R. Geballe
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CONFERENCE ON GASEOUS ELECTRONICS

MELLON INSTITUTE
PITTSBURGH, PA.

NOVEMBER 3, 4, 5, 1949

ABSTRACTS OF PAPERS

(Received Before October 15, 1949)

To Be Presented At The

CONFERENCE ON GASEOUS ELECTRONICS

Mellon Institute

Pittsburgh, Pa.

November 3, 4 and 5, 1949

PROGRAM

A. SPARKS AND CORONA
Chairman, W. P. Allis, M.I.T.

Thursday November 3 10:00 A.M.

A1. Absolute Absorption in N_2 in the Vacuum Ultraviolet and Related Problems, G. L. Weissler, University of Southern California.

A2. Point-to-Plane Corona Pulses, W. N. English, Chalk River, Ontario, Canada.

A3. Recent Developments in Corona and Gaseous Discharge Studies, L. B. Loeb, University of California.

A4. Photon Production in Externally Sustained Discharges, Ronald Geballe and James M. Templeman, University of Washington.

A5. Further Measurements of Formative Time Lags in Spark Breakdown, L. H. Fisher and B. Bederson, New York University.

A6. Interpretation of Formative Time Lags of Spark Breakdown in Air at Low Overvoltages, B. Bederson and L. H. Fisher, New York University.

B. HIGH FREQUENCY DISCHARGES
Chairman, L. H. Fisher, N.Y.U.

Thursday November 3 2:15 P.M.

B1. Some Microwave Properties of Gaseous Discharges, J. D. Cobine, General Electric Company.

B2. Ultra High Frequency Oscillations in a Mercury Vapor Gas Discharge at Low Pressure, J. H. Bryant, Federal Telecommunication Laboratories.

B3. Diffusion of Electrons in a Spherical Cavity, A. D. MacDonald, Dalhousie University, Canada.

Intermission

B4. Diffusion of Electrons in Magnetic Field, B. Lax, M.I.T.

B5. Spectra and Breakdown Voltage for Gases at High Frequency, J. G. Winans, Clarence S. Clay and Keith Hayes, University of Wisconsin.

B6. Plasma Electron Oscillations, K. G. Emeleus, Queen's University Belfast, Ireland. To be read by W. P. Allis, M.I.T.

B7. Gas Discharge Plasmas in High Frequency Electromagnetic Fields, L. Goldstein, Federal Telecommunications Laboratories.

C. JOINT MEETING WITH PITTSBURGH PHYSICAL SOCIETY
Chairman, R. C. Mason, Westinghouse Research Laboratories
President, Pittsburgh Physical Society

Thursday November 3 8:00 P.M.

C1. Lecture and Demonstration
Imprisonment of Resonance Radiation in Mercury Vapor, D. Alpert, A. O. McCoubrey and T. Holstein, Westinghouse Research Laboratories.

D. EXCITATION AND DIFFUSION
Chairman, L. B. Loeb, University of California

Friday November 4 9:00 A.M.	D1.	Persistence of Band Fluorescence in Mercury Vapor, A. O. McCoubrey, D. Alpert and T. Holstein, Westinghouse Research Laboratories.
	D3.	Transfer of Excitation in Atomic Collisions, T. Holstein, Westinghouse Research Laboratories.
	D4.	Microwave Zeeman Spectrum of Nitric Oxide, H. Margenau and A. F. Henry, Yale University.
Intermission		
	D5.	Electron Density Decay and Spectroscopic Measurements in Mercury Afterglows, R. B. Holt and P. Dandurand, Harvard University.
	D6.	On the Kinetic Theory of Ion Mobilities, G. H. Wannier, Bell Telephone Laboratories.
	D7.	Ambipolar Diffusion of Ions and Electrons Axially in a Cylinder, J. Slepian and L. S. Frost, Westinghouse Research Laboratories.

E. γ-PROCESSES: PLASMA STUDIES
Chairman, J. D. Cobine, General Electric Company

Friday November 4 2:00 P.M.	E1.	Studies Employing Pulses Townsend Discharges on a Microsecond Time Scale, J. A. Hornbeck, Bell Telephone Laboratories.
	E2.	Studies Employing Pulsed Townsend Discharges on a Millisecond Time Scale, J. P. Molnar, Bell Telephone Laboratories.
	E3.	Studies Employing Monoenergetic Beams of Slow Ions, H. D. Hagstrum, Bell Telephone Laboratories.
Intermission		
	E4.	Double Probe Method for Measurements in Steady and Time-Varying Gas Discharges, E. O. Johnson and L. Malter, RCA.
	E5.	Equilibrium Potential Through a Plasma Maintained by Equal Ion and Electron Production, L. P. Smith, Cornell University.
	E6.	A Continuous Solution of Langmuir's Plasma-Sheath Equation, O. G. Harrold, University of Tennessee, and Raymond Murray, Carbide and Carbon Chemicals Corporation, Oak Ridge, Tenn.
	E7.	Mass Spectrographic Measurement of Positive Ion Energies in an Arc Discharge, Raymond Murray, Carbide and Carbon Chemicals Corp.
	E8.	Test of Child's Law for an Arc in a Magnetic Field, C. B. Mills, Carbide and Carbon Chemicals Corporation, Oak Ridge, Tenn.

F. LOW PRESSURE DISCHARGES
Chairman, J. A. Hornbeck, Bell Telephone Labs.

Saturday November 5 9:00 A.M.	F1.	Electron Emission in Caesium Vapor, A. W. Hull, General Electric Company.
	F2.	Characteristics of a Low-Pressure Discharge with Square-Wave Modulation, B. T. Barnes, General Electric Company.
	F3.	Characteristics of Pulsed Discharges in Neon and Argon, W. S. Huxford and H. N. Olsen, Northwestern University.
	F4.	A New Form of Low Current Discharge in Gas Mixtures: The Flashing Discharge, C. Kenty, General Electric Company.
Intermission		

F5. Some Results on Hindered Glow-Discharge Studies, Heinz Fischer, Cambridge, Massachusetts

F6. Some Observations on the Radiation Time-Function of Short Spark-Discharges, Heinz Fischer, Cambridge, Massachusetts.

F7. High and Low Speed Striations in Mixtures of Mercury and Inert Gases, H. Steele, Westinghouse Electric Corporation.

F8. Voltage Hysteresis of Voltage Regulator Tubes Filled with Noble Gases, F. C. Todd, Battelle Memorial Institute, Columbus, Ohio.

F9. Electrode Deterioration in T-R Type Tubes, J. C. French, National Bureau of Standards, Washington, D. C.

G. MOSTLY ARCS

Chairman, J. Slepian, Westinghouse

Saturday November 5 2:00 P.M.

G1. Probe Measurements and Anodic Mechanism of Carbon Arcs, W. Finkelnburg, Ft. Belvoir, Virginia.

G2. Retrograde Motion of the Arc Cathode Spot, C. J. Gallagher, General Electric Company.

G3. Stability of Arcs Drawn by Separating Contacts in Oxidizing, Neutral and Reducing Atmospheres, W. M. Brubaker, Westinghouse Research Laboratories.

Intermission

G4. Some Aspects of Geiger-Mueller Tube Discharges, O. S. Duffendack, Philips Laboratories, New York.

G5. Toward a Physics of the Arc Spot Microvolume, J. Rothstein, Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey.

G6. Holes and Retrograde Arc Spot Motion in a Magnetic Field, J. Rothstein, Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey.

G7. Studies of an Anchored Mercury Arc, C. G. Smith, Raytheon Manufacturing Company, Waltham, Massachusetts.

Program Committee

W. P. Allis, M.I.T.
T. Holstein, Westinghouse
C. Kenty, General Electric
J. P. Molnar, Bell Labs.
D. Alpert, Westinghouse

THURSDAY, NOVEMBER 3, 1949

10:00 A.M.

SESSION A

SPARKS AND CORONA

CHAIRMAN, W. P. ALLIS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CAMBRIDGE, MASSACHUSETTS

A1. ABSOLUTE ABSORPTION IN N_2 IN THE VACUUM ULTRAVIOLET AND RELATED PROBLEMS.

G. L. Weissler, University of Southern California

In order to evaluate experimentally the contributions of high energy photons (8 to 25 e.v.) to the propagation of various types of gaseous discharges it seemed worthwhile to apply vacuum spectroscopic techniques in order to obtain quantitative results for specific mechanisms. The most basic of these is the absolute absorption coefficient measured as a function of wavelengths. Preliminary results in N_2 between 550 and 1300 A will be presented.[1] A normal incidence vacuum spectrograph[2] has been built which can also be used as a monochromator. Work is underway to study with this instrument the photoelectric efficiencies of various metal surfaces as a function of wavelengths and to determine photo-ionization cross sections in gases, again as a function of wavelength. It is anticipated to use a "Kingdon cage" positive ion space charge detector. Results on the calibration of such a detector will be presented. Without a great deal of experimental refinement we were able to detect an estimated number of 40 positive ions of thermal energies. Work is in progress to increase the sensitivity, possibly to the point of registering individual positive ions.

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1. A report on this will also be made at the APS meeting in November, 1949, in Chicago.
2. Blueprints and photographs of the normal incidence spectrograph (radius of curvature of grating: 1 meter) and its component parts are available upon request.

A2. POINT-TO-PLANE CORONA PULSES

W. N. English, Chalk River Laboratories, Ontario, Canada

Positive point-to-plane corona in air is intermittent over two voltage regions. Just below steady corona onset the "Geiger" region gives rise to "burst pulses" and "pre-onset streamers"; the region for steady corona reaches its upper limit in the advent of "breakdown streamers", which culminate in spark breakdown. Negative point-to-plane corona in air is intermittent over the whole of its range, producing the so-called "Trichel pulses".

The shape and duration of these pulses, which is of some importance in corona theory, has been studied with a Dumont Type 280 cathode ray unit using very short direct connection to the deflector plates of the 5RP11 tube. Visual observations with various time constants of the collector (the plane) indicate that:

(i) There is apparently no effect which would require interpretation in terms of the rate of propagation of the corona process. This suggests that the propagation is very fast compared with the velocity of separation of the resultant positive and negative charges and is in agreement with cloud chamber results of Raether and others.

(ii) The observed rise time is governed by the velocity of electrons and/or positive ions in the high field region near the point. It is not very different for the three types of pulses and is roughly 10^{-7} sec.

(iii) The observed decay time is governed by the time constant of the collector, or by the transit time through the high field region, whichever is longer. For short time constants the decay appears to be of the order of half a microsecond.

An attempt is being made to correlate observed pulse shapes with shapes calculated from motion of charges in the divergent field, to check whether any mechanism but separation of the charge is involved.

A3. RECENT DEVELOPMENTS IN CORONA AND GASEOUS DISCHARGE STUDIES

L. B. Loeb, University of California

PART I

THE SIGNIFICANCE OF THE CORONA GAP IN BREAKDOWN STUDIES, THE CHOICE OF SUITABLE GAP FORM, AND THE FIELD ALONG THE AXIS OF A HEMISPHERICALLY CAPPED POINT-TO-PLANE GAP

The work being here reported was a joint contribution of the speaker, James H. Parker, E. E. Dodd, W. N. English, and H. W. Bandel.

The various corona gap forms suitable for the convenient investigation of corona phenomena of both signs in the laboratory that are capable of yielding quantitative data involving the Townsend integral for the thresholds of the manifold phenomena are discussed. For laboratory study the most convenient form of gap is the hemispherically capped cylindrical point-to-plane system. Analysis of the potential fall along the axis in such gaps by means of electrolytic model studies indicates that the essential parameter is L/r, the ratio of gap length, L, from point surface to plane relative to the point radius $\underline{r}$. The model study potentials are, however, incapable of giving accurate values of the field strength. These fields must be obtained by computation. Laboratory studies of corona indicate the desirability of relatively large values of L/r. Practical considerations based on studies at atmospheric pressure indicate point radii $\underline{r}$ of 0.025 and 0.05 cm with a ratio $L/r = 160$ to be those giving the greatest flexibility and most widely separated thresholds at convenient potentials. The use of such point systems to standardize data is recommended. On this basis the field along the axis for the hemispherically capped cylindrical point-to-plane gap as computed by E. E. Dodd is given and here applied to the calculation of the point-to-plane Townsend integral for preonset burst pulse thresholds in air as observed by H. W. Bandel. The value is compared with the values obtained by W. N. English for confocal paraboloids where the fields are accurately known. The results are satisfactorily consistent. Discrepancies in the fixing of burst pulse thresholds by various observers are discussed.

PART II

RECENT DEVELOPMENTS IN POINT-TO-PLANE CORONA STUDIES

H. W. Bandel has carried out a systematic study of the various current and corona phenomena for several standard point-to-plane gaps in filtered air over a considerable pressure range, paralleling Miller's measurements with co-axial cylinders. Measurements are now practically completed, and it is hoped that a report will shortly be published giving the sequence of events for air coronas.

Aside from giving us for the first time a consistent over-all view of both negative and positive coronas with this geometry, two rather interesting observations merit mention. It was observed that the rather important and interesting preonset streamers occurring slightly above the burst pulse threshold and terminating with the onset of steady burst pulse corona appeared with only the larger points and atmospheric pressure in Bandel's chamber. Previous studies by English and others had revealed them to exist in room air over a wide range of point sizes. The cause of the absence of these phenomena in Bandel's studies was proven to arise from the absence of water vapor in the air, since the other observations were made in room air with about sixty precent relative humidity at around twenty degress centigrade. It appears that water vapor, with its very strong absorption bands in the ultraviolet, is essential in the more strongly divergent fields for the propagation of pre-onset corona streamers. Introduction of water vapor made the streamers appear at atmospheric pressure and extend down to somewhat lower pressures in Bandel's chamber. This influence of water vapor had not been noted before, and it has a bearing on the mechanism of streamer formation.

In studying the negative Trichel pulse corona at relatively low pressures with increasing currents and potentials, it was observed that the intermittent, or better, completely interrupted regular Trichel pulses are changed to a fluctuating discharge on a continuous negative current as the voltage was raised beyond certain critical values appropriate to each low pressure. Eventually, even these pulses ceased and a steady corona current with no fluctuations was observed. The explanation for this is obviously that with decreasing pressures, the negative ion space charge which chokes off the corona current, giving the Trichel pulses, is formed further and further out in the gap because of the relatively decreased attachment of electrons at the lower pressures. Increasing the potential applied to the point at a given pressure insures the passage of the electrons as such out of the critical volume for choking off the discharge at such a rate that they do not have time, or have too much energy to attach. The transition from a complete interruption of the discharge to a steady discharge must obviously pass through a region where attachment is still sufficient to diminish the current by increasing gap resistance. The most striking feature of this observation was that as the oscillations ceased the well-marked fan corresponding to a positive column with Trichel pulse corona and its accompanying Faraday dark space next to the negative glow disappeared. This was replaced by the negative glow with its Crooke's dark space next the point and beyond the negative glow a continuous and very faint positive column which filled the whole chamber. This seemed to confirm Loeb's conviction that the Faraday dark space might be associated with oscillations in the discharge.

PART III

THE CLUSTERING OF IONS AND THE MOBILITIES IN GASEOUS MIXTURES

Finally, a further contribution to the field of gaseous discharge comes from a theoretical study of the clustering of ions and mobilities in gaseous mixtures by Albert W. Overhauser, which recently appeared in the Physical Review.

It is shown by direct analysis that the deviations from Blanc's law for mobilities of ions in mixtures of gases observed when a strongly polarizable gas is mixed with one less polarizable cannot be ascribed to a statistical clustering effect as proposed by Loeb. Analysis involving the assumption that the ion undergoes labile clustering of the simplest type indicates that the observed results can be completely accounted for within the realms of simple theory. Thus assuming that the active gas can attach a single molecule to the ion and that this attachment molecule may be detached with different probabilities by collisions with the two types of gas molecules leads to an equation for the resultant mobilities which will cover practically all cases observed. The forces assumed can be dielectric but may also be secondary valence or van der Waals' forces. It is indicated how, with appropriate experimental procedures possible under modern techniques, most of the constants required for the solution of the equation can be directly determined or computed enabling evaluations of the probabilities of attachment and detachment.

A4. PHOTON PRODUCTION IN EXTERNALLY SUSTAINED DISCHARGES

Ronald Geballe and James M. Templeman, Department of Physics,
University of Washington

The rate of production of photons in an externally sustained Townsend discharge between parallel disc electrodes has been measured in H_2 as a function of X/p in the region from 14 volts/cm/mm to 60 volts/cm/mm and in more limited regions in N_2 and impure Argon. A Geiger counter, operating within the discharge chamber and exposed directly to the radiation passing through a hole in its copper cathode, was used as a detector. The observed intensities were at times less than background, necessitating long counting periods. Measurements were made in H_2 at pressures between 8.7 mm Hg to 100 mm Hg, in N_2 at 15 mm Hg and 32 mm Hg, and in Argon at 15 mm Hg. After correcting in so far as possible for geometry and counter efficiency, and using published values for α/p; a function, θ/p, analagous to α/p was computed. The curves for θ/p as a function of X/p are markedly dependent on p. In H_2 they rise to maxima at values of X/p which shift from 21 volts/cm/mm at 100 mm pressure to 42 volts/cm/mm at 10 mm pressure. The amplitudes increase by a factor of about 8 for this change in pressure. In N_2, θ/p rises monotonically in the region studied and is of about the same magnitude as in H_2. In Argon (contaminated with air) θ/p rises very sharply until breakdown and has a magnitude about ten times that in H_2 and N_2. These curves will be discussed with reference to absorption effects in the gases.

A5. FURTHER MEASUREMENTS OF FORMATIVE TIME LAGS IN SPARK BREAKDOWN

L. H. Fisher and B. Bederson, New York University

Previously[1] reported measurements of the formative time lags of spark breakdown in a plane parallel gap in air have been extended with an improved power supply. With the new circuit, the delays can be measured extremely close to the threshold voltage for breakdown. The new measurements have been carried out as a function of pressure, plate distance, and over-voltage. The formative time lags very close to threshold have been found to be of the order of 100 microseconds and longer. These lags are at least ten times as long as those we have previously reported. Varying the approach voltage by as much as 4 kv does not affect the results appreciably. The number of initiating electrons at the cathode has been varied by a factor of ten and this again does not materially alter the results.

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1. L. H. Fisher and B. Bederson, Brookhaven Gas Discharge Conference 1948; Phys. Rev., 75, 1615, 1949

Supported by the Office of Naval Research and the Research Corporation

A6. INTERPRETATION OF FORMATIVE TIME LAGS OF SPARK BREAKDOWN IN AIR AT LOW OVERVOLTAGES

B. Bederson and L. H. Fisher, New York University

An attempt has been made to account for the long formative time lags observed in the passage of an electric spark in air in a plane parallel gap by (1) secondary emission by positive ions at the cathode, and (2) by the enhancement of field intensified ionization due to field distortion.[1]

For mechanism (1) an equation for electron and positive ion charge densities as a function of position, time, and overvoltage is developed (no field distortion), and it is assumed that the time for a spark to form is the time for the positive ion density to reach a critical value at the anode. It is then assumed breakdown could proceed by the streamer mechanism. It is shown that mechanism (1) is not in accordance with the experimental data as regards the variation of the time lags with pressure and plate distance.

For mechanism (2), the positive ions created by the primary electron avalanches produce a locally strengthened field upon approaching the cathode, thus magnifying Townsend's first coefficient in that region. Thus an effective secondary mechanism is produced. The transient equation for the growth of the current by mechanism (2) is more in accordance with the experimental facts. The role of photoionization in mechanism (2) will be discussed qualitatively.

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1. See, for example, Varney, White, Loeb, and Posin, Phys. Rev., 48, 818, 1935

Supported by the Office of Naval Research and the Research Corporation

THURSDAY, NOVEMBER 3, 1949

2:15 P.M.

SESSION B

HIGH FREQUENCY DISCHARGES

CHAIRMAN, L. H. FISHER

NEW YORK UNIVERSITY

NEW YORK, NEW YORK

B1. SOME MICROWAVE PROPERTIES OF GASEOUS DISCHARGES

J. D. Cobine, General Electric Company, Cleveland, Ohio

(A) The 1000 mc./sec. impedance of an atmospheric-pressure d-c arc was measured with the arc burning as the terminating portion of the inner conductor of coaxial line. The arc length was sufficiently short relative to a wavelength of the measuring frequency that it could be considered essentially a lumped load. Air, argon and helium were studied at currents from 1-4 amperes. The resistance thus measured decreases with increasing current and is approximately the same as the d-c resistance. The reactance is capacitative and nearly independent of current.

(B) A 1000 mc./sec. "electronic torch" has been developed and found to have interesting properties. Various polyatomic gases, such as N_2, CO_2, air, etc. give a very intense flame capable of melting quartz and tungsten. Noble gases, when pure, produce little heating effect. Electron temperatures from 6000° to 30,000°K were indicated. The heat developed at surfaces appears to be almost entirely due to recombination of dissociated atoms.

B2. ULTRA HIGH FREQUENCY OSCILLATIONS IN A MERCURY VAPOR GAS DISCHARGE AT LOW PRESSURE

J. H. Bryant, Federal Telecommunication Laboratories, Inc., Nutley, N. J.
Formerly, University of Illinois, Urbana, Illinois

A study was made of oscillations in the wavelength range of 10 to 25 cm in a low pressure (order of 1 micron) mercury vapor gas discharge. The discharge is cylindrical in shape. It is formed by two cathodes placed opposite each other, and an anode surrounding the discharge.

The axial D-C potential distribution in the discharge was determined by use of a fine, high velocity beam of electrons shot transversely through the discharge. There was found to be no difference in D-C potential distribution between oscillating and non-oscillating conditions. The axial potential gradient was practically a linear function of distance in the cathode dark spaces; being maximum at the cathodes, zero at the plasma boundaries; and was practically zero in the plasma. Small r-f probes inserted into the discharge showed, when oscillations were present, that, 1) r-f energy appears throughout the plasma, and 2) field components present are H_φ, E_z, and probably E_ρ. Tests using variable spacing between cathodes showed modes in the axial direction. There is also a minimum diameter for which oscillations may be obtained.

The plasma is considered a cylindrical dielectric resonator. R-f waves propagated in the plasma in the axial direction experience multiple reflections at the boundaries, and, for frequencies considered here, the plasma is a dispersive medium. Waves having velocity of propagation near the velocity of the D-C beam of electrons from cathode No. 1 traversing the plasma at uniform velocity corresponding to anode potential can extract energy from the beam. Their amplitude grows until limited by non-linear effects. Waves of other frequencies will not extract energy; so that they die away rapidly because of damping. An expression is derived relating frequency to electrode geometry and anode potential.

B3. ELECTRON DIFFUSION IN A SPHERICAL CAVITY

A. D. MacDonald, Dalhousie University, Canada

The diffusion equation for electrons in a non-uniform field is solved and the breakdown condition derived. The breakdown condition is expressed in such a manner that an effective characteristic diffusion length Λ_e is determined; the meaning of Λ_e expresses the equivalent characteristic diffusion length for uniform electric fields. From the experimental breakdown fields, in which the electric field is uniform Λ_e is determined and used to predict theoretical breakdown curves for the non-uniform case. Theory and experiment are compared, the agreement verifying the correctness of the approach.

B4. DIFFUSION OF ELECTRONS IN MAGNETIC FIELD
Benjamin Lax, Air Force Cambridge Research Laboratories, Cambridge, Massachusetts

The free diffusion of electrons in the presence of a magnetic field is non-isotropic. Under these conditions the usual diffusion coefficient is replaced by a tensor, which is then used to derive a more general flow equation. The resulting effect upon the high frequency breakdown of helium is investigated when the electric and magnetic fields are transverse and parallel to each other respectively. Experimental and theoretical curves are presented.

B5. SPECTRA AND BREAKDOWN VOLTAGE FOR GASES AT HIGH FREQUENCY

J. G. Winans, Clarence S. Clay, and Keith Hayes, University of Wisconsin
+W Culp

Spectra of some gas mixtures with c.w. excitation frequencies 10-3000 mc differ from the spectra at frequencies below 1 mc. Tubes containing Ne with a small quantity of A showed only Ne lines at low frequencies but both A and Ne lines at high frequencies. Tubes containing A and a small quantity of N_2 showed only N_2 second positive bands at low frequency but both first and second positive bands at high frequency. Pure N_2 showed no difference between the spectra at high and low frequency. Spectra for pulsed high frequency excitation were no different from spectra for low frequency excitation.

Voltage measurements of breakdown field strength in He, Hg, and He + Hg were made for frequency 550 mc at different pressures. The resulting curves are in agreement with calculations made from the equations derived by Herlin, Brown, and MacDonald.[1, 2]

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1. Herlin and Brown, Phys. Rev. 74, 291 (1948)
2. MacDonald and Brown, Phys. Rev. 75, 441 (1949)

B6. PLASMA ELECTRON OSCILLATIONS

K. G. Emeleus, Queen's University, Belfast, Ireland

Read by W. P. Allis

Studies have been made of the conditions under which u.h.f. oscillations can be generated in hot-cathode, low-pressure gaseous conductors. It has been confirmed that frequencies are of the order predicted from the theory of electrostatic plasma-electron oscillations. The variation with position on the i/V characteristic of h.f. current that can be withdrawn by coupling to anode and cathode, and the internal oscillation patterns found with probes, are semi-quantitatively consistent with Merrill and Webb's suggestion that the primary electrons undergo velocity modulation in thin sheets of oscillating plasma, and bunch subsequently. The energy balance for an oscillating sheet is considered on the basis that energy is supplied through transit-time oscillations of the primary electrons between cathode and sheet, and lost by collisions between plasma-electrons and molecules (Lorentz collisional friction). Whilst this picture of the discharge may need extension to allow for travelling wave effects, it is thought it is likely to form an integral part of any more complete description. Irrespective of its detailed explanation, attention is drawn to the disturbed condition of the ionized gas indicated near the cathode, and to the possibility that the oscillations may be necessary for maintenance of the discharge.

B7. GAS DISCHARGE PLASMAS IN HIGH FREQUENCY ELECTROMAGNETIC FIELDS
L. Goldstein, Federal Telecommunication Laboratories, Inc., Nutley, N. J.

It has recently been shown[1] that the techniques now generally available in the field of high frequency electromagnetic waves constitute a valuable tool for the investigation of some or most of the phenomena occuring in gas discharges.

The conditions of validity and limitations of this method, which is based upon the complex conductivity of these media in microwave fields, are discussed.

Experimental results obtained with low power high frequency guided waves in discharge-plasmas, are reported. Both steady and transient discharges have been studied. The plasmas are produced in various gases, mono-atomic and/or molecular, at low pressure. The transient or disintegrating plasmas are produced by pulsed discharges of microsecond duration.

The dispersion properties, normal and anomalous, of a discharge plasma which, under certain conditions, has its proper frequencies in the microwave region, the plasma electron oscillation frequencies, are discussed.

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1. S. C. Brown et al. MIT Research Laboratory of Electronics, Technical Report 66

   L. Goldstein, N. L. Cohen, Phys. Rev. 73, 83, 1948

THURSDAY, NOVEMBER 3, 1949

8:00 P.M.

SESSION C

JOINT MEETING WITH PITTSBURGH PHYSICAL SOCIETY

CHAIRMAN, R. C. MASON

WESTINGHOUSE RESEARCH LABORATORIES

EAST PITTSBURGH, PENNSYLVANIA

C1. IMPRISONMENT OF RESONANCE RADIATION IN MERCURY VAPOR
D. Alpert, A. O. McCoubrey, and T. Holstein, Westinghouse Research Laboratories, East Pittsburgh, Pa.

Of fundamental importance in the field of gaseous electronics is an understanding of the phenomenon of "imprisonment of resonance radiation". This term describes the situation wherein resonance radiation emitted in the interior of a gas-filled enclosure is strongly absorbed by normal gas atoms before it can get out; the eventual escape of a quantum of radiation then takes place only after a number of successive atomic absorptions and emissions. Wood's original experiments showing the properties of resonance radiation will be demonstrated.

An experiment[1] will be described in which the persistence of resonance radiation in optically excited mercury vapor was determined. Measurements were made of the time of decay of resonance radiation after the exciting beam of 2537A light was cut off. The emerging diffuse light was detected by a photomultiplier and the resulting decay signal displayed on a properly synchronized oscilloscope. Values of the decay time, T, were determined over a wide range of vapor density, N. Agreement between experiment and theory[2] is quite satisfactory over the entire region in which the spectral line shape is determined by Doppler broadening. Zemansky's observation that the time constant is appreciably lowered for N greater than 7×10^{15} atoms/cc is not confirmed.

Further experiments in the study of excited atoms can be carried out with the experimental techniques used in this research.

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1. D. Alpert, A. O. McCoubrey, and T. Holstein, Phys. Rev. 76, 1257 (1949)
2. T. Holstein, Phys. Rev. 72, 1212 (1947)

FRIDAY, NOVEMBER 4, 1949

9:00 A.M.

SESSION D

EXCITATION AND DIFFUSION

CHAIRMAN, L. B. LOEB

UNIVERSITY OF CALIFORNIA

BERKELEY, CALIFORNIA

D1. PERSISTENCE OF BAND FLUORESCENCE IN MERCURY VAPOR *

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

When mercury vapor is excited with 2537A radiation it emits not only the resonance line itself, but also a continuous spectrum whose main constituents are two bands in the visible and near ultra-violet regions. The visible band extends from 4000A to 5300A with maximum intensity at 4850A. The near ultra-violet band extends from 3000A to 3700A with maximum intensity at 3350A.

The persistence of these bands was investigated with essentially the same apparatus as that used in the experiment on imprisonment of resonance radiation[1]. It was found that, after cut-off of the exciting beam, both bands decay with a common time constant, τ. It was observed that, for constant temperature, τ decreases with increasing pressure; at constant pressure τ increases with increasing temperature. The intensity ratio of the visible to the ultra-violet band, $\frac{I(4850)}{I(3350)}$ was also studied. For constant temperature $\frac{I(4850)}{I(3350)}$ increases with pressure, while for constant pressure the ratio decreases with rising temperature. Neither the temperature variation of τ nor the pressure variation of $\frac{I(4850)}{I(3350)}$ are in accord with Mrozowski's energy-level diagram[2] for Hg_2.

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

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

2. S. Mrozowski, (a) Zeits. f. Physik 106, 458 (1937);
(b) Rev. Mod. Phys. 16, 153 (1944) especially p.p. 160, 161.

D3. TRANSFER OF EXCITATION IN ATOMIC COLLISIONS

T. Holstein, Westinghouse Research Laboratories, East Pittsburgh, Pa.

The problem considered here is the determination of the cross-section, Q_t, for the transfer of excitation in a binary atomic collision. The general method[1] consists in treating the system of colliding atoms as an unstable diatomic molecule. In this formulation, Q_t is directly related to the transition probability between two electronic levels of the molecule.

Specific calculations are carried out for the case in which (1) the interaction between the two colliding atoms is predominantly of the dipole-dipole type, $\frac{K}{R^3}$ (R denotes internuclear distance), and (2) the difference, ΔE, between the initial and final atomic energy levels is small compared to kT. Under these conditions it is feasible to treat the motion of the nuclei classically. One then obtains, apart from unimportant numerical factors,

$$Q_t = 4\pi R_c \frac{v\hbar}{\Delta E} \exp\left[-\frac{\Delta E}{\hbar}\frac{R_c}{v}\right]$$

where v is the relative velocity of the colliding atoms, $\hbar$ is Planck's constant divided by 2π, and $R_c = \left(\frac{2K}{\Delta E}\right)^{1/3}$. The expression for Q_t holds only when the exponential factor is small compared to unity; as ΔE goes to zero, Q_t actually approaches a limiting "resonance" value, $\frac{\pi^2 K}{\hbar v}$. Numerical estimates indicate that, except in the case of very light atoms, the resonance region is quite small: $\lesssim 10^{-3}$ volts.

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1. F. London, Zeits. F. Phys. 74, 143 (1932)

D4. MICROWAVE ZEEMAN SPECTRUM OF NITRIC OXIDE

Henry Margenau and Alan F. Henry, Yale University

Beringer and Castle have measured the magnetic absorption spectrum arising from transitions between the Zeeman components of the $^2\Pi_{3/2}$ - state of NO. Their unusual measurements throw interesting light on the structure of this molecule.

According to simple theory the spectrum should show three lines with approximately equal intervals between them. The observed spectrum, however, consists of nine lines; it contains two different intervals, not one. One of these intervals is to be ascribed to the coupling of the nuclear spin of N^{14} with the magnetic field. We show in this paper that the other is of molecular origin and can be calculated with the use of a variational method which combines several molecular states in the usual zero-order representation ("Case-b eigenfunctions"). The result is in very gratifying agreement with the measurements.

$m = 3/2$ — spacing $3/2\,A$

$1/2$ — spacing $\frac{1}{2}A$

Paschen-Back effect with nuclear spin $I = 1$

$J = 3/2$ $-1/2$ —

$-3/2$ —

$\Delta M_I = 0$ sel. rule

D5. ELECTRON DENSITY DECAY AND SPECTROSCOPIC MEASUREMENTS IN MERCURY AFTERGLOWS

R. B. Holt and P. Dandurand, Department of Physics, Harvard University

Measurements have been made of the rate of electron density decay following the removal of the excitation for pulsed microwave (3000 mc/sec) discharges through mercury vapor. Simultaneous observations of the emission spectrum of the discharge plasma were made. The apparatus for the high speed electron density measurements was similar to that developed by S. C. Brown and co-workers at MIT; the shift of the resonant frequency of a microwave cavity due to the presence of the electrons was observed. Spectroscopic measurements were made by means (1) of a high speed mechanical shutter (resolving time 2 microseconds) plus a high intensity spectrograph and (2) of a pulsed photomultiplier equipped with various optical filters.

The electron density measurements at low pressures (below 0.2 mm Hg) showed an exponential decay as a function of time, with time constants on the order of 1000 microseconds. The ambipolar diffusion coefficients calculated on the basis of the observed decays were in reasonable agreement with previously available values based of D. C. discharge measurements and decreased with increasing pressure, as might be expected. Electron temperatures for the plasma calculated on the basis of the observations were reasonable. At higher pressures (1-10 mm Hg) the decay was still exponential, but time constants of the order of 100 microseconds were observed. Attempts to calculate ambipolar diffusion coefficients from the data gave abnormally high values with a very marked <u>increase</u> with increasing pressure. Electron temperatures calculated from the data were also abnormally high for this pressure range. This data indicates that some process other than ordinary ambipolar diffusion may be operating.

The atomic line spectrum of mercury was observed from the plasma, with no molecular band spectrum apparent. Interpretation of the results of the spectroscopic measurements is complicated, of course, by the imprisonment of radiation and by the existence of metastables in mercury vapor, but measurements of light intensities as a function of time showed several interesting features which will be discussed.

D6. ON THE KINETIC THEORY OF ION MOBILITIES

G. H. Wannier, Bell Telephone Laboratories, Murray Hill, N. J.

The Boltzmann integral differential equation for the velocity distribution function of gaseous ions is examined. Attention is focussed on the special case of ions moving in the parent gas under the influence of a steady uniform field.

A complete solution is presented for the case in which charge exchange predominates over elastic collisions, and the cross-section varies inversely as the speed of encounter. As a more realistic situation, the hard sphere collision model is examined with or without charge transfer. There exists for this case a scaling law of the form

$$w = \sqrt{\frac{kT}{m}}\ \phi\left(\frac{eE}{NokT}\right) = \sqrt{\frac{kT}{m}}\ \phi\left(\frac{eE}{p\sigma}\right)$$

Here w is the drift velocity, σ the collision cross-section, p the (true) pressure, N the number density; k,T and m have their obvious meanings. This law alone determines the dependence of the drift velocity on the field for high fields.

In the high field limit the distribution law $f(\vec{c})$ obeys the equation:

$$\frac{1}{\pi c}\iint f\,(\vec{c}+\vec{w}_{\perp})\,d\vec{w}_{\perp} - cf(\vec{c}) = \frac{a}{N\sigma}\,\frac{\partial f(\vec{c})}{\partial c_2}$$

where the integration is to be extended over all vectors $w_{\perp}$ lying in a plane perpendicular to $\vec{c}$. This equation is explicitely soluble in terms of Bessel functions if the assumption

$$f(\vec{c}) = f_o(c) + f_1(c)\cos\theta$$

is introduced where θ is the angle between the velocity and the field. Unfortunately, it is found that this assumption is not even approximately correct here as it is for the case of electrons because f_o is not the dominant term in a spherical harmonic expansion. A more educated guess concerning the structure of $f(\vec{c})$ will be given.

Returning from the high field case to the general case it is shown that a transformation of the form

$$f(\vec{c}) = \int d\vec{w}\, e^{-B(\vec{c}-\vec{w})^2}\, \phi(\vec{w})$$

$$B = \frac{m}{2kT}$$

permits evaluation of all collision integrals. The transformation is suggested by the explicit solution given earlier for charge transfer, and it sets up the solution in the form of a "distribution of Maxwell distributions". The equation left over is a pure integral equation of the form

$$\int K(\vec{c},\vec{w})\, \phi(\vec{w})\, d\vec{w} = 0$$

with a known nucleus K. Such an equation should at least have great advantages for numerical work since it is an identity for every value of $\vec{c}$.

D7. AMBIPOLAR DIFFUSION OF IONS AND ELECTRONS AXIALLY IN A CYLINDER

J. Slepian and L. S. Frost, Westinghouse Research Laboratories

At the last conference, the senior author presented the results of experiments which seemed to indicate that the simultaneous diffusion of ions and electrons axially into and along a circular cylinder with insulating walls did not follow the expected relationship,

$$(1) \quad n/n_o = e^{-2.40\ z/r}$$

The slope of the experimental curve obtained, when plotted on semi-log paper, did not have the theoretical constant value, "-2.40" of equation (1), but was generally much less, being about half that value near the beginning of the tube and dropping to less than 1/10 of the theoretical value at 6 radii down the tube.

Since equation (1) above should be obtained for any particles, diffusing entirely and only in virtue of their independent individual velocities, the failure to corroborate (1) experimentally would indicate that the state of a system of diffusing electrons and ions is not sufficiently described by giving particle density and temperature (or more generally, particle velocity distribution), and that some significant form of energy and momentum density must exist, other than that arising from the random velocities of the particles. The authors can only suggest plasmoidal oscillation for this other form of energy and momentum density.

It has been suggested that radiation capable of ionizing an impurity might be passing down the tube with intensity not following(1), so that after the normally diffusing ions had decayed to a low density, it would be the decay of intensity of the ionizing radiation which would be observed, rather than the density of diffusing ions. For this reason, it seemed desirable to repeat the experiments in mercury vapor for which, in contrast to neon and argon, the resonance potential is so low, 4.9 volts, that the resonance radiation can hardly be expected to ionize any likely impurity. Preliminary results were reported for mercury at the last conference, but now it can be definitely stated that entirely similar results are obtained for mercury as for the other gases.

The probe characteristics obtained in the earlier reported experiments did not show a good saturation, and left open the possibility that the failure to corroborate (1) might be due to misinterpretation of the probe data. Experiments have now been made in mercury vapor with a new type of floating double probe, which gives a very much sharper saturation characteristic. The departure of the decay curve from (1) of the kind and amount described before is still indicated.

With the earlier mercury tube, it has been found that the initial slope of the ion density decay curve can be increased from the more usually obtained half theoretical value up to the theoretical value by increasing the filament current of the arc producing the ionization. However, further down the tube the unexpected low decay continued to be found. This seems to confirm the authors' belief that more than the densities and random velocities of the ions and electrons must be given to properly describe their properties when diffusing axially into a cylinder.

FRIDAY, NOVEMBER 4, 1949

2:00 P.M.

SESSION E

γ-PROCESSES: PLASMA STUDIES

CHAIRMAN, J. D. COBINE

GENERAL ELECTRIC COMPANY

SCHENECTADY, NEW YORK

THE γ-PROCESSES OF ELECTRON EMISSION FROM COLD CATHODES

E1. STUDIES EMPLOYING PULSED TOWNSEND DISCHARGES ON A MICROSECOND TIME SCALE
John A. Hornbeck, Bell Telephone Laboratories, Murray Hill, New Jersey

E2. STUDIES EMPLOYING PULSED TOWNSEND DISCHARGES ON A MILLISECOND TIME SCALE
J. P. Molnar, Bell Telephone Laboratories, Murray Hill, New Jersey

E3. STUDIES EMPLOYING MONOENERGETIC BEAMS OF SLOW IONS
H. D. Hagstrum, Bell Telephone Laboratories, Murray Hill, New Jersey

Electron emission from cathodes in glow and Townsend discharges has been identified as arising from bombardment by positive ions, metastable atoms, and photons. The following three papers report the progress of experiments at the Bell Telephone Laboratories investigating these processes, commonly known as the γ-processes.

E1. STUDIES EMPLOYING PULSED TOWNSEND DISCHARGES ON A MICROSECOND TIME SCALE
John A. Hornbeck, Bell Telephone Laboratories, Murray Hill, New Jersey

The transient current resulting from the liberation of a very short (0.2 μ sec) pulse of photoelectrons at the cathode of a gas-filled tube has been observed experimentally. The sharp discontinuity in current that is resolved can be accounted for only by postulating the γ_i-mechanism, viz, electron emission from the cathode by positive ion bombardment. Agreement between experiment and Newton's[1] theory, which predicted the discontinuity, is sufficiently quantitative that the experiment can be utilized as a technique for measurement of gas and surface parameters. Semi-quantitative measurements of γ_i indicate that ions contribute importantly to the total γ. There is evidence under some experimental conditions of an additional current component not of ionic origin, but presumably resulting from resonance radiation through the γ_r-mechanism. The experiment also provides a direct technique for measuring positive ion mobilities in their own gases over a wide range of E/p, but not including low values of E/p.

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1. R. R. Newton, Phys. Rev. 73, 570 (1948)

E2. STUDIES EMPLOYING PULSED TOWNSEND DISCHARGES ON A MILLISECOND TIME SCALE

J. P. Molnar, Bell Telephone Laboratories, Murray Hill, New Jersey

When stimulated by light pulses of approximately five milliseconds duration, a Townsend discharge exhibits a current form which can be analyzed into two components having time constants of approximately 10^{-6} and 10^{-3} seconds. The first component is associated with the current build-up and decay caused by γ-processes involving photons and ions, while the second component is associated with γ-processes involving metastables. When these current data are fitted to a Townsend equation, the fraction of the γ-coefficient attributable to metastables can be established.

A modification of the experiment permits measurement of the relative efficiency of electron emission by photons and metastables. This is accomplished by converting metastables into radiating atoms by irradiation of the discharge space with light of appropriate wavelengths. In most observations to date the metastables are the more efficient.

An analysis of the make-up of the γ-coefficient based on these experiments and others show that the yield per ion, metastable and photon for three cathodes in argon is

	Ta	Mo	BaO
ion	.020	.064	.21
meta.	.021	.060	.25
photon	.008	.005	.025

At E/p_o of 117 volts/cm x mm the ion contribution to γ is approximately 75%, with the metastables contributing most of the remainder. At lower E/p_o values, now under study, it is expected that the photon contribution will be more important.

E3. STUDIES EMPLOYING MONOENERGETIC BEAMS OF SLOW IONS

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

An instrument has been developed for the investigation of the ejection of electrons from metals by slow ions. It is a modification of the type of mass spectrometer commonly used in the study of ionization processes in gases. The ions produced by electron impact in a gas are mass analyzed and focussed by suitable ion lenses onto a target. The ion beam is homogeneous in energy to about 0.5 ev. and may be varied in mean incident energy at the target from several hundred ev. to less than 10 ev. The target consists of a ribbon which can be flashed at high temperature for cleaning. Correlation with flash filament vacuum experiments is thus possible.

With this apparatus one measures the efficiency of electron emission and the velocity distribution of the ejected electrons as a function of the incident velocity of the ions. A variety of ion-target combinations may be investigated. The ultimate goal is to correlate this work with the theoretical picture of the electron ejection process.

The capabilities of the experimental apparatus have now been studied quite extensively and preliminary results on the ejection of electrons from a Mo target by slow He^+ ions have been obtained.

E4. DOUBLE PROBE METHOD FOR MEASUREMENTS IN STEADY AND TIME-VARYING GAS DISCHARGES

E. O. Johnson and L. Malter, RCA, Princeton, N. J.

The Langmuir probe is not well suited for measurements in time-varying and in particular not in decaying plasmas. In the latter case this is due to the fact that the plasma potential always sets itself positive with respect to the probe.

These difficulties are overcome by the use of two floating probes connected thru a resistor and variable potential source. Instantaneous current i_d is measured on a scope as a function of potential difference V_d between the probes. The resultant characteristic is always S shaped with regions of positive ion saturation currents I_{p1} and I_{p2} to one or the other probe. On the rising portion of the characteristic the electron current to one of the probes, say No. 2 is given by the difference between the total current i_d and I_{p2}. Then the instantaneous temperature is obtained from a logarithmic plot of:

$$\left[\frac{I_{p1} + I_{p2}}{I_{e2}} - 1\right] = K\, e^{-11{,}600 \frac{V_d}{T_e}}$$

$$\text{where:} \quad K = \frac{A_1}{A_2}\,\frac{j_{o1}}{j_{o2}}\, e^{+11{,}600 \frac{V_c}{T_e}}$$

A_1 and A_2 are probe areas.

j_{o1} and j_{o2} are random current densities at the probes.

V_c is abscissa intercept of i_d-V_d characteristic.

T_e is electron temperature.

I_{e2} is the electron current to probe No. 2.

Several more rapid means for determining T_e which do not require a logarithmic plot will be presented. The corrections to be applied when the positive ion saturation regions are not parallel to the abscissa will be discussed. Means for estimating charge density will also be given.

Data will be presented showing the following phenomena:

1 - Rapid temperature fluctuations during plasma ion oscillations of a "steady discharge."

2 - Temperature decays following interruption of a discharge in contact with a hot cathode. The electron temperature locks at a value determined by the degree of contact with the cathode reservoir.

3 - Temperature decays of decaying plasma in contact with room temperature electrodes. In this case the "locking" temperature is close to room temperature.

E5. EQUILIBRIUM POTENTIAL THROUGH A PLASMA MAINTAINED BY EQUAL ION AND ELECTRON PRODUCTION

Lloyd P. Smith, Cornell University

An approximate solution of Poisson's equation is given for the case of a plasma wherein equal numbers of electrons and ions are produced uniformly in a region bounded by two metal planes at the same potential and from which region the electrons and ions move at right angles to the metal planes. It is assumed that a Maxwell Distribution of velocities is quickly established for the electrons and that the ion mean free path is long enough so that they move from the point of generation solely under the action of the space potential. The potential problem is then solved subject to the condition that the potential is symmetric with respect to the median plane and that the potential difference between the median plane and the bounding metal planes is just such that the number of electrons and ions reaching the metal planes per unit time is the same. The resulting potential distribution therefore represents the mean equilibrium or steady state distribution.

For a large variety of conditions it is found that the difference of potential from the median plane and the bounding metal plane is given by $\left|\Delta V\right| = 2^{-1/3}\pi^{4/3}e^{-1/3}M^{1/3}g_{+}^{2/3}d^{2}$ where M is the mass of the ion, g_{+} is the number of ions generated per cm^3 per second, and d is the distance from the median plane to one of the bounding metal planes.

E6. A CONTINUOUS SOLUTION OF LANGMUIR'S PLASMA-SHEATH EQUATION

O. G. Harrold, Jr., University of Tennessee, Knoxville, Tenn.
Raymond Murray, Carbide and Carbon Chemicals Corporation, Oak Ridge, Tenn.

A solution in series of Langmuir's[1] potential distribution problem (3A) for the steady-state discharge has been obtained. Poisson's space charge equation is solved in one dimension under the assumption that the ion generation is uniform, the spatial electron distribution is Maxwellian, that a mobility constant characterizes ion flow and that the electrodes are grounded. Terms in the series are simple algebraic functions of a parameter that includes arc constants and the central potential. No approximations with reference to the neglect of the second derivative of the potential or of the electron density are made, so that the solution joins the plasma and sheath regions in a natural manner. One consequence is that the sheath effect is not as pronounced as would appear from the approximate plasma formula. This is based on work performed under contract with the Atomic Energy Commission.

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1. A General Theory of the Arc Plasma, I. Langmuir, L. Tonks, Phys. Rev. 34, 876 (1929)

E7. MASS SPECTROGRAPHIC MEASUREMENT OF POSITIVE ION ENERGIES IN AN ARC DISCHARGE

Raymond Murray, Carbide and Carbon Chemicals Corporation, Oak Ridge, Tenn.

An experimental method of determining the energy distribution of ions emerging from an arc plasma is described. A thin slit is cut in the grounded wall surrounding a low pressure arc. Emerging ions are bent in characteristic circles by the same uniform magnetic field that supports the arc, and currents are measured on the 180° plane of this resulting mass spectrograph. As the magnetic field strength is changed, the peak of the current distribution shifts in accord with the basic spectrograph relation, demonstrating that the currents are real. Most probable energies lie close to one electron volt. It is hoped that the dependence of this energy on field strength may be ascertained. It may be inferred that the distribution curve is the superposition of the arc potential drops and the energy of random motion. This is based on work performed under contract with the Atomic Energy Commission.

E8. TEST OF CHILD'S LAW FOR AN ARC IN A MAGNETIC FIELD

C. B. Mills, Carbide and Carbon Chemicals Corporation, Oak Ridge, Tenn.

An experiment was conducted which had the objective of correlating ion current, applied potential, and dark space thickness for ion emission from an arc in a magnetic field. The experimental set-up consisted of an arc, a defining slot, a collecting electrode with its guard ring, and a cathetometer. The separation of the arc and the collector (the dark space) was measured as a function of applied voltage for constant arc conditions, in a direction parallel with the magnetic field. The central part only of the ion stream was collected and metered. The remainder was collected on a co-planar guard ring. The relation of ion current, potential, and dark space thickness obtained in this way very closely approximates results expected from the planar form of Child's Law. One can conclude from this that the effects of sheath forces are small. This is based on work performed under contract with the Atomic Energy Commission.

SATURDAY, NOVEMBER 5, 1949

9:00 A.M.

SESSION F

LOW PRESSURE DISCHARGES

CHAIRMAN, J. A. HORNBECK

BELL TELEPHONE LABORATORY

MURRAY HILL, NEW JERSEY

F1. ELECTRON EMISSION IN CAESIUM VAPOR

A. W. Hull, General Electric Company, Schenectady, New York

The electron emission from a monatomic film of Cs on a metal surface is unique in that the coating is maintained by the process of condensation and evaporation, as an equilibrium condition. Langmuir and others[1], working at low Cs pressures, showed that the electron emission from tungsten was a maximum when the coating was 0.67 of a monatomic layer, and was consistent with a work-function of 1.7 volts.

We have studied the emission from a number of metals at vapor pressures up to .08 mm. (corresponding to a Cs temperature of 200°C). We find, in agreement with Langmuir and Taylor, that the emission at a given Cs pressure rises to a sharp maximum as the cathode temperature increases, and falls rapidly above this temperature. A Richardson plot of these maxima for Ni leads to the equation, for zero field emission:

$$i = 460\ T^2 \exp.\left[-\frac{1.68e}{kT}\right] \text{amps/cm}^2\ \text{deg.K}^2$$

This corresponds to 1 amp./cm.^{2} at a Cs temperature of 185°C. Values 4 to 5 times higher than this, which are observed with hollow cathodes, are believed to be due in part to strong ion fields.

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1. Langmuir and Taylor, Phys. Rev. 44, 423-57, 1933.

F2. CHARACTERISTICS OF A LOW-PRESSURE DISCHARGE WITH SQUARE-WAVE MODULATION

B. T. Barnes, General Electric Company, Cleveland, Ohio

Square-wave variations in current with a repetition frequency of 167-400 c.p.s. were imposed on a d.c. discharge with an average current of 0.6-0.7 amp. The discharge tube was 36 mm. in diameter, contained Hg (6 μ) plus argon (3.5 mm.). A cathode-ray oscilloscope, plus a 35 mm. camera, recorded probe data and λ2537.

The mobility equation shows that each sudden change in current is accompanied by a still larger sudden change in voltage. The electron temperature T_e also must change quickly to keep the energy expenditure equal to the input. With the ratio of the higher to the lower current 3.9, T_e rose abruptly to nearly 20,000°K. when the current increased, dropped below 11,000° within 0.4 milliseconds, fell to about 5000° when the current changed to the lower value, and rose above 10,000° in about two milliseconds. With less modulation, T_e varies less during a cycle and approaches equilibrium faster. Ion densities approach equilibrium much faster when the current is raised than when it is reduced. In the latter case, excess ions must flow to the walls.

Ion production ranged from 1.5 to 6 times that computed for single-stage ionization and a Maxwellian distribution, using Nottingham's cross-sections. Since probe data indicate that 10.4-volt electrons may be completely absent, two-stage ionization must predominate. Ion production per electron at a given T_e increased with arc current. This indicates increased metastable-atom concentrations at higher currents.

The number of electrons per cc, computed from the mobility equation, using collision probabilities listed by Brode, agrees roughly with the measured value. Computed elastic losses are much too low to account for the input at low T_e's, but seem reasonable at T_e's above 10,000°, when one assumes reasonable values for the power radiated in spectral lines.

F3. CHARACTERISTICS OF PULSED DISCHARGES IN NEON AND ARGON

W. S. Huxford and H. N. Olsen, Department of Physics, Northwestern University

A study has been made of the radiation emitted by intense flash discharges in rare gases. Condenser discharges were set up in quartz tubes filled with argon and neon at a pressure of 75 mm of Hg. Discharge potentials were varied from 1000 to 4000 volts, and various pulsing rates were employed in the range from 1 to 60 per second. The discharge was initiated by a steep potential wave having a rise time of $\leq 10^{-7}$ sec. applied to an external trigger electrode. Syncroscope measurements of current and potential were recorded photographically, and the power and total energy supplied to each flash discharge were calculated. Using three types of photomultipliers observations were made of the variation with time of radiation in the ultraviolet, visible and infrared regions. The radiation is chiefly a continuum and its maximum intensity occurs several microseconds after the peak input power; the lag of this maximum behind peak power is greater the longer the wavelength of the spectral region observed. The radiation output increases approximately as the <u>square</u> of energy input in the ultraviolet, nearly as the <u>three-halves</u> power of the energy in the visible, and <u>linearly</u> with energy per flash in the infrared. An interpretation of the results is proposed on the basis of recent theories of emission of radiation from highly ionized plasmas.

F4. A NEW FORM OF LOW CURRENT DISCHARGE IN GAS MIXTURES: THE FLASHING DISCHARGE

C. Kenty, General Electric Company, Cleveland, Ohio

The voltage of a 1 ma hot cathode resistance ballasted discharge in a 3.6 mm tube containing ~1 mm rare gas plus Hg at ~ 20-40°C is markedly raised by adding traces of molecular impurities, e.g., ~1 μ N_2. Absorption experiments reveal high populations of metastable Hg atoms, and that the 6^3P_2 atoms, which furnish a large fraction of the ions, by two-stage collisions, are strongly destroyed by the impurity (three times as strongly by CO as by N_2). Strong irradiation by the visible Hg lines produces similar effects. In pure rare gas plus Hg the discharge has ordinary running striations and a positive characteristic. As N_2 (e.g.) is added, the striations are gradually suppressed. Beyond about 4 μ N_2, the (now) steady discharge changes abruptly to a form which is both striated and highly current modulated (flashing discharge). The current jumps abruptly to a high value from a low one and then decreases slowly again. The voltage across the tube varies in inverse fashion. Frequency (25-2000 per second) increases with N_2, with current, and with ballast resistance (50K - 9000K ohm). Flashing occurs easily with A, more difficultly with Kr, and ordinarily not at all with Xe. The following explanation is indicated: At high voltage, the gradient suddenly goes over to a sharply stepped form; A (e.g.) is strongly excited at steps; wings of A resonance lines diffuse quickly; A atoms in s states ionize Hg strongly, producing overabundance of ions everywhere; stepped gradient collapses, while current jumps; voltage thereafter rises slowly till point of instability and stepping is again reached. Xe plus Hg will flash if a little NO is added (ionizing potential 9.5 V, s_3, s_2 states of Xe: 9.40 and 9.55 V).

F5. SOME RESULTS OF HINDERED GLOW-DISCHARGE STUDIES
Heinz Fischer, Cambridge, Massachusetts

The paper is a short extract of earlier studies of the author which only partly have been published. The plasma constants (electron temperature, plasma potential, ion density) of the negative glow (n.g.) of glow discharges in H_2, He, Ne, A with extremely varied electrode arrangements have been studied. The ionization fraction within dark space (cathode drop) and n.g. were estimated. The electron temperatures (0.5 and 8 e.v. group) seem not to change substantially within a wide range of cathode drop and gas pressure. It is found that the ionization shifts almost entirely into the n.g. with increasing cathode drop. However, only a relatively small fraction of the total amount of positive ions which are produced within the n.g. appear at the cathode. The overwhelming part of the ions may recombine within the n.g. itself as well as in the surrounding walls, anode included.

F6. ON THE RADIATION TIME - FUNCTION OF SHORT SPARK-DISCHARGES
Heinz Fischer and Martin Reger, Cambridge, Massachusetts

Time functions of spark current and spark radiation indicate that the maximum of the spark radiation may occur 0.2 microseconds after the time of the maximum energy density of the spark channel. The effect is explained by the large amount of short-wave ultraviolet radiation which is absorbed in the boundary layer of the spark channel. This effect of "radiation diffusion" determines the channel expansion immediately after the breakdown of high pressure sparks.

F7. FAST AND SLOW MOVING STRIATIONS IN A MIXTURE OF MERCURY AND INERT GASES
Howard Steele, Westinghouse Lamp Division, Bloomfield, New Jersey

The discharge to be discussed is in mixtures of mercury vapor, from 1 to 50 microns pressure, with argon or krypton at 4 or 2 mm pressure respectively. It is confined by 3.8 cm diameter glass tubing with 110 cm between oxide-coated, coiled-coil electrodes. The discharge which appears homogenous often is composed of bright regions located periodically along the positive column. These regions are moving from anode toward cathode at about 1000 cm/sec so that they are not visible to the eye.

The striations are photographed with a shutterless moving film camera - the film moving continuously through the camera at right angles to the axis of the discharge. As the striations move through the discharge they trace out lines on the film whose slope is a measure of their velocities. The product of mercury vapor pressure and lamp current above which these moving striations do not exist is found to be constant. At a given mercury vapor pressure with a discharge current a few milliamperes below the critical value, the moving striations disappear from the cathode end of the positive column. As the current is increased toward the critical value the region without striations lengthens until at and above the critical current no striations of this type exist.

Since they travel away from the anode, it would appear that the anode were the source. However, using single pulse technique the moving film picture shows that the anode to cathode striations first appear only in the region in front of the cathode, with each succeeding striation starting on the anode side of the striated region until the whole discharge is striated. In the region above the critical current for slow striations another type is found which moves at least 1000 times faster. These can be eliminated by high series resistance in the circuit. When fast striations appear with the slow ones they synchronize at the same frequency.

F8. VOLTAGE HYSTERESIS OF VOLTAGE REGULATOR TUBES FILLED WITH NOBLE GASES

F. C. Todd, Battelle Memorial Institute, Columbus, Ohio

The voltage-current characteristic of the usual VR tube shows peaks and hysteresis with a relatively slow increase and decrease of the current. This hysteresis is believed to result from the adsorption on the cathode of gaseous impurities or of the heavier noble gases. These are released by heating of the cathode and by the bombardment of the cathode as the discharge current is increased, and they are slowly readsorbed as the current is decreased and the cathode cools. The evidence to support this conclusion will be presented. Unless the hysteresis is very bad under the above test conditions, it will be decreased or eliminated by a current cycle of a few seconds. The amount of hysteresis is different for different metals under the same conditioning technique and can be reduced or eliminated by heating of the cathode. The hysteresis is practically eliminated without heating when the VR tube is filled with helium because of its very low heat of sorption.

F9. ELECTRODE DETERIORATION IN T-R TYPE TUBES*

J. C. French, National Bureau of Standards, Washington, D. C.

An investigation of the failure of a modified 1B24 T-R type tube revealed the cause to be the short circuiting of the pulsed keep alive cathode to its anode. This was due to the formation of an unusual deposit on the cathode insulation and concentric anode.

Analysis of the deposit showed that it originated at the cathode. To facilitate the investigation, diodes were constructed in which such parameters as distributed capacity, cathode material, current density, water vapor in the gas fill, pulsing of current, and anode shape could be varied more readily while still maintaining the construction features of the modified 1B24 which were relevant to the problem. From a study of these parameters it was learned that the glow discharge normally present breaks into a momentary arc which by local heating of the cathode frees the metal which forms the deposit.

Factors in the process which were critical were determined, and by their proper control the deposit could be reduced to a negligible quantity, or under some circumstances, eliminated.

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* This paper is based on work performed at the National Bureau of Standards under sponsorship of the U.S. Navy Bureau of Ordnance.

SATURDAY, NOVEMBER 5, 1949

2:00 P.M.

SESSION G

MOSTLY ARCS

CHAIRMAN, J. SLEPIAN

WESTINGHOUSE RESEARCH LABORATORIES

EAST PITTSBURGH, PENNSYLVANIA

G1. PROBE MEASUREMENTS AND ANODIC MECHANISM OF CARBON ARCS

Wolfgang Finkelnburg, Engineer Research and Development Laboratories, Fort Belvoir, Virginia

Measurements of the potential distribution in the positive crater of a variety of low- and high-current carbon arcs under a number of operating conditions have been made by means of a new probe method which will be described in detail. For the first time, the potential drop immediately in front of the crater bottom has been measured directly. Values of this anode drop proper, of the maximum extension of the anode drop region, and of the potential gradient in the vapor volume of the crater are presented, and the bearing of these new results on the theory of the anodic mechanism, as developed previously by the author, are discussed.

G2. RETROGRADE MOTION OF THE ARC CATHODE SPOT

C. J. Gallagher, General Electric Company, Schenectady, New York

The motion of the cathode spot in a direction opposite to that predicted by Ampere's Law depends on the arc current, gas pressure, kind of gas, and magnetic field strength. Studies of the effects of these variables have been made, including measurements of velocity and the critical pressure at which reversal of motion occurs. The phenomena observed have not been clearly explained by any of the pictures presented to date. The existence of the retrograde motion indicates very strongly that the positive-ion space charge outside the cathode is all important in determining the mechanism of current transfer.

G3. STABILITY OF ARCS DRAWN BY SEPARATING CONTACTS IN OXIDIZING, NEUTRAL AND REDUCING ATMOSPHERES

W. M. Brubaker, Westinghouse Research Laboratories, East Pittsburgh, Pa.

An arc drawn between separating contacts is known to be very unstable, in the absence of oxygen, in the usual power circuit. To study this instability experiments have been made in which a four ampere arc in a 125 volt d-c resistive circuit was repeatedly restruck between separating contacts. Various metals were used as cathodes, with spectroscopic carbons as anodes, in various gases.

Data has been obtained showing the dependence of arc duration on the cathode material and on the pressure and kind of surrounding atmosphere for a number of metals in oxygen, hydrogen, helium, and natural gas. Oxygen exhibits an extraordinary stabilizing influence for most metals, whereas in hydrogen the mean life of the arc is generally less than ten milliseconds even at atmospheric pressure.

G4. SOME ASPECTS OF GEIGER-MUELLER TUBE DISCHARGES

O. S. Duffendack, Philips Laboratories, Inc., Irvington-on-Hudson, N.Y.

This report is based on some unreported work by Francis E. Throw, a graduate student in the Department of Physics, University of Michigan, Ann Arbor, Michigan, in 1940.

One objective of the investigation was to determine whether there is any essential difference in the mechanism of the discharge in a self-quenching type counter tube and in a non-quenching type counter tube. The requirement of Werner that within a zone extending out n free paths from the wire an electron must fall through a certain potential difference, U, was found to give an adequate explanation of the starting voltage and the current-voltage characteristic of gas-filled tubes; and the requirement of a certain minimum field intensity within such a zone (proposed by Trost) led to a satisfactory expression for the starting voltage of vapor-filled counters. Trost's electrostatic theory of the quenching of the discharge was shown to be essentially correct although a number of modifications in detail were necessary. Some calculations and experiments by Mr. Throw showed, however, that the essential difference between the two types of counters was that the lower mobility of the positive ions in the vapor-filled type led to a very much higher "resistance" (overvoltage/current) so that there was a long interval of unstable corona discharge between V_s and V_{min} although I_{min} was almost unchanged. The characteristic properties of vapor-filled counters is due to their operation in this region of unstable corona discharge rather than to a complete difference in character as had generally been supposed.

G5. TOWARD A PHYSICS OF THE ARC SPOT MICROVOLUME

Jerome Rothstein, Signal Corps Engineering Laboratories,
Fort Monmouth, New Jersey

The arc spot is considered as a microvolume of dense matter with exceedingly high average particle energy. Ionic bombardment, aided to some extent by photons and perhaps metastables, transports energy to the spot which is dissipated predominantly by electron emission, to a lesser extent by jet formation, and least by conventional processes of heat transfer (conduction, convection, radiation, evaporation). Spot excitation (energy density) is so high that solid or liquid binding presumably plays a secondary role and the spot can be viewed as a dense plasma with an excited degenerate electron gas. Reasons are advanced for believing that the spot has a surface, i.e. a boundary between high density of spot and low density in the gas so that the spot is properly considered part of the cathode. Discussion of conventional electron liberating mechanisms (thermionic, photoelectric, and field emission, thermal ionization, emission due to bombardment by positive ions or metastables) indicates that all of them necessarily require an excited microvolume to account for observed current densities whereby all mechanisms coalesce into what may be called a quasi-thermionic mechanism. Many properties of arcs (striking, extinction, anchoring, retrograde motion, high temperature Ag, Cu, Fe, Ni arcs, discontinuous glow-arc transition in general and for hot W in particular) are easily explained on this theory, while Mierdel's and Smith's experiments on spot extinction which are difficulties for a thermionic theory are consequences of the present theory.

G6. HOLES AND RETROGRADE ARC SPOT MOTION IN A MAGNETIC FIELD

Jerome Rothstein, Signal Corps Engineering Laboratories,
Fort Monmouth, New Jersey

If cathode spot current density is 10^5 amp/cm^2 with a sixth ionic, 10^{23} ions arrive per cm^2 per sec. With spot surface atomic density 10^{16}/cm^2, the area occupied by a surface atom emits five electrons and collects one ion every 10^{-7} seconds on the average. Ions transport both vacant energy levels to the electronic configuration and energy to maintain spot excitation (high electron "temperature"). A fraction of the current in the spot must thus consist of holes which increases with hole lifetime. It is proposed that as in the anamalous Hall effect the holes are deflected in the "wrong" (retrograde) direction, nascent electron emission following the effectively positive holes, whence ions later formed by collision outside the spot return bringing holes and excitation to a region shifted in the retrograde direction. At high pressure photons could contribute substantially to spot excitation without hole generation, whence reversal of motion as observed. Increased magnetic field gives larger hole deflection and so greater retrograde velocity and higher reversing pressure as observed. Very large increases slow down and then reverse the motion possibly because the pre-annihilation trajectory doubles back on itself, hole effects thereby progressively cancelling out.

G7. STUDIES OF AN ANCHORED MERCURY ARC
Charles G. Smith, Raytheon Mfg. Co. and Harvard University

The apparent line along which a mercury arc anchors at a wetable metal projecting up through the liquid is in reality a rapidly varying serrated structure[1]. A continuous line free from these spurs is much to be desired for optical and electrical studies of the arc spot. We have made the line smooth by disposing a magnetic field with a component tending to drive the arc spot furthur onto the solid metal. In one arrangement there was a polished cone of molybdenum with vertex in the mercury and base projecting above the liquid. The arc anchored under the circular ledge of the molybdenum cone. A transverse magnetic field of 200 gauss drove the arc line over to one side (the retrograde way) and tended to force it further along on the overhanging molybdenum. The arc line was free from spurs. Upon cooling the tube under various reproducible conditions there was observed a well defined maximum cathode drop above which the arc is self extinguished. The maximum was about three volts above the ten volt minimum. Further studies of the continuous spectrum regarding its origin, color distribution and state of polarization are being made.

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1. Lewi Tonks Physics _6_ 294, 1935

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