The First Book of Abstracts of the Gaseous Electronics Conference (Brookhaven, 1948)

This document contains the manuscript of a talk by Leonard B. Loeb (1891-1978),

"Some of the Outstanding Problems in Gaseous Electronics"

(p. 29 of the pdf file)

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ABSTRACTS OF PAPERS

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To Be Presented At The

GAS DISCHARGE CONFERENCE

Brookhaven National Laboratory

Upton, N. Y.

October 27, 28, and 29, 1948

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SESSIONS

A. SPARKS AND CORONA

B. COUNTERS

C. Evening Session

D. DIFFUSION

E. HIGH FREQUENCY

F. SHORT GAPS

G. ARCS; GLOWS

H. OSCILLATION AND EXCITATION

Program Committee

L. H. Fisher, New York University
W. P. Allis, Massachusetts Institute of Technology
J. B. H. Kuper, Brookhaven National Laboratory
J. P. Molnar, Bell Telephone Laboratories, Murray Hill

A. SPARKS AND CORONA

Wednesday, October 27; 1:00 p.m.
Chairman, J. P. Molnar, Bell Telephone
Laboratories, Murray Hill

A1. Characteristics and Fundamentals of the "Back Corona" Discharge

H. J. White, Research Corporation, Bound Brook, N. J.

"Back corona" is the descriptive term for the local discharge which occurs from the normally passive electrode in a corona discharge system when the electrode is covered with a poorly conducting dust or fume; such discharges are deleterious in electrical precipitation. With negative corona the observed effects are: substantial reduction in sparkover potential, greatly increased currents accompanied by visible discharge craters, and production of positive ion space charges in the corona gap. The effects with positive corona are similar but less pronounced. Onset of back corona is due to local breakdown of the dust layer, caused by Ohm's law build-up of voltage, and usually occurs in electrical precipitators when the bulk dust resistivity exceeds 10^{10} ohm-cm. The initial stage is characterized by lowered sparking potential, while the more advanced stage which occurs only with high dust resistivity is characterized by the stable crater form of back corona.

Dust and fume resistivities are strong functions of temperature and humidity, with values usually ranging between 10^7 and 10^{15} ohm-cm. Slight traces of certain chemical contaminants, known as conditioning agents and specific for each type dust, have the property of greatly lowering resistivity, even at high temperatures.

A2. The Basic Mechanisms of Negative Corona*

L. B. Loeb, University of California, Berkeley

Investigations have shown that the character of processes occurring in the concentrated high field regions leading to negative corona are such as to be autocatalytic, once the Townsend threshold has been reached. This self-accelerative ion multiplication will proceed directly to a breakdown as a power arc unless limited either by external circuit constants or internal resistance in the gas of the corona gap. The internal resistance can consist of a space charge limitation of the current in the low field regions by formation of negative ions either on impurities or otherwise. It may go further, however, and in certain gases lead to such heavy ion production near the point that the discharge is choked off and one has the interrupted Trichel pulse type of discharge. The conditions leading to, and characteristics of, such discharges will be presented. Once the point or wire is locally conditioned by clean up through positive ion bombardment to the autocatalytic stage, the discharge will tend to concentrate at a single spot if the current density can maintain the surface condition. In all cases the discharge structure is that characteristic of a glow discharge, the very fine Crook's dark space being hidden at atmospheric pressure, but appearing at lower pressures. Analysis of the structure with concentrated discharge enables one to infer the potential distribution along the discharge axis with some precision. From the consequent radial distortion of the equi-potential surfaces about the discharge axis, it is then possible to explain the observed constrictions and flaring of the discharge, and thus the mechanism of concentration.

This principle may also be applied to the concentration of the discharge at the cathode spot in arcs. The single discharge spot either with constant or pulsed current can carry only a limited current. When this is exceeded multiple spots appear which are self-repellent through space charge field action. The factors affecting conditioning of the surface and the role of oxygen as it influences the starting potentials is now becoming clarified.

*This work was done under contract with the Office of Naval Research.

A3. A Criterion for the Transition from the Townsend to the Streamer Mechanics of Breakdown in Gases

R. Geballe, University of Washington

The recently formulated condition for streamer breakdown voltage [1,2,3] depends on photoelectric processes in the gas. Such processes can be consistent with the observed filamentary character of breakdown at high $p\delta$, where P is gas pressure in mm of mercury and δ is electrode separation in cm, only if photon absorption is large in the neighborhood of the diffusion-broadened avalanche head and subsequent advancing streamer head. A condition is thus implied on the lowest value of $p\delta$ at which ionizing photons of absorption coefficient μ_o (at one mm of mercury) contribute to streamer advance. This condition can be written in the form $p\delta \gtrsim 1/K^2\mu_o^2$, where K is a number near unity. The transition from Townsend to streamer breakdown takes place at a $p\delta$ for which the number of photons satisfying this condition is first sufficient to permit streamer growth. For example, in air the transition occurs in the neighborhood of $p\delta \approx$ 200 mm x cm, leading to the conclusion that the number of photons produced with $\mu_o \gtrsim 0.07$

is insufficient for streamer formation.

[1]L.B. Loeb, Physical Review 73, 798 (1948)
[2]L.B. Loeb, Review of Modern Physics 20, 151 (1948)
[3]L.B. Loeb, Physical Review 74, 210 (1948)

A5. On the Mechanism of Discharges from Point Electrodes in Air
O. Yadoff, Columbia University

The physical phenomena of point discharges are yet considered as complex and not well-known. The author of this paper introduces a new theory of the mechanics of discharge. This theory is based upon his hypothesis of electro-airy films being formed around all electrostatically charged bodies. This theory explains also the conditions which permit the maintenance of free charges in an insulated conductor.

If we accept the existence of the electro-airy films, the point discharges become easily understandable. The considerations developed by the author can be adapted to all electrostatically charged bodies, irrespective of the sign of the charge.

The theory is supported by many experimental observations which are enumerated. Several physical factors, as electric field, variations of gaseous components and of the atmosphere, cause, under some conditions, changes in the mechanics of discharge. These factors and their roles are also described. The author concludes with a description of a new application realized by him, concerning the use of point discharges for the study of the turbulent movements in hydraulic ducts and measurement of speeds in the turbulent flows or laminas.

A7. Point-to-Plane Impulse Corona in Air*
D. B. Moore, University of California, Berkeley, and W. N. English, National Research Council, Chalk River, Canada

Positive and negative impulse coronas have been studied with square pulses of 1 and 2 microseconds duration at potentials up to 12,000 volts, using 0.1 mm diameter points with 1 to 3 cm gap in air at atmospheric pressure. The positive point corona shows the burst pulse glow close to the point, and also a strong development of the pre-onset streamers, radially from the point, which may be attributed to the lack of inhibiting space charge.

The *negative* point corona exhibits a striking development as the potential is increased. The Trichel-pulse fan-shaped luminosity observed in D.C. corona first appears, then in addition a concentrated central "streamer" spike, and at higher pulse voltages two side spikes, At still higher voltages the spikes develop into long luminous purple filaments which weave out into the gap and curve back parallel to the shank of the point, in vivid ever-changing patterns which suggest an inverted roman candle.

These spikes and filaments are attributed to positive streamer discharges between the intense positive space charge near the point, left by an interrupted Trichel pulse, and negative space charge further out in the gap. At lower voltage the "streamers" are between the space charges left by individual Trichel pulses, giving the spikes. At higher potentials, where the long luminous filaments are observed, it seems likely that the streamer discharges take place between clouds of accumulated space charge, thus producing, in the laboratory, miniature lightning discharges of the "cloud-to-cloud" variety. Probably the course and motion of these filaments is considerably affected by the "electric wind" set up by movement of ions.

To test this hypothesis the negative corona was run in pure nitrogen where negative ions are not formed, and in various nitrogen-oxygen mixtures. The "streamer" discharges were absent in pure nitrogen, and gradually developed as the amound of oxygen was increased. A similar effect was found in hydrogen and hydrogen-oxygen mixtures. Thus, the role of the negative ion space charge seems to be established.

*This work was done in L.B. Loeb's laboratory at Berkeley, and was supported by the Office of Naval Research.

A4. Time Lags In Spark Breakdown

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

Experimental work is now in progress to determine the formative time lag of spark breakdown in air as a function of pressure and gap length. The region of investigation is at and slightly above threshold.

It is expected that by the differences in time lags at various pressures, one can discover at what region of pressure and gap length a transition occurs from the Townsend to the streamer mechanism of breakdown.

Preliminary experimental results will be presented.

Wednesday, October 27; 3:30 p.m.
Chairman, J. B. H. Kuper, Brookhaven National Laboratory

B1. Electron Contribution in Geiger Counter Discharge

G. G. Kelley, P. R. Bell and W. H. Jordan, Oak Ridge National Laboratory

An analysis has been made of the variations in series current during and after a Geiger discharge, using such a value of series resistance between the tube and energy source that the voltage across the tube does not change appreciably with discharge. The pulses thus obtained are a measure of the rate of change of electrical energy in the circuit.

It is found that the shape of these pulses cannot be accounted for on the assumption that all ions are formed essentially at the anode. The theoretical equation based on this assumption may be made to fit the tails of these pulses quite well; but when it is so fitted the predicted value is too low by a constant amount during discharge. This difference is attributed to electron collection, requiring that the initial ion sheath be of appreciable thickness. The mean radius of this sheath is calculated for various values of overvoltage from the electron current. Spread of the sheath as it moves outward and its effect on the theoretical equation are discussed.

B2. The Problems of Using a Spark Discharge in Nuclear Detection

R. W. Pidd and L. Madansky, Johns Hopkins University

A parallel plate spark counter was constructed[1] to provide a uniformly sensitive avalanche volume for detecting ionizing radiations. Further work has shown that the rise time and average delay error time is compatible with time interval measurements of 10^{-9} second. The recovery time of the counter is critically dependent on the cathode material suggesting some sort of surface emission phenomena. However, recovery times of 1 millisecond are obtained with lead and tin cathodes. Quantitative results on all the characteristics of the counter will be given.

[1]L. Madansky, R.W. Pidd, Physical Review 73, 1215 (1948)

B3. Some Tests of Parallel Plate Counters

M. E. Battat and R. N. Varney, Washington University

A parallel plate counter was constructed of circular steel plates 4 inches in diameter. The plates were ground and lapped and heavily plated with chromium. They were mounted in a glass bulb or tungsten supports with 3 mm space between plates. Cleanliness in construction and operation were emphasized. High vacuum techniques were employed in degassing the tube; and a completely mercury-free system was used. Argon and ethylene mixtures at various pressures were tried as fillers.

Quenching of the discharge was essentially accomplished by means of resistance in the circuit ranging from 20 to 35 megohms. An accompanying vacuum tube quenching circuit made only minor improvements. The tube showed excellent characteristics of rise and recovery. Details of performance are described.

B4. Ionic Mobilities in Geiger-Mueller Counter Tubes

P. B. Weisz, Socony-Vacuum, Paulsboro, N. J.

The technique of H.G. Stever for the measurement of Geiger counter recovery time has been extended to study the mobility of the moving ions over a life of about 10^{-4} sec. The mobility of a series of organic molecules has been studied. The measurements allow conclusions to be drawn concerning the nature of the ions moving to the cathode, and ionization transfer phenomena to be observed experimentally.

C. Evening Session

Wednesday, October 27; 8:00 p.m.
Chairman, L. H. Fisher, New York University

C1. Fundamental Processes of Ionization and Dissociation in Gases by Electron Impact
H. D. Hagstrum, Bell Telephone Laboratories, Murray Hill

It is well known that, in atomic gases, electron collisions may lead to excitation and ionization. Similar processes may occur in molecular gases. Since the molecule may simultaneously dissociate, however, a variety of other results of electron impact are possible. Dissociation processes in which one or more ions are formed have been studied more extensively because they may be detected electrically. These may involve electron capture followed by dissociation to form negative ions, ionization followed by dissociation to form positive ions, or splitting of the molecule into a positive and negative ion, in each case one or more uncharged fragments of the molecule being formed. Since they are products of molecular dissociation these ions may possess appreciable amounts of initial kinetic energy. In experimental studies, attempts have been made to identify the charged fragments and to measure the minimum electron bombarding energy necessary to cause the process to occur, the kinetic energy of the fragments, and the probability of occurrence as a function of electron energy. Various types of mass spectrometric and retarding potential apparatus have been employed. This paper is a review of theoretical and experimental work in this field.

C2. Outstanding Problems in the Fundamental Processes and Interpretation of Electric Discharge in Gases
L. B. Loeb, University of California

Invited paper.

D. DIFFUSION

Thursday, October 28; 9:00 a.m.
Chairman, H. Margenau, Yale University

D1. Ambipolar Diffusion of Ions

J. Slepian, Westinghouse Research Laboratories, East Pittsburgh

Particles diffusing in one direction axially down a cylinder, should show a density varying as $e^{-2.30\frac{\delta}{r}}$, where δ is distance along the axis and r is radius of cylinder, provided that the particles diffuse isotropically.

The Schottky ambipolar diffusion theory states that, for a high enough density of diffusing ions and electrons, electric fields will appear which will cause the ions and electrons to effectively diffuse together with a common isotropic diffusion coefficient. In the axial cylindrical case, therefore, the formula given above should hold for the ion density.

Experimental verification was attempted in neon, argon, and mercury. Apparent large deviations were obtained in all three gases.

D2. Transition from Free to Ambipolar Diffusion*

W. P. Allis and D. J. Rose, Massachusetts Institute of Technology

The solution of the equations for the simultaneous diffusion of electrons and positive ions is sought when the densities are intermediate between those for free diffusion and ambipolar diffusion. The stationary state is considered in which the ionization rate is proportional to the electron density. Simple expressions are found giving upper and lower bounds for the ion density at the center of the container, consistent with a given electron density. Approximate explicit formulas for the electron and ion density distributions and the effective diffusion coefficient for the entire range are given.

*This work has been supported in part by the Signal Corps, the Air Materiel Command, and the Office of Naval Research.

D3. Measurements of Ambipolar Diffusion and Recombination in Noble Gases*
M. A. Biondi, Massachusetts Institute of Technology

A microwave method of observing the removal of electrons from initially ionized gases has been developed.[1] The change in the resonant frequency of a cavity is proportional to the concentration of free electrons within the cavity. The rate of removal of electrons from a gas is determined by measuring the change in resonant frequency as a function of the time after the ionizing field is removed from the gas in the cavity. This method has been applied to studies of ambipolar diffusion and electron-ion recombination in helium, neon, and argon in the range 0.01 - 0.05 ev energy. The observed variation of the ambipolar diffusion coefficient D_a with positive ion energy and mean free path agrees with the predictions of kinetic theory. For helium, $D_a p = 580 \frac{cm^2}{sec}$ - mm Hg at $T = 300^\circ K$. It is believed that a new mechanism for electron-ion recombination has been observed. Measured values of the recombination coefficient, α, are in the range 10^{-8} to 10^{-6} $(\frac{ions}{cc} - sec)^{-1}$ for the noble gases. Studies of neon have shown that α does not depend on electron or ion energy over the measured range and that α does not vary with pressure in the range 1 - 30 mm Hg.

*This work has been supported in part by the Signal Corps, the Air Materiel Command, and the Office of Naval Research.

[1]Massachusetts Institute of Technology, Research Laboratory of Electronics, Technical Report No. 66

D5. Imprisonment of Resonance Radiation in Gases
T. Holstein, Westinghouse Research Laboratories, East Pittsburgh

It is known that resonance quanta are highly absorbable by normal atoms of a radiating gas; hence, under suitable conditions of gas density, the eventual escape of these quanta from a gas-filled enclosure may require a large number of repeated absorptions and emmissions. In such cases the radiation is said to be "imprisoned."

In a previous paper,[1] it has been shown that the rate of escape of imprisoned resonance radiation is a sensitive function of the shape of the resonance line. Following the method of that paper, we have calculated escape rates for a variety of line shapes and enclosure geometries. The results are compared with

a) Zemansky's measurements[2] of the decay of excitation in an infinite slab, and

b) Mohler's measurements[3] on the emission of resonance radiation from a cesium vapor discharge.

[1] T. Holstein, Physical Review 72, 1212 (1947)
[2] M.W. Zemansky, Physical Review 29, 513 (1927)
[3] F.L. Mohler, Bureau of Standards Journal of Research 9, 25, 493 (1932)

D6. Lifetimes of Rare Gas Metastable Atoms
J. P. Molnar, Bell Telephone Laboratories, Murray Hill

When a Townsend discharge is suddenly initiated in a rare gas, the current exhibits a delayed component with a time constant of the order of one millisecond. This current component has its origin in electrical effects originated by the destruction of the metastable atoms either at the electrode or in special types of collisions with other molecules in the gas. The shape of the current rise is nearly exponential; and from its time constant the lifetime of an atom in a metastable excited state can be obtained. From the variation of this lifetime with electrode spacing, the rate of the destruction of metastables by diffusion to the electrodes can be separated from the rate of loss by collisions with the atoms. The diffusion constant for metastable atoms of neon, argon, and xenon at one mm pressure, and 20^{0}C has been found to be 120, 40, and 13 cm^{2} sec^{+1} respectively. These values are from 2.5 to 3 times smaller than those corresponding to the self-diffusion of the respective normal atoms.

Thursday, October 28; 2:00 p.m.
Chairman, . P. Allis, Massachusetts Institute of Technology

E1. The Correlation and Classification of High Frequency Gas Discharge Phenomena*

S. C. Brown, Massachusetts Institute of Technology

The purpose of this paper is to introduce the limits within which diffusion phenomena control the breakdown of the discharge, to correlate the experiments of other workers in this field, and to suggest classifications of alternating current gas discharges. The discussion is based on proper variables from dimensional analysis, using the parameters $p\Lambda$, $p\lambda$, and V, where p is the pressure, Λ is a characteristic diffusion length, λ the wavelength of the excitation, and V the breakdown voltage. The limits of applicability of the diffusion theory are found to be a standing wave limit, a mean free path limit, and an oscillation amplitude limit. Within these limits, a single function for the ionization coefficient correctly predicts breakdown voltages for all published data tested, covering a frequency range from 3000 mc to 1 mc. A classification is suggested in which ultra high frequency discharges are those controlled by diffusion in which the electron makes many oscillations per collision, and high frequency discharges are those controlled by diffusion in which the electron makes many collisions per oscillation. Intermediate frequency discharges occur when the drift distance of the electrons under the action of the field per half cycle is greater than the diffusion length Λ, but the positive ion loss is by diffusion. Low frequency discharges occur when both electrons and positive ions collide with the walls every half cycle.

*This work has been supported in part by the Signal Corps, the Air Materiel Command, and the Office of Naval Research.

E2. Initiation of Microwave Discharges

D. Alpert, A. O. McCoubrey, S. Krasik, Westinghouse Research Laboratories, East Pittsburgh

Breakdown potentials for argon at a wavelength of ten centimeters have been measured for various pressures. Microwave energy of continuously variable power level is incident on a resonant cavity. From a measurement of the transmitted power at the point of breakdown, and a knowledge of the cavity characteristics, the breakdown potential is readily obtained. The measured values are in good agreement with those predicted[1] from ionization and electron temperature measurements in DC discharges.

[1] T. Holstein, Initiation of high frequency gas discharges, Physical Review 69, 50 (1946)

E3. Maintenance Fields of Microwave Discharges

S. Krasik, A. O. McCoubrey, D. Alpert, Westinghouse Research Laboratories, East Pittsburgh

A high frequency (3,000 megacycles per second) gas discharge is formed in the gap region of a two window cylindrical reentrant cavity filled with argon at pressures between 5 and 50 mm Hg. The power transmitted by the cavity is measured over a range of incident powers. The maintenance voltage of the discharge is computed from the transmitted power and the appropriate cavity parameters, i.e., shunt resistance and coupling coefficient. A value for the gas discharge admittance may be obtained for each incident power from the circuit relations and the ratio of transmitted to incident power by making an assumption concerning the phase of the admittance. The discharge admittance and voltage give the current-voltage characteristic of the discharge.

E4. The Admittance of High-Frequency Gas Discharges

E. Everhart, Dartmouth College

The admittance of a high-frequency gas discharge between parallel plates has been measured at microwave frequencies. A non-linear relationship between discharge susceptance and conductance is observed. The discharge susceptance, which is inductive at low pressures and low electron concentrations, becomes capacitative at high pressures and high electron concentrations.

This behavior is explained in terms of an electromagnetic solution for the discharge admittance which incorporates the effect of the non-uniform spatial distribution of electrons in the field direction.

E5. Effect of Coulomb Interactions on the Velocity Distribution of Electrons

H. Margenau and J. H. Cahn, Yale University

The usual form of the Boltzmann transfer equation for the electron distribution function is augmented by a term which accounts for the energy transfer between charged particles. This is accomplished by adopting a suggestion of Landau's, who showed that, if only small momentum exchanges between charged particles are considered, this term is the divergence of a certain flow vector in momentum space. The first step is to compute this vector and to obtain the transfer equation. Employing the ordinary method of decomposing the distribution function into an isotropic part and a part proportional to the velocity in the field direction, the transfer equation reduces to two differential equations, whose general solution cannot be obtained. However, under two conditions solutions are available: a) The mean free time of electrons between impacts with molecules is constant; b) the mean free path is constant. For high electron densities, the solution is Maxwellian; and the approach to that limiting form is discussed.

Thursday, October 28; 4:30 p.m.
Chairman, W. P. Allis, Massachusetts Institute of Technology

F2. A Low Voltage Discharge Between Close Electrodes
L. H. Germer, Bell Telephone Laboratories, Murray Hill

The discharge of a condenser across a gap comparable in length with the m.f.p. of electrons is initiated by field emission from the cathode. Although the current is carried almost entirely by electrons, the process is catastrophic after its initiation, the duration of the discharge being determined solely by the electrical circuit with the potential across the gap fairly constant at about 15 volts. If the original potential is above about 50 volts the first discharge may be followed by a second in the reverse direction. Successive discharges may occur until the initial condenser energy is dissipated; or at any stage the phenomenon may end in open circuit.

F3. Electrode Separations in Discharges at Very Small Distances
F. E. Haworth, Bell Telephone Laboratories, Murray Hill

Discharges described by Germer in a previous paper occur at electrode separations which vary widely on repeated tests at calculated fields in the range from 0.2 to 15 x 10^6 volts/cm, the variations being due to changes in surface roughness. Each discharge melts metal on the anode, most of which is deposited in a ring surrounding the pit from which the metal came. Sometimes this ring is of sufficient height to short the electrodes. The height can be calculated from the energy of the discharge; and it is found that shorting occurs whenever the discharge takes place at a distance less than the calculated height.

F4. Steady State Measurements on the Close Electrode Discharge
H. J. Juretschke, Harvard University

The discharge described by Germer can be maintained for a longer time under proper circuit conditions, and can be initiated by a high voltage pulse at fixed separation, or by drawing the electrodes apart. The characteristic discharge voltages vary for different electrode materials, and are independent of the initial gap distance in the range studied ($0 < d < 10^{-3}$ cm). Thermionic emission as a starting mechanism may be ruled out from the discharge behavior of non-thermionic metals.

F5. Low Pressure Arcs

J. M. Richardson, Bell Telephone Laboratories, Murray Hill

The processes considered by Germer, Haworth, and Juretschke fall into the category of "low pressure" arcs in which the pressure-distance product is less than, say, 10^{-2} mm cm. These phenomena are characterized by the fact that collisions in the volume are relatively unimportant (at least in the initial phase). Here we consider from a theoretical viewpoint the possible elementary processes which may be important. Also, we attempt to understand the conditions giving rise to 1) an extinction, and 2) a catastrophic build-up of the over-all process.

Friday, October 29; 9:00 a.m.
Chairman, J. Slepian, Westinghouse Research Laboratories, East Pittsburgh

G1. The Mechanism of the High Current Carbon Arc

W. Finkelnburg, Engineer Research and Development Laboratories, Fort Belvoir

The high current carbon arc with maximum crater brightness of 2000 candles per mm^2, axial intensity of more than 10^6 candles, power inputs up to 600 kw, light efficiencies exceeding 90 lumens per watt, radiation efficiency of 73 percent, crater temperatures up to 8000°K, and arc stream temperatures of the order of 12,000°K is the most powerful and one of the most interesting radiation sources known. The rising voltage characteristic, the anodic vapor stream which causes its excellent radiation properties, and the contracted arc stream distinquish the high current carbon arc from the well known low current carbon arc. The properties of the contracted arc stream are discussed and a general theory of arc streams is presented. Starting from the anodic mechanism for the low current carbon arc, the anodic mechanism of the high current arc is developed. The rising voltage characteristic, the anodic vapor stream, and the high crater brightness are explained as a consequence of an abnormal anode drop which increases with increased current density and is caused by a very rapid evaporation of the anodic material. The important role which the magnetic field of the arc current plays in the stabilization of all high current arcs is pointed out. The author believes that this unique high temperature arc has bearing on other arc and spark discharges, and also will play an important role in future developments of high temperature physics and chemistry.

G2. An Important Difference Between Arcs at Small and at Heavy Currents

R. Holm, Stackpole Carbon Company, St. Marys, Pa.

It is shown that the combined heat and field effect of releasing electrons, but not the tunnel effect, is responsible for the production of primary electrons in arcs working on the basis of a considerable current of primary electrons. Here the temperature in the cathode spot will be of the order of the boiling point of the metal. A high current density is necessary to generate the temperature in the case of small current intensity. Nevertheless, only some few percent of the heat transferred to the cathode is used for vaporization of metal. In heavy current arcs much more heat is transferred to the cathode than can be conducted through the metal, and the greater part of this heat is used for vaporization. Curves are calculated giving the volume of vaporized metal, per coulomb passing the arc, plotted against the total current.

G3. The Spectrum of High Intensity Flash Discharges
W. S. Huxford and W. R. Sittner, Northwestern University

The spectra emitted by condensed flash discharges in rare gases and mercury have been examined at various intervals during the period of the flash. For this work a synchronously driven disc is employed which carries two slits, about .1 mm in width, near its outer edge. The disc is driven at a speed of 3600 r.p.m. The flash tube is initiated by means of a light pulse transmitted by one of these slits, using a phototube multiplier and hydrogen thyratron triggering circuit. Light from the flash tube itself is transmitted by the second slit. The time in the cycle at which this radiation is allowed to fall on the spectrograph slit can be varied by means of a phase changing arrangement. The spark spectrum of these gases is strongly developed upon initiation of the discharge. During the high current arc phase a strong continuum usually appears. In the afterglow well marked recombination spectra are observed, and the spark lines are entirely absent. Lines due to transitions involving high spectral terms show evidence of strong perturbations of the atoms due to local fields in the dense plasma.

G4. On the Formation, Stability, and Anchoring of Cathode Spots
J. Rothstein, Signal Corps Engineering Laboratories

Experiments of Plesse and Höfert show that the discontinuous glow-arc transition (DGA) is facilitated by vapor in the cathode region,[1] that normal evaporation is inadequate for supplying vapor where the cathode is its source,[1] and that the probability of a DGA on superimposing a large current pulse on a glow increases with increasing pulse magnitude and rate of rise.[2] This agrees with a recent suggested mechanism of cathode spot emission,[3] according to which ionic bombardment of the cathode spot creates a microvolume into which current flows by ordinary conduction and from which it flows thermionically. Added vapor near the cathode means more ions (created by electron impact) to bombard the cathode, resulting in more electrons and sputtered or "evaporated" atoms from the cathode; hence still more vapor, etc., culminating in arc microvolume conditions. Added energy input, e.g., by current pulses, acts similarly, but if insufficient in amount or supplied too slowly to overcome dissipating effects, e.g., heat conduction, a DGA is not obtained. Anomalies reported earlier,[4] cold C and W arcs,[5] and arc instability with pure electrodes in pure rare gases[6] also seem to be explained by the theory;[3] cathode vapor, liberated by chemical reaction or by surface bombardment, facilitates a DGA or stabilizes an arc otherwise extinguishing for lack of it.

General features of the anchoring of the Hg cathode spot described by Tonks[7] receive a natural interpretation according to the same theory.[3] When anchored, the spot can be maintained by virtue of the vapor blasted off the surface of the wet metal anchor by ion bombardment. Anchoring, being preferred to mobility, would follow if the critical rate of energy input to maintain an arc spot is less for a surface layer than for bulk liquid. This seems likely as the energy interchange between the spot microvolume and anchor would be governed by a kind of accommodation coefficient, doubtless smaller than that governing energy transfer from the spot to the rest of the liquid. Anchor erosion, akin to sputtering, would be expected to be less for the more refractory metals. Anchoring would be poor if the surface is not wet by Hg. Heating the anchor would tend to drive off the surface layer and free the spot. A junction well wet by a large current should permit a spot carrying a comparatively small current to wander over the wet surface. The slight tendency to anchor before the metal is wet may be explained by reflection of spot vapor by the projecting anchor giving a slight increase in local vapor density. This type of anchoring would also occur with insulators.

[1]H. Plesse, Annalen der Physik 22, 473 (1935)
[2]H.J. Höfert, Annalen der Physik 35, 547 (1939)
[3]J. Rothstein, Physical Review 73, 1214 and 74, 228 (1948)
[4]J. Rothstein, Physical Review 73, 1245 (1948)
[5]O. Becken and K. Sommermeyer, Zeitschrift f. Physik 102, 551 (1936)
[6]G.E. Doan et al, Physical Review 40, 36 (1932); 46, 49 (1934); 47, 983 (1935)
[7]L. Tonks, Physics 6, 294 (1935)

G5. The Surface Excitation Theory of the "Cold Arc" Cathode
C. G. Smith, Harvard University and Raytheon Mfg. Co.

Experimental evidence is cited against the field theory of liberation of electrons from the cathode of the mercury arc and other so called "cold arcs." The surface excitation theory of these arcs, previously advanced, assumes that the cathode is intensely bombarded by electrons from the adjacent negative glow, and that the cathode material is cumulatively excited locally to emit the current carrying electrons and also a continuous spectrum. The latter theory readily fits in with the observations that a "cold arc" cannot be maintained or even established between clean electrodes of iron, tantalum, or tungsten if these are in a pure inert gas; whereas by the field theory such arcs are confidently expected. Furthermore, the surface excitation theory accounts rather directly for the retrograde (wrong way motion) of the cold arc in a transverse magnetic field, long with explanations for the change to proper motion above certain critical values of magnetic field. Argument is advanced along with experimental evidence against any known interpretation of these motions in terms of the field theory.

G6. The Clean-Up of a Noble Gas in an Arc Discharge

M. J. Reddan, National Bureau of Standards

It is generally recognized that most of the gas which disappears during the operation of a gas-filled tube is driven into the metal parts of the tube under ion bombardment. To study this particular process, a simple set-up has been devised consisting of a probe of the test metal exposed to a low pressure arc plasma in the gas. By placing a high negative voltage upon the probe, positive ions of the gas are driven into the metal. An investigation of the clean-up of helium ions striking a tantalum target has been made. Results obtained indicate that:

1) The fraction of ions cleaned up is a function of the ion velocity

2) A large portion of the gas cleaned up in this way may be recovered by heating the target and,

3) The relationship between sputtering and clean-up mentioned by some earlier workers has not been confirmed.

H. OSCILLATION AND EXCITATION

Friday, October 29; 2:00 p.m.
Chairman, J. P. Molnar, Bell Telephone Laboratories,
Murray Hill

H1. Oscillatory Phenomena in Gas Discharges
G. H. Dieke, Johns Hopkins University

The simplest case of a glow discharge is one under stationary conditions. However, under experimental conditions where a stationary discharge should be expected, oscillations are usually observed with frequencies in the audio range. These oscillations are largely independent of the external circuit but depend strongly on the type of gas, its pressure, the current density, and the shape of the tube. The oscillations manifest themselves in modulations of a few percent on the tube voltage and current and modulation of the light intensity (often 100%) at a given spot.

The comparison of the intensity pattern in different parts of the tube shows intensity waves traveling usually from anode to cathode, but often also simultaneously from cathode to anode with a much higher velocity. Where the two types meet, the waves pause momentarily and there is spectroscopic evidence of a high rate of ion recombination. There are usually several sharply distinct modes, often capable of existing under the same conditions. These intensity waves are identical with the moving striations sporadically mentioned in the literature. The stationary striations appear closely related to them. It should be emphasized that these oscillations are a very general phenomenon in all glow discharges with a positive column, within a very wide range of current and pressure, and should be considered as essential phenomena for the mechanism of the discharge. Well-studied examples are given in the following two papers.

H2. Striations in Argon Discharges
T. M. Donahue and G. H. Dieke, Johns Hopkins University

A detailed study has been made of the oscillatory phenomena discussed in the preceding paper for the "direct current" glow discharge in argon at pressures ranging from 0.5 mm to 100 mm. For tubes of 8 mm radius with plane zirconium electrodes about 40 cm apart, oscillations in voltage current and light intensity (moving striations) were found at all pressures and for all currents in the normal and abnormal glow regions, except for pressures above 30 mm, where the oscillations sometimes cease at high current. The frequency of oscillations ranges between 1,000 cycles/sec and 7,000 cycles/sec and depends on the current and the pressure in much the same way as the discharge voltage. For all currents, it decreases with increasing pressure to a minimum at about 7 mm, and then rises steadily for high pressures. For increasing current it decreases rapidly at first and then breaks sharply to essentially a constant value along the normal glow characteristic. When the discharge becomes abnormal, the frequency, unlike the voltage, does not rise. The separation of the moving striations has a maximum at about 6 mm pressure. (For example at 15 ma it rises from 3.9 cm at 1.84 mm to 5.6 cm at 5.4 mm, and then decreases to 1.29 cm at 26 mm.) At low pressure the separation increases with increasing current; at pressures between 2 mm and 10 mm it passes through a maximum, while for higher pressures it decreases uniformly.

The speed of the chief moving striations behaves in the same way as the frequency, and ranges from 200 m/sec at 8 ma and 2 mm pressure to 40 m/sec at 40 ma and 9 mm pressure.

A detailed analysis has been made of the motions of the striations at several pressures. Striations moving in both directions are always found, those travelling toward the anode rather faint and relatively fast (10^6 cm/sec), those toward the cathode bright and slow (10^4 cm/sec). Stationary striations result from the meeting of these two types of moving waves. The current maxima coincide in time with the presence of striations of either type at the electrodes. The behavior of the striations near the anode and in the negative glow and cathode glow will be discussed in detail.

H3. Audio Frequency Resonance Phenomena in Glow Discharges

A. B. Stewart, Antioch College and G. H. Dieke, Johns Hopkins University

A number of gas discharge tubes containing argon and other rare gases at pressures from 4 to 30 mm Hg exhibit standing patterns of light when excited by applying an audio frequency alternating potential difference across the electrodes. These patterns occur when the frequency of the alternating potential is of the same order of magnitude as the d.c. oscillations observed by Donahue[1] in these same tubes; and the patterns are particularly stable when a steady applied potential is modulated by an a.c. generator.

In all cases where the discharge is stable enough for detailed measurements, striations moving from the anode to the cathode can be traced with the intensity of the accompanying light varying periodically along the tube. It is this periodic variation of light intensity of the moving striations that produces the standing pattern. At certain positions striations running from the cathode to the anode are also observed. Where these two types of striations meet, they are nearly stopped for a time interval of the order of 10^{-4} sec. There is spectroscopic evidence that in the plasma at these places there is an increased rate of recombination of electrons and ions.

The distance between successive striations in the modulated discharge is found to be directly proportional to the frequency of the discharge. Other regularities are also noted.

[1]T.M. Donahue, Johns Hopkins University Dissertation, 1947

H4. Excitation of Hg Vapor by Li^+, Na^+, and K^+ Collisions
E. Clark, L. Baker, and R. N. Varney, Washington University

Results by one of the writers (RNV) in 1939-40, using the electron space charge method, showed that Na^+ ions had seemed to ionize mercury vapor by collision when the Na^+ ions had energies exceeding 89 ev, whereas K^+ ions failed to produce ionization in mercury vapor even at several hundred ev. The surprising selectivity of these processes led to the present investigation by an independent method.

A tube was designed, constructed, and tested, with the object of permitting the indicated collisions to occur in a region readily observable with a quartz prism spectroscope. The design was further planned to give an absolutely minimum number of free secondary electrons which might excite the mercury vapor and lead to false conclusions.

Curves showing the excitation of the mercury 2537 radiations by the various alkalis have been obtained. An additional result, however, is that Li^+ and Na^+ excited numbers of other lines in the mercury spectrum including mercury ion lines whereas no radiation beside the 2537 resonance line was found with the K^+ ions. The last result is believed to confirm the observations described in the first paragraph.

Ronald Geballe

A4. Time Lags In Spark Breakdown

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

Experimental work is now in progress to determine the formative time lag of spark breakdown in air as a function of pressure and gap length. The region of investigation is at and slightly above threshold.

It is expected that, by the differences in time lags at various pressures, one can discover at what region of pressure and gap length a transition occurs from the Townsend to the streamer mechanism of breakdown.

Preliminary experimental results will be presented.

A8. Corona Studies in Nitrogen, Oxygen, and Mixtures*

C. G. Miller, University of California, Berkeley

D.c. corona studies have been carried out in concentric cylindrical systems covering the pressure range 715 mm to 27 mm in pure nitrogen, pure oxygen, and in mixtures.

Self-sustaining corona discharges in pure nitrogen depend exclusively on γ at the cathode. In positive corona this leads to a discharge visible as anode spots; in negative corona this leads to disruptive currents if the nitrogen is quite pure.

Self-sustaining positive corona in pure oxygen gives streamers at high pressures, burst pulses at low pressures, indicating high photon absorption and high photoionization in the gas; self-sustaining negative corona in oxygen depends on Trichel pulses.

It is shown that the Trichel pulse onsets in oxygen and mixtures are not real thresholds set by a second Townsend coefficient. These negative thresholds depend on a preliminary Townsend discharge cleaning up the cathode, giving way to Trichel pulses as a second mode.

It is shown that Trichel pulses in oxygen depend on O_2^- , while Trichel pulses in mixtures depend also on negative ions of nitrogen oxides.

Comparisons of the onset potentials, positive and negative, at various percentages of oxygen are made at various pressures, and throw some light on the relative importance of factors affecting corona thresholds.

An application of the negative corona in pure nitrogen is described, in which a voltage-regulator tube action is realized, regulating in the region of 400 to 700 volts depending on pressure, with good voltage-regulating characteristics.

* This work was supported in part by the Research Corporation.

** Now at University of California, Santa Barbara.

B5. Design And Operation of BF_3 Filled Pulse Chambers for Neutron Detection

H. F. Schulz and F. G. LaViolette, General Electric Co., Schenectady

Three models of boron trifluoride filled ionization chambers were constructed for use in neutron counting. These were made of steel parts with insulation assemblies of type AO glass and fernico.

Model	1	2	3
Length of Chamber space (cm)	20	20	20
Radius of outer electrode (cm)	2.14	1.18	2.14
" " inner " (cm)	.235	.127	.127
Pressure of BF_3 gas (cm Hg)	70	70	70
B^{10} enrichment of BF_3 (%)	20	20	96

Collection voltage saturation occured at an outer electrode field strength of 250 to 300 volts/cm at one atmosphere of BF_3. Collection voltages of 1500 to 1750 volts were used. Very reproducible bias plateaus were obtained having slopes of less than 1 % change in counting rate per volt change in bias. Signal to noise ratios of from 5 to 7 were obtained. Electron collection times of 0.4 to 0.5 microseconds were measured with a calibrated variable delay line clipper indicating on electron mobility of 2 to 3×10^5 (cm/sec)/(volt/cm)/(cm)/(cm Hg). Relative efficiencies of 1.5, 0.44 and 4.6×10^{-5} (counts/source neutron) were obtained for models 1, 2, and 3 respectively with a neutron source 100 cm from the chamber moderator. One ion chamber was operated for 4 to 5×10^{10} counts with no measurable decrease in the slope of the bias plateau. The counting loss was found to be $y = 2.0 \times 10^{-8}$ c where y is the percent loss in counting rate and c is the counting rate in counts/min. This represents a 2% loss at 10^6 counts/min.

The BF_3 gas for filling the counters was obtained by thermal decomposition of the double salt $CaF_3:BF_3$. Further purification of the gas was carried out in the filling system. It was necessary to bake the counter tubes at 140° to 150° C under vacuum for 4 to 8 hours before filling.

The pulse amplifiers were carefully constructed to avoid microphonics and the 6AK5 input tubes were selected to obtain low noise level.

C1. SOME OF THE OUTSTANDING PROBLEMS IN GASEOUS ELECTRONICS

Leonard B. Loeb
University of California, Berkeley

In attempting to speak on this subject, it is obvious that a great deal of material will have to be covered in a limited time. This requires that a general background in discharge theory be assumed and that sketchy discussions of some subjects and omissions of others must be made. Such superficial treatment and omission must not be considered as reflecting on the subjects involved, but rather represents a consideration of the relative importance of the topics at this time. In presenting the material it will be subdivided for discussion under the headings of fields of investigation rather than on the basis of technical or methodological approach. While the development of certain new techniques and their recent application to the problems on hand might be a better basis of presentation, it is my desire to stress the acquisition of basic knowledge in certain fields relative to the general background rather than certain concrete experiments or proposed applications.

1. Ionic Mobilities

This field of study was fairly well terminated before the war with the excellent studies of the group working in Bristol, England, under the guidance of A.M. Tyndall and C.F. Powell.[1] The high degree of perfection of their four gauze electrical shutter method, which enabled normal ions of all origins to be studied over a large range of pressures, field strengths, purity of gases, and ion age in absolute magnitude, set a standard for past and future studies. The development of pulse techniques and oscilloscopic or other detecting devices during the war will permit of even greater accuracy and refinement of this method and could lead to improved methods. The work achieved by Tyndall, Powell et al, and that of A.V. Hershey[2] at very low pressures, has settled most of the controversial questions of the past concerning ions, and has brought theory and experiment into agreement insofar as fundamental theory and data concerning atomic and ionic force fields permits. Further experimental work is desirable to clarify the complex ion and ion cluster formation at lower temperatures about which too little is known. Very recently A.W. Overhauser[3] in the speaker's laboratory analyzed the mobility laws in gaseous mixtures, furnishing a nice method of study for this problem. Further measurements over greater ranges of pressures and ion energies, together with theory, might lead to a better knowledge of the force fields, especially at close encounter where high divergent fields no longer permit the use of the ordinary dielectric constant. There is another study that has never been undertaken by this method and that is of the mobility and behaviour of negative ions about which today all too little is known. These problems are, however, of more interest to atomic theory than to application.

2. The Recombination of Ions

Basically the complex character of the many recombination processes occurring under different conditions of observation have been clarified and classified by L.B. Loeb.[4] A further more rigorous mathematical physical analysis of some of these processes in relation to the conditions causing them is due to G. Jaffe.[5] As may not be generally realized, all recombination measurements evaluate a coefficient α defined by a general relation $\frac{dn}{dt} = -\alpha n^2$. The n term cannot be directly measured, but the quantity q involved is. Since this must be divided by an appropriate volume V to yield n, which volume effectively changes independently with time by diffusion, the need for such analysis as indicated can be understood. In general, it can be said that further knowledge of the value and character of α in ion-ion recombination is not of great importance, since loss of carriers by this process where high ion densities are not involved is small. At high densities the negative carriers are usually electrons. Of theoretical and basic interest is the fact that in the only pure gas where negative ions of a known character can form, the appropriate theory and experiment are in satisfactory agreement. In all other gases, either there are not many negative ions, or the gases are so complex under ionization that unique coefficients which do not alter continuously and differently with time, depending on the relative gaseous purity, are not observable, so that further study is not justified.

On the contrary, however, the problem of electron-ion recombination, because of its serious discrepancy with theory and its importance in some discharge tube and ionospheric research, requires further investigation. The earlier studies of C. Kenty and F.L. Mohler had established values of the order of $2x10^{-10}$ for α at electron energies of the order of 1000° K and more and ion densities of the order of 10^{12}-10^{14} per cm^3 in Hg and the inert gases. Some indications of pressure dependence were observed. Recently, the studies of these coefficients in spark channels as a function of time by J.D. Craggs and J.M. Meek[6] and Craggs and Hopwood,[7] with temperatures from 30,000°K and concentrations in excess of 10^{17} per cm^3, gave values of α in H_2 and inert gases of the order of 10^{-12} decreasing to 10^{-10} at 1000 or so degrees as the columns cooled. Afterglows extending long after recombination were observed and remain unexplained. More recently, studies by the group under S.C. Brown and W.P. Allis[8] at M.I.T. gave indications of values of $\alpha \sim 10^{-8}$ in neon at essentially thermal energies in the pulsed ultra high frequency electrodeless discharge. When it is considered that theory for the simple atom types indicates an α of 10^{-12} for thermal velocity electrons, it is obvious that further study, especially in regard to the interaction of force fields of neighboring atoms in these processes, is urgent. O. Oldenburg and his group at Harvard are currently engaged in a study of this problem.

3. <u>Electron Energies and Energy Distributions in Electrical Fields in Gases, and the Evaluation of Electron Velocities.</u>

Despite a great deal of work before the war on this subject, it is still in an unsatisfactory state. The urgency today can be recognized when it is realized that, especially in the region where electrons undergo inelastic impacts with atoms, there is no way for the experimentor, measuring processes in terms of the ratio X/p of field strength X to pressure p, to correlate this with the average energy of the electrons. The use of Townsend's experimentally measures ratio of the average electron energy to its thermal energy is only crudely satisfactory, as the energy distributions are far from the Maxwellian distribution assumed, and many gases studied by his group were of questionable purity. The speaker and others are unable to conceive of any experimental method by which the energy distribution in a given field can be determined, in which the distribution will not be changed by the measurement, in view of the high collision frequency of electrons. This statement excludes the studies which can be accomplished by means of probes in ionized plasma at higher energies and X/p values and at ion densities in excess of 10^9 ions/cm^3. Probes thus cover only a portion of the range of X/p values needed.

J.A. Smit[9] has shown how to calculate the energy distributions for cases where the variation of free path with energy and the excitation and ionization probabilities are known. He carried out the intricate analysis for four values of X/p in helium. The range covered was not adequate in the higher electron energy range for the application to the calculation of the first Townsend coefficient in He. Dunlop,[10] in an as yet unpublished thesis under K.G. Emmeleus at Belfast, has checked Smit's calculations and extended them to higher electron energies. T.R. Holstein[11] proceeding more along the method initially laid down by P.M. Morse, W.P. Allis, and E.L. Lamar[12] has worked out an elegant method for calculating these distributions. So far no one has taken the trouble to carry over these calculations to actual gases. This laborious procedure can yield these very vital data for gases such as the inert gases, and for Hg, where the various excitation and ionization functions as well as Ramsauer cross sections are known.

To be able to carry over to molecular gases, more experimental work such as that of H. Ramien[13] with H_2 will have to be done to take account of the energy losses due to inelastic impacts going to molecular levels. In fact, the studies of energy losses of electron impacts in gases like H_2, O_2, and N_2 have never been made over a sufficient energy range as to render them useful where they have even been attempted. This also represents an urgent field of research which, with modern techniques, should now be easier. In any case, it is urged that both the theoretical evaluation and the experimental studies, tedious though they are, be carried out for the commonly used gases. The theoretical calculation is today the only possible method of getting these indispensable data.

As regards electron velocities in gases, one can cite the work of N.E. Bradbury and R.A. Nielsen[14] as being of a satisfactory quality as regards purity and precision up to values of X/p of 20. These studies should be extended to higher ranges in some gases where sparking lies above this value. Much greater accuracy is now possible in such studies as a result of wartime techniques. In Holstein's laboratory, D. Barbiere[15] recently calculated electron velocities in Ne and A, using Holstein's method, with some interesting results.

4. Probe Studies

The development of probe methods for studying the space potentials, wall potentials, and electron energy distributions showed great promise initially. Before the war, however, the field was largely neglected in this country, though work was carried on in Germany, Holland, and at Belfast. The greatest progress came from the suggestions of M.J. Druyvesteyn[16] for the determination of energy distributions by this means. This method was developed through the use of a superposed a.c. of small amplitude, to yield distributions directly, by R.H. Sloane and E.I.R. Mc Gregor[17] at Belfast. Further unpublished applications of this method at Belfast encountered difficulties owing to peculiar effects produced by plasma oscillations; so the a.c. procedure requires caution. While the probe method is applicable, in general, only where ion densities are sufficiently great, i.e., in excess of 10^9 ions/cm^3, and where only electrons and positive ions are present and the probe does not become a strong electron emittor, it is extremely useful. It is believed that the method should be investigated further in order to see how far it can go in evaluating energy distributions, and in extending it down to lower ion densities as a means of measuring potential gradients in space charge accumulations. It is the one method capable of giving information about these important conditions in many cases where the charge is not confined to minute volumes.

5. The Formation of Negative Ions

The study of the attachment of electrons to molecules in a gas to form negative ions was satisfactorily clarified by the experimental researches of N.E. Bradbury and Tatel[18] by 1934. Much information as to the general nature of the processes of the reactions of different atomic and molecular species in relation to their spectral types and dissociation energies was obtained and correlated with the work of theoretical atomic physicists. The most important problem of the lot, the peculiar formation of O_2 ions from electrons and O_2 molecules was believed to have been solved through the experimental estimate of the energy of attachment to O_2 by L.B. Loeb[19] and the theoretical work of N.E. Bradbury and F. Bloch.[20] This work and the theory have been questioned in detail by D.R. Bates and H.S.W. Massey,[21] the chief difficulty lying in the value of the attachment energy. This had been taken as lying below 0.2 volt, but Massey and Bates believe it to be materially higher. The problem is more than academic, as higher energies would affect the detachment of electrons in high fields essential to electrical breakdown thresholds in coronas and sparks.

The general problem of ion formation with O_2 is also of great import in the analysis of the reflecting layers of the upper atmosphere for electromagnetic waves. This problem requires further investigation experimentally, although it is not clear how to measure the energy of negative ion formation other than by the method used by the speaker. The pulsed nature of the negative point or wire discharge in the presence of O_2 in N_2 gas also requires further study. The pulses can only occur by a choking off of the discharge by the formation of relatively immobile negative ions in the plasma of the discharge. This aspect is under study by F.H. Coensgen in the speaker's laboratory, since it is suspected that the ion formation responsible for choking is much greater than that to be expected from Bradbury's study of O_2. It is possible that reaction products of the discharge may furnish the ions in air or N_2-O_2 mixtures as indicated by the work of C.G. Miller[22] in the speaker's laboratory on mixtures of O_2 in N_2.

The original work of F.L. Arnot[23] on the formation of negative Hg ions on impact with metal surfaces has been questioned both by K.G. Emmeleus[24,25] and by W.H. Bennett.[24] R.H. Sloane[25] in Emmeleus' laboratory has, however, studied the formation of other negative atomic ions by this process, including Li^-, and, in conjunction with C.S. Watt,[25] ions from oxide coated cathodes. It would seem that a great deal more work could be done in this area to discover the basic atomic or molecular character of both processes. W.H. Bennett[26] at the Bureau of Standards is initiating some work along these lines.

6. The First Townsend Coefficient for Ionization by Collision.

In the present state of investigations on discharges, a proper set of data on the ionization coefficient α of Townsend, or its equivalent in the terminology initiated by the Eindhoven group, for all pure standard gases as a function of X/p, over the whole range of values, is urgently needed. The need for such data is probably even more imperative than that of the electron energy distributions, as it lies at the basis of the calculations for breakdown thresholds and is of importance in evaluating the secondary processes active in discharge.

At the present writing, data are at hand for a limited range of X/p values in pure, mercury free, H_2, N_2, A, and Ne. Even in H_2 and N_2, the range of values in X/p at both ends of the scale is inadequate for breakdown studies. It is not even known with certainty whether the value of α begins to decrease at higher values of X/p, say in excess of 1000. What data there are may have suffered by the gap lengths being inadequate to insure that the electron cloud had reached its terminal energy, or as a result of instrumental effects. Data especially is needed at the lower end of the range to cover sparking potential data at atmospheric pressure. There is urgent need for data on pure, mercury free, He, O_2, air, Kr, Xe, and for Hg vapor. The techniques have been developed to a point where they are nearly standard. Data should be expressed both in the representation used by the Eindhoven group and in the standard form of Townsend's α.

With this urgent need of both industry and pure physics and since the chief techniques have been fairly well standardized, it would seem fitting that the problem be exploited by the National Bureau of Standards. Towards this end, the speaker proposes that this Brookhaven Conference, together with the support of the industrial laboratories interested, call this urgent need to the attention of the Director of the Bureau of Standards with a request that the work be undertaken there with the advice and help from members of this conference. The theoretical evaluations of these functions are possible if electron velocities and energy distributions are known, as shown by K.G. Emmeleus, R.W. Lunt and J.M. Meek[27] and by Dunlop.[10]

7. The Second Townsend Coefficient

It is apparent that gaseous discharge physicists have become second coefficient conscious since the war, judging from the interest and activity displayed along this line in various research laboratories. A study of various types of discharges under different conditions of gas filling, pressures, and electrode materials has shown the very complicated nature of such processes and how, with relatively small changes in impurities or state of electrodes, the whole discharge or breakdown mechanism can be altered by these processes. No one can be more impressed with this than the speaker. The processes active are as follows:

a. Secondary Emission by Positive Ion Bombardment. This appears to depend on the nature of the metal, its past history, the condition of gas coating, especially by Hg, or O_2, etc. It also depends on the nature of the positive gas ions, their ionization potential, and their energy of impact.

b. Secondary Emission by Photoelectric Processes at the Cathode Surfaces. This depends on the nature and number of photons present, which is determined by the energy distribution of the electrons in the gas producing them, as well as on the gas. It further depends on the nature and condition of the cathode surface and the absorption coefficients of the gas for various photons. It also depends on geometrical conditions in the gap, since these affect loss. Finally it depends on the gaseous pressure as this influences back diffusion and loss of electrons.

c. The Action of Metastable Atoms on the Cathode. This action depends on the energy of the excited state of these atoms, the condition of the surface, the rate of diffusion of these atoms, the metastable atom destroying impurities, and on geometry, as well as on pressure. It is not an insignificant agency in inert gases and Hg.

d. The Photoelectric Ionization in Gases by Photons from the Electron Avalanches. This action is particularly prominent at higher pressures and is responsible for higher pressure breakdown. It depends on the gases present and on the energy of the electrons. It occurs in a small measure even in pure H_2 and N_2 at higher pressures. It is very effective in metastable atom forming gases and even in pure O_2. It is also most effective in all mixed gases of different ionizing potentials. It is strongly dependent on the higher states of excitation and on ionizing potentials and absorption coefficients. It is, therefore, strongly pressure dependent.

e. The Ionization of Gases by Admixture with Metastable Atoms of Higher Ionizing Potentials. The effectiveness of this action has been demonstrated by F.M. Penning[27] and associates, especially with small quantities of more easily ionizable gases, in gases with metastable atoms of high energy. It is for this reason that traces of Hg are particularly bad in the evaluation of α and in changing breakdown thresholds.

f. The Secondary Action of Space Charge. Space charge accumulation resulting from differences in mobility in certain ranges of variation of the first Townsend coefficient with X/p can cause a breakdown, possibly without the action of other secondary mechanisms, though in practice they will also contribute. R.N. Varney[28] and others have shown that if α/p increases faster than linearly with X/p, the formation of space charges near the cathode can act autocatalytically to cause a breakdown. This field has been little studied except to show that it can lead to a breakdown simulating a γ if there are enough avalanches of sufficient magnitude. The methods of studying these coefficients are many:

1) First one may list the classical approach by Townsend. The studies of D.H. Hale[29] and W.E. Bowles[30] indicate that, by a careful analysis of the second Townsend coefficient as a function of X/p, where the first Townsend coefficient is known, much can be learned of the nature of this action. The method has not been developed to its logical conclusion as yet. It is not as valuable as some methods for interpreting what happens in actual individual cases of breakdown, especially where bombardment of the cathode by positive ions alters conditions.

2) Another approach lies in the directions probably initially used by W.S. Huxford and R.W. Engstrom,[31] and followed up independently and more recently by A.L.v. Guggleberg[32] and by R.R. Newton,[33] using the time scale of the phenonema. Guggleberg utilizes a technique by which, with an approximate solution of the equation for the growth of current in the Townsend discharge, the particular factor and percentage contribution of each among the secondary factors, metastable atoms, positive ion bombardment, and photoelectric action at the cathode can be evaluated by characteristic breakdown time studies with different gap lengths at constant field. J.P. Molnar[34] and his associates at the Bell Laboratories have developed techniques using pulsed potentials and an analysis of the time characteristics of the discharge by means of an oscilloscope, with striking success. Analogous analysis by Louis Malter[35] using pulse techniques on actual thyratrons leads to similar results. The microwave breakdown studies of the Massachusetts Institute of Technology group under S.C. Brown and W.H. Allis,[36] using pulse techniques, allow following some of the factors leading to secondary action, such as the disappearance of metastable atoms or of electrons and ions by recombination, in time. These data are useful in the interpretation of measurements such as those noted above. T.R. Holstein[37] has pointed out the influence of the capture of resonance radiations as a factor that cannot always be neglected in some geometries and gases since it can materially prolong the lifetime of radiant atoms without metastable states. This alters the time constants of some of the secondary processes considerably.

3) Another approach lies in a study of the actual fundamental actions occurring in the isolated processes above. In this direction H.D. Hagstrum[38] at Bell Laboratories and P. Lee and J.L. Parker in the speaker's laboratory are attempting to study directly the liberation of electrons by slow positive ion bombardment on various surfaces, extending the original work of M.L.E. Oliphant and P.B. Moon.[39] The findings of W.N. English and C.G. Miller in the speakers laboratory point to an amazingly strong effect of O_2 which appears to form as an absorbed gaseous layer -- <u>not an oxide film</u> -- and tends to equalize the thresholds <u>for all metals</u>. Along this line the influence of gases on changing the work function of surfaces is being studied, using C.W. Oatley's[40] method, by G.L. Weissler.[41]

There are numerous studies on the photoionization of gases by photons now in progress. J.D. Craggs and G. Hopwood[42] at Liverpool are investigating this spectroscopically as is G.L. Weissler.[43] Weissler's program calls, however, for direct measurement of photoionization with balanced space charge detector for individual spectral lines, as well as evaluation of absorption coefficients. In the speaker's laboratory, C.D. Maunsell will attack the problem by a modification of the Franck and Hertz method of excitation of spectral lines, using the space charge detector to measure ionization and absorption coefficients following work by F.L. Mohler[44] in 1926.

It is urgent that further work along the lines attempted by R. Geballe[45] and L.H. Fisher[46] be continued. In that work the actual photon yields giving ionization in the gas and at auxiliary electrodes, produced by the light emitted near the anode of a Townsend gap as used in studies of α was attempted.

The photoelectric ionization by single corona streamers is being investigated by D.B. Moore at Berkeley, using pulsed corona streamers and high fields to multiply the electrons created laterally, collecting them on rings concentric with the axis of the point.

In general, these and other problems are being investigated in the course of discharges, using pulsed discharges and observing the changes in light intensity for different spectral lines by means of photo multipliers and oscilloscopes, or Kerr cell shutters. Among current studies along these lines should be mentioned the work of G.H. Dieke, H.Y. Loh,[47] and T. Donahue[48] on various discharges, and of J.M. Meek, and of R.F. Saxe,[49] on leader strokes and impulse corona in long gaps. The remarkable results of the latter, which are in report stage only, merit some mention. With these very long and intense discharges the striking revelation is the intensely luminous photon excitation in the visible and near-ultraviolet along the axis and radially about the actual leader strokes. The luminosity and its range as detected photo-electrically is most remarkable. Simiilar techniques have been employed by J.R. Haynes[50] on mercury arc jets, and with Kerr cell shutter by K.D. Froome[51] on such arcs, the latter with important, as yet unpublished, results which will be detailed later.

Yet to be studied are the photoelectric effects at surfaces and the role of imprisoned resonance radiation as well as the effects of space charge accumulations. These offer inviting fields for study.

8. Spark and Corona Discharges

These phenomena are being investigated from many different angles and still require a great deal of study, much of which cannot be presented in this survey. The most recent studies of the lower pressure Townsend discharges have been made by Guggleberg32 and his predecessors who studied the growth of the discharge in time oscillographically. Some of this work has in the past been neglected because of its publication in the relatively obscure Helvetia Physica Acta. The studies involve two aspects. The first, as elsewhere stated, involves analysis of the various Townsend factors under different conditions of the length of avalanches, i.e., ion densities. The second involves studies of the actual rate of breakdown and the factors influencing it. This study is of considerable interest to those in the applied fields where gas tubes are used for various purposes such as triggers, valves, etc. Further studies of this character are a suitable subject for industrial electronics research laboratories.

In the field of higher pressure sparks, the streamer mechanism is becoming daily more generally accepted and established. Especially notable are the, as yet unpublished, results of J.M. Meek's group in Liverpool.[49] Here with revolving mirror and photocell-oscilloscopic techniques, the progress of the breakdown of longer point-to-plane spark gaps, with and without resistance, and of corona streamers is being studied. The mechanism is complex and, as in lightning, the leader and return stroke can be clearly observed and the velocities of advance measured. Especially notable is the intense luminosity about the leader and its increase in velocity as it nears the cathode. There is as well evidence of an anologue of the negative glow and Faraday dark space just behind the streamer tip. The pilot leader, or better, the initial streamer cannot as yet be observed being masked by the luminosity about the leader tip. Such studies are doing much to advance knowledge.

Particularly lacking at present in our knowledge of spark breakdown are two items. First is the determination of the region of transition from the Townsend discharge at lower pressures to the streamer breakdown at higher pressures. In fact, we know only that at low pressures there is a Townsend breakdown and at higher pressures streamers cause the spark. At what minimum pressures streamers can no longer propagate is as yet undetermined. It is possible that corona studies may help to solve this problem. It is certain that, contrary to Raether[52] and the speaker's expectations, corona breakdown streamers occur in air down to 10 cm of air pressure according to C.G. Miller.[22] The spark breakdown transition may not be sharp, and will be a separate function of pressure and gap length, but not of $p\delta$. L.H. Fisher is initiating an investigation of this problem using time lag studies. The general problem is outlined in a paper by the speaker in the Proceedings of the Physical Society of London, 1948.[53] The question of statistical and formative time lags in this regard needs further study.

A real contribution to the statistical character of time lags as affected by the combination of $\gamma e^{\alpha\delta} = \mu$ in Townsend discharge has been completed by R.J. Wijsman,[54] and has been submitted to the Physical Review for publication. In it he finds that the probability of a spark is $P_0 = (1 - \frac{1}{\mu})$. This indicates that in terms of the threshold value of $\mu = 1$, the sparking probability increases very slowly with μ, although this manifests itself over a much narrower range in potential values. The theory does not apply where space charge distortion or streamer mechanisms occur. In the light of this work, some more critical studies of formative and statistical time lags which are amenable to interpretation would probably be in place. Such studies will benefit by being guided by the discussions of the speaker and Wijsman, for earlier studies were made with no complete theory to guide them.

The second urgent problem in the study of sparking is a study of the breakdown potential in N_2 or air over an extended range of pressure and gap length. The streamer theory inevitably leads to the conclusion that the sparking potential-gap length curve at any given pressure should undergo a change in shape to a linear relation after a given gap length δ, is exceeded. This critical lengths should vary with pressure and may be 10-20 cm at atmospheric pressure. A study using a plane parallel gap and a pressurized Van de Graaf generator, such as the 4 Mev machine on the linear accelerator at Berkeley, should be made from 1/4 atmosphere to the limit of high pressures available with gap lengths from 1 cm up to 20 cm. If atom smashing can be discontinued long enough for the relatively simple installation of such electrodes and for the time required to make the runs over a fixed schedule, a great deal can be learned about the failure of Paschen's law and of the Meek streamer criterion. Such information will be invaluable to engineers on all high voltage projects. The work of J.G. Trump, F.J. Stafford, and R.W. Cloud[55] along this line at high pressures and shorter gaps has been most significant in indicating the failure of Paschen's law, but requires extension as indicated.

In the field of corona studies, considerable progress has been made in interpreting the many phenomena observed. Much remains yet to be done. The most recent advance is the paralleling of studies using concentric cylinders with point to plane geometry. In the point to plane gap, it is very desirable that the field along the axis of the hemispherically capped cylindrical point to plane be calculated. This knowledge is urgently needed in threshold studies with this very convenient geometry. The correlation and interpretation of the comparative data on these two gaps over an extended pressure range with gases ranging in composition from pure N_2 to pure O_2, with intervening mixtures, by C.G. Miller[22] is most revealing. It bears especially interestingly on the relative role of the second Townsend coefficients in such discharges under differing conditions. It should, with proper extension to other gases and electrodes, be invaluable to Geiger counter design.

One of the outstanding problems in corona studies has to do with the energy of the incoming positive ions in negative point corona. This may be investigated by G.L. Weissler using the heating of the point by the ions. The problem is important as there are indications that the high fields at the point lead to much sputtering and possibly very efficient secondary emission by high energy ion bombardment; however, nothing is known about positive ion energies under such conditions. The fields in such negative corona breakdown owing to positive ion space charge may even lead to field emission of electrons, a subject which merits study in relation to triggering, if not to secondary processes.

Further study of positive and negative corona discharge with admixture of halogens, such as Cl_2, should throw light on the effect of these gases as breakdown deterrents, particularly in regard to the most efficient concentrations and the character of the action.

In regard to Geiger counters, the speaker is reminded of a remark made by a distinguished colleague, who uses such counters, to the effect that perhaps one of the speaker's students might be assigned to a "really useful task of working on the counters." The speaker replied that this expressed viewpoint was at the bottom of all the confusion, controversy, and lack of success with counters. Entirely too many workers, with no adequate background and interested primarily in instrumentation, have developed counters on the basis of semi-empirical trial and error methods. What is really lacking in this whole field is basic knowledge of the mechanisms operative in positive coronas, in general, and in the concentric cylindrical corona tube, in particular, over a wide range of gases, electrode materials, gaseous mixtures, and pressures. Such studies involve primarily a knowledge of the first Townsend coefficients in the gases studied and probably more vitally the nature and relative intensity of the various secondary processes earlier mentioned under the very widely differing conditions. With such knowledge, together with, perhaps, some data on ionic mobilities, which are not critically important, the behaviours of such coronas under any given set of conditions can be pretty well predicted in advance.

The studies of C.G. Miller, as well as such basic studies as those of F.M. Penning and A.A. Kruithoff, on Townsend coefficients and on corona thresholds, as well as the countless earlier basic studies of Sven Werner et al on counters, and later work of the speaker's group on coronas, all point to the very critical effects of small quantities of certain gaseous admixtures, and the relatively critical change in importance of the secondary processes under such conditions. Doubtless much of the controversial and apparently contradictory nature of experimental findings by different workers can be ascribed, rather to correct interpretations of the observations by the different observers resulting from the relative predominance of certain mechanisms under their operating conditions, than to incorrect or sloppy techniques. Thus, the speaker urges that the problem be attacked from the basis of a fundamental analysis of the various secondary factors and their relative importance under different conditions rather than by analyzing the action of this or that empirically-developed counter within narrowly defined operating conditions. Specifically , it is urged that Miller's study of the concentric cylindrical corona using all methods of analysis be carried out with various gases, mixtures of gases, and electrodes from1mm to 760mm. Armed with this knowledge, properly interpreted, it should then not be difficult to design a proper counter for a given purpose, leaving only the finer adjustment of optimum working conditions to empirical study.

In making this statement there are certain limitations which must clearly be stated. First, there is and will be no universal general-purpose Geiger counter. Each counter must be developed to satisfy certain specific requirements. Again, gaseous discharges are subject to fluctuations and variations which make them an imperfect and limited tool, at best. All counters, like other engineering developments, are subject to mutually exclusive design features that require compromise. Background counts can never be entirely eliminated. Nice flat counting plateaus of any considerable scope can only be gained at the cost of time resolution and slower recovery times. Greater stability and longer life can be achieved by the use of proper halogen-inert gas mixtures, and proper electrodes, rather than by using the organic gas admixtures. What amazes the speaker is that, with all the data on hand in 1939, it took until 1946 for the value of the halogens to be discovered. It is probable that the counting rate of the present type tubes can hardly be exceeded. The breakdown rate of lower pressure discharges is generally limited to the microsecond range and the recovery time depends on clearing times of space charges which depend on ionic mobilities in low fields. Probably spark counters in more uniform higher fields will solve this aspect of the problem. In any case, no great improvement of Geiger counters can be expected without more fundamental investigations.

There is one more feature in the studies with atmospheric pressure coronas. These are the role and magnitude of the electrical wind effects. The effects should be less with negative points in air than with positive. A.L. de Graffenreid is studying some of the effects with an eye to practical application. However, basic studies are much desired as to magnitudes and effects produced.

9. Glow Discharges

This field has in the past had much attention paid to it, but, except for many routine studies of a non-revealing character and good quantitative data on the positive column, there is much left to be done. One of the most crying needs is a knowledge of the potential gradients in the Crookes dark space, i.e., in the cathode fall. Aston has shown that, by the deflection of a fine cathode ray beam, this condition can be explored to advantage. With modern techniques the method should yield most important results. A study along this line is being carried out in the speaker's laboratory. It should be paralleled in other laboratories and also applied to the anode fall. There is all too little known about the latter region which, as will be seen, is most important. According to K.G. Emmeleus,[56] it is the seat of plasma oscillations leading to the moving striations. In fact, the whole question of striations and the related plasma oscillations, if they are related, is most unclear.

Fortunately, in the last weeks the speaker received a full report of the work undertaken by G.H. Dieke and T. Donahue[48] using their admirable technique of photocell and oscilloscope in a study of the columns of a number of discharges. Contrary to common belief as indicated by visual observations, a large number of the so-called stationary direct current glow discharge columns with no visible striations are actually being traversed by groups of moving striations belonging apparently to two systems. The frequencies of these vary from values of the order of 10^3 to much higher values. These systems consist of striations moving from the anode to the cathode, as indicated by Emmeleus, and of other striations moving from the cathode to the anode at different velocities. Where the two meet they interfere and progress is slowed up. These may or may not lead to striations visible to the eye and those visible may be moving or stationary. The oscillations are correlated with potential fluctuations of some percent across the tube, and especially at the cathode. It is most desirable that these be correlated with cathode ray oscillographs of probes at various points in the plasma. While some discharge conditions of pressure and current density show no striations, it is Diekes' belief that the so-called stationary discharge is never really stationary.

Correlated with Dieke's tentative explanation, the speaker proposes the following explanation. Conditioned cathodes, when bombarded with positive ions, can autocatalytically increase the rate of secondary electron emission and, unless inhibited by space charges or too low a gas density, will strive towards arc over. Such a burst of ionization playing into the negative glow can build up an excess of electrons in the anode end of the glow to the end that a very high potential gradient across the Faraday dark space suddenly, builds up. This can reach such a value that a negative striationary pulse of electron ionization sweeps up the conducting column towards the anode. At the anode the burst of ionization will build up an excess wave of positive ions which will propagate as an anode striation back towards the cathode. As the negative space charge in the glow from the first burst of ionization builds up, the potential falls inhibiting the autocatalytic growth of current from the cathode and reducing the current. The potential at the cathode then recovers. With the release of the electrons to the negative striational wave the autocatalytic discharge at the cathode will again have built up. Thus, a chain of successive pulses from the cathode keeps the negative striations going and the succession of positive and negative striations observed by Dieke continues. Naturally, the positive striations arriving in the negative glow region can either aid in building up and sustaining the system of oscillations, or they can interfere with them, producing the occasional unstable conditions observed by Dieke. Non-striationary stable discharges should also be possible.

It is clear that the whole field of glow discharge study has been revolutionized by these observations, and it takes very little further mention to indicate to those present a multitude of possible investigations along this line. Whether these striations have any bearing on plasma oscillations it is impossible to say. Even the slower positive ion plasma oscillations in theory and practice have much higher frequencies than most of those observed by Dieke. The very much higher frequency electronic plasma oscillations occur only at the low pressures where cathode ray beams appear. Much work has been done on these by Armstrong under Emmeleus[57] and these results are, I believe, ready for publication. In this case, instabilities, perhaps of the same sort that cause Dieke's low frequency oscillations, start the plasma oscillations lying in the centimeter wave length region. These in turn velocity modulate the cathode rays which, regeneratively under appropriate circuit conditions, sustain the oscillations. With modifications, both W.O. Schumann[58] and G. Wehner,[59] in Germany during the war and, later, in this country, investigated these oscillations in an attempt to utilize them as sources of ultra high frequency waves. To this end, the glow discharge was used in tubes designed to accentuate regenerative action. It is not impossible that the oscillations of Dieke correspond to similar conditions of instability not with, however, local ion or electron cloud oscillations, but of the discharge plasma as a whole. The whole question of observed plasma oscillations needs experimental study to indicate the regenerative conditions sustaining them, for these are not clearly defined by theoreticians so far.

In connection with the glow discharge, three other studies come to mind. P.L. Morton[60] pointed out that in the Crookes dark space the field gradients are so high and pressures are so low that electrons cannot remain in equilibrium with the field. Experiment in concentric cylindrical electrode fields showed that this surmise was correct. The electrons gain energy rapidly in the high field regions and dissipate the energy in more efficient ionization when the low field regions are encountered. Thus, all previous quantitative theory of the glow discharge based on the use of Townsend coefficients is valueless, as it is, in greater measure anyway in consequence of Dieke's work. Morton's studies were carried further by G.W. Johnson,[61] who succeeded, in the speaker's laboratory, in evaluating the ion multiplication in such fields for H_2 and air. Much more work is required on other gases, and especially with other geometry, where the field variation with distance is different. With knowledge gained from measurements of the fields in the Crookes dark space, the future studies of this problem will be clearly delineated.

A second subject, which has, except for one instance only, been studied conventionally in glow discharges where conditions are complicated, is cathode sputtering. Sputtering was only once investigated under a set of circumstances where controlled study of yield with unique ion energies was possible, by G. Timoshenko.[62] He used a positive ion source and beam of positive ions of known energy to study sputtering. It should be possible to carry this method over to a number of different ions of a large range of energies. Using a hot filament ionization detector it could be made to give valuable data on the angular distribution of scattered sputtered atoms. It could also be used in connection with pulse techniques to yield velocity distributions.

The third problem of some importance to industry is the gas clean up in discharge tubes. Recently J.E. White[63] at the Bureau of Standards, in an, as yet unpublished, investigation, has shown that most of the absorption of gases is not by the sputtered material plastered on the walls, as usually assumed. It is lost largely through absorption of fast positive ions by the cathode on impact. Apparently one in 10^4 of the incoming positive ions in the discharge is thus absorbed and quantitatively can be recovered by outgassing. This interesting development needs further study for itself, and because of its possible influence on the secondary processes at the cathode and conditioning thereof.

There is one field of investigation which does not properly belong in any general classification, but which is of great importance to the gaseous electronic investigator. It belongs perhaps in the regime of secondary processes at a cathode but is not properly in this class. This is the question of field emission and vacuum breakdown. Subsequent to the work in the late nineteen twenties on field emission, W.H. Bennett[64] added to the mechanism of high field vacuum sparking the concept of self-focusing beams. Since then J.G. Trump and R.J. Van de Graaff[65] have shown that at very high energies, lying in the order of 10^5 volts, electron impact on metal surfaces can liberate positive ions, and that, through the progressive increase of field emission of electrons together with ions released by these and secondary electron liberation by positive ion impact, a spark could materialize. This very important discovery opens up a whole field of investigation into vacuum breakdown, which at present limits so much of our equipment in the high voltage region. In general the vacuum spark and the conditions of the surface as regards polish and gaseous coating merit much further study.

One more phenomenon which has been observed time and again and goes by many names, such as the Malter or Paetow[66] effect, needs further study. This is the effect of fine particles of supposed insulators, such as MgO, Al_2O_3, etc., which once subjected to the action of a gas discharge, continue to serve as a source of triggering electrons for some time. It is useful where triggering is required. It is fatal in discharge tubes or Geiger counters where it furnishes a very undesirable background. Is this phenomenon a field emission process, a photoelectric delayed emission process, or what? How can it be prevented? Much research of a most valuable nature can be done here.

10. Arc Discharge

The outstanding problem in this field of study today is the mechanism of the cathode spot in the low boiling point metal vapor arc. It is clear that there is a complication in arc studies when, as in the refractory arcs, it is not known what fraction of the current is carried by the thermionically emitted electrons from the cathode, and what by the ions created by collision in the gas. If, in the low boiling point metal vapor arcs, the ions are all created in the gas, this problem does not present itself, for the electrons and the ions must be present and carry the current in equal numbers. Recent studies are throwing some light on the character of the hot spot and its behaviour which may help to answer this question.

Work of K.D. Froome,[51] some of it as yet unpublished, using a pulsed Kerr cell shutter and photographic observation, indicates to the speaker that, much as in the negative corona discharge at high pressures when current densities are high at a conditioned spot, there is a marked axial constriction of the Crookes dark space and negative glow by the curving of the equi-potential lines resulting from space charges of positive and negative ions relative to adjoining regions free from discharge. The heavier the emission, the higher is this distortion, and it results in the Hg arc in constrictions of the spot, giving current densities of the order of magnitude of 1 to $5x10^6$ amperes per cm^2, as indicated by Froome and also Gallager[67] of General Electric. This enormous concentration of energy in a confined area leads to actions causing the necessary ionization. These, however, are neither equilibrium processes nor processes which can glibly be explained by such conventional terms as "field emission", "temperature ionization", or liberation by "conventional positive ion bombardment." A suggestion of R.R. Newton[68] in connection with short sparks observed by L.H. Germer and by Rothstein may furnish one clue to the mechanism. In any case, the possible violent and concentrated actions make the spot unstable and it wanders over the surface of the metal at high speed. Above a given current load one spot cannot carry the current and other spots start at conditioned points on the surface. As the arc develops, what is seen visually as the "hot spot" starts, as shown by Froome, as one of these minute hot spots, which rapidly becomes overloaded and leads to others in time. The spots, as indicated by field studies, repel each other and continually advance along the surface, spreading apart and growing in number, within limits set by the current supply. The eye sees the total moving group. Froome has sent the speaker recent pictures of the gradual development and spread of these spots as revealed by his shutter. With this general picture to guide one and a realization of the energy conditions, problems for further study and possible modes of attack should make themselves clear.

Where urgent information is needed is in a study of the mercury and presumably other metal vapor jets, initially observed in H_2 by F.G. Dunnington[69] and others, but lately reported by J.R. Haynes in the development of the arc. Are such jets usual? They are more general than supposed, according to Finkelnburge. What is their mechanism? How are they related to the wandering of the hot spot and to metal transport? This whole field is just beginning to open up, and new data is needed before any proper theory of the mechanism can be formulated. The tools are at hand; workers are now needed.

In connection with the racing of the cathode spots in strong magnetic fields, the mechanism has been clarified by other than thermodynamic considerations in recent work by G.I. Cohn and G.J. Himler[70] of Illinois Institute of Technology. Their explanation has to do with the alteration by the field of electron paths emerging from the hot spot in such a way as to further ionization and advance in one direction and retard it in the other. A further analysis of this mechanism with Kerr cell shutters may assist in explaining what happens at the spot.

Yet another study of arc behaviour is that of G.F. Hull, Jr.[71]. at Dartmouth, whose interesting investigations on the drawing out of arcs between metal points is yielding further data of interest to workers in the field.

With this full but incomplete summary of fields of study, I will close. I wish in closing, however, to pay tribute to one agency that in these post-war years has done more to further and stimulate research in gaseous electronics than any other agency. Were it not for the assistance given by the Office of Naval Research, many of the current advances would not have been possible because of the inability of university laboratories to compete in the student market with the more remunerative and alluring inducements of certain popular fields of research.

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