times found by Kingdon[1]. The pulse number decreased with decreasing pressure with no pulses in a very high vacuum. However, dry, pure He does not increase the pulse number until the anode voltage is raised to the He-ionization potential. Using a Kunsman ion source external to the detector, no induced pulses were observed in agreement with calculations on electron shot noise and ion pulse heights. An internal ion source produced pulses with very low efficiencies. Differential counting rates will be presented for various instrument parameters and pulse heights. These results were in agreement with expectations. Under certain conditions of electrode potentials and geometry sustained sinusoidal ion oscillations were observed. It will be shown that they are analogous to electron Barkhausen oscillations. The ion oscillation periods are in good agreement with calculated ion transit times.

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1. K. H. Kingdon, Phys. Rev. 21, 408 (1923).

*Sponsored by Office of Naval Research.

D3. FURTHER RESULTS ON ABSORPTION COEFFICIENTS OF N_2 IN THE VACUUM ULTRAVIOLET.* Po Lee and G. L. Weissler, University of Southern California

Previous work reported using a continuous wavelength Lyman source for absorption determination[1] yielded semi-quantitative information on the general trend of absorption, indicating abrupt changes in the coefficients k_λ particularly in the N_2-band region from about 800A to 1000A. More quantitative results have been obtained with a line spectrum source, and the absorption law $I_x = I_o \exp(-k_\lambda x)$ has been verified for 26 lines. In contrast to the Lyman source work, general scattering or fluorescence in the absorbing gas did not obscure the results. Values of the coefficients between 1300A and 1050A are generally small, 10 cm^{-1} or less, in agreement with Schneider's work in air[2]. In the N_2-band region from 1050A to 800A the coefficients oscillate rapidly attaining maximum values of about 350 cm^{-1} in agreement with Schneider[2] and Clark[3]. They must be regarded with caution due to blending of source lines and absorption bands. From 800A to 500A, k_λ is nearly constant at about 600 cm^{-1}, indicating a decrease toward shorter wavelengths. At 303A, $k_\lambda = 120\ \mathrm{cm}^{-1}$. Very strong absorption was observed on several plates at 775.9A with a k_λ of at least 2200 cm^{-1} ($N_2^+ = 795.8$A). Agreement between the results presented and Wulf's predictions from N_2 dispersion[4] is fair.

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2. E. G. Schneider, J. Apt. Soc. Am. 30, 128 (1940).
3. K. C. Clark, Phys. Rev. 73, A1250 (1948), private communication.
4. O. R. Wulf and L. S. Deming, Terr. Magn. Atmos. Elect. 43, 283 (1938).

*Supported by O.N.R.

D4. PROGRESS REPORT OF THE GASEOUS ELECTRONICS RESEARCH GROUP.

L. B. Loeb, University of California, Berkeley

The very important investigations of C. G. Miller on a comparative study of coaxial cylindrical geometry in comparison with the point-to-plane studies of coronas in very pure nitrogen, oxygen and mixtures over an extended range of pressures has been finally written up for publication but the 42 page paper has, to date, not found a publisher. Carrying further these investigations, Mr. Eugene Lauer has practically completed hydrogen and is undertaking argon. As noted by Weissler, hydrogen was exceedingly difficult to purify. In this gas, from atmospheric pressure down, positive corona showed no pre-onset streamers but burst pulses were uniformly observed. This indicates more photo-ionization of hydrogen with less transparency than Miller observed for nitrogen. Atmospheric pressure onset was abrupt at 3,500 volts and approximately one micro-ampere current. Owing to dispersion the discharge did not become visible below 50 micro-amperes. Negative wire burst into a glow with several spots from an initial current of 10^{-12} ampere. There were no pulses but multiple spots wandering up and down on the clean wire. Reduction of voltage reduced the spots to one with an offset in the neighborhood of 2,100 volts atmospheric pressure. With onset the current tended to arc over but never reached it because the voltage supply went out of control with the currents drawn. There were no other strikingly notable features but complete data have been obtained on hydrogen. In connection with questions involving atmospheric electrical discharges, work has been carried on by H. W. Bandel on corona from ice points using point-to-plane geometry. The necessary cooling of the chamber introduced changes in density at atmospheric pressure in air which reflected on the value of the thresholds. One millimeter diameter ice points and similar brass points were studied in a standard chamber. The observed currents gradually rose from very low values of the order of 10^{-13} ampere to 10^{-8} or 10^{-9} ampere at onset with the ice point compared to 10^{-6} ampere for the metal point. The burst pulses, streamers and Trichel pulses characteristic of positive and negative point corona from metal points in air were not observed with the ice point. However, discharge or breakdown would set in at about the same potential on the ice point as on the metal point. The oscilloscope revealed low amplitude pulses with time durations of milliseconds for both positive and negative points for heavier currents. The distilled water ice points gave currents about two orders of magnitude lower than tap water ice points, in which case there were no pulses. Complications are obvious, owing to the high resistance of the ice points (10^{13} and 10^{14} ohms). No visible discharge could be detected by eye. The camera, on long exposure, however, for both negative and positive ice points indicated a discharge penetrating a millimeter or two into the air from the point. There were indications that microcrystalline ice points on the surface of the large points were responsible for some of the discharge. Thus far it seems very doubtful that discharges from ice points or crystals can play any significant role in lightning or other electrical discharges.

D5. TIME STUDIES IN POSITIVE POINT-TO-PLANE CORONA.*

M. Menes, New York University

Since the positive point-to-plane corona was of fundamental importance in establishing the streamer theory of sparking, it seemed desirable to study the formative time lags of the various types of discharges encountered with positive points. Tungsten points ranging from about 0.1 to 0.5 mm in radius were used with gaps of the order of 1 cm. Continuous ultraviolet illumination of the cathode provided initiating electrons. An approach voltage well below onset was used and an additional voltage step applied. The time lags were measured from the application of this step by means of an amplifier and synchroscope. The gases studied were air, oxygen, and nitrogen at pressures from atmospheric down to a few mm of Hg. At higher pressures, formative time lags were found to be well defined only for nitrogen. In air and especially in oxygen, a large scatter in the times exists. This scatter (which decreases with increasing illumination) has been tentatively ascribed to electron attachment by oxygen molecules. At higher pressures, the formative time lags for pre-breakdown pulses in nitrogen have been found to be of the order of a microsecond or less very near threshold (overvoltages of the order of 0.1 per cent).

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*Supported by the Office of Naval Research and the Research Corporation.

D7. EXPERIMENTS UPON THE INITIATION OF AN ELECTRIC ARC.

L. H. Germer, Bell Telephone Laboratories

When a condenser charged to a potential of the order of 50 volts is discharged by bringing two electrodes together, field emission current flows before contact is made. Whether or not an arc is initiated by this current depends upon the nature of the electrode surfaces and upon the circuit voltage and inductance. For clean noble metal electrodes an arc occurs only if the quotient of the voltage and inductance exceeds about 10^7 amperes per second. For carbon surfaces an arc is struck if this quotient is greater than about 5×10^4. Noble metal surfaces contaminated by very thin carbonaceous films or grease, or by very thin insulating films, or by insulating particles such as magnesia powder, behave much as do carbon surfaces. When an arc occurs the potential across it is characteristic of the electrode material and independent of the nature of the film, if any, by which the arc was initiated, and independent also of the current except during the first 2×10^{-8} second of the arc's duration. The characteristic voltages for silver, copper, gold, palladium, platinum and carbon are respectively 11, 12, 12, 14, 15 and 20-30. The arc voltage is much higher during the first 2×10^{-8} second.

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D8. ON THE PRODUCTION OF EXTREME TEMPERATURES BY ELECTRICAL DISCHARGES. Louis Gold, Watertown, Mass.

Recently stellar temperatures have been identified with nuclear explosions[1]. In the face of literature which attests both mechanical and electrical means for producing such high temperatures, it has been improperly adduced that the above represents our only known approach[2]. Theory and experiment indicate that intense heating occurs in the shock-front of ultra-velocity projectiles[3]. Indeed, Anderson[4] resorted to the exploding wire in simulating the excitation presumed to originate by meteors plunging into the sun. Appropriate analysis of the temperatures in such sparks must take cognizance of two facets: (1) collision and radiative processes involving particle-wave interactions, and (2) the circuitry question. Item (1) concerns the opacity in a variable star and is so grossly complicated that it is expedient to deal initially with the circuitry aspect, assuming negligible radiative losses during the energy build-up stage, an assumption for which there is

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1. P. Caldirola, "Detonation Wave in Nuclear Explosives" J. Chem. Phys. 18, 846-74 (1948).
2. R. F. Bacher, "The Hydrogen Bomb" III Sci. Amer. 182, 11-15 (1950).
3. J. B. Zeldovich and I. Leipunsky, "Obtaining of Extremely High Temperatures" J. Phys. USSR 7, 246 (1943).
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reasonable experimental justification[5]. The circuitry influence is contained in an energy-time function which permits suitable evaluation of the salient features of energy build up in discharges and on which basis one can show temperatures of millions of degrees are attainable.

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[5] J. D. Craggs and W. Hopwood, "Electron-Ion Recombination in Hydrogen Spark Discharges" Proc. Phys. Soc. 59, 771-781 (1946)

E1. MOTION OF AN "ANCHORED" ARC IMPELLED BY A MAGNETIC FIELD. C. G. SMITH, Raytheon Manufacturing Company

A cylinder 2 cm in diameter of polished molybdenum or such with axis vertical projects well above a surface of mercury in an evacuated tube. The anode is above and radially larger than the cylinder. An arc anchors along the circle where the mercury wets the molybdenum. A magnetic field of 1000 to 10,000 oersteds applied vertically is parallel to the arc stream except for a few thousandths of a cm where the arc current is radial to the molybdenum. The cathode spot races around on the cylinder in the retrograde direction. Observations were made through a rotating toothed wheel, and with photocell and oscillograph, and with radial probe and oscillograph. The velocity does not change from retrograde to proper for any field strength but usually approaches asymptotically to approximately 120 meters per sec. Current density is greatest at the leading edge of the spot. Spot may be single or a unified flock of two or more equal segments separated by darker regions. A mode of one, two, or more, once established is stable.

E2. STUDIES IN STATIONARY HOT-CATHODE ARCS. L. Malter and E. O. Johnson, RCA Laboratories, Princeton, N.J.

Studies were made of non-oscillatory, hot-cathode discharges, including measurements of plasma potential, arc drop, plasma density, and electron temperatures. The conclusions were supplemented by visual observations. The tests were conducted in cylindrical diodes. In all cases when the cathode emission is strongly space-charge limited, the major portion of the tube is filled with a plasma whose potential is in the neighborhood or <u>below</u> that of the cathode. In the most extreme cases of space-charge-limited emission, the ionization occurs in a very thin layer at the anode which is close to ionization potential. The balance of the tube is filled with plasma in which the electron temperature is close to that of the cathode. As the anode current is increased the discharge goes over into one of two other forms depending upon pressure. At low pressures the ionization region extends inward from the anode, the arc drop remaining at about ionization potential. At high pressures, the discharge goes over into a spectacular form in which the ionization occurs within a floating sphere of luminosity. The arc drop falls to very low values of the order of one tenth of the ionization potential. Except within the "ball of fire" the plasma potential is close to that of the cathode. The electron temperature in this plasma is of the order of 10,000° K. At conditions near the borderline between space-charge and temperature-limited conditions, an as yet imcompletely studied form of discharge occurs in which the cathode is surrounded by a fairly thick dark space, the rest of the tube glowing and being above ionization potential. At definitely temperature-limited conditions the potential rises very steeply from the cathode. In general, under space-charge-limited conditions, the discharge properties are violently different from commonly accepted pictures. Visual demonstrations of the various forms of discharge will be given in large display tubes.

E3. AFTERGLOW STUDIES IN HOT-CATHODE ARCS.

E. O. Johnson, RCA Laboratories, Princeton, N. J.

Whereas the potential distribution in a cold-cathode discharge has been the subject of intensive study, relatively little attention has been focused on the hot-cathode (externally heated) arc. This isagogical investigation is directed towards an understanding of the current and potential relations in the simplified case which exists when a hot cathode, along with its anode, is immersed in a decaying plasma. Results of this investigation throw light on the behavior of the more complicated "going" discharge. By the use of pulse techniques a plasma is generated in a region which contains a hot cathode, an anode, and a pair of probes. In the decay period measurements are made of the plasma space potential as a function of cathode emission and anode potential. The results are corrected for contact potentials which are measured by a novel method. It is found that for a strongly emitting cathode the plasma potential remains <u>below</u> that of the cathode and is almost independent of the anode potential. The retarding field at the cathode serves to limit the net cathode current to a value equal to that being collected by the probe-like action of the anode. As closely as can be determined, the plasma electron temperature is identical with the thermal temperature of the cathode. If the cathode is non-emitting, the plasma space potential remains very close to that of the most positive electrode.

These cases and those which occur for intermediate cathode emission can be analyzed to a first approximation by treating the plasma as a saturable conductor which erects appropriate sheaths at the anode and cathode to absorb the external circuit potentials as well as to maintain a current balance.

E4. EXCEPTIONALLY LOW VOLTAGE DROPS IN HOT CATHODE GAS DIODES. Gustav Medicus and Gottfried Wehner, Dayton, Ohio

The potential-, plasma density- and electron temperature distribution in Xe low voltage arcs without oscillations and with voltage drops lower than the lowest excitation potential of Xe (8.3 V) were measured. Minimum arc drops of about 1.5 V in the amp. range were obtained without an indication of this being a lower limit. It was observed that under cylindrically or spherically uniform geometrical conditions the discharge normally confines itself to regions of preference, for instance to regions of lowest work function of the anode. Under such conditions the discharge shuns the region of the probe and no potential- or plasma density maxima are observed, in spite of their doubtless existence in regions not impaired by the probe. Even in cases of visibly uniform discharge distributions around an axis or a center, the probe may impair the discharge conditions locally to such an extent that no maxima can be detected, the discharge otherwise behaving quite similar to where such maxima are measured. This may explain some hitherto enigmatic cases described in the literature. Taking these observations into account, the findings of and the discharge mechanism proposed by Compton and Eckart[1] and by Druyvesteyn[2] for somewhat different conditions are confirmed. By artifically increasing the plasma density near its "natural" maximum by means of an auxiliary discharge with fast electrons being extracted from a saturated cathode, the arc drop could be considerably decreased.

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1. K. T. Compton and C. Eckart, Phys. Rev. 25, 139 (1925).
2. M. J. Druyvesteyn,Zeitschr. f. Phys. 64, 782, (1930).

E5. EXPERIMENTAL TECHNIQUES FOR THE MEASUREMENT OF THYRATRON BREAKDOWN. Hanns J. Wetzstein, Cambridge, Mass.

Throughout all tests the anode of the thyratron is connected to the vertical deflection plates of a cathode ray oscilloscope. A sinusoidal voltage of normal operating frequency is applied to it through a series load impedance of any desired value. (1) A d-c voltage varied about once a second over the control range desired is applied to the grid and the horizontal deflection plates simultaneously. The upper edge of the pattern resulting on the screen is the grid control characteristic. (2) A fixed value of d-c voltage is applied to the grid (through the usual RC network), and the horizontal deflection plates are connected directly to the grid. The complex pattern gives the grid-anode voltage relationship at all times, including breakdown. (3) The grid is made to fire using d-c and some synchronizing voltage. A sinusoidal voltage of anode supply frequency in series with a suitable r-f voltage is applied to the horizontal deflection plates. A Lissajous figure is obtained with a straight vertical line (breakdown) on which there is superimposed the r-f sine wave, thus allowing accurate measurement of breakdown times. The relative ease and simplicity of the techniques allows close investigation of the influence of all parameters under operating conditions.

E6. THE USE OF AN ARC-CATHODE AS A SOURCE OF EMISSION FOR HIGH POWER TUBES.*

P. H. Kafitz, D. H. Goodman, and D. H. Sloan, University of California, Berkeley

In an attempt to circumvent the emission density limitation of present cathode materials, an investigation has been made to determine the practicability of using an arc as a source of emission for high power, high frequency vacuum tubes. A number of experimental tubes have been constructed and various geometries have been investigated. The arc-cathode tube as presently constructed is essentially a triode whose source of electrons is the plasma of a high frequency gaseous discharge, rather than the usual thermionic cathode. Several tubes have been operated as self-excited oscillators. One of these developed 100 kilowatts at 100 megacycles on pulsed operation. The peak current drawn from the plasma was 3 amp/cm^2 of grid area. Direct current tests indicate, however, that maximum emission may exceed this by a factor of 10 to 100. In its present form the device is pumped continuously. A trigger spark in the cathode region provides the necessary gas for the main discharge by vaporizing some of the metal. The main discharge is created and maintained by the r-f fields in the grid-cathode region. When the grid is positive and aided by the positive anode, a considerable portion of the electrons accelerated toward the grid pass on through to the anode, traversing a region that is essentially high vacuum. This high vacuum will be maintained for a considerable time if most

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of the gas in the arc is ionized. Very few neutrals drift into this region and these condense on the first available surface. Being neutral atoms of metal vapor, the low pressure of neutrals does not rise with time because of this condensation. Pulse lengths as great as 40 microseconds have been obtained experimentally.

E7. THE REIGNITION OF SHORT ARCS AT HIGH PRESSURES.

Lauriston P. Winsor, Rensselaer Polytechnic
Institute, Troy, N.Y.

Arc reignition data are presented for electrodes of pure silver, copper, and graphite, and commercial contacts of silver, silver-cadmium, tungsten, and silver-tungsten carbide, in nitrogen. The pressure range studied is between 76 cm Hg and 400 cm Hg, and the current range between 0.2 amperes and 2.0 amperes, with a fixed gap of 1 mm. The reignition potential shows marked random variation from half cycle to half cycle for metal electrodes. The average value of reignition potential increases with increased pressure, and decreases with increased current, as expected. Some correlation is shown to exist between an increase in the reignition potential and an increase in the thermal conductivity of the electrode material; also between an increase in the reignition potential and an increase in the work function. No correlation is observed between the reignition potential and the melting or boiling points of the electrode material for the current range studied. A conditioning effect is noted whereby the average reignition potential for newly cleaned electrodes increases by as much as 25% with the first few arcings. This is attributed to increased smoothness of the electrode surface caused by the action of the arc.

E8. IMPROVED POTENTIAL-PROBE MEASUREMENTS IN CARBON ARCS.

Wolfgang Finkelnburg, Fort Belvoir, Virginia

The potential distribution along the arc-stream axis, in the potential drop regions close to the electrodes, and in certain boundary layers of carbon arcs has been studied, despite arc temperatures up to 12,000° K, by means of fast moving potential probes. Tungsten wires covered by insulating glass or quartz, except for a small tip, were whipped through the arc stream, or pneumatically shot against and retracted from the electrodes, while the probe potential with reference to one of the electrodes, the total arc voltage, the arc current, and the position of the probe's tip with respect to the electrode surface were simultaneously recorded by a Hathaway oscillograph. Tungsten probes plated with different metals were used for checking a possible influence of oxide formation, differences of work function, etc. However, the results proved to be independent of the probe material and, in a fairly wide range, of the probe speed. Results concerning potential distribution and potential drops in different regions of carbon arcs at low and high current density will be discussed, together with possible sources of error and their elimination.

E9. OSCILLATIONS IN DIRECT CURRENT ARCS.* T. B. Jones and B. H. List, The Johns Hopkins University

Two types of oscillations have been discovered in direct current carbon arcs in air. One type, consisting of low audio frequency oscillations of one hundred to four hundred cycles per second, occurs in a narrow current range just below the hissing point. Simultaneous oscillations of voltage, current, light and sound have been observed. High speed motion pictures show that these so-called "quiet" oscillations are the result of the rotation of the anode spot around the anode crater circumference. The voltage oscillations are a result of the varying arc length as the spot rotates. Their frequency was found to be dependent on the material, size, and separation of the electrodes and the arc current.

The second type of oscillations begins as soon as the arc enters the hissing stage. They occur in the radio frequency spectrum in definite bands up to at least ninety megacycles. The frequency in this case appears to be independent of electrode material, arc length or current but dependent on the atmosphere. Both types of oscillations are independent of any external inductance or capacitance in the arc circuit. Oscillations are present in materials other than carbon, e.g. tungsten, aluminum, and copper. However, the "quiet" oscillations in these materials are very unstable due to melting of electrodes.

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

E10. CHARACTERISTICS OF THE HELIUM-TUNGSTEN ARC WITH HIGH CURRENTS.* T. B. Jones and Merrill Skolnik, The Johns Hopkins University

The fundamental properties of the electric arc are investigated for tungsten rod electrodes in helium at a pressure slightly above one atmosphere and for currents ranging from 15 to 80 amperes. These properties include the voltage-current and voltage-arc length characteristics, the physical appearance of the arc, and arc starting phenomena. The helium-tungsten arc may exist in either of two forms: (1) the cold-cathode arc, or (2) the thermionic arc. The cold-cathode arc always appears on starting and may last a few seconds before extinguishing if the current is not sufficiently high to initiate a thermionic arc. If the current exceeds 70 amperes (approximately), the cold cathode arc will change quickly to the stable thermionic arc. The voltage-current curves are similar in appearance to the usual V-I characteristics for the arc except that in most cases two different curves, displaced by several volts, may be obtained for the same arc length. The arc voltage usually follows the upper of these two curves for low currents and makes a transition to the lower curve for the high currents. This transition is accompanied by a change in arc appearance and is believed to be caused by vaporization of the cathode material which influences the character of the discharge. For short electrode separations and the higher values of current the arc voltage approaches 20 volts, which is near the first resonance potential of helium.

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

F1. PROBE TECHNIQUE FOR THE MEASUREMENT OF ELECTRON TEMPERATURE.

M. A. Easley, General Electric Company, Nela Park

A study has been made of the characteristics of the positive column of the low pressure mercury arc in the presence of one to 3.5 mm pure argon or krypton gas. Under some conditions, non-linear probe characteristics were found, similar to those reported by others for discharges in pure mercury. This discontinuity in the slope of the log i_p - V_p plots for wire probes was eliminated in many cases by heating the probe by electron bombardment before each reading. With this technique, linear probe characteristics over the measurable range of electron current (i.e., over a 10,000-fold range in probe current) were obtained for discharges in 0.5 to 46μ mercury vapor mixed with one to 3.5 mm pure krypton or argon gas, provided the discharge was free of oscillations. Non-linear plots were obtained for discharges with striations and for gas contaminated by a fraction of a micron of CO or CO_2. The linear probe characteristics lead to the conclusion that in the discharges with no oscillations, the electron velocity distribution followed the Maxwell Distribution Law, at least to 10 or 11 volts from space potential. The report will include typical probe plots and electron temperature measurements illustrating the results described.

F2. GAS TEMPERATURES AND ELASTIC LOSSES IN LOW PRESSURE MERCURY ARGON DISCHARGES, C. Kenty, M. A. Easley and B. T. Barnes, General Electric Company, Nela Park

The increase ΔT in average gas temperature for a-c and d-c has been determined from measurements of the increase in pressure. A small McLeod gauge was used. Wall temperature was regulated. Corrections for end effects were made by comparing results for long and short tubes of 3.6 cm diameter. Assuming the radial variation of heat input to be parabolic, the temperature distribution was calculated using published values of heat conductivity K. From the results the heat input P_m per centimeter length was calculated. This value was compared with the elastic loss P_c computed from electron temperature T_e and number of electrons N_e per centimeter column, taking into account the variation of mean free path with electron velocity. The table indicates the good agreement obtained.

t_{Hg}	Amp.	p_A mm	ΔT	T_e	$N_e \times 10^{-12}$	P_m	P_c
17°	.42	3.5	42.7	15,000	2.5	.16W	.19W
60	.42	3.5	15.8	9,800	2.65	.061	.064
42	.20	3.5	13.1	11,900	1.15	.047	.047
42	.60	3.5	27.1	10,800	3.3	.107	.104
42	.42	1.7	10.0			.037	
42	.42	5.1	30.3			.12	

F3. CHARACTERISTICS OF MOVING STRIATIONS IN A MERCURY-KRYPTON MIXTURE. H. L. Steele, Jr., Westinghouse Electric Corporation, Bloomfield, N.J.

Experimental work has been continued on the characteristics of moving striations for various currents and pressures in a fluorescent lamp type of discharge containing mercury and krypton. The work supplements that reported at the 1949 Conference on Gaseous Electronics. The discharge is photographed with a shutterless camera which moves the film at right angles to the discharge. At low currents and pressures bright regions move from anode toward cathode at thousands of cm/sec with a frequency of hundreds per second. The distance between striations decreases to 5.2 cm as the mercury pressure is increased and usually changes so that a whole number of bright regions exists. This is explained by a synchronization of these striations with an oscillatory phenomenon at the anode, and at the cathode with high speed striations caused by the anode oscillations. The bright regions are believed to be regions of high metastable population. When the discharge is pulsed, the first striations are created near the cathode, later ones further from the cathode. If a second pulse is applied soon enough (within 8 milliseconds), striations also carry over from those in the first pulse. This can only be explained on the basis of metastable lifetimes.

F4. MOVING STRIATIONS IN H_2 AND D_2 GLOW DISCHARGES.*

T. M. Donahue, The Johns Hopkins University

A study of glows in hydrogen by means of photomultiplier tubes used in conjunction with an oscillograph[1] has revealed that such "d.c." discharges can exist in both oscillatory and non-oscillatory states. The oscillations found generally have a frequency of a few times 10^4 sec^{-1}. Two distinct regimes for these discharges will be discussed. (1) Low pressure, low current (below 0.2 mm and 1.0 ma). The positive column appears homogeneous, but there exist in it moving striations. The most prominent of these travel toward the cathode at a speed higher than 5×10^7 cm/sec. The frequency of oscillation increases linearly with current and decreases with pressure. (2) Higher pressure and current. Stationary striations begin to appear in the column. Oscillations do not usually exist but they may appear. Generally this occurs when there are a few standing striations at the head of a homogeneous column. In the homogeneous column, then, moving striations are found, all of which move toward the anode. The light intensity in the stationary striations also oscillates. When deuterium glows were studied under conditions identical with these no essential differences were noted. Thus the prominent oscillation parameters in these glows are independent of the mass of the positive ions.

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1. T. Donahue and G. H. Dieke, "Oscillatory Phenomena in Direct Current Glow Discharges", Physical Review, in the press.

* Work supported through an ONR contract under the direction of G. H. Dieke.

F5. ELECTRODE REACTIONS IN THE GLOW DISCHARGE. F. E. Haworth

Bell Telephone Laboratories

The reactions which occur at silver electrodes in a <u>normal</u> glow discharge in air have been determined. These are: (1) formation of $AgNO_2$ and some Ag_2O at the anode at the rate of 3.4 µg/coulomb; (2) loss of metal from the cathode by chemical action at the rate of 3.5 µg/coulomb (probably the same reaction as (1) with subsequent loss of the reaction products by the greater heating of the cathode, but this hypothesis has not been established); and (3) normal sputtering loss at the cathode at the rate of 0.4 µg/coulomb. These processes result in building a conducting layer on the anode. If the electrode separation is so small that the anode extends into the region of the cathode fall, then the high electric field pulls the newly formed and not very coherent growth upon the anode across into a bridge between the electrodes.

F6. DYNAMIC CHARACTERISTICS OF GLOW DISCHARGES IN THE RARE GASES AT ULTRASONIC FREQUENCIES.* W. D. Parkinson, The Johns Hopkins University

A systematic study has been made of the dynamic characteristics of glow discharges in the rare gases in the frequency range 10 to 300 kc. This region is approximately free from the influence of voltage and current fluctuations associated with moving striations, which play a dominant part at lower frequencies. The peak voltage is always well below the sparking voltage except at the lowest pressures. To a first approximation the glow discharge behaves as a linear resistance at these frequencies. This is especially true of He. In the heavier gases there is a tendency for the discharge to have a lower conductance while the voltage and current are increasing. During this phase of the cycle there is a brief period in which the current is higher than would be expected. This effect is slight in Ne and much more marked in A and Kr. This is interpreted as due to the low cross-section for elastic collision of low energy electrons with rare gas atoms. This is supported by the fact that phototube observations of the positive column during this period show practically no light output in the case of A and Kr, indicating a lack of excitation in spite of the high current.

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*This work was supported through an ONR contract under the direction of Dr. G. H. Dieke.

F7. DECIMETER OSCILLATIONS IN MERCURY PLASMAS, EXPERIMENTS AND CONSIDERATIONS. L. Brennan, J. Saloom and R. Wellinger, University of Illinois

A three-electrode oscillator, as described by G. Wehner[1], has been investigated extensively. It is shown that this structure displays the same behavior as some gas diode oscillators enclosed in glass, thus establishing a close relation between the diode type oscillators and the particular Wehner structure. A systematic set of data shows the variation of wavelength with each of the parameters involved in the oscillation. These experimental results disagree with the majority of the formulas published to date. The system oscillates in different modes, and as the cathode current is increased continuously, the frequency remains constant except for discrete jumps. Further, the transit time of the beam electrons between two electrodes is always an integer plus one quarter times the period of oscillation. A theory similar to Wehner's, based on the model of the double gap klystron oscillator, should describe the oscillations satisfactorily. However, this model implies the questionable assumption that within each dark space there exists a layer with marked resonant properties.

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[1] G. Wehner, "Plasma Oscillator", Jour. Appl. Physics, January 1950.

F9. MOMENTARY INTENSIFICATION OF THE ELECTRON BEAM OBTAINED FROM A HIGH-VOLTAGE COLD-CATHODE DISCHARGE. John H. Park, National Bureau of Standards

A method for obtaining a 10- to 50-fold momentary increase in the intensity of the electron beam obtained from a high-voltage cold-cathode discharge tube has been developed. Its application for increasing the recording speed of a high-voltage cathode-ray oscillograph is described. Oscillograms have been obtained in which the trace speed is about three-fourths the velocity of light. The intensification is caused by superposing a steeply rising voltage pulse on the normal steady voltage across the electrodes of the discharge tube serving as the electron beam source. The voltage pulse momentarily disrupts equilibrium conditions in the discharge and produces an intense discharge that lasts for about 2 microseconds. Measurements of the magnitude and duration of the superposed pulse and of the changes in discharge current have been made. A tentative explanation of the mechanism of intensification based on these measurements is given.

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F10. SOME CHARACTERISTICS OF LOW-PRESSURE DISCHARGES IN PURE NOBLE GASES. F. C. Todd and J. E. Drennan, Battelle Memorial Institute

The characteristics of low-pressure electrical discharges in very pure noble gases deviate from those in slightly contaminated gases. The voltage-current characteristics do not have the irregularities so often observed in the standard VR-tube, although humps may remain which are characteristic of the metal surface of the cathode. Hysteresis may be present, depending on the noble gas and the cathode temperature. For metal cathodes of zirconium and molybdenum, the cathode temperature at which hysteresis disappears is approximately proportional to the atomic weight of the noble gas. The discharges in very pure, unmixed noble gases show oscillations. This is in contrast to the slightly contaminated gases which rarely show oscillations. Barium films are not efficient getters to remove the last trace of impurities. The relative gettering rate of molybdenum, tantalum, and titanium for the last traces of impurities will be shown.

AUTHOR INDEX TO PAPERS