10th ANNUAL GASEOUS ELECTRONICS CONFERENCE

PROGRAM

and

ABSTRACTS OF PAPERS

CAMBRIDGE, MASSACHUSETTS

OCTOBER 2-4, 1957

Under the Joint Sponsorship of

DIVISION OF ELECTRON PHYSICS, AMERICAN PHYSICAL SOCIETY

SYLVANIA ELECTRIC PRODUCTS, INC.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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	Single Rooms with Bath	Double Rooms with Bath
Bellevue - 21 Beacon St., Boston Room Reservations	$ 6.75 - 9.50	$11.00 - 13.50
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Commander - 16 Garden St., Cambridge	6.50 - 9.50	10.00 - 14.00
Continental - 29 Garden St., Cambridge	8.00	10.00 - 12.00
Essex - 695 Atlantic Ave., Boston	5.00 - 8.00	8.50 - 10.50
Kenmore - 490 Commonwealth Ave., Boston	7.50 -14.00	11.50 - 16.00
Lenox - 61 Exeter Street, Boston	5.25 - 8.50	8.25 - 12.50
Lincolnshire - 20 Charles St., Boston	8.00 - 9.00	11.00 - 14.00
Parker House - 60 School St., Boston	9.00 -11.00	12.50 - 14.00
Ritz-Carlton - 15 Arlington St., Boston	13.00 -15.00	18.00 & 20.00
Sheraton Plaza - Copley Square, Boston	7.50 -15.00	12.00 - 19.00
Sherry Biltmore - 150 Mass. Ave., Boston	6.00 - 9.00	11.00 - 14.00
Somerset - 400 Commonwealth Ave., Boston	7.50 -13.50	11.00 - 18.50
Statler - Park Square, Boston	8.00 -13.50	13.50 - 17.00
Vendome - 160 Commonwealth Ave., Boston	5.00 - 7.00	8.50 - 20.00

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Research Laboratory of Electronics
Cambridge 39, Massachusetts

Tenth Annual Gaseous Electronics Conference

Final Announcement

The Tenth Annual Gaseous Electronics Conference will be held at the Massachusetts Institute of Technology, Cambridge, Massachusetts, from Wednesday, October 2 through Friday, October 4, 1957. The sessions on Wednesday and Thursday will be held in the Kresge Auditorium and the meeting on Friday will be held in the Compton Laboratory Auditorium.

The Conference is sponsored jointly by the Division of Electron Physics, American Physical Society, the Sylvania Electric Products, Inc., and the Massachusetts Institute of Technology. A copy of the Conference program is enclosed.

Registration will take place in the lobby of the Kresge Auditorium starting at 9:00 A.M., Wednesday, October 2. There will be a registration fee of $2.50.

A booklet of printed abstracts of the contributed papers will be furnished to all those registering for the Conference. Additional copies of the abstracts can be obtained at $2.50 each.

The Conference banquet will be at 6:00 P.M. on Friday evening, October 4, in the M.I.T. Faculty Club, preceded by cocktails from 5:00 to 6:00. Banquet tickets at $3.15 will be available at the registration desk. The after-dinner speaker will be Professor Giorgio D. de Santillana of the Massachusetts Institute of Technology, who will speak on the "Trials of Galileo."

A Ladies' Program has been arranged. The details are included with this announcement.

Further inquiries should be directed to the Conference Secretary, Professor S. C. Brown, Research Laboratory of Electronics, 20-A-125, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

Sincerely yours,

Gaseous Electronics Conference Committee

W. P. Allis, MIT, Chairman
S. C. Brown, MIT, Secretary
O. Oldenberg, AFCRC
K-B Persson, GE Research Laboratory
A. V. Phelps, Westinghouse Research Labs.
J. F. Waymouth, Sylvania Electric Prod., Inc.

TENTH ANNUAL GASEOUS ELECTRONICS CONFERENCE

October 2, 3, and 4, 1957

PROGRAM

Wednesday, October 2 9:00-9:30 a.m. — Registration in Lobby Kresge Auditorium

-

A. POSITIVE COLUMN

Chairman: H. Hagstrum, Bell Telephone Laboratories

Wednesday, October 2

9:30 a.m.

A-1 LOW TEMPERATURE HIGH DENSITY PLASMAS
R. C. Knechtli and W. Knauer
Radio Corporation of America

A-2 TEMPERATURE MEASUREMENTS IN HIGH CURRENT ARC PLASMAS
H. N. Olsen
Linde Company

A-3 DYNAMIC RESPONSE OF ARCS IN VARIOUS GASES
T. E. Browne, Jr., K. H. Yoon, and H. E. Spindle
Westinghouse Electric Corporation

A-4 DEVIATIONS FROM IONIZATION BALANCE - A TOOL FOR STUDYING IONIZATION PROCESSES IN A PLASMA
John F. Waymouth
Sylvania Electric Products, Inc.
Francis Bitter
Massachusetts Institute of Technology

\- Intermission -

A-5 TRANSITION FROM NON-MAXWELLIAN TO MAXWELLIAN ELECTRON ENERGY DISTRIBUTIONS IN RARE GAS DISCHARGES
G. Medicus
Wright-Patterson Air Force Base

A-6 THEORY OF MOVING STRIATIONS
P. J. Walsh
Westinghouse Electric Corporation

A-7 STUDIES OF CATAPHORESIS IN DISCHARGES IN MIXTURES OF GASES; TWO NEW EFFECTS
Carl Kenty
General Electric Company

Wednesday, October 2, 1:00 p.m. — Luncheon

B. CATHODES

Chairman: G. Wehner, General Mills, Inc.

Wednesday, October 2, 2:00 p.m.

B-1 HOLLOW CATHODE GLOW DISCHARGE IN MERCURY VAPOR
K. G. Hernqvist
Radio Corporation of America

B-2 THE CATHODE SHEATH IN A LOW DENSITY DISCHARGE
P. L. Auer, H. Hurwitz, Jr., and S. Tamor
General Electric Research Laboratory

B-3 MOTION AND SPECTRUM OF HIGH SPEED CATHODE SPOTS
Dino Zei and J. G. Winans
University of Wisconsin

B-4 THE MECHANISM OF ELECTRON EMISSION IN ARCS ON LOW BOILING POINT CATHODES
T. H. Lee
General Electric Company

- Intermission -

B-5 TRANSPORT WITH DISSIPATION
Don E. Harrison, Jr.
University of Toledo

B-6 DETAILS OF BEHAVIOR OF A WIRE DURING ELECTRICAL EXPLOSION
William G. Chace
Air Force Cambridge Research Center

B-7 ARC INITIATED DISCHARGE IN MAGNETIC FIELD IN HIGH VACUUM.
II. MAGNETO-IONIC EXPANDER TYPE OF DISCHARGE
Joseph Slepian
Westinghouse Research Laboratories

C. CROSS SECTIONS & INVITED PAPER

Chairman: O. Oldenberg, Harvard University

Thursday, October 3
9:00 a.m.

C-1 FURTHER STUDIES OF THE IMPRISONMENT OF RESONANCE RADIATION
A. V. Phelps
Westinghouse Research Laboratories
A. O. McCoubrey
The National Company, Inc.

C-2 EXCITATION FUNCTIONS AND RATES FOR THE PRINCIPAL LEVELS OF HELIUM
L. S. Frost and A. V. Phelps
Westinghouse Research Laboratories

C-3 TOTAL IONIZATION BY LOW ENERGY ELECTRONS IN NEON
B. T. McClure
Bell Telephone Laboratories, Inc.

C-4 MOBILITIES OF IONS IN RARE GASES AT LOW E/p_o
Earl C. Beaty
National Bureau of Standards

\- Intermission -

Business Meeting

C-5 (Invited Paper) ROCKET INVESTIGATION OF ATMOSPHERIC PHOTOCHEMISTRY
Frederick F. Marmo
Air Force Cambridge Research Center

C-6 ELECTRON ATTACHMENT IN OXYGEN AT LOW ENERGIES
Lorne M. Chanin and Manfred A. Biondi
Westinghouse Research Laboratories

C-7 NEGATIVE ION FORMATION AND ELECTRIC BREAKDOWN FOR SOME HALOGENATED GASES
W. M. Hickam and D. Berg
Westinghouse Research Laboratories

Thursday, October 3
1:00 p.m.

Luncheon

D. HIGH TEMPERATURE PLASMAS

Chairman: J. L. Tuck, Los Alamos Scientific Laboratory

Thursday, October 3
2:00 p.m.

D-1 PINCH EFFECT IN ARGON AND HELIUM
J. W. Mather
University of California
Los Alamos Scientific Laboratory

D-2 CURRENT DISTRIBUTION IN AN IMPULSIVE PINCHED DISCHARGE
L. C. Burkhardt
University of California
Los Alamos Scientific Laboratory

D-3 INSTABILITIES IN A PINCHED DISCHARGE
R. H. Lovberg
University of California
Los Alamos Scientific Laboratory

D-4 NEUTRON GENERATION FROM STRAIGHT PINCHES (Columbus I')
Robert E. Dunaway
General Atomic Division of
General Dynamics Corporation

\- Intermission -

D-5 SPECTROSCOPIC OBSERVATIONS OF PINCHED DISCHARGES
Emory J. Stovall, Jr.
University of California
Los Alamos Scientific Laboratory

D-6 A MAGNETICALLY DRIVEN ELECTRODELESS SHOCK TUBE FOR THE PRODUCTION OF HIGH ENERGY PLASMAS
G. Sargent Janes
Avco Research Laboratory

D-7 EXTREMELY LARGE GAS TEMPERATURES IN THE HIGH PRESSURE COAXIAL CAPACITOR DISCHARGE
Heinz Fischer
Air Force Cambridge Research Center

E. MICROWAVES; COULOMB INTERACTION

Chairman: A. Simon, Oak Ridge National Laboratory

Friday, October 4
9:00 a.m.
Compton Laboratory

E-1 STUDY OF RADIATED NOISE FROM AN ARC DISCHARGE
H. A. Schafft
University of Maryland
A. D. Krumbein
Nuclear Development Corporation of America

E-2 MICROWAVE INVESTIGATION OF DISINTEGRATING PLASMAS IN MIXTURES OF THE RARE GASES
H. J. Oskam
Philips Research Laboratories

E-3 MICROWAVE DIAGNOSTICS FOR CONTROLLED FUSION RESEARCH
Charles B. Wharton
University of California
Radiation Laboratory

E-4 OSCILLATIONS IN A PLASMA IN A MAGNETIC FIELD
H. W. Bandel and R. M. Hill
Sylvania Electric Products, Inc.

- Intermission -

E-5 MICROWAVE PROPAGATION IN A HOT MAGNETO-PLASMA
J. E. Drummond
Stanford Research Institute

E-6 EFFECTS OF ELECTRON - ELECTRON INTERACTIONS ON CYCLOTRON RESONANCES IN GASEOUS PLASMAS
Rudolph C. Hwa
University of Illinois

E-7 THE ELECTRON-ELECTRON INTERACTION and HEAT CONDUCTION IN GASEOUS PLASMAS
T. Sekiguchi
University of Tokyo
L. Goldstein
University of Illinois

E-8 THE THEORY OF RUN-AWAY ELECTRONS
H. Dreicer
University of California
Los Alamos Scientific Laboratory

Friday, October 4
1:00 p.m.

Luncheon

F. BREAKDOWN

Chairman: J. F. Waymouth, Sylvania Electric Products, Inc.

Friday, October 4
2:00 p.m.

F-1 LOW PRESSURE MICROWAVE PLASMA IN A MAGNETIC FIELD
D. O. Akhurst, S. J. Buchsbaum, E. I. Gordon
Massachusetts Institute of Technology

F-2 ELECTRON DIFFUSION WITHIN A CYLINDRICAL MICROWAVE CAVITY
R. J. Munick
Hughes Research Laboratories

F-3 MULTIPACTING MODES OF HIGH FREQUENCY BREAKDOWN
Albert J. Hatch
Argonne National Laboratory
H. Bartel Williams
New Mexico College of Agriculture and Mechanical Arts

F-4 A THREE DIMENSIONAL POTENTIAL WELL PRODUCED BY THE SECONDARY ELECTRON RESONANCE MECHANISM
H. Bartel Williams
New Mexico College of Agriculture and Mechanical Arts

F-5 HIGH-FREQUENCY BREAKDOWN IN AIR AND HYDROGEN
Elsa Huber Solt and Philip M. Platzman
Hughes Research Laboratories

F-6 CURRENT AND TIME STUDIES OF THE POSITIVE POINT CORONA IN HYDROGEN
L. A. Bornstein and L. H. Fisher
New York University

Friday, October 4

5:00-6:00 p.m. Cocktails at Faculty Club

6:00 p.m. Conference Banquet at Faculty Club
Professor Giorgio D. de Santillana
"Trials of Galileo"

10th ANNUAL GASEOUS ELECTRONICS CONFERENCE

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SYLVANIA ELECTRIC PRODUCTS, INC.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

TENTH ANNUAL GASEOUS ELECTRONICS CONFERENCE

October 2-4, 1957

Program

Wednesday
October 2
9:00 - 9:30 A. M.

Registration in Lobby
Kresge Auditorium

A. POSITIVE COLUMN

CHAIRMAN: H. Hagstrum, Bell Telephone Laboratories

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B. CATHODES

CHAIRMAN: G. Wehner, General Mills, Inc.

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October 4
1:00 P. M.

Luncheon

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October 4
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Wednesday, October 2

9:30 A. M.

SESSION A

POSITIVE COLUMN

Chairman, H. Hagstrum

Bell Telephone Laboratories

LOW TEMPERATURE HIGH DENSITY PLASMAS

R. C. Knechtli and W. Knauer
Radio Corporation of America
David Sarnoff Research Center
Princeton, N. J.

A method for producing a "cool" or monochromatic electron beam is described. It is based on the reduction of the thermal energy of thermionically emitted electrons by thermalizing collisions of these electrons with the molecules of a cool gas. Such a low temperature electron beam could be used for ultra-low-noise traveling-wave tubes, or for basic physical research.

Because the electrons can drift only very slowly through the cooling gas (otherwise they would heat up instead of being cooled!), their density must be very large. The resulting space charge is neutralized by means of cesium ions produced by contact ionization. Electrons and ions are confined in a plasma beam by means of a magnetic field of a few hundred gauss. After having drifted through the cooling gas, this plasma beam extends through a differential pumping system and emerges in high vacuum. There, the electrons are extracted from the cool plasma, and a monochromatic electron beam of controllable energy is formed.

An analysis was made of the properties of the magnetically confined dense plasma beam. Probe measurements were found to be compatible with the theory. Interesting recombination effects have been discovered.

A-2

TEMPERATURE MEASUREMENTS IN HIGH CURRENT ARC PLASMAS

H. N. Olsen
Speedway Laboratories
Linde Company
Indianapolis, Indiana

Temperatures in the range 10,000 to 22,000°K have been measured spectroscopically in thermal plasmas of high current argon arcs. The method used was developed originally by Fowler and Milne[1] and later adapted for measurements in transparent plasmas by Larenz.[2] Spectrally resolved radiation intensity maps, corrected for variation of depth of radiation with position in the plasma, were obtained on a relative intensity scale for arcs burning in both the normal mode and the cathode-spot mode. Isotherm maps covering the above temperature range were constructed from the spectral maps.

Plasmas studied were those of non-consumable-electrode arcs provided with sufficient electrode cooling to prevent metal vapor contamination. The arcs, operating in an enclosed chamber to avoid atmospheric contamination, burned between a tungsten-rod cathode and a plane copper anode. Chamber gas was argon at atmospheric pressure. Currents ranged from 100 to 400 amperes.

1. R. H. Fowler and E. A. Milne. See A. Unsold, Physik der Sternatmospharen, Berlin, 1938.
2. R. W. Larenz, Z.f. Phys. 129, 327-342 (1951).

DYNAMIC RESPONSE OF ARCS IN VARIOUS GASES A-3

T. E. Browne, Jr., K. H. Yoon, and H. E. Spindle
Westinghouse Electric Corporation
Trafford, Pennsylvania

The dynamic volt-ampere behavior of an arc column can be described by means of differential equations in which energy storage in and power loss from the column account for time lag effects. The ratio of an energy quantity to power loss appears as a "time constant." This constant and the steady-state voltage gradient are sufficient as parameters in simple arc "model" equations. Such equations can be solved simultaneously with those of the supply circuit to determine, for example, arc stability limits.

A method for measuring arc time constants for use in a modified Mayr type equation will be described. Results will be given showing close correspondence between computed behavior and observed behavior of low current vertical semi-confined arcs in still gas. Arc currents from 1 to 6 amperes and gas pressures from 1/4 to 7 atmospheres have been used. Time constants have been found to increase with enclosure diameter, gas pressure, and arc current, and to be extremely dependent upon gas medium. Values range from 1/4 microsecond in sulfur hexafluoride at low pressure to hundreds of microseconds in nitrogen at higher pressures. Physical explanations for these variations are being sought.

A-4 DEVIATIONS FROM IONIZATION BALANCE – A TOOL FOR STUDYING IONIZATION PROCESSES IN A PLASMA

John F. Waymouth
Sylvania Electric Products Inc.
Salem, Massachusetts

Francis Bitter*
Massachusetts Institute of Technology
Cambridge, Massachusetts

An experiment has been devised for switching an operating discharge to a zero-impedance power supply, whose voltage can be varied above or below the equilibrium discharge voltage just prior to switching. If the zero-impedance voltage is above the discharge voltage, the electron density and discharge current increase with time, tending toward infinity. If the zero impedance voltage is below the equilibrium discharge voltage, the electron density and discharge current decrease with time, tending toward zero. The discharge is switched back to its ballasted power supply before catastrophic damage or extinction occur. From the rate of change of electron density with time, information can be obtained about the ionization processes in the discharge.

* Work done at Engineering Laboratories of Sylvania Electric Products Inc., Salem, Massachusetts.

TRANSITION FROM NON-MAXWELLIAN TO MAXWELLIAN ELECTRON ENERGY DISTRIBUTIONS IN RARE GAS DISCHARGES A-5

G. Medicus, WCLKD
Wright-Patterson Air Force Base, Ohio

In hot-cathode rare gas discharges in the mm pressure range, high-energy (8-16 ev) electron groups, superimposed on a Maxwellian, are usually observed. In a Ne fire-ball discharge, families of electron energy spectra were determined from automatically plotted probe curves by a short cut[1] to Druyvesteyn's method, with the probe location and the discharge current as parameters. At low currents the high-energy group is clearly separable and is found to obey simple diffusion laws, with no interaction within itself, but with energy transfer to the Maxwellian group. The temperature of the latter group initially rises in proportion to the total current. With increasing total current and rising temperature the energy transfer increases, and the fast group progressively disappears into the Maxwellian, until at total currents in the ampere range, at electron temperatures of about 20,000°K, the deviations from the Maxwellian practically disappear except for a persistent deficiency in the high-energy Maxwellian tail.

1. G. Medicus, J. Appl. Phys. 27, 1242 (1956).

A-6 THEORY OF MOVING STRIATIONS

P. J. Walsh
Westinghouse Electric Corporation
Bloomfield Lamp Division
Bloomfield, New Jersey

The coupled continuity equations for the electrons and ions in a plasma have been treated by Watanabe and Oleson.[1] Unfortunately, the simultaneous diffusion of electrons and ions to the tube walls was handled incorrectly by them. When this diffusion is treated correctly it is found that the striation wavelength and velocity are determined solely by non-linearity in the ionization rate and by any change in the electron parameters produced by the energy variation within the striations. This energy variation is determined by the use of the power balance equation for the electrons. Preliminary calculations show good agreement with experiments conducted in mercury-krypton discharges.[2]

1. S. Watanabe and N. L. Oleson, Phys. Rev. 99, 1701 (1955).
2. H. L. Steele, Gaseous Electronics Conference, 1950, paper F 3.

STUDIES OF CATAPHORESIS IN DISCHARGES IN MIXTURES OF GASES; TWO NEW EFFECTS

C. Kenty
General Electric Company
Nela Park, Cleveland, Ohio

Measurements have been made of the transport of Hg along the positive column of a D.C. discharge in mixtures of Hg with the rare gases.

The unexpected retrograde transport of Hg in Xe is due to a drift of neutral Hg toward the anode under the impact of the electrons which exceeds the drift of Hg ions toward the cathode. This is made possible by the relatively large Ramsauer cross section of Hg and the inferred presence of numerous Xe ions.

An A.C. discharge in Ne plus a trace of A concentrates the A axially toward the middle of the column. Similarly, Hg is concentrated toward the middle of a column in Ne + Hg, A + Hg or Kr + Hg but toward the ends in Xe + Hg. The effect increases with current and rare gas pressure and decreases with increasing Hg pressure. It is probably caused by non-uniformity of field due to traveling striations or other asymmetric effect.

Wednesday, October 2
2:00 P.M.

SESSION B

CATHODES

Chairman, G. Wehner
General Mills, Inc.

HOLLOW CATHODE GLOW DISCHARGE IN MERCURY VAPOR*

B-1

K. G. Hernqvist
Radio Corporation of America
RCA Laboratories
Princeton, N. J.

The hollow cathode glow discharge operates with a metal cathode having a spherical cavity and a small exit aperture. The main glow is situated inside the cathode cavity. This discharge has been operated in mercury vapor by keeping the inside of the cavity wetted with mercury. The volt-ampere characteristic does not exhibit any regions of negative resistance. An analysis based on the energy balance relation will be shown to yield a volt-ampere characteristic which is in good agreement with experiment. Microwave measurements of the plasma density also corroborate the analysis. These studies indicate that plasma densities in excess of 10^{15} cm^{-3} may be obtained in this discharge.

300 kmc plasma osc.

* This research was supported by the United States Army Signal Corps.

B-2

THE CATHODE SHEATH IN A LOW DENSITY DISCHARGE

P. L. Auer, H. Hurwitz, Jr., and S. Tamor
General Electric Research Laboratory, The Knolls,
Schenectady, N. Y.

We consider a gaseous discharge between two plane parallel electrodes under the assumption that the electron current at the cathode is space charge limited. We shall be particularly interested in studying the variation of the potential distribution with gas pressure. When the gas pressure is very low, little ionization is produced so that the potential distribution follows the Langmuir-Child's law. As the gas pressure is increased, the positive ion space charge reverses the curvature of the potential near the anode and eventually leads to the formation of a positive column.

The present work is an extension of the classical paper published by Langmuir in 1929.[1] We shall exhibit self-consistent solutions for the cathode sheath potential distribution on the basis of a model in which the space charge results from the primary electrons and from ions generated within the cathode sheath region. Also considered is the case in which the anode (which may be regarded as the boundary of the positive column next to the cathode sheath) emits additional ions contributing to the space charge.

1. Irving Langmuir, Phys. Rev. 33, 954-989 (1929).

MOTION AND SPECTRUM OF HIGH SPEED CATHODE SPOTS

B-3

Dino Zei and J. G. Winans
University of Wisconsin
Madison, Wisconsin

The motion and spectrum of a mercury arc cathode spot was observed at a junction between metal and mercury and at a groove above the liquid-metal junction. For all magnetic field strengths the spot velocity at the groove was greater than at the junction. For constant field, the spot velocity at the groove showed a maximum at about two amperes with increase in current. The spot velocity at the junction increased with current for all currents. The spot at the groove was about 5 mm long and 1 mm wide. The spectrum of the spot at the groove showed Hg 1, Hg 11, and Hg 111 lines. There is no broadening of the spectrum lines at the spot as observed for a spot at the junction. The mechanism proposed by St. John and Winans[1] accounts for both groove and junction modes of operation of the arc.

1. R. St. John and J. G. Winans, Phys, Rev. 94, 1097 (1954).

B-4

THE MECHANISM OF ELECTRON EMISSION IN ARCS ON LOW BOILING POINT CATHODES

T. H. Lee
General Electric Company
Philadelphia, Pennsylvania

There has been considerable difficulty in explaining the mechanism of electron emission in arcs on low boiling point cathodes such as copper or silver. Cobine and Burger[1] have shown that thermionic emission is unlikely and the electric field at the cathode calculated from the MacKeown equation[2] is too low to account for the electron emission by the Fowler-Nordheim mechanism of field emission.

Thermionic emission (including the Schottky effect) and field emission are really the limiting cases of a more general emission equation treated by Murphy and Good.[3] In the intermediate range, where both field and temperature are high the emission process is strongly dependent on both variables. Dolan and Dyke[4] have proposed the term "T-F" emission for this region. In this paper, the "T-F" emission is calculated over a wide range of temperature and field. It is then shown that the electron emission in arcs on low boiling point cathodes may be explained by the mechanism of "T-F" emission.

1. J. D. Cobine and E. E. Burger, J. Appl. Phys. 26, 895 (1955).
2. S. S. MacKeown, Phys. Rev. 34, 611 (1929).
3. E. L. Murphy and R. H. Good, Jr., Phys. Rev. 102, 1464 (1956).
4. W. W. Dolan and W. P. Dyke, Phys. Rev. 95, 327 (1954).

TRANSPORT WITH DISSIPATION

Don E. Harrison, Jr.
University of Toledo
Toledo, Ohio

This paper describes a technique which will solve the Boltzmann transport equation for a special case in which kinetic energy is not conserved in an individual collision. It consists of a neutron cooling type analysis combined with a suitably modified energy, or "lethargy", transition function.

Conservation of momentum is maintained by a transformation to the center of mass system, but kinetic energy is removed by fractionally reducing the final velocity of both the striking and struck particles. The fraction retained introduces a new dissipation parameter into the theory. The usual transition probability analysis can then be carried through, and all functions retain the same general characteristics although they now depend upon both the mass ratio and the dissipation parameter.

The new method will be applied to the author's theory of cathode sputtering;[1] and certain other analytic techniques which simplify that analysis will also be discussed. As modified, the theory compares satisfactorily with a much broader range of experimental data.

This new method is particularly useful because it makes no restrictions on the way in which energy is being removed from the kinetic system. In the case to be discussed, this energy is available to rupture lattice bonds, but it could equally well be utilized for electron excitation or radiation.

1. Don E. Harrison, Jr., Phys. Rev. 102, 1473 (1956) and Phys. Rev. 105, 1202 (1957).

B-6 DETAILS OF BEHAVIOR OF A WIRE DURING ELECTRICAL EXPLOSION

William G. Chace
Air Force Cambridge Research Center
Geophysics Research Directorate
L. G. Hanscom Field, Bedford, Mass.

Wires subjected to very high current densities (>10^5 amps/cm^2) become highly superheated and vaporize "instantaneously". The term "transplosion" is proposed for this process. The conductivity changes from metallic to gaseous type with a decrease in magnitude of 10^3 to 10^4 times.

How these changes effect the current behavior depends on composition and dimensions of the wire and on capacitor voltage. Oscillograms record five types of behavior, but it will be shown that all are really variations of the D type. This is the type with the well known exploding wire "dwell" or "dark" time. It is proposed that this is not a time of zero current, but one of low current.

Based on oscillograms and fractional microsecond photographs, a hypothesis is advanced that dwell is the result of a high ratio of field strength to pressure which prevents avalanching and restricts current flow to scarce carriers. Reignition is, then, breakdown made possible by decreasing pressure.

An equation based on this theory predicts dwell times with satisfactory accuracy as composition and dimensions of wire are changed.

ARC INITIATED DISCHARGE IN MAGNETIC FIELD IN HIGH VACUUM
II. MAGNETO-IONIC EXPANDER TYPE OF DISCHARGE

B-7

Joseph Slepian
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

A short arc between electrodes in a parallel magnetic field set in the middle of a relatively not so short, high vacuum tank giving a current to the tank wall positive or negative, not limited by space charge, was described here last year. This Ionic Centrifuge took a high voltage but was ineffective for isotope separation. The same arc placed between two Expander Electrodes between which a high enough difference of electrical potential is applied feeds ions and an equal amount of electrons to a set of insulated slats which terminate the Expander tube, and thus forms a discharge of quite different properties.

The Expander Electrodes are placed initially at less than an inch respectively from the arc, but they expand so they embrace a distance of two or more feet at the insulated slats. A net current is induced which is entirely closed within the gas itself; termination upon the Expander Electrodes is prevented by the action of the magnetic field. The action of this induced net current upon the ions and electrons which pass through it en route to the insulated slats causes the random velocity to approach zero, and the mean velocity of approach to the individual slats to be common to the isotopes.

The isotopes of the ions become separated. The enrichment giving light ions on the slats near the negative Expander and heavy ions on the slats near the positive Expander is great enough so that essentially pure isotopes are obtained in one stage.

An arc of 100 amperes will give approximately a cost per gram of U 235 of $8.00; a 1000 ampere arc, less than $2.00. The cost of the presently used diffusion method is more than $15.00 per gram of U 235.

Thursday, October 3
9:00 A.M.

SESSION C

CROSS SECTIONS AND INVITED PAPER

Chairman, O. Oldenberg
Harvard University

FURTHER STUDIES OF THE IMPRISONMENT OF RESONANCE RADIATION

A. V. Phelps and A. O. McCoubrey*
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

The relative importance of the diffusion of resonance atoms and the escape of resonance radiation for mercury 6^3P_1 resonance atoms has been determined from studies of decay of the 2537A resonance radiation following a period of optical excitation.[1] Holstein's theory of the imprisonment of resonance radiation[2] predicts decay constants at fixed temperature which are a function only of the product of the mercury density and the radius of the cell. Diffusion theory predicts decay constants which are inversely proportional to the product of the mercury density and the square of the radius.[3] Using a combined theory, the results show that diffusion is negligible and that the predictions of imprisonment theory are confirmed to within 15 per cent. The experiment sets an upper limit to the product of the diffusion coefficient and the gas density of 5×10^{17} atoms/cm-sec at 340°K, which is consistent with a value of 4×10^{16} atoms/cm-sec from theory.[4]

* Now at The National Company, Incorporated, Melrose, Massachusetts.

1. D. Alpert, A. O. McCoubrey, and T. Holstein, Phys. Rev. 76, 1257 (1949).
2. T. Holstein, Phys. Rev. 72, 1212 (1947); Phys. Rev. 83, 1159 (1951)
3. R. G. Fowler, Handbuch der Physik (Springer, Berlin, 1956), Vol. 22, p. 226.
4. T. Holstein, D. Alpert, and A. O. McCoubrey, Phys. Rev. 85, 985 (1952). As in the case of charge transfer collisions, the diffusion coefficient was calculated by assuming the cross section for momentum transfer to be twice the cross section for excitation transfer.

C-2 EXCITATION FUNCTIONS AND RATES FOR THE PRINCIPAL LEVELS OF HELIUM

L. S. Frost and A. V. Phelps
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

Cross sections and rates of excitation by electrons have been evaluated for the 2^1S and 2^3S metastable and the 2^1P resonance levels of the helium atom. The cross section for excitation to each He level up to a principal quantum number n equal to 6 was arrived at using the available optical and electrical measurements and theoretical results.[1] Cascading was computed to obtain the total excitation cross section to the principal n = 2 levels; effects of collisional transfer of excitation and of imprisonment of resonance radiation were included in the analysis. The rates of excitation obtained by integrating the total cross sections over published electron energy distribution functions[2] are in essential agreement with the microwave measurement of total metastable production by MacDonald and Brown.[3]

1. H. S. W. Massey and E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Oxford University Press, London, 1952), Chapters II and III.
2. I. A. Smit, Physica 3, 543 (1936); F. H. Reder and S. C. Brown, Phys. Rev. 95, 885 (1954).
3. A. D. MacDonald and S. C. Brown, Phys. Rev. 75, 411 (1949).

TOTAL IONIZATION BY LOW ENERGY ELECTRONS IN NEON

C-3

B. T. McClure
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey

The average number of ions, n, which are created by low energy electrons when they are stopped in a field free region is an important parameter in connection with certain gas discharge problems. Johnson[1] measured n in a number of gases and found general agreement with the values obtained by stopping highly energetic α and β rays. In extending Johnson's work, we inject electrons having well defined energies up to 200 volts into neon.

When the primary electrons are neither reflected to their source nor collected by the container before being cooled below the ionization potential, the total number of ions which they produce is a good measure of n. When the primary electron energy is less than the sum of the ionization and minimum excitation energies (38 volts for neon), n determines the ratio of the total excitation probability to the ionization probability. Preliminary data indicate that the total excitation probability increases rapidly with energy up to a peak and thereafter decreases in the manner generally expected for excitation. The magnitude and energy dependence of n for neon are of the same order as reported by Johnson.

1. J. B. Johnson, Phys. Rev., 10, 609-623 (1917).

C-4 MOBILITIES OF IONS IN RARE GASES AT LOW E/p_o

Earl C. Beaty
National Bureau of Standards
Washington, D. C.

An apparatus to measure the mobilities of ions in gases with greater accuracy and resolution, and at lower values of E/p_o than has been previously possible, has been developed to a point where useful data is being obtained. A double shutter method is used with fast square pulses driving the shutters. Detection of the ions is currently being done by an amplifier-oscilloscope combination, and the time of flight of the ions is measured using the calibrated oscilloscope sweeps. The second shutter is not now used but eventually will serve to isolate the detection equipment from the timing equipment permitting greater sensitivity and resolution.

Data in the rare gases have been obtained at values of E/p_o less than 1.0 volts/cm-mm Hg, in argon, making the extrapolation to zero E/p_o much more reliable. The lowest value of E/p_o for which measurements have been made previously is about 8 volts/cm-mm Hg. Preliminary results will be presented and compared with those of other investigators.

2.60
1.84
1.52

ROCKET INVESTIGATION OF ATMOSPHERIC PHOTOCHEMISTRY

Frederick F. Marmo
Air Force Cambridge Research Center
Cambridge, Massachusetts

C-6

ELECTRON ATTACHMENT IN OXYGEN AT LOW ENERGIES

Lorne M. Chanin and Manfred A. Biondi
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

Measurements have been made of the electron attachment cross section in oxygen using a double shutter drift tube of the type developed by Pack and Phelps.[1] This tube permits attachment studies at lower electron energies than have been reached previously (~.2 ev).[2,3] Thus we have a means of investigating the apparent anomaly between the drift tube measurements of Bradbury[2] and of Doehring[3] which yield attachment cross sections of $\sim 10^{-19}$ cm^2 at .2 ev and the microwave value[4] of $\sim 10^{-22}$ cm^2 at .04 ev. The present measurements are in reasonable agreement with the results of Bradbury and of Doehring, but indicate a decrease in the cross section with decreasing electron energy starting at .2 ev in contrast to the Bloch-Bradbury theory[5] which predicts a rise in cross section from .2 ev to .1 ev followed by a decrease at lower energies.

1. J. L. Pack and A. V. Phelps, Phys. Rev. 100, 1229A (1955).
2. N. E. Bradbury, Phys. Rev. 44, 883 (1933).
3. A. Doehring, Zeit. fur Naturforschung 7a, 253 (1952).
4. M. A. Biondi, Phys. Rev. 84, 1072A (1951).
5. F. Bloch and N. E. Bradbury, Phys. Rev. 48, 689 (1935).

NEGATIVE ION FORMATION AND ELECTRIC BREAKDOWN FOR SOME HALOGENATED GASES

C-7

W. M. Hickam and D. Berg
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

The formation by resonance electron capture of SF_6^- from SF_6 has been shown[1] to occur at less than 0.1 electron volt and to possess an energy width less than .05 ev. Utilizing a conventional electron gun and mass spectrometer, the formation of negative ions at low electron energies have been investigated for a number of halogen containing gases used in electric breakdown studies. The SF_6^- peak is used as an energy calibration for establishing the appearance potential and the energy width over which capture occurs for the individual gases.

Investigations[2, 3] have shown the significance of electron attachment in electric breakdown. It is found that the relative areas of the negative ion curves can be correlated with the electric breakdown voltages. The results suggest that the formation of SF_5^- rather than SF_6^- may be the important process in providing the relatively high electric breakdown value for SF_6. Electron attachment associated with SF_6 and CCl_4 is found to be an extremely sensitive function of the gas temperature. The gases investigated include CCl_4, CCl_3F, CCl_2F_2, $CClF_3$, CF_4, CF_3SF_5, SeF_6, C_2F_3Cl, and $CHCl_2F$.

1. W. M. Hickam and R. E. Fox, J. Chem. Phys. 25, 642, (1956).
2. J. W. Marriott and J. D. Craggs, Electrical Research Association L/T301 (1953).
3. M. A. Harrison and R. Geballe, Phys. Rev. 91, 1 (1953).

Thursday, October 3
2:00 P.M.

SESSION D

HIGH-TEMPERATURE PLASMAS

Chairman, James L. Tuck
Los Alamos Scientific Laboratory

PINCH EFFECT IN ARGON AND HELIUM* D-1

J. W. Mather
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Experimental evidence will be given showing the self contraction of a high current gas discharge in a Columbus (linear) geometry. The inward radial velocity is shown to depend on the square root of the applied electric field and inversely on the fourth root of the mass density of the gas. The agreement with theoretical predictions (M-Theory)[1] will be indicated.

* Work performed under the auspices of the U.S. Atomic Energy Commission.

1. M. Rosenbluth, Los Alamos Scientific Laboratory Report, LA-1850, "Infinite Conductivity Theory of the Pinch", September, 1954.

D-2 CURRENT DISTRIBUTION IN AN IMPULSIVE PINCHED DISCHARGE*

L. C. Burkhardt
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Los Alamos, New Mexico

A magnetic probe technique has been employed to measure the distribution of current as a function of time in a Columbus (linear) pinched discharge whose current rises to 1.5×10^5 amperes in six microseconds. A positive current sheath forms first near the tube wall and then moves toward the axis with a velocity in agreement with simple theoretical calculations. During this inward motion of the main current, a reversed current flows between it and the tube wall. By the time the main sheath reaches one-third the tube radius, a second positive current sheath forms near the tube wall. Instabilities destroy the pinch after two microseconds, precluding measurements during the rest of the current cycle.

* Work performed under the auspices of the U.S. Atomic Energy Commission.

INSTABILITIES IN A PINCHED DISCHARGE* D-3

R. H. Lovberg
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Los Alamos, New Mexico

Observations of the instabilities which characteristically destroy the axial symmetry of a pinched discharge have been made using image converter and magnetic probe techniques. It is observed that the predominant instability in a simple discharge in one which pinches off the plasma column at regular intervals ("sausage") and that this instability is removed by the application of a longitudinal magnetic field. The remaining instability is found to distort the discharge column into a helical shape. These results all confirm the theoretical predictions of Kruskal and Tuck.[1]

* Work performed under the auspices of the U.S. Atomic Energy Commission.

1. Los Alamos Scientific Laboratory Report, LA-1716, "Instability of a Pinched Fluid with a Longitudinal Magnetic Field", November, 1953.

D-4 NEUTRON GENERATION FROM STRAIGHT PINCHES* (COLUMBUS I')

Robert E. Dunaway†
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Experiments on the neutrons produced in a high-current pulse discharge in deuterium are described. With 15 kv applied to a straight discharge tube 30 cm in length neutrons are produced at ~1.4 μsec after gas break-down in a pulse 0.1 μsec in length. The yield, 10^7 - 10^8 neutrons per discharge, is quite sensitive to gas purity and discharge tube wall material. The axial asymmetry in neutron energy indicates that the neutrons were produced in reactions whose center of mass moves preferentially towards the cathode. Several mechanisms for the production of these neutrons are discussed.

* Work done under the auspices of the United States Atomic Energy Commission.

† Present address, General Atomic Division of General Dynamics Corporation, San Diego 12, California.

SPECTROSCOPIC OBSERVATIONS OF PINCHED DISCHARGES* D-5

Emory J. Stovall, Jr.
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico

The temperature produced in a pinched discharge in Xenon has been determined by the application of the Saha equation of ionization equilibrium to the observed relative intensities of the spectral lines of the consecutive stages of ionization of Xenon in the spectrum of the pinch. The degree of compression in density achieved in pinched deuterium has been determined by measuring the broadening of the Balmer series spectrum lines at the time of the pinch. The method is based upon the Holtsmark[1] theory of the stark effect in ionized gases. Similar observations were made in much greater detail on the He II line at 4686 A. in a pinched Helium discharge under conditions of somewhat higher density and temperature. In this case the shape of the line does not agree with that predicted by existing theories of line broadening. The intensity in the wings of the line varies as $(\Delta \lambda)^{-1}$ whereas the Holtsmark theory predicts a variation as $(\Delta \lambda)^{-5/2}$, and the collision theory $(\Delta \lambda)^{-2}$. An attempt to develop a theory consistent with these observations is underway.

* Work performed under the auspices of the U.S. Atomic Energy Commission.

1. J. Holtsmark, Am. Physik 58, 577 (1919).

D-6 A MAGNETICALLY DRIVEN ELECTRODELESS SHOCK TUBE FOR THE PRODUCTION OF HIGH ENERGY PLASMAS

G. Sargent Janes
Avco Research Laboratory
Everett, Massachusetts

High temperatures have been produced in fully ionized hydrogen and deuterium at pressure between .08 and .8 mm/Hg by means of magnetically driven shock waves. The system is electrodeless. A light gas in a cylindrical shaped 4" diameter pyrex chamber is driven radially inward toward the axis by an axial magnetic field associated with currents in a surrounding single turn coil. A 200,000 ampere current is built up in this coil in 0.5 μseconds by means of a capacitive energy storage power supply and a pressurized spark gap.

Velocities up to 15 cm/μsec have been measured with the use of photomultipliers and slits. These velocities can be interpreted as leading to temperatures up to 350,000 °K by use of the conservation equations.

Experimental velocities are in agreement with theoretical predictions assuming that the gas excludes the field by surface currents.

It is anticipated that this work can be extended to produce temperatures greater than 1,000,000 °K at particle densities of the order of 10^{16}. Under these conditions, the magnetic field terms in the Boltzmann equation will dominate over the collision terms, and anomalous hydrodynamic phenomena may be expected.[1]

1. Arthur R. Kantrowitz and Harry E. Petschek, Magnetohydrodynamics, edited by Rolf K. M. Landshoff, Stanford University Press, Stanford, California.

EXTREMELY LARGE GAS TEMPERATURES IN THE HIGH PRESSURE COAXIAL CAPACITOR DISCHARGE

D-7

Heinz Fischer
Air Force Cambridge Research Center (ARDC)
Bedford, Massachusetts

Maximum energy with shortest pulse length is released into the gap of a capacitor discharge when the inductance L of the circuit is reduced to its minimum. As a result of this consideration, special toriodal capacitors were developed which surround the gap coaxially. Maximum gas temperatures in Helium (gap 0.2 cm, 35 atmospheres, breakdown voltage 7 KV, maximum current approximately 63 K Amps, current density approximately 1.5×10^6 Amp/cm^2) exceeding 250,000 degrees Kelvin are calculated from the spectral radiation density, which is measured. The method is described. – Photographs of the spark channel as short as 0.1 microseconds after "zero" time (exposure 0.1 μsec) are taken in the gases H_2, He and A by means of a gated image converter (Mullard 1201) and the growth of the channel as a function of time observed. – The opacity of the channel is measured directly, applying a spherical mirror which images the reflected light back through the channel.

Friday, October 4

9:00 A. M.

SESSION E

MICROWAVES; COULOMB INTERACTIONS

Chairman, A. Simon

Oak Ridge National Laboratory

STUDY OF RADIATED NOISE FROM AN ARC DISCHARGE E-1

H. A. Schafft and A. D. Krumbein*
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College Park, Maryland

The radiated noise spectrum of an aluminum arc discharge in air was investigated quantitatively between 100 mc and 650 mc at atmospheric pressure and as a function of pressure. Pulse studies were also made. Radiated noise, which is believed to be caused by relaxation oscillations, could be detected in the entire range from 80 kc to 2200 mc. Quantitative data, however, could not be obtained except in the limited region stated above. Copper and mild steel arc discharges radiated almost no noise in the larger frequency range. In general, the results confirm the work of Skolnik and Puckett[1] for noise obtained with the receiver coupled directly to the arc discharge circuit.

* Now at Nuclear Development Corporation of America, White Plains, N. Y.

1. M. I. Skolnik and H. R. Puckett, Jr., Relaxation Oscillations and Noise from Low Current Arc Discharges – J. Appl. Phys. 26, 74 (1955).

E-2 MICROWAVE INVESTIGATION OF DISINTEGRATING PLASMAS IN MIXTURES OF THE RARE GASES

H. J. Oskam
Philips Research Laboratories
Eindhoven, Netherlands

Measurements concerning the behavior of the afterglow in mixtures of the rare gases are presented. An admixture of atoms with a lower ionization potential than that of the main gas is found to have a great effect on the disappearance of the electrons from the plasma. The afterglow is studied in helium, in the binary gas mixtures of helium with a small concentration of neon, argon and krypton respectively, further in neon, neon-argon and neon-krypton mixtures. Measurements in these mixtures all show the replacement of the molecular ions of the main gas by atomic ions of the admixture even at very low concentrations of the latter. The process concerned in helium-neon may be a charge-exchange process between a molecular helium ion and a neon atom; in the other mixtures the Penning effect cannot be excluded. At higher concentrations the atomic ions of the admixture are converted into molecular ions by three-body collisions with an atom of the main gas and an atom of the admixture. The data obtained for the various processes will be presented.

MICROWAVE DIAGNOSTICS FOR CONTROLLED FUSION RESEARCH*

E-3

Charles B. Wharton
University of California Radiation Laboratory
Livermore, California

High temperature plasma research, aimed mainly toward controlled thermonuclear reactions, has been greatly facilitated by the development of a number of microwave measuring techniques, called "microwave diagnostics." These schemes are based in part on previous plasma microwave studies, but mostly on ideas generated at UCRL over the past five years in conjunction with the AEC Project Sherwood.

The properties of a plasma of arbitrary geometry measurable by these techniques are: average spatial density, density distribution, collision frequency, electron "kinetic temperature," recombination and other loss rates, all as a function of time, with or without strong magnetic fields present.

The quantities measured directly are the phase and absorption coefficients of the dispersive propagation "constant," the electron and ion gyrofrequencies, intensities of electromagnetic radiations emanating from the plasma and emission spectra of these radiations.

A brief theoretical discussion of the mechanisms involved and experimental results indicating satisfactory correlation are presented. Experimental setups and millimeter wavelength equipment employed in the experiments are described.

* Work performed under auspices of the U. S. Atomic Energy Commission.

E-4 OSCILLATIONS IN A PLASMA IN A MAGNETIC FIELD

H. W. Bandel and R. M. Hill
Microwave Physics Laboratory
Sylvania Electric Products Inc.
Mountain View, California*

A study has been made of oscillations which occur within a gas filled smooth anode magnetron. As has been previously observed by Nelson,[1] the modes of oscillation indicate that there are two conditions on the frequency which must be satisfied simultaneously; the frequency must be approximately equal to an integral multiple of the electron cyclotron frequency and it also depends on the electron density. Rough relative density measurements give evidence that the oscillations follow the dispersion law $\omega^2 = \omega_c^2 + \omega_p^2$. Here ω_p is the Langmuir-Tonks plasma angular frequency and ω and ω_c are the oscillation and cyclotron angular frequencies respectively. Using probes inside the anode, simultaneous measurements of relative phase and amplitude of signals as a function of azimuthal angle have shown that there is no azimuthal variation. This result rules out Nelson's theory which postulated the existence of azimuthal oscillations. Hard tube magnetron oscillations at angular frequencies of approximately $\frac{\omega_c}{\sqrt{2}}$ also have been found to have no azimuthal variation.

* This work performed under Signal Corps Contract No. DA-36-039-SC-73188.

1. D. Nelson, Final Report Contract No. W19-122-ac-34 (1954).

3×10^6 → 3×10^7 °K.
Static mag. field.
How measure density of ions + electrons?

GASEOUS ELECTRONICS CONFERENCE

OCTOBER 4, 1957

NOTES ON PAPER E-5

MICROWAVE PROPAGATION IN A HOT MAGNETO-PLASMA

by

J. E. DRUMMOND

POULTER LABORATORIES
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA

Thermal effects on the propagation of microwaves in very hot, dense plasmas in magnetic fields were described. The effects are all quantitatively contained in the following conductivity tensor elements[1] for the frequency component $e^{-i\omega t}$:

$$\sigma_{xx} = \sigma_{yy} = \frac{\omega_p^2(i\omega - \nu)}{4\pi[(\omega+i\nu)^2 - \omega_c^2]} \cdot \frac{1 + \dfrac{3k_\perp^2 KT}{m[(\omega+i\nu)^2 - 4\omega_c^2]} + \dfrac{KTk_\parallel^2}{m}\left(\dfrac{3\omega_c^2 + (\omega+i\nu)^2}{[(\omega+i\nu)^2-\omega_c^2]^2} + \dfrac{2}{(\omega+i\nu)^2}\right)}{\mathcal{D}(\omega_c)} \tag{1}$$

$$\sigma_{xy} = -\sigma_{yx} = \frac{-\omega_c\omega_p^2}{4\pi[(\omega+i\nu)^2 - \omega_c^2]} \cdot \frac{1 + \dfrac{6k_\perp^2 KT}{m[(\omega+i\nu)^2 - 4\omega_c^2]} + \dfrac{k_\parallel^2 KT[\omega_c^2 + 3(\omega+i\nu)^2]}{m[(\omega+i\nu)^2 - \omega_c^2]^2}}{\mathcal{D}(\omega_c)} \tag{2}$$

[1] J. E. Drummond, Ph.D. thesis, Stanford University, 1956, to be published.

$$\sigma_{xz} = -\sigma_{zx} = \frac{\omega_c \omega_p^2 KT[3(\omega + i\nu)^2 - \omega_c^2]}{4\pi m\omega^2 [(\omega + i\nu)^2 - \omega_c^2] \mathbb{D}(\omega_c)} \frac{\partial^2}{\partial y \partial z} \tag{3}$$

$$\sigma_{yz} = -\sigma_{zy} = \frac{-\omega_c \omega_p^2 KT[3(\omega + i\nu)^2 - \omega_c^2]}{4\pi m\omega^2 [(\omega + i\nu)^2 - \omega_c^2] \mathbb{D}(\omega_c)} \frac{\partial^2}{\partial x \partial z} \tag{4}$$

$$\sigma_{zz} = \frac{\omega_p^2 (i\omega - \nu)}{4\pi(\omega + i\nu)^2} \frac{\left[1 + \frac{3k^2 KT}{m(\omega + i\nu)^2}\right]}{\mathbb{D}(0)} \tag{5}$$

where the denominators $\mathbb{D}(\omega_c)$ are given by

$$\mathbb{D}(\omega_c) = 1 - \frac{2\omega\omega_p^2 KT}{mc^2(\omega + i\nu)\ [(\omega + i\nu)^2 - \omega_c^2]} \tag{6}$$

with $\omega_c \equiv eH/mc$, the electron cyclotron frequency where the uniform static magnetic field is $\mathbf{1}_z H$. The electron plasma frequency is $\omega_p = (4\pi ne^2/m)^{1/2}$. The (small) momentum transfer collision frequency between an electron and neutral particles is called ν. The constant K is Boltzmann's constant and T is the electron temperature. The electric field $\mathbf{E}_\omega(\mathbf{r})$ was supposed to be a "normal mode" satisfying the following equations

$$\mathbf{E}_\omega(\mathbf{r}) = \mathbf{E}_\omega(x, y)\ \gamma(z) \quad , \tag{7}$$

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) \mathbf{E}_\omega(x, y) + k_\perp^2\, \mathbf{E}_\omega(x, y) = 0 \tag{8}$$

$$\frac{\partial^2}{\partial z^2} \gamma(z) + k_\parallel^2 \gamma(z) = 0 \quad , \tag{9}$$

$$\frac{k^2 KT}{m\,\omega_c^2} \lesssim 0.1 \tag{10}$$

where $k^2 \equiv k_\perp^2 + k_\parallel^2$. In addition the following requirements were imposed.

$$\frac{KT}{mc^2} \leqslant 0.01 \tag{11}$$

$$\left(\frac{k_\perp^2 KT}{m\,\omega_c^2}\right)^2 \leqslant \frac{\nu}{\omega} \leqslant 0.1 \tag{12}$$

Small signal theory Boltzmann analysis was applied.

More general results are to be presented in a forthcoming paper.

MICROWAVE PROPAGATION IN A HOT MAGNETO-PLASMA

J. E. Drummond
Stanford Research Institute
Menlo Park, California

A theoretical study of the propagation of transversely polarized microwaves through a very hot, dense plasma in a magnetic field is presented. This study is based upon a more general conductivity tensor presented at an earlier conference and to be published. It is shown that for certain ranges of the parameters the index of refraction, (n), differs widely from that predicted from the usual theory; regions of non-propagation (i.e., for which n is imaginary) now become propagating regions, and the index of refraction depends upon electron density and temperature in such a way that a microwave thermometer and densitometer seem feasible. The temperature range considered is such that $10^{-3} < \frac{\overline{v_\perp^2}}{c^2} < 10^{-2}$ where $\overline{v_\perp^2}$ is the mean square electron speed normal to the magnetic field and c is the speed of light. The density range considered is such that $40 < \frac{\omega_p^2}{\omega^2} < 400$ where ω_p is the electron plasma frequency and ω the microwave frequency.

E-6 EFFECTS OF ELECTRON-ELECTRON INTERACTIONS ON CYCLOTRON RESONANCES IN GASEOUS PLASMAS*

Rudolph C. Hwa
University of Illinois
Urbana, Illinois

The long-range part of the Coulomb interactions has been found to have a negligible effect on the velocity distribution function of the electrons for densities less than 10^{12} cm^{-3}. To account for the short-range forces the Boltzmann-Fokker-Planck equation was set up in cylindrical coordinates, and was solved numerically on the digital computer for various values of magnetic field and charge densities. The results indicate that the electron-electron scattering reduces the absorption at the peak of the cyclotron resonance and broadens its width.

With the magnetic field equal to zero it is found that the electron-electron interaction alters the AC conductivity of the plasma by no more than a few percent.

* Supported by the Air Force Cambridge Research Center.

THE ELECTRON-ELECTRON INTERACTION and HEAT CONDUCTION IN GASEOUS PLASMAS*

E-7

T. Sekiguchi** and L. Goldstein
Department of Electrical Engineering, University of Illinois
Urbana, Illinois

The phenomenon of heat conduction in gaseous plasma is observed in order to explore the problem of the mutual electron interaction. In addition to the technique of interaction of pulsed microwave in decaying plasmas, the phenomenon of "afterglow quenching" is exploited in the experiments. The experimental values of the thermal conductivity, in low gas pressure neon and xenon plasmas of adequately high charge density, are determined by two different methods. They have been found to be of the order of $10^{-6} \sim 10^{-5}$ (joules/cm sec degree) for the electron density range $10^{11} \sim 10^{13}$ ($1/cm^3$) at room temperature (~300°K). The most significant result of these experiments is that the thermal conductivity in the plasmas described is chiefly determined by heat flow in the electron gas of the plasma. Thus the mutual interaction of the electrons plays a predominant role in the phenomenon of heat conduction. The experimentally obtained values of the thermal conductivity are in agreement within less than one order of magnitude with those given by the theory of Spitzer and Härm.

* Supported by Air Force Cambridge Research Center.

** Visiting from University of Tokyo, Japan.

10 x 20

E-8 THE THEORY OF RUN-AWAY ELECTRONS*

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Los Alamos Scientific Laboratory
Los Alamos, New Mexico

This paper applies the Boltzmann method to the problem of electrons moving through a gas of positive ions under the influence of a static uniform electric field, E, of arbitrary strength. In sufficiently large fields the zero order electron velocity distribution is chosen to be Maxwellian, displaced by the electron drift velocity. This assumption is based upon the fact that the rate of energy partition due to electron-electron encounter is larger than the rate at which electron-ion encounter converts drift energy into random energy. The Boltzmann equation shows that at constant temperature, electrons are accelerated indefinitely for E larger than a critical field, i.e., runaway. If Joule heating occurs, stationary solutions do not exist, even when the critical field exceeds E.

For sufficiently small fields the problem changes its nature. Only high energy electrons in the "tail" of the distribution run away, the time scale for appreciable depletion of the "body" being determined by a diffusion process in velocity space from the body into the tail. The Boltzmann formulation yields the probability for depletion as a function of time. Time scales for this type of runaway are large compared to mean free collision times.

* Work performed under the auspices of the U.S. Atomic Energy Commission.

Friday, October 4
2:00 P.M.

SESSION F

BREAKDOWN

Chairman, J. F. Waymouth
Sylvania Electric Products, Inc.

LOW PRESSURE MICROWAVE PLASMA IN A MAGNETIC FIELD*

F-1

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Massachusetts Institute of Technology
Cambridge, Massachusetts

A low pressure hydrogen plasma in a magnetic field is described. The plasma is contained in a narrow cylindrical quartz tube along the axis of a cylindrical microwave cavity that oscillates in the TE_{111} mode at a resonant wavelength of 10 cms. The configuration and strength of the magnetic field is such that electrons can gain energy from the microwave field through the cyclotron resonance effect.

At high pressures both the breakdown and maintaining fields exhibit the well-known cyclotron resonance effect. However, at low pressures when the electron mean free path (in the absence of a magnetic field) is larger than the length of the quartz tube, it is easier to produce and maintain the plasma with a magnetic field a few per cent off the value of magnetic field required for cyclotron resonance.

Phenomena responsible for this "displaced" resonance will be described.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission.

F-2 ELECTRON DIFFUSION WITHIN A CYLINDRICAL MICROWAVE CAVITY

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Culver City, California

The equation for the diffusion of free electrons in a gas subjected to a microwave electric field within a cylindrical cavity under the influence of a continuous source of ionization has been solved for the concentration of electrons as a function of position and time, subject to the boundary condition that the concentration at the walls is proportional to its gradient. It was assumed that the ionization and diffusion coefficients are constant and that recombination of electrons with ions is negligible. The continuous-wave breakdown criterion agrees with that of Herlin and Brown,[1] but the diffusion length is altered by the boundary conditions. The continuous source of ionization does not affect the breakdown threshold. A paradoxical result is that the application of a microwave field of less than threshold strength can reduce the equilibrium concentration of electrons already present.

1. M. A. Herlin and S. C. Brown, Phys. Rev. 74, 910 (1948).

MULTIPACTING MODES OF HIGH FREQUENCY BREAKDOWN*

Albert J. Hatch
Argonne National Laboratory
Lemont, Illinois

H. Bartel Williams
New Mexico College of A. and M.A.
State College, New Mexico

A previously developed average electron theory for the 1/2 cycle multipacting mode of low pressure high frequency breakdown (secondary electron resonance) has been extended to higher order modes. A semi-theoretical plot of breakdown voltage V vs the product of frequency times electrode separation fd using representative fitting parameters is given for the 1/2 through 9/2 cycle modes. In addition to the customary 1/2 cycle cutoff the theory predicts a modified cutoff in each of the mode transition regions. Breakdown data for machined alclad electrodes at 2 microns show 1/2 cycle cutoff at about 100 Mc-cm/sec and 3/2 cycle cutoff at about 450 Mc-cm/sec. The 3/2 cycle cutoff is indicated by a dip in the breakdown curve and is strongly dependent on electrode surface conditions. The concept of higher order multipacting modes clarifies the breakdown mechanism in the transition region between multipacting and diffusion controlled breakdown. An examination of typical microwave diffusion breakdown data shows that at pressures sufficiently below the mean free path limit the observed breakdown voltages are consistent with those observed for various multipacting modes.

* The major portion of the work described here was performed at New Mexico College of A. and M.A., supported by the Bureau of Ordnance, U. S. Navy.

F-4

A THREE DIMENSIONAL POTENTIAL WELL PRODUCED BY THE SECONDARY ELECTRON RESONANCE MECHANISM

H. Bartel Williams
New Mexico College of A. and M.A.
State College, New Mexico

When the secondary electron resonance mechanism (multipacting) operates at low pressures, 0.1 micron Hg. or less, a region in space is created in which the averaged charge density is negative. A positive ion sees this region as a three dimensional potential well. Computations based on computed electron trajectories and experimentally measured parameters have been made. Curves of force and potential functions derived from these computations will be presented. A discussion of the magnitude, shape and stability of this potential well will be presented. Some uses of the potential well will also be discussed.

HIGH-FREQUENCY BREAKDOWN IN AIR AND HYDROGEN F-5

Elsa Huber Solt and Philip M. Platzman
Hughes Research Laboratories
Culver City, California

Breakdown electric fields between parallel-plate electrodes have been measured for air and hydrogen at a frequency of 10 mc, with plate separations varying from 0.5 to 4.0 cm. The measurements have been carried out to considerably higher values of pd than have previously been reported for high frequencies, viz., to 150 and 400 mm Hg. × cm in air and hydrogen respectively. For electrode separations greater than the electron oscillation amplitude, results are in general agreement with measurements of other workers at the lower pd values, both at microwave frequencies and 200 mc. However, the independence of breakdown field on gap length reported by Prowse and Lane[1] at 11.5 mc was not observed. In the present work, E/p was still decreasing slightly in both gases at the highes pd, indicating that diffusion still contributes to removal of electrons from the gap.

1. W. A. Prowse and P. E. Lane, Appl. Sci. Res. B5, 127 (1955).

F-6

CURRENT AND TIME STUDIES OF THE POSITIVE POINT CORONA IN HYDROGEN*

L. A. Bornstein and L. H. Fisher
New York University
New York, New York

The previous positive point-to-plane corona studies in air, nitrogen, and argon[1, 2] have been extended to hydrogen, with strikingly different results. Observations have been made of steady state current-voltage characteristics at pressures near atmospheric, and at voltages below onset of a self-sustained discharge. These measurements provide strong evidence that a secondary mechanism must be invoked to account for the observed currents. Using Rose's[3] measurements of α, values of γ were computed to be of the order of 10^{-4}, in good agreement with those found in uniform field studies in H_2.[4]

Time lag measurements of the pulsed glow corona in H_2 yield formative lags less than 0.1 μsec even very close to threshold. This rules out the cathode as an agent in the discharge build-up of the pulsed glow corona in H_2. A gas-dependent mechanism is proposed to account for the short formative times. An unusual quenching of the discharge current by ultraviolet irradiation has been observed.

* Supported by the Office of Naval Research.

1. M. Menes and L. H. Fisher, Phys. Rev. 94, 1 (1954).
2. L. A. Bornstein and L. H. Fisher, Phys. Rev. 100, 1228 (1955).
3. D. J. Rose, Phys. Rev. 104, 273 (1956).
4. D. J. DeBitetto and L. H. Fisher, Phys. Rev. 104, 1213 (1956).

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