11th Annual

GASEOUS ELECTRONICS

OCTOBER 22–25, 1958

BARBIZON-PLAZA HOTEL, N.Y.C.
BELL TELEPHONE LABORATORIES
MURRAY HILL, N.J.

UNDER THE JOINT SPONSORSHIP
OF THE
DIVISION OF ELECTRON PHYSICS,
AMERICAN PHYSICAL SOCIETY
AND THE
BELL TELEPHONE LABORATORIES INC.

Conference

PROGRAM AND ABSTRACT OF PAPERS

PROGRAM

for the

ELEVENTH ANNUAL GASEOUS ELECTRONICS CONFERENCE

October 22 - 25, 1958

Wednesday
October 22
8:45 A. M. — Registration - Theater Foyer of Barbizon-Plaza Hotel

9:30 A. M. — Session A: CROSS SECTIONS

Chairman: B. Bederson
New York University

Intermission

12:30 P. M. - Recess for Lunch

Wednesday
October 22
2:00 P. M.

Session B: SPUTTERING AND ARCS

Chairman: L. M. Chanin
Westinghouse Research Laboratories

Murray Hill
Thursday
October 23
9:30 A. M.

Session C: RECOMBINATION AND SIMILAR PROCESSES

Chairman B. T. McClure
Bell Telephone Laboratories, Inc.

1:00 P. M. - Recess for Lunch in the Murray Hill Cafeteria

Murray Hill
Thursday
October 23
2:30 P. M.

Session D: BREAKDOWNS AND TRANSIENTS

Chairman: R. M. Hill
Sylvania Electric Products Inc.

Friday
October 24
9:00 A.M.

Session E: PLASMAS AND INSTABILITIES

Chairman: A. C. Kolb
U. S. Naval Research Laboratory

12:00 Noon - Recess for Lunch

Friday
October 24
1:30 P.M.

Session F: DIAGNOSTICS

Chairman: H. Dreicer
Los Alamos Scientific Laboratory

Saturday
October 25
9:00 A. M.

Session G: THERMONUCLEAR PROGRAM I

Chairman: Wulf B. Kunkel
University of California Radiation Laboratory

12:10 P. M. - Recess for Lunch

Saturday
October 25
1:30 P.M.

Session H: THERMONUCLEAR PROGRAM II

Chairman: E. Frieman
Princeton University

SESSION A
Wednesday, October 22
9:30 A. M.

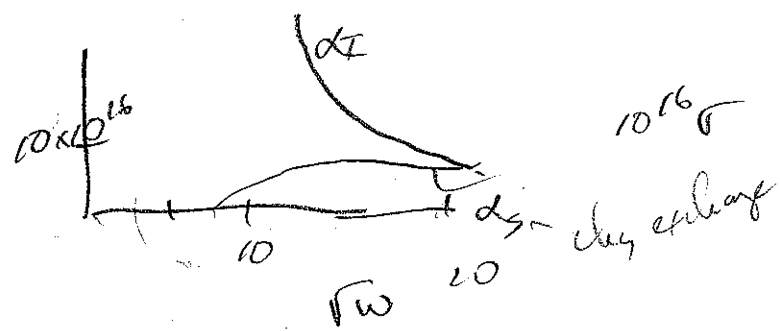
Chairman
B. Bederson
New York University

CROSS SECTIONS

LOW ENERGY COLLISION CROSS SECTIONS FOR D^+ IONS IN DEUTERIUM*

W. H. Cramer
University of Florida
Gainesville, Florida

The apparatus and experimental techniques previously employed in studies of the interactions of inert gas ions in the inert gases[1,2] have been used for measurement of elastic and charge exchange cross sections of D^+ ions in deuterium in the energy range from 4 to 400 ev. Charge exchange was observed only at energies of 80 ev and higher. The elastic cross sections are qualitatively similar to those of Simons and co-workers[3] for H^+ ions in hydrogen; however these authors did not detect any charge exchange up to energies of 135 ev. Constants for empirical potential energy functions for the interaction of D^+ and deuterium have been evaluated.



* Supported by a grant from the National Science Foundation.

1 W. H. Cramer and J. H. Simons, J. Chem. Phys. 26, 1272 (1957).

2 W. H. Cramer, J. Chem. Phys. 28, 688 (1958).

3 Simons, Fontana, Muschlitz, and Jackson, J. Chem. Phys. 11, 307 (1943).

A-2 PHOTOIONIZATION ANALYSIS BY MASS SPECTROSCOPY*

G. L. Weissler
Department of Physics, University of Southern California
Los Angeles, California

A vacuum ultraviolet monochromator has been combined with a mass spectrometer similar to previously reported instrumentation[1] to study photoionization processes between 1570A and 430A. Monochromatic photons were used to ionize A, Ne, He, O_2, N_2, CO, NO, CO_2, N_2O, and NO_2; and preliminary measurements of ion intensity as a function of photon energy have been obtained for the parent ions together with their fragments. The onset of ionization and the plot of ions per unit photon flux versus λ will be compared to previously reported work on photoionization cross sections;[2] dissociative ionization energies have also been determined for some of the above gases, and the results for N_2O favor the N_2 dissociation energy of 9.8 ev.

Ions measured with multiplier - pulses.

Evidence for charge exchange $N_2^+ \rightarrow A^+$ in source at ~~[illegible]~~.

In N_2O find N_2O^+, NO^+, O^+, N_2^+, N^+
12 - 24 ev.

Haven't looked for ion pair formation yet.

* Supported in part by the Geophysical Research Directorate of the Air Force Cambridge Research Center, and the Office of Naval Research.

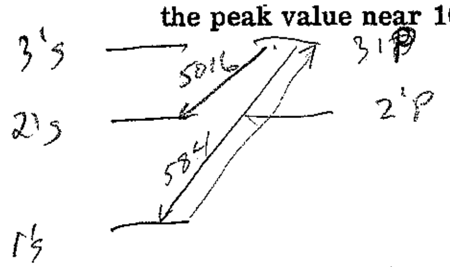
1 Hurzeler, Inghram, and Morrison, J. Chem. Phys. 28, 76 (1958).

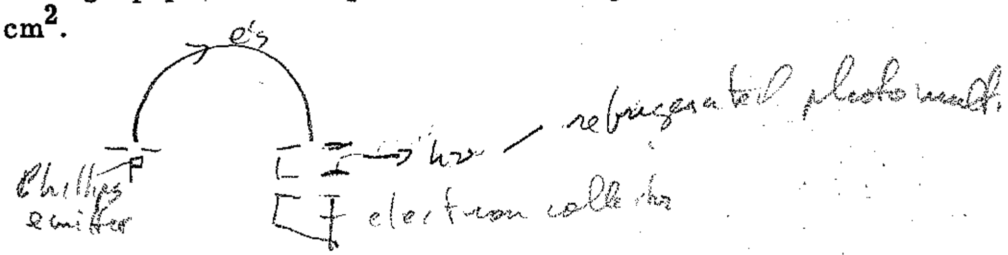
2 G. L. Weissler, Photoionization in Gases, Handbuch der Physik, XXI, Berlin: Springer-Verlag (1956).

OPTICAL EXCITATION CROSS SECTION MEASUREMENTS OF HELIUM 3^1P LEVEL* A-3

R. M. St. John, C. G. Bronco, R. G. Fowler
University of Oklahoma
Norman, Oklahoma

Absolute measurements on cross sections for excitation of atoms by electrons are being made. The helium 3^1P level is being studied by observing 5016A light from the collision chamber. Low gas pressures and small electron beam currents require the use of single pulse counting techniques in which a high gain photomultiplier, linear amplifier, and scaler are used. The photomultiplier is employed at liquid air temperatures to reduce dark counts. The apparent cross section for the helium 3^1P level was found to be independent of electron beam current. It showed a broad maximum whose peak occured at an electron energy of about 120 ev. The cross section appeared to be independent of pressure for pressures as high as 10^{-2} mm Hg. Thus, secondary processes presumably were not taking place. Absolute values of the excitation cross section of the 3^1P level will be obtained when calibration of the light measuring equipment is completed. Estimates place the peak value near 10^{-18} cm^2.





Dark current ~ 1 count/sec.
Pressure ~ 10^{-3} or 10^{-4} — multiplier current is linear with p.

Resonance rad. appears not to affect results.

Measurements from 50 to 200ev.
σ_{max} at ~ $\frac{1}{2} \times 10^{-18}$

* Work supported by the U. S. Air Force Office of Scientific Research.

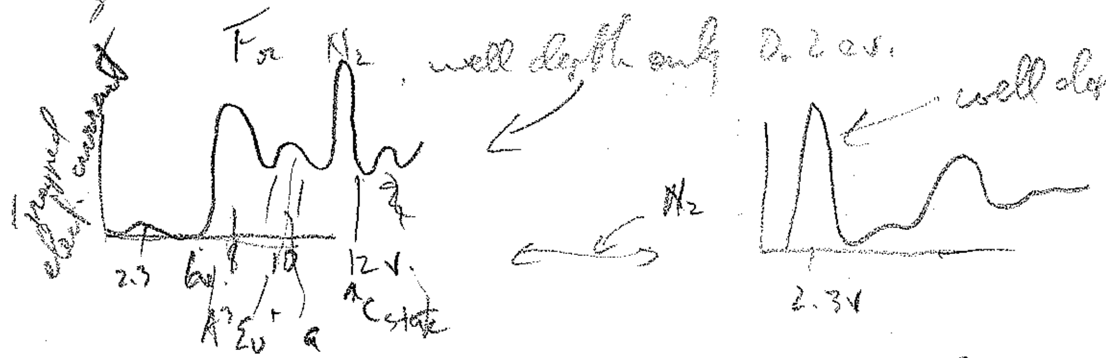
A-4

STUDY OF INELASTIC COLLISIONS OF ELECTRONS IN MOLECULAR GASES USING THE TRAPPED-ELECTRON METHOD

G. J. Schulz
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

The energy loss processes in N_2, H_2, O_2 were studied using electron beam techniques. Those electrons which have undergone an inelastic collision, and therefore lost a portion of their initial energy, are trapped in a potential well which prevents their escape to the electron beam collector. These "trapped" electrons can reach a cylindrical collector surrounding the electron beam. The potential well can be varied from 0 to about 1.5 volts. We can therefore obtain the cross section for the appearance of electrons of energy up to 1.5 volts as a function of the energy of the electron beam. For the simple case of helium, the method measures the excitation cross section up to energies 1.5 ev above threshold, and the results are in good agreement with previous experiments. The excitation functions for electronic transitions in H_2, O_2, N_2 were obtained. An anomalous energy loss process in N_2, with a peak cross section at 2.3 volts, was observed, similar to that reported by R. Haas.[1]

1000 gauss



2.3 v – temp. formation of N_2^- ? purely speculative
cross sections linear with current (10^{-9}–10^{-10} amp)
essentially linear with pressure –

* Work supported in part by the Office of Naval Research.

1 R. Haas, Z. f. Physik, 148, 177 (1957).

need a certain minimum p to ~~trap the~~ collect trapped electrons

Find effect like 2.3 v one in CO, but not H_2 + O_2

IONIZATION OF HYDROGEN AND OXYGEN ATOMS NEAR THRESHOLD*

Wade L. Fite and R. T. Brackmann
John Jay Hopkins Laboratory for Pure and Applied Science
General Atomic Division of General Dynamics Corporation

Using modulated atomic beam techniques, the cross sections for ionization of groundstate hydrogen and oxygen atoms upon electron impact have been measured, in the neighborhood of threshold. For both atoms the cross section appears proportional to the excess incident electron energy, and confirms the prediction of Geltman.[1] For the hydrogen atom the absolute value of the cross section slope is 0.078 (±0.006) πa_0^2/ev, while Geltman's S-wave theory predicts 0.044 πa_0^2/ev. The discrepancy is understood on the basis of the theory's consideration of only the S-wave contributions to the total cross section.

up to 18V.

2-300μ pressure

Changed to RF source - get larger beams & can work near threshold.

Beam density in O_2 + H_2 is ~ 10^8/cm^3 from furnace. Background density is greater. Modulate neutrals. ~ 10^{10} from RF source

Cooled H discharge - 81°K, instead of 3000°K

H beam 90% dissoc., Oxygen 50%

At high energy (> 25V) σ for $O + e = O^+ + 2e$ agrees with calc. of Seaton.

In O, linearity holds near threshold for 10V. Slope is closely ~~that~~ the same as for H.

* Supported in part by the United States Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command under contract No. AF49(638)-356.

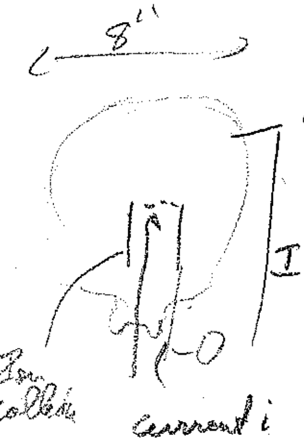
1 S. Geltman, Phys. Rev. 102, 171 (1956).

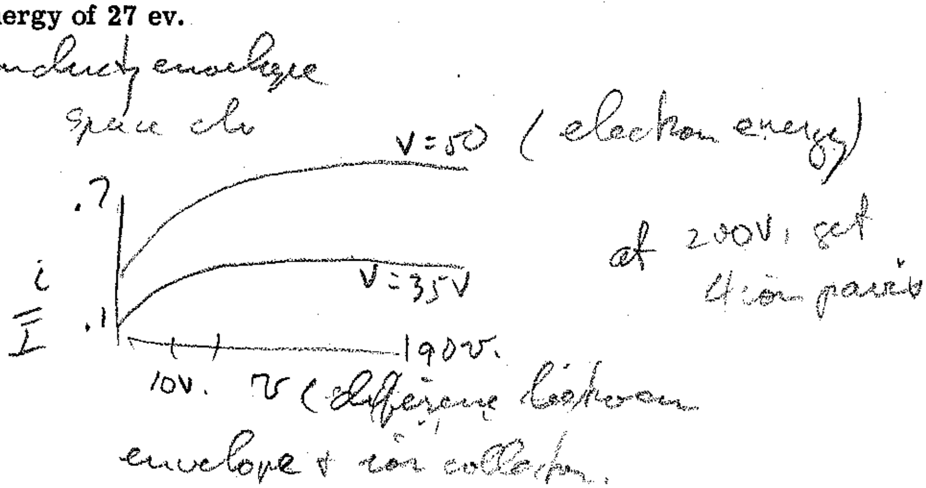
Thinks he can tell that Wannier's theory is not borne out.

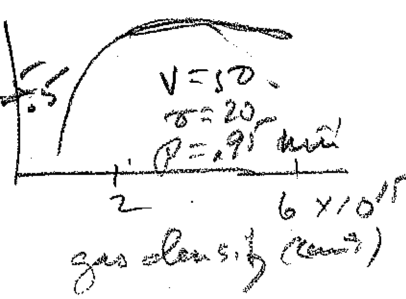
THE MEASUREMENT OF TOTAL IONIZATION BY LOW ENERGY ELECTRONS

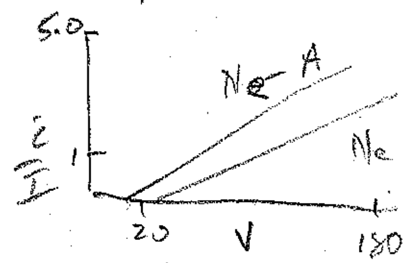
B. T. McClure
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey

An earlier investigation[1] of the number of ions, n, created by an electron which is stopped by collisions with gas molecules in a field-free region has been extended. The effect of electrons reflected to their source and the effect of the loss of high energy electrons at the wall of the apparatus have been considered quantitatively. The influence of these phenomena is taken into account in the interpretation of the data. The number, n, has been measured as a function of primary electron energy ranging from the ionization energy up to 200 ev in neon and in neon containing a small admixture of argon. The data obtained are used to extend Maier-Leibnitz' measurement[2] of the total excitation probability in neon up to 43 ev. This probability goes through a broad maximum (about 1 cm^{-1} mm Hg^{-1}) at an electron energy of 27 ev.



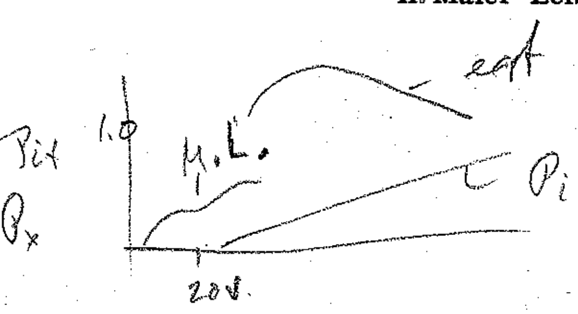






1 B. T. McClure, Bull. Am. Phys. Soc. Ser. II 3, 83 (1958).

2 H. Maier-Leibnitz, Zeits. f. Physik 95, 499 (1935).



QUANTUM EFFECTS IN IONIC MOBILITY AT LOW TEMPERATURES

S. Geltman
Atomic Physics Section, National Bureau of Standards
Washington, D. C.

At low relative velocities of impact between ions and gas atoms, the diffusion cross section departs from its classical value. In particular, the Langevin ion-atom potential (hard sphere repulsion of radius σ, and $-c/r^4$ attraction for $r>\sigma$) gives classical $Q_d \sim (c/m)^{1/2} v^{-1}$ in the low velocity limit, while zero-energy quantum cross section is $4\pi\sigma^2(\gamma\,\mathrm{ctn}^2\sqrt{\gamma})$, where $\gamma = (2m/\hbar^2)(c/\sigma^2)$. The limiting low temperature behavior of the mobility is $T^{-1/2}Q_d^{-1}$, which will have Ramsauer-like variations as a function of the potential parameters. It is suggested that quantum effects may help explain some of the anomalously low mobility measurements at low temperatures which were previously ascribed to clustering.

At room T, Mason + Chan have made good fits with $1/r^{12} - 1/r^4$ pot.

5 low T values exist - below μ_0
Li^+ - He, He_2^+ - He, Rb^+ - Kr, K^+ - Ar
have been attributed to clustering, but Geltman suggests quantum expl.

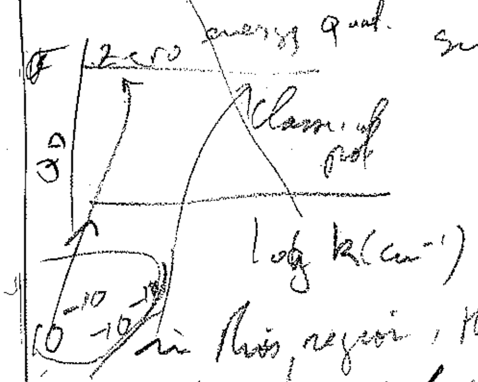
c/r^4

For s wave, Langevin potential
scattering length $a = \sigma\sqrt{\gamma}\,\mathrm{ctn}\sqrt{\gamma}$ $\gamma = \frac{2m}{\hbar^2}\frac{c}{\sigma^2}$

σ = hard sphere radius

He_2^+ - He $\gamma \sim 500$

$Q_D = 4\pi\sigma^2(\gamma\,\mathrm{ctn}^2\sqrt{\gamma})\{1 + \cdots\}$
small change in σ means large change in Q_D
$c = 2.36\times10^{-44}$ erg cm^4 } He
$\sigma = 1.95\times10^{-8}$ cm



Join classical + quant.

in this region, the quantum μ < classical

SESSION B
Wednesday, October 22
2:00 P. M.

Chairman
L. M. Chanin
Westinghouse Research Laboratories

SPUTTERING AND ARCS

MONTE CARLO SPUTTERING CALCULATIONS

R. R. Coveyou, D. T. Goldman,* and D. E. Harrison**
Oak Ridge National Laboratory***
Oak Ridge, Tennessee

In previous treatments of the sputtering problem both at high energies[1] and in the medium-low energy range[2] many of the approximations are quite questionable because their range of validity is highly uncertain. In an effort to resolve some of these difficulties we have turned to Monte Carlo techniques. Using an IBM 704 we have calculated a large number of ion histories, following the birth, progeny, and death of the ion and all of its daughters, assuming that death occurs when a particle no longer has sufficient energy to pass the surface energy barrier. In our preliminary analysis we examined hard sphere, screened coulomb, and pure coulomb (suitably cut off) interactions in appropriate energy ranges. Based on this analysis, we used screened coulomb interaction in all incident ion collisions, and assumed a hard sphere interaction for the production of all grandchildren and later generations. These histories were then analyzed under various assumptions. Assuming that the primaries are produced with a uniform distribution in depth, valid for high energies, we computed the sputtering ratio and also energy and angular distributions for the outgoing particles. Other models will be used at lower energies. We shall present preliminary results of this continuing program.

* Now at the University of Pennsylvania, Physics Department.

** Permanent address, the University of Toledo, Toledo, Ohio.

*** Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission, Oak Ridge, Tennessee.

1. D. T. Goldman and A. Simon, Phys. Rev. 111, (1958).

2. D. E. Harrison, Phys. Rev. 102, 1473 (1956).

B-2

VELOCITIES OF SPUTTERED ATOMS*

G. Wehner
Mechanical Division of General Mills, Inc.
Minneapolis, Minnesota

The average velocities of atoms sputtered from Ni, Pt, and Au targets by Hg^+ ions of 200 to 1000 ev energy are measured with a method which was used previously for the velocity determination of vacuum evaporated atoms.[1] Sputtered atoms are received by the underside of a pan suspended from a quartz helix in the tube. The deposited atoms exert a force, $\dot{M} \times \bar{v}_z$, which displaces the pan upward when the target is connected with the negative bombarding voltage. The continuous deposition of sputtered material increases with time the weight of the pan and one can determine the time interval, t, after which the pan has returned to its original position or the momentum force has been compensated by the weight increase. From $\dot{M} \times \bar{v}_z = \dot{M} \times t \times g$ follows that $\bar{v}_z$ can be determined by a simple time measurement without the knowledge of $\dot{M}$ or the constants of the balance. The average velocities turn out to be unexpectedly high, corresponding to energies of between 10 and 20 ev. Curves are given for the velocities as functions of bombarding energy and angle of ejection.

* Partly supported by Office of Naval Research Contract Nonr 2353(00).

1 Paul and Wessel, Z. Physik 124, 691 (1948).

SPUTTERING YIELD OF GERMANIUM IN RARE GASES* B-3

N. Laegreid and G. Wehner
Mechanical Division of General Mills, Inc.
Minneapolis, Minnesota

Sputtering yields of germanium bombarded by Xe^+, Kr^+, A^+, Ne^+ and He^+ ions under normal incidence at energies up to 400 ev have been determined. The yield versus ion energy curves consist of three parts: a low energy tail (probably caused by a process of stepwise sputtering), a region where the yield rises proportionally with ion energy, and above ion velocities of $\sim 3 \times 10^6$ cm/sec, a region where ions seem to penetrate below the surface and yields rise less than proportionally with ion energy. The slope in the proportional region is largely determined by the energy transfer factor $\eta = 4\, m_1 m_2/(m_1 + m_2)^2$. Surprisingly, the "cut in" energies do not follow $V_o \sim H/\eta$ (H = heat of sublimation), but are found to be much lower for the lighter gases than expected. The empirical result, $V_o \sim H \sqrt{m_1}/\eta$ (m_1 = atomic weight of ion), is not yet understood.

* In part supported by Office of Naval Research Contract Nonr 2353(00).

B-4 SPUTTERING OF COPPER BY VARIOUS IONS

O. C. Yonts, C. E. Normand, and Don E. Harrison, Jr.
Oak Ridge National Laboratory
Union Carbide Corporation
Oak Ridge, Tennessee

Sputtering ratios of copper have been determined in the energy range 10 - 40 kev. Bombarding ions were A^+, He^+, and D^+. Additional bombardments of copper have also been made with N^+, Ne^+, Cu^+, Kr^+, and U^+; all at 30 kev. Some measurements have also been made on Al, Mo, and Ta, at 30 kev using He^+, and A^+.

MECHANISM OF ARGON CLEANUP IN A GAS DISCHARGE

K. B. Blodgett and T. A. Vanderslice
General Electric Research Laboratory
Schenectady, New York

It is known that cleanup of noble gases at room temperature requires a gas discharge, but the role of the discharge has not been completely understood. A study of the cleanup of argon has been made in an attempt to elucidate the fundamentals involved. The present investigation shows that cleanup is not due to a simple ion penetration of surfaces or to "chemical" gettering of excited argon atoms, but rather is due to a covering up of argon ions by sputtered metal. The cleanup can best be understood as the difference in rate between the imbedding of ions in a surface where they are covered by sputtered metal and their subsequent release by re-sputtering of the surface in which the argon is imbedded.

B-6 THERMAL AND ELECTRICAL PROPERTIES OF HIGH CURRENT ARGON ARC PLASMAS

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

The effects of cathode geometry, electrode separation and arc current on temperature, current density and electric field intensity distributions in high current arc plasmas have been observed. Plasmas studied were those of nonconsumable electrode arcs operating in an enclosed chamber filled with argon at atmospheric pressure. The arcs burned between tungsten rod cathodes and plane copper anodes at currents ranging from 200 to 800 amps. Temperatures were measured spectroscopically according to a method previously described.[1] The internal consistency of the method is demonstrated by comparison of temperatures obtained from radial intensity distributions of both atomic and ionic spectral lines. The respective measured temperatures differ by less than 5% from the mean value. Radial electrical conductivity distributions, calculated from measured temperatures using Spitzer's[2] theory for the completely ionized gas, were converted to current densities and electric field intensities. Radial current density distributions obtained from temperatures measured near the anode are compared with those measured directly on the anode by Nestor.[3] Integration of measured electric field intensities along the arc axis yields plasma potentials which are compatible with the measured arc voltages.

1 H. N. Olsen, Gaseous Electronics Conference, Paper A-6 (1957).
2 L. Spitzer and R. Harm, Phys. Rev. 89, 977-981 (1953).
3 O. H. Nestor, Linde Company, private communication.

ARC RECOVERY STRENGTH AT HIGH CURRENTS

J. D. Cobine and G. A. Farrall
General Electric Research Laboratory
Schenectady, New York

The free recovery strength of arcs at 400 and 1600 amperes has been studied in hydrogen, helium, nitrogen, and sulfur hexafluoride. This investigation has been conducted by means of an impulse system, described elsewhere, in which 1/2 cycle of current from a 60 cps source is used for the arc, and the residual plasma is "probed" by a 3 μs high-voltage pulse. The arcs were drawn between the flat end surfaces of 1 inch diameter cylindrical electrodes of copper-impregnated tungsten. The gap length for all data was 1/4 inch. The arc was drawn in a coaxial structure to minimize the effects of external magnetic fields. Recovery strength curves are given in the time range from 1 to 100,000 μs. Oscillograms of gap voltage show glow and glow-arc transition for as long as 100 μs in He and 60 μs in N_2 after current zero. The glow phenomenon was observed in H_2 and SF_6 for only short delay times.

B-8 THE COOLING EFFECT OF T-F ELECTRONS AND THE POSITIVE ION CURRENT DENSITY IN THE CATHODE DROP REGION OF A HIGH CURRENT ARC

T. H. Lee
General Electric Company
Philadelphia, Pennsylvania

It has been shown in a previous paper[1] that electron emission from low boiling cathodes, such as silver or copper, of a high current arc can be explained by the combined effect of temperature and electric field. This so-called T-F theory demands a certain relationship between the cathode spot temperature and the positive ion current density. But these quantities are also regulated by energy balance at the cathode. A plausible cathode spot theory must not only explain the electron emission from the cathode but also show that the energy input and output can be balanced at the cathode. The cooling effect of emitted electrons plays a very important role in the energy balance problem because it determines the lower limit of positive ion current density. This paper describes the calculation of the energy distribution and the average cooling effect of electrons emitted by the T-F process. In calculating the average cooling effect of electron emission, electrons are assumed to obey the Fermi-Dirac statistics and the transmission coefficient is the same as the one used by Murphy and Good.[2] The energy distribution and the average energy of electrons are then evaluated numerically over a wide range of temperatures and electric fields for several values of work functions. At low temperatures, the average cooling effect approaches zero and at high temperatures, it approaches asymptotically the work function of the material. These correspond to the two cases of field emission and thermionic emission. As an example, for a work function of 4 electron volts, the average cooling effect per electron at a temperature of $3500^{\circ}K$ and a field of 2×10^{7} volts/cm is 2.7 ev. If the cathode drop is 10 volts, then energy balance demands that the positive ion current density be at least 17.5% of the total current, to account for electron cooling. Consideration of evaporation and heat conduction would bring up the positive ion current density to such a value that both the electron emission and the energy balance conditions can be satisfied.

1 T. H. Lee, 10th Annual Gaseous Electronics Conference; J. Appl. Phys. 26, 895 (1955).

2 E. L. Murphy and R. H. Good, Jr., Phys. Rev. 102, 1464 (1956).

ON THE THEORY OF THE "RETROGRADE MOTION" B-9

K. G. Müller and G. Ecker
University of Bonn
Bonn, Germany

There is extensive experimental information about the retrograde motion of the cathode spot defining the retrograde velocity and the critical point as a function of pressure, magnetic field, current, etc. Theoretical models proposed could not be used to calculate the various dependencies. The theory of the cathode mechanism - which distinguishes the thermal (I), the contraction-stabilized (II), and the field-stabilized (III) type - led us to the following conclusions. The thermal and the contraction-stabilized type (I, II) must be expected to move with the column in pondormotoric directions. The field-stabilized type, however, should give rise to retrograde motion in consequence of the electron-ion space charge coupling. The ions are properly deflected in pondoromotoric directions. The electrons, however, emitted near the cathode ends of the ion path and coupled to the ion path by space charge forces are bound to develop a velocity component in retrograde directions. As it is characteristic for the type III mechanism that the electrons participate decisively in the ion production, the whole ensemble must move in the retrograde direction. The formulation and mechanical evaluation of this theoretical conception yields quantitative results in good agreement with the experimental observations.

* Research supported in part by the United States Department of the Army, through its European Research Office.

SESSION C
Murray Hill
Thursday, October 23
9:30 A. M.

Chairman
B. T. McClure
Bell Telephone Laboratories, Inc.

RECOMBINATION AND SIMILAR PROCESSES

MEASUREMENT OF THE PROBABILITY OF THE TRANSITION $A^3\Sigma_u - X^1\Sigma_g$ IN N_2*

O. Oldenberg, N. P. Carleton, and D. G. Bills
Harvard University
Cambridge, Massachusetts

The state $A^3\Sigma_u$ in N_2 is metastable, but radiation from it is observed (the Vegard-Kaplan bands). We measure the absolute intensity of these bands as emitted from a discharge through very pure nitrogen. Under the same conditions we measure the absorption of light by the metastable molecules (transition $B^3\Pi_g - A^3\Sigma_u$, the first positive bands). This measurement gives us the population of molecules in the $A^3\Sigma_u$ state, in terms of the probability of this second transition, which is being determined independently.[1] Now, from the absolute population of metastable molecules and the absolute number of photons emitted in the Vegard-Kaplan bands, we can calculate immediately the Einstein coefficient of the transition $A^3\Sigma_u - X^1\Sigma_g$. The measurement of the absolute emission intensity is a straight-forward comparison with a standard tungsten filament. To measure the weak absorption by the matastable molecules, we employ as a background a second discharge tube emitting the first positive bands. By means of mirrors and a rotating sector disk, we illuminate a photomultiplier first with light which has passed through the main discharge tube, and then with a monitor beam, at a 31 cps alternation rate. An interference filter in front of the photomultiplier selects the 1, 0 first positive band. When the main discharge is turned on, it also emits the first positive bands strongly, but its light is not modulated, so there is a large undesired increase in the dc level in the photomultiplier, but also a small change in the ac signal due to absorption by metastables created in the discharge. This change is observed by a phase sensitive detector.

Steady state - emits n photons/cm³/sec
$n = A_{AX} N_A$ ← to find this measure absorption A→B

For 6-0 band of A - X [illegible]

* This work is supported by the U. S. Air Force Cambridge Research Center.

1 R. W. Nicholls, private communication.

0.15 sec for total lifetime of A - X

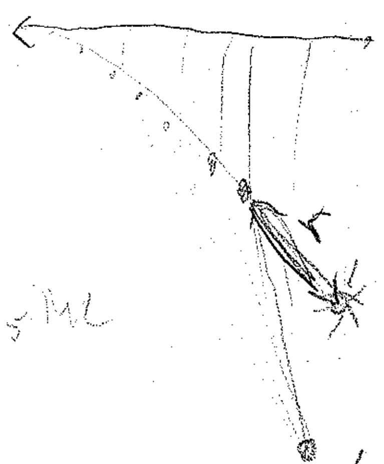
C-2 THERMAL ELECTRON ATTACHMENT COEFFICIENT OF OXYGEN MOLECULES

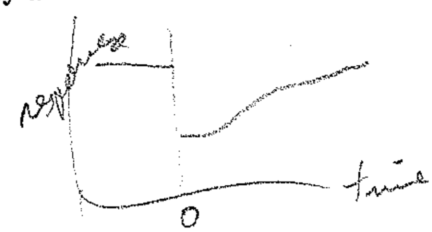
C. W. Dubs and H. K. Sen
Air Force Cambridge Research Center
L. G. Hanscom Field, Bedford, Massachusetts

The coefficient of attachment, β , of thermal electrons to oxygen molecules in the upper part of the troposphere has been calculated using the data from a nuclear burst. Total initial gamma radiation doses were measured at a number of points in the vicinity of the burst and the attenuation of a telemetering signal from each of these points to a ground point was measured. The doses and a fraction of dose rate at a certain short time after burst lead to an inverse square and exponential attenuation formula for the electron production rate. The electron density at this time is essentially the production rate divided by the product of β and the oxygen number density. It is calculated (assuming a value of β) at points along the telemetering ray path. It, the electron collision frequency, and the ray frequency (nearly 225 megacycles per second) give the index of attenuation at the points which is numerically integrated over the ray path to give the attenuation. The value of β is chosen to make the calculated attenuations (inversely proportional to β) agree with the measured attenuations. The result for β divided by the oxygen number density at burst altitude is 4.2×10^{-30} cm^6 sec^{-1}.

4.0×10^{-30}

> 10,000 ft





11 points

For larger distances, abs. by neg ions increases gives factor of 2.6

Photo det. due to thermal rad. - 11% at close distances.

MASS SPECTROMETRIC DETERMINATION OF THE ELECTRON AFFINITY OF ATOMIC OXYGEN*

P. L. Randolph** and R. Geballe
University of Washington
Seattle, Washington

Using a previously described mass spectrometric technique,[1] thresholds for O^- ion formation by dissociative attachment have been found for electron energies of 3.75 ± 0.15 ev, 12.7 ± 0.2 ev, and 14.1 ± 0.2 ev. The peak ion current associated with the first of these lies at an electron energy of 6.2 ev; the second two are associated with a peak at 15.0 ev having an amplitude 3% of the first. Measurements of appearance potential as a function of ion kinetic energy for the first peak carried out since the report in Ref. 1 give a dissociation limit for the O_2^- ion at 3.60 ± 0.10 ev above the ground state of O_2. Ion pair formation through the reaction $O_2 + e = O^+ + O^-$ was found to have a threshold approximating a step function. Its dissociation limit occurs 17.23 ± 0.05 ev above the ground state of O_2. Evidence for transitions to other repulsive states of O_2 also has been obtained. The above dissociation limits are combined with spectroscopic data to give values of 1.52 ± 0.1 ev and 1.50 ± 0.05 ev for the electron affinity of atomic oxygen. A third determination, 1.48 ± 0.05 ev, is obtained from a direct comparison of the threshold for ion pair formation with that for the reaction $O_2 + e = O^+ + O + 2e$. These three values for the affinity are in substantial agreement with the result, 1.465 ev, of photo detachment studies by Branscomb, Burch, Smith and Geltman.[2]

* Supported in part by the Office of Ordnance Research of the U. S. Army.

** Now at University of California Radiation Laboratory, Livermore, Calif.

1 P. L. Randolph and R. Geballe, Bull. Am. Phys. Soc. 8, 376 (1957).

2 Branscomb, Burch, Smith and Geltman (manuscript submitted to Phys. Rev.)

C-4 ELECTRON LOSS PROCESSES IN THE OXYGEN AFTERGLOW*

E. Howard Holt
Rensselaer Polytechnic Institute
Troy, New York

The measurement of the propagation constant of a microwave signal passing through a decaying electrical plasma established in oxygen gas permits calculation of the electron number density and electron collision frequency as a function of time in the afterglow. Working in the gas pressure range 0.3 to 10 mm Hg and detecting the electron number density in the range 10^8 to 10^{11} cm^{-3}, the electron losses due to recombination, diffusion and attachment for $300^{o}K$ electrons are separated according to the respective loss laws. The recombination coefficient does not change appreciably with the gas pressure. However, it does depend upon the direct current level of the active discharge which establishes the plasma. It is also changed when the electrons are heated by a second microwave signal. This is the "afterglow quenching" observed in other gases. The largest value obtained, which is considered the most accurate from the point of view of truly characterizing a dissociative recombination, is 3×10^{-7} cm^3/ion-sec. The attachment coefficient is computed to be 3×10^{-15} cm^3/ion-sec, and the probability of attachment is 1.4×10^{-7}. The attachment cross section is 2.5×10^{-22} cm^2. The ambipolar diffusion coefficient is very dependent upon the direct current level in the active discharge. Values are in the range $D_a p$ = 160 to 710 cm^2/sec in general agreement with the work of Schulz-Du Bois[1] using a different microwave technique.

* Work performed at the University of Illinois.

1 E. Schulz-Du Bois, Z. f. Physik 145, 269-278 (1956)

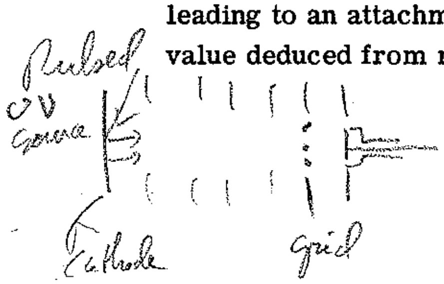
Mobilities (2.6 — low en.
2.9 — high en.

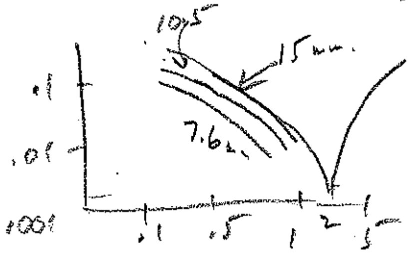
THE ATTACHMENT OF SLOW ELECTRONS IN OXYGEN*

C-5

L. M. Chanin, A. V. Phelps and M. A. Biondi
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

Electron drift tube measurements[1] of the attachment of low energy electrons have been extended to near-thermal energies. Results of these measurements indicate that the attachment consists of two separate processes: a pressure independent, two-body process for $E/p > 2$, and a pressure dependent, three-body process for $E/p < 2$. The present results for $E/p > 2$ give an attachment cross section increasing with average electron energy, with a value of $\sigma \simeq 2 \times 10^{-19}$ cm^2 at an estimated electron energy $\bar{u} \simeq 3$ ev. These results are in agreement with the swarm experiments of Bradbury and of Doehring,[2] and the resonant capture data of Craggs, Thorburn, and Tozer,[3] assuming a Druyvesteyn electron energy distribution. However, at low E/p, the present data show a three-body pressure dependence, in disagreement with the results of earlier workers.[2] These measurements have been extended down to $E/p = 0.07$. The three-body coefficient for the reaction is of the order of 5×10^{-30} cm^6/sec for $\bar{u} \simeq 0.09$ ev, leading to an attachment rate more than one hundred times the thermal value deduced from microwave measurements.[4]



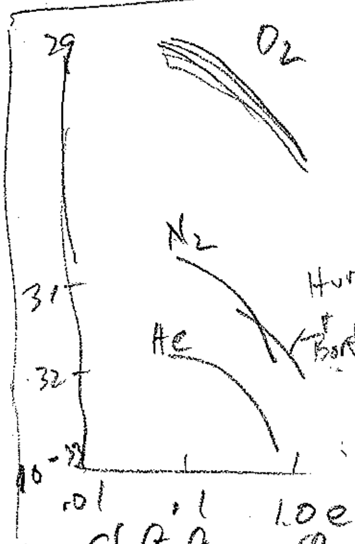


$\frac{dn_e}{dt} = -\{\beta n + K n^2\} n_e$

$\beta = \sigma v \rightarrow O + O^-$

K = 3 body coeff.

$O_2 + O_2 + e = O_2^- + O_2$



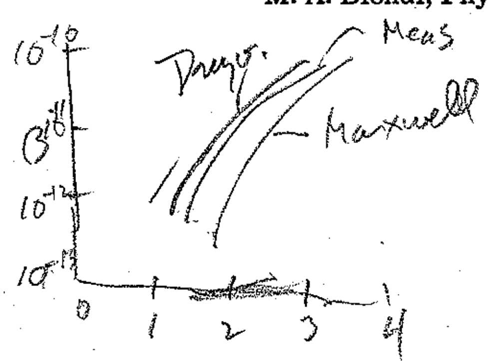
* Supported in part by the Air Force Special Weapons Center, Albuquerque, New Mexico.

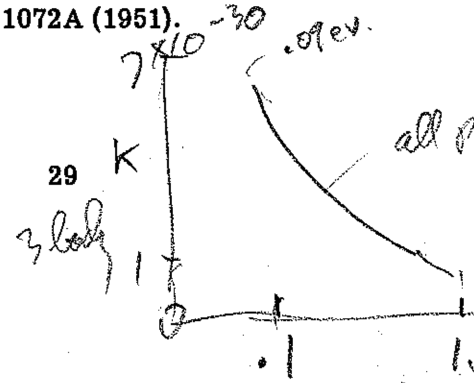
1 L. M. Chanin and M. A. Biondi, Bull. Am. Phys. Soc. II, 3, 84 (1958).

2 N. E. Bradbury, Phys. Rev. 44, 883 (1933); and A. Doehring, Z. f. Naturforschung 7a, 253 (1952).

3 J. D. Craggs, R. Thorburn and B. A. Tozer, Proc. Roy. Soc. A, 240, 473 (1957).

4 M. A. Biondi, Phys. Rev. 84, 1072A (1951).





at .09 ev, 100x smaller

C-6

RECOMBINATION BETWEEN ELECTRONS AND HELIUM MOLECULAR IONS*

Donald E. Kerr and Claude S. Leffel, Jr.
The Johns Hopkins University
Baltimore, Maryland

Simultaneous measurements of electron density in and radiation from the decaying plasma following a pulsed discharge in helium has permitted identification of the principal ion as He^+ at pressures below about 3 mm Hg, and He_2^+ above 3 mm.[1] At the higher pressures, the radiation is predominantly from the He_2 molecule, and is believed to result from recombination between electrons and He_2^+ ions. Although under these conditions diffusion represents the predominant electron-loss mechanism, an upper limit can be set for the total recombination coefficient, which we believe to be considerably less than 10^{-8} cm^3/sec. Absolute light intensity measurements permit estimates of a lower limit of recombination coefficient, which we find to be about 10^{-10} cm^3/sec. This range is considerably smaller than has been reported by others. Detailed investigation of emitted light as a function of pressure and electron density permits comparison of several recombination mechanisms and discussion of the effects of collision quenching of excited molecular states. The central question, still not satisfactorily resolved, concerns the mechanism of formation of these states.

* Work supported by U. S. Air Force Office of Scientific Research.

1 Donald E. Kerr and Merle N. Hirsh, Bull. Am. Phys. Soc. Ser. II 3, 258(1958).

LOW PRESSURE AFTERGLOWS IN HELIUM

C-7

W. A. Rogers and M. A. Biondi
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

Simultaneous studies of electron density, spectral intensity, and atomic line broadening in the afterglow of a pulsed microwave discharge in pure helium have led to the formulation of a model for the afterglow at pressures of the order of one mm Hg and temperatures of 77^{o} and $300^{o}K$. In the first few hundred microseconds, the afterglow is dominated by electron production and radiation resulting from ionization and excitation of metastable atoms. The later afterglow is characterized by ambipolar diffusion loss of electrons and ions, and by the line spectra attributed to electron-ion recombination. Early afterglow measurements indicate initial metastable atom concentrations of about $10^{12}/cc$ and a cross section of about $5 \times 10^{-16}\ cm^2$, for excitation of metastable atoms to states which lead to population of the 3^3D state. Late afterglow absolute intensity and electron density measurements indicate production of diatomic ions from atomic ions by three body collisions and their destruction by dissociative recombination at rates which agree with the previous measurements by Phelps and Brown[1] and Biondi and Brown.[2] The line broadening and spectral intensity measurements indicate dissociative recombination influenced by metastable vibrational excitation in the diatomic ion.

2×10^{-8} for diss. recomb.

Disagree with Kerr. at low p ions may be in hi vib state with larger recomb coeff

1 A. V. Phelps and S. C. Brown, Phys. Rev. 86, 102 (1952).
2 M. A. Biondi and S. C. Brown, Phys. Rev. 75, 1700 (1949).

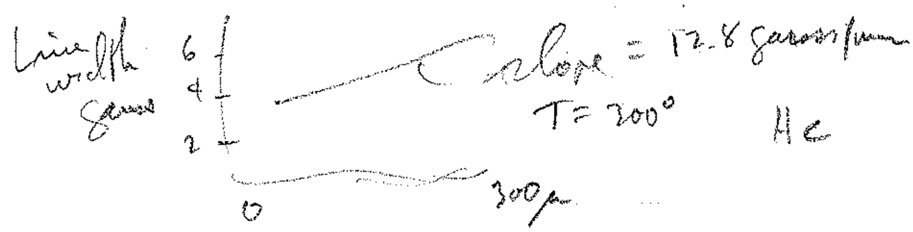
C-8 MEASUREMENT OF P_c IN THERMAL ENERGY RANGE BY CYCLOTRON RESONANCE*

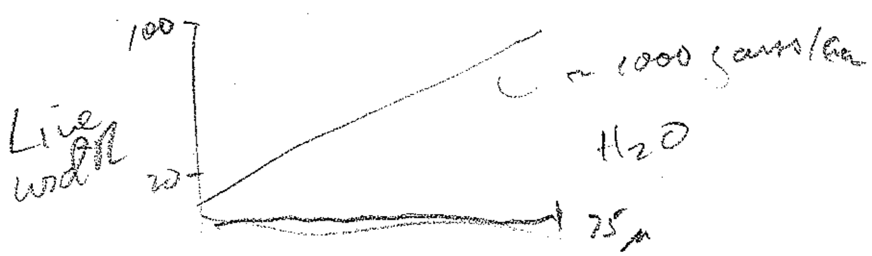
R. M. Hill and A. J. Penico
Sylvania Electric Products Inc.
Mountain View, California

Measurements of the line width of the microwave electron cyclotron resonance absorption have been used to determine P_c for water vapor at thermal energies. Collision cooled electrons diffuse into a waveguide measurement cell. The magnetic field is slightly modulated at 1000 cycles and slowly swept through the resonance line. The resultant line represents a derivative of the absorption line and ΔH between the inflection points is measured as a function of pressure. The microwave absorption coefficient has been calculated assuming a Maxwellian distribution and $\nu_c = \text{const}\ v^h$, where h = 0, ±1, ±2. P_c for helium was checked and a value in essential agreement with previous measurements obtained. Water vapor was then measured resulting in a value for P_c close to theoretical prediction. The measurements further indicate that P_c for water is inversely proportional to energy. The technique appears applicable to a wide number of polyatomic gases.

Assume Maxwell dist - low power input   Complicated analysis

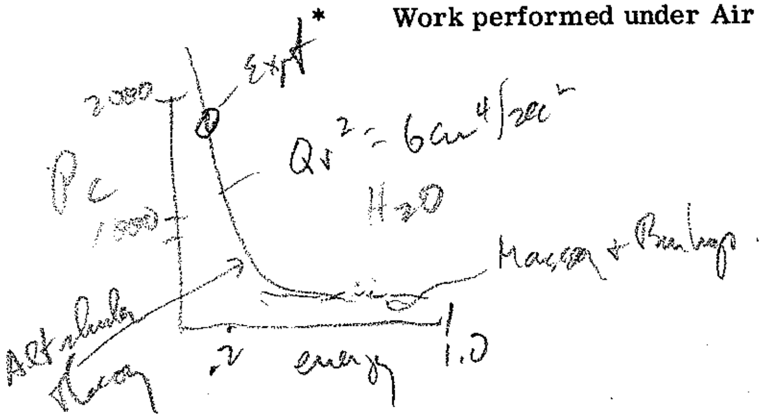
Line width vs pressure





* Work performed under Air Force Contract No. AF 04(647)-113.

Pc = 22 in He



MICROWAVE INVESTIGATION OF ELECTRON LOSS PROCESSES IN DISINTEGRATING WATER VAPOR PLASMA*

S. Takeda** and A. A. Dougal
University of Illinois, Urbana, Illinois

Water vapor is used as a quenching gas in several types of commercial tubes, and is one of the more prevalent impurities present in gaseous discharges. Microwave transmission measurements were performed in disintegrating water vapor plasma and the prevailing electron loss processes were determined. An improved experimental procedure was developed for rapidly recording the time-varying microwave phase shift and attenuation. This improved by an order of magnitude the minimum resolvable electron density. Interpretation of the experimental data showed that electron-ion recombination is the predominant electron loss process for electron densities down to 10^8 cm^{-3}. Recombination coefficients for different discharge conditions, as calculated from the decay curves, varied from 10^{-6} to 10^{-5} cm^3/sec for water vapor pressure between 0.5 to 7.0 mm Hg. Electron loss through electron attachment was found to be too small to be measured, i.e., a probability less than 10^{-7} at 300^0K. Experiments with small amounts of water vapor added to noble gases showed much faster decays than in pure noble gases, and this is attributable to the recombination loss. A measured value of the electron-water vapor molecule collision frequency was 1×10^{10} sec^{-1} mm Hg^{-1} at 300^0K, and was found to decrease steeply with increasing electron energy.

* Sponsored by USA Signal Corps Engineering Laboratories.

** On leave from the University of Yokohama, Japan.

SESSION D
Murray Hill
Thursday, October 23
2:30 P. M.

Chairman
R. M. Hill
Sylvania Electric Products Inc.

BREAKDOWNS AND TRANSIENTS

ELECTRICAL BREAKDOWN BETWEEN CLOSE ELECTRODES IN AIR

L. H. Germer
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey

Pre-breakdown electron current between electrodes closing at voltages below the minimum which can give breakdown by successive ionization of air molecules has been measured by two different methods. This field emission current varies widely in successive experiments, increasing in general with decreasing voltage, with maximum values of the order of 10^{-7} amp. At the small electrode separations characteristic of breakdown at voltages below 300 it is shown that the ions necessary for breakdown come from the anode surface. The number of ions in the space at one time is so small that they cannot cooperate to enhance the gross field at the cathode, which is a conclusion having important consequences for the theory of breakdown.

D-2

ELECTRON EMISSION AT HIGH FIELDS DUE TO POSITIVE IONS

P. Kisliuk
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey

To account for the large yield of secondary electrons in gaseous breakdown at high electric fields, it has been proposed that a positive ion approaching the cathode surface creates a "pass" for electrons by decreasing the width of the potential barrier.[1] The magnitude of this effect has been recalculated and is found to be sufficient to account for the breakdown of extremely small gaps at atmospheric pressure. It is also likely to be effective in the breakdown of gases at high pressure and of liquid and solid dielectrics.

1 R. R. Newton, Phys. Rev. 73, 1122 (1948).

MEASUREMENTS OF THE IONIZATION COEFFICIENT α IN A STRONGLY INHOMOGENEOUS ELECTRICAL FIELD FOR ARGON - ALCOHOL 9 : 1

D-3

K. van Duuren
Philips' Research Laboratories, Synchrocyclotron Group
Amsterdam, Netherlands

The ionization coefficient may be determined by measuring the gas multiplication factor A in cylindrical proportional counters as long as an equilibrium exists between the mean electron energy and the electrical field, that is to say, as long as a single valued relation between α/p and F/p exists. Accurate measurements of A were done for a number of proportional counters with various wire diameters ranging from 0.0030 to 0.1 cm and for various gas pressures ranging from 67 to 220 mm Hg. Intercomparison of the results obtained from different counters showed that the equilibrium between the mean electron energy and the electrical field was only slightly disturbed at high values of F/p (>100 volts/cm·mm Hg). In the convergent cylindrical field the apparent reduction of electron energy due to the field inhomogeneity was found to be determined by the quotient:

$$\frac{\text{increase of mean electron energy per cm path length}}{\text{amount of energy taken from the electrical field per cm path length}}.$$

The work was carried out at the Free University in Amsterdam and the author wishes to acknowledge the helpful discussions with which Professor G. J. Sizoo offered his kind assistance.

D-4 ROLE OF RESONANCE RADIATION IN BREAKDOWN OF RARE GASES

A. V. Phelps
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania

The Holstein-Bieberman[1] theory of imprisoned resonance radiation is applied to a calculation of the role of resonance radiation as a source of photoelectrons during the buildup of current preceding the breakdown of a rare gas. The electron density is assumed to increase exponentially with time and with distance between cathode and anode. The transport equation for the density of atoms in the resonance state is solved numerically[2] for infinite parallel plane electrodes to find the fraction of the resonance photons arriving at the cathode for an arbitrary rate of buildup of the discharge current. The results of this theory are used to show the relative importance of ions and photons as sources of secondary electrons and to calculate the constant characteristic of the exponential current rise for comparison with experiment.[3]

1 T. Holstein, Phys. Rev. 72, 1212 (1947), and 83, 1159 (1951); and L. M. Bieberman, J. Exper. Theor. Phys. USSR 17, 416 (1947).

2 For the solution of a similar problem see A. V. Phelps, Phys. Rev. 110, 1362 (1958). In the present case the transmission of radiation is assumed to be controlled by pressure broadening rather than by Doppler broadening.

3 H. L. von Gugelberg, Helv. Phys. Acta. 20, 307 (1947); and M. Menes, Phys. Rev. 98, 561A (1955).

EARLY STAGES OF SPARK CHANNEL EXPANSION

J. M. Somerville
The University of New England
Armidale, N. S. W., Australia

The growth of the anode mark left by sparks of brief duration in air have been studied under two sets of conditions. In the first, the spark current consists of a single rectangular pulse of variable length. In the second, the spark channel is initiated by a 30 amp 30 millimicrosecond pulse and allowed to expand freely for a variable interval of time after which a second probing pulse is passed through the channel. Both methods indicate that after a few tens of millimicroseconds most of the current in the channel flows near its periphery. It is suggested that the radii of the mark and the channel are probably identical during the first hundred millimicroseconds. The variation of channel radius with time and gas pressure is discussed and compared with theoretical expectation.

D-6 LIGHT TRANSIENTS IN LOW PRESSURE ARGON MERCURY DISCHARGES

Robert H. McFarland and Tillman Tucker
Kansas State College
Manhattan, Kansas

Square current modulation of 4 watt germicidal lamp gave rise to light modulation transients which limited the upper frequency for which efficient modulation was practical. For all mercury lines observed with the exception of the 2537A line, an increasing light output transient was observed for decreasing current and voltage. A tentative explanation will be given in terms of imprisonment, change of electron temperatures, and depletion of metastable levels.

PULSATIONS IN THE POSITIVE COLUMN OF A Ne-Hg DISCHARGE DUE TO ELECTRICAL Hg CLEAN UP AND RE-EVOLUTION

Carl Kenty
General Electric Company
Nela Park, Cleveland, Ohio

Under certain circumstances, pulsations are found to occur in the positive column of a discharge in Ne + Hg. The phenomenon appears as a red wave travelling along an otherwise blue discharge. Other rare gases than Ne do not give the effect. Pulsing has been found with both ac and dc. It occurs with 1-3 mm of Ne, but not with 0.33 mm; it occurs with currents of 0.2 to 3-1/2 amp in tubes of 11 mm to 34 mm i.d., and with Hg saturation temperatures (T_s) of 20 to 40°C. Pulse frequencies are from 3 to 60 per minute; they increase with current and with wall temperature; they decrease with increasing Ne pressure and increasing T_s. The current range for pulsing increases with T_s; the range of T_s for pulsing increases with decreasing tube diameter. Pulsing occurs with pyrex and lime glass walls, to a lesser extent with lead glass and apparently not at all with phosphor coated walls. Pulsing can sometimes be induced by a suitably periodic variation of the current. Pulsing is probably due to electrical clean-up of Hg on the wall during the blue stage and a liberation of Hg by the Ne discharge in the red stage which assists the natural Hg re-evolution.

SESSION E
Friday, October 24
9:00 A. M.

Chairman
A. C. Kolb
U. S. Naval Research Laboratory

PLASMAS AND INSTABILITIES

Invited Paper

E-5 CONFINEMENT OF PLASMAS BY MAGNETIC FIELDS
C. L. Longmire

ROLE OF SPACE CHARGES IN COLD-CATHODE GAS DISCHARGES

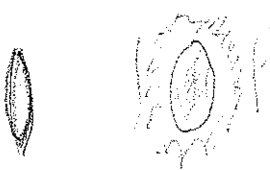
A. L. Ward
Diamond Ordnance Fuze Laboratories
Washington 25, D. C.

Results of machine calculations of the effect of positive-ion space charge in cold-cathode gas discharges between parallel plates have been reported at the Ninth Annual Gaseous Electronics Conference.[1] The effect of electron space charge has now been included in new calculations. Although the effect of the electron space charge is negligible in the breakdown region, it becomes important at higher current densities, i. e., in the normal glow region. For low pd products, a second positive slope region is found at still higher current densities, indicating an abnormal glow. Field and charge distributions across the gap are shown for the various current density regions. A positive column plasma is indicated in the glow regions. Ionization by metastable-metastable collisions has been included in some calculations. Also, the effect of the loss of current to the wall, or to a probe, has been simulated. Comparison of calculated curves with experimental data, although made difficult by the constriction of glow discharges, is favorable.

1 Ward, A. L., Bull. Am. Phys. Soc. Ser. II, 2, 68 (1957); 2, 82, (1957).

HIGH FREQUENCY PLASMOIDS*

Albert J. Hatch
Argonne National Laboratory
Lemont, Illinois



Experimentally observed characteristics of two types of high frequency plasmoids[1] will be reported. These plasmoids were observed in air between large diameter plane parallel electrodes at separations up to 25 cm. Frequencies were in the range of 5 to 50 Mc/sec and pressures in the range of 0.1 to 10 microns Hg. These conditions correspond approximately to those for the multipacting mechanism of high frequency breakdown. The principal characteristic of both types of plasmoid is their well-defined steady state form which is usually axially symmetric. The "dark ring" plasmoid is a region of uniform luminous intensity completely surrounded by a dark space a few mm in width. Immediately outside this dark ring, the plasma luminous intensity is approximately the same as inside the plasmoid, decreasing near the discharge tube walls. This plasmoid occurs at pressures from 0.3 to 5 microns. The "low pressure" plasmoid appears at about 0.1 to 0.3 microns. Its luminous intensity is uniform but quite low, and the surrounding dark space extends to the boundaries of the discharge tube. The transition between the two plasmoids is always abrupt. Possible plasmoid formation mechanisms will be discussed.

Dark sheath plasmoid gives oscillations
Wave form distorted with 2nd harmonic
+ phase shifts 180° w/r to fundamental —
indicates plasma oscillations

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

1 The term "plasmoid" was originally applied by R. W. Wood (Phys. Rev. 35, 673-693 (1930) to the luminous balls, spindles, etc, observed in certain low pressure high frequency plasmas.

THE THERMAL CONDUCTIVITY OF AN ELECTRON GAS IN A GASEOUS PLASMA *

T. Sekiguchi** and R. C. Herndon
Department of Electrical Engineering, University of Illinois
Urbana, Illinois

The thermal conductivity of an electron gas in a gaseous plasma is determined by experimental techniques which have been improved over those reported in a previous article by Goldstein and T. Sekiguchi.[1] A quantitative comparison with theory is made by taking special care to obtain the accurate values of plasma parameters (electron concentration and initial electron temperature) as well as those of the thermal conductivity itself. A pulsed microwave is utilized to probe the plasma parameters as well as to selectively heat up the electron gas in a small volume of the elongated plasma. The photomultiplier tube detects the change in electron temperature by taking advantage of the phenomenon of "Afterglow quenching." The experimental values for the thermal conductivity, which are determined by two different methods ("Transient method" and "Steady-State method"), are in good agreement. In the plasmas investigated, neon and helium with pressure range 1~20 mm Hg, the degree of ionization is very low ($10^{-5} \sim 10^{-6}$). It has been found, however, that the measured values of the thermal conductivity are still consistent (within the experimental error) with those obtained from the theoretical expression given by Spitzer and Harm[2] for a fully ionized gas.

* Supported by Air Force Cambridge Research Center.

** On leave from the Faculty of Engineering, University of Tokyo, Tokyo, Japan.

1 L. Goldstein and T. Sekiguchi, Phys. Rev., 109, 625 (1958).

2 L. Spitzer, Jr., and R. Harm, Phys. Rev., 89, 977 (1953); L. Spitzer, Jr., "Physics of Fully Ionized Gases," Interscience Publishers, Inc., N.Y. (1956).

E-4 INSTABILITIES IN A MAGNETICALLY CONFINED PLASMA

M. Scotto
Johns Hopkins University, Baltimore, Maryland
P. Parzen
Brooklyn Polytechnic Institute, Brooklyn, New York

Instabilities in a magnetically confined plasma have been observed by measuring the noise power in a coaxial line which is coupled to a Philips Ionization Gauge type discharge. The noise power density is of the order of 60 db/kt between 40 and 100 mc and decreases to about 40 db/kt at 2 kmc. A theory of the noise generation has been developed and agrees qualitatively with experiment. The theory is based on the instabilities in the plasma, which are characterized by the propagation of initial disturbances in the form of growing waves. The mode of propagation depends essentially on the transverse movement of the surface of the magnetically confined plasma, and is affected very slightly by any action in the interior of the discharge. This type of propagation is very similar to the scalloping modes in microwave tubes, except for the presence of positive ions which are lacking in most microwave devices. The frequency at which the peak of the noise occurs is determined by the gyro frequency of the positive ions, and occurs in the megacycle range.

INVITED PAPER

E-5

CONFINEMENT OF PLASMAS BY MAGNETIC FIELDS

C. L. Longmire
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

E-6

PLASMA OSCILLATIONS WITH DIFFUSION IN VELOCITY SPACE

Andrew Lenard and Ira B. Bernstein
Project Matterhorn, Princeton University
Princeton, New Jersey

A model of plasma oscillations in the presence of small angle collisions is presented which admits of exact analytic solution. Certain features of the true collision terms are maintained. Namely, the effect is represented by a diffusion in velocity space, which makes the distribution function tend to the Maxwell distribution, and which conserves the number of particles. In the limit of infrequent collisions the results of Landau are recovered.

$\frac{Df}{Dt} = \beta \nabla_v \cdot (\vec{v} f + v_0^2 \nabla_v f)$ v_0 = thermal speed

β = const

$\nabla \cdot \mathcal{E} = -4\pi e n_0 \left(\int d^3v\, f - 1 \right)$

$f = f_0 + f_1$ Fourier tfm of f_1 in space + vel space
LaPlace tsfm in time

THE EXCITATION OF ELECTROSTATIC INSTABILITIES BY RUN-AWAY ELECTRONS*

H. Dreicer and R. Mjolsness
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico

This paper deals with a fully ionized gas situated in an externally applied electric field, E, and investigates its stability to electrostatic disturbances. The normal mode technique is used to perturb the system about its quasi-equilibrium state, and the linearized Boltzmann equation is solved for a dispersion relation which includes the effects due to E as well as collisions. Central to this work is the specification of the equilibrium velocity distribution, F^o. We choose the displaced Maxwellian when E exceeds E_c, the critical field for run-away. When $E << E_c$, F^o is obtained by solving the Boltzmann equation in the run-away region of velocity space and joining the result to a solution obtained earlier[1] for the low velocity "body" region where collisions dominate. In the run-away region F^o develops a maximum in the neighborhood of a moving front, ahead of which there are very few particles, and behind which F^o decays exponentially. This second maximum in F^o plays a significant role in the growth of electrostatic instabilities.

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

1 H. Dreicer, "The Theory of Run-away Electrons," 10th Annual Gaseous Electronics Conference, 1957, Cambridge, Mass.

SESSION F
Friday, October 24
1:30 P. M.

Chairman
H. Dreicer
Los Alamos Scientific Laboratory

DIAGNOSTICS

POSITIVE ION COLLECTION BY A PROBE IN A PLASMA

Ira B. Bernstein and Irving N. Rabinowitz
Project Matterhorn, Princeton University
Princeton, New Jersey

The theory of the collection of positive ions by spherical and cylindrical probes immersed in plasmas in which the collisions suffered by the ions can be neglected is presented. The appropriate Boltzmann equation is solved, yielding the ion density and current as functionals of the electrostatic potential and the particle distribution function in the body of the plasma, which information is inserted in Poisson's equation to determine the potential. Numerical results for the potential have been obtained for the case of mono-energetic ions. These indicate that the potential is not so insensitive to ion energy as has been believed, and that if the probe radius is sufficiently small there enters the possibility of a class of ions which are trapped in troughs of the effective radial potential near the probe. The population of these latter is determined by collisions, however infrequent; is difficult to calculate; and can possibly have a marked effect on the local potential.

$\frac{df}{dt} = 0$

$\nabla^2 \varphi = 4\pi e (n_+ - n_-)$

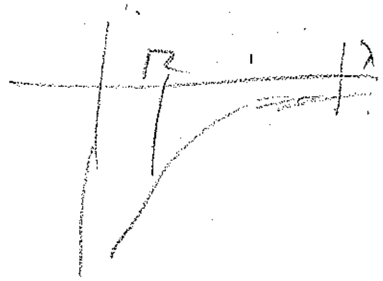
$\mathcal{E} = \frac{m}{2}(v^2 + r^2) + Ze\varphi$

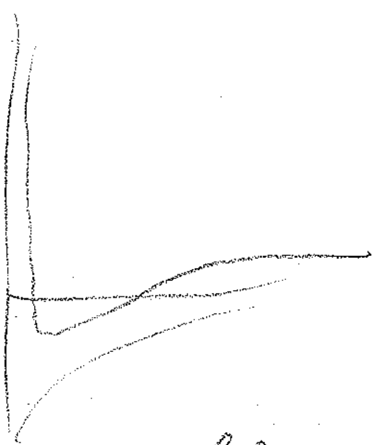
$J = mr\omega$

$f \leq f(\mathcal{E}; J)$

$N_e = N_0 e^{+\frac{e\varphi}{kT_e}}$

$e\varphi(R) \gg kT_e \gg Ze\varphi(\lambda)$





Planar probe is qualitatively different
Here, there is no saturation effect in this model
Planar probe requires collisions

In what way does this differ from Langmuir?

F-2

MEASUREMENTS ON HIGH PRESSURE AND HIGH ELECTRON DENSITY PLASMAS

K. B. Persson
General Electric Research Laboratory
Schenectady, New York

The investigation of the limits of the conventional microwave cavity method for measuring the electron density in the plasma lead to the conclusion that this method can be greatly extended by applying solenoidal probing electric fields on plasmas with rotational symmetry. The limit associated with the plasma resonance mechanism in the conventional cavity method is then replaced with the skin depth limit. The range available for measurements is extended many orders of magnitude in terms of the electron density and the pressure without any loss in time resolution when the frequency of the applied field is decreased from the microwave range into the Mc-range. The interaction between the plasma and the solenoidal electric field is exceedingly complex when the collision frequency of the electrons is less than the frequency of the applied field. The reverse is true when the collision frequency is larger than the frequency of the applied field. The design of a bridge based on the principles mentioned above and useful in the high pressure range when the collision frequency of the electrons is larger than the frequency of the applied field is described. The bridge is capable of measuring the ratio between the average electron density and the collision frequency over five to six orders of magnitude and has a time resolution of less than a microsecond. The upper limit for measurements with the bridge occurs when the skin depth of the plasma is comparable with the plasma radius and the lower limit occurs when the noise level in the electronic devices that are used for measuring the unbalanced signal in the bridge is comparable with the unbalanced signal itself.

coll freq > field freq - high pressure plasmas only ($> 10^{-2}$ mm)

cylindrical conducting

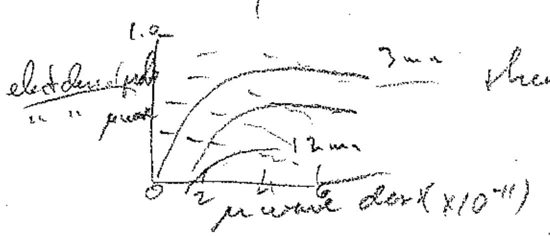
some sort of shield to protect plasma from axial component of field.

ULTIMATE AND SECONDARY ELECTRON ENERGIES IN THE COLD-CATHODE NEGATIVE GLOW

J. M. Anderson
General Electric Research Laboratory
Schenectady, New York

The "ultimate" electron density in the negative glow plasma of a cold-cathode discharge in helium at gas pressures 4 - 12 mm Hg has been determined by simultaneous Langmuir probe and microwave transmission methods. A correlation, obtained at densities above $\sim 4 \times 10^{11}$/cc, points up the influence of electron-positive ion scattering on the accuracy of the Langmuir metallic probe. The probe further permits a determination of ultimate and "secondary" electron temperatures and their spatial variations. This leads to the interesting result that the ultimate electron temperature in the central regions of the discharge plasma may be as low as $\sim 400^{o}$K. Measurement of the microwave noise power radiated by the negative glow has been made with a Dicke-type radiometer. Under conditions of complete absorption of microwave energy in the plasma, the effective noise temperature is found to be $\sim 1000^{o}$K. A calculation of the noise contributed by the ultimate and secondary electrons (with the aid of appropriate probe and microwave absorption measurements) is compared with the above experimentally determined total noise power.

Section of X-band [illegible] guide - [illegible] 3-12 mm of He
[illegible] difficult to interpret [illegible] e's.



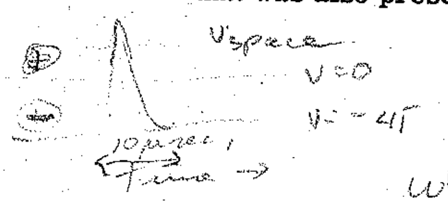
[illegible] --- Record + exp. agree for ≥ 6 mm

F-4 PROBE MEASUREMENTS IN THE NEGATIVE GLOW OF A THERMIONIC ARC

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

A pulse technique is described for making probe measurements in the negative glow of a hot-cathode fluorescent-lamp discharge in mercury plus a rare gas. The very small size of the probes which can be used, together with a self-cleaning effect due to ion bombardment, permit meaningful probe measurements to be made to within one mm of an oxide cathode at $\sim 1000^{o}C$ despite very high electron densities and rapid evolution of contaminants from the cathode. The electron cloud in the negative glow is found to consist of a secondary electron group having a Maxwellian distribution of velocities and a primary electron group having an energy approximately equal to the cathode fall; the velocities of the latter have, however, been randomized in direction by many elastic collisions with rare gas atoms. These results are quite similar to those recently reported by Medicus in neon ball-of-fire discharges.[1] Contrary to the findings of Medicus, however, we observe that primary electrons are Maxwellianized, presumably, by losing a large fraction of their energy in an inelastic collision, followed by thermalization by the secondary electron cloud. This difference is undoubtedly due to the fact that the measurements of Medicus were taken in a region of the discharge where the primary electrons had insufficient energy to undergo inelastic collisions, while in the case of our measurements, the energy of the primary electrons always exceeded the excitation potential of the mercury that was also present.

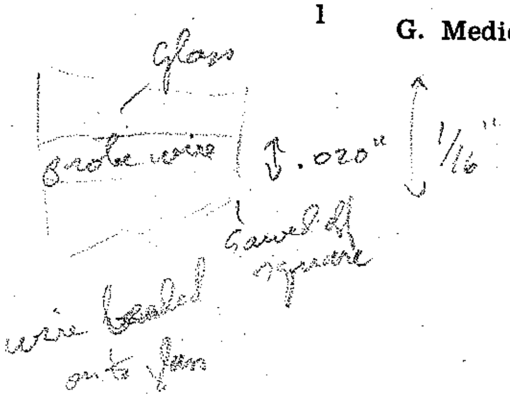
Sheath formed quickly, in time scale << 10 μsec.

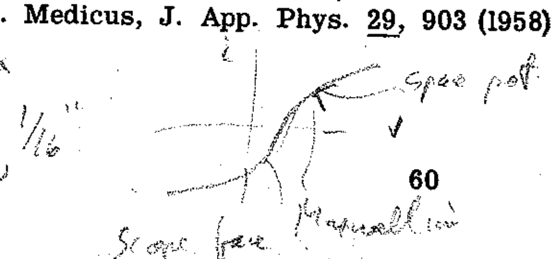


probe work function const during pulse. Changes in it show up as steady drift.
While bias is on, ions bombard probe & sputter it clean.

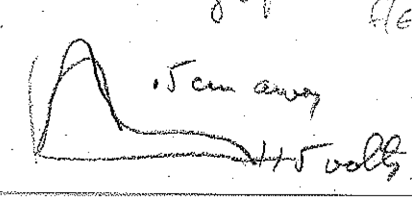
Also probe temp is const during measurement
Sheath thickness at least 25% of probe dia in [illegible]
No attempt to present electron density measurements.

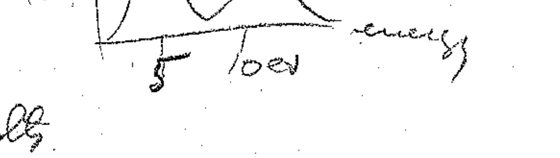
1 G. Medicus, J. App. Phys. 29, 903 (1958).





Turn switch off & [illegible] pulse & measure contact pot.





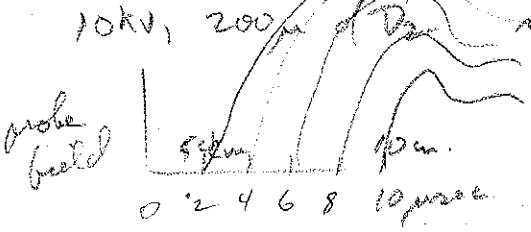
DYNAMIC PINCH MEASUREMENTS*

D. Birdsall, Stirling A. Colgate
Harold P. Furth and Milton Birnbaum
University of California Radiation Laboratory
Livermore, California

Dynamic pinch measurements have been made in a tube 1 inch long and 4 feet in diameter with peak currents at first bounce time up to 6 million amperes. The interaction of the plasma flow across the electrodes during the dynamic motion will be discussed. Apparently this interaction is much smaller than might be expected. Probe measurements indicate a well-defined shock front and its velocity will be related to theory. Screw dynamic pinch measurements in a tube 18 inches in diameter and 18 inches long with a 10^6 joule 300 kv Marx bank will also be shown. The screw dynamic pinch configuration is one in which there is an encasing magnetic field entrapped in the low plasma density region external to the principal gas column.[1]

Unstable in time det. by sound speed - few μsec.
MSp ~ 1 cm is a limit to length also viscosity along face. vacuum flow

Magnetic probe measurements (coils in glass tubes)
current flows is symmetric to 10%, even if triggered at one pt.
10kV, 200μ of D2 in 1"x48" tube.



Field should get larger as shock approaches center. Actually, it decreases. Some current flows outside pinch. This is a limitation perhaps not serious.

Trial effort, 25 cm Ø > 100μ

* Work supported by U. S. Atomic Energy Commission.

1 S. A. Colgate, et al, "A Partly Stabilized Dynamic Pinch," 2nd Conference Peaceful Uses of Atomic Energy, Geneva, Switzerland. (To be published.)

Pinch vel ~ 10^7 cm/sec. Not as fast as it should.
Maybe 1/5 ratio would be good.
steel → copper no help.

F-6 MEASUREMENTS OF MICROWAVE NOISE RADIATION FROM PLASMAS*

G. Bekefi and J. L. Hirshfield
Department of Physics and Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Massachusetts

The magnitude of the noise power emitted from a plasma is strongly dependent upon the opacity that the plasma presents to the electromagnetic radiation that is generated within its volume. Variation of the electron density from approximately 10^8 to 10^{13} cm^{-3}, and of the gas pressure from 0.05 to 20 mm Hg, makes possible the study of the transition from a black-body to a transparent plasma. The experimental results can be explained by means of a simple model of the attenuation sustained by a wave as it progresses through a plasma slab. The radiation emitted from a plasma permeated by a dc magnetic field has also been studied. The observed enhancement of the noise radiation observed at the electron cyclotron frequency is discussed.

* 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 Atomic Energy Commission.

DETERMINATION OF ELECTRON CONCENTRATIONS $\sim 10^{17}$ cm^{-3} BY MEASUREMENT OF OPTICAL REFRACTIVITY

F-7

Donald R. White and Ralph A. Alpher
General Electric Research Laboratory
Schenectady, New York

Interferometric studies of highly ionized argon plasmas produced in a shock tube have shown that the plasma dispersion formula may be applied to obtain the electron concentration from the observed refractivity. A Mach Zehnder interferometer has been used to obtain interferograms from which the integrated index of refraction across the 8.2 cm width of the shock tube is determined. Such interferograms, obtained with a 0.1 μ sec effective duration spark light source, depict in striking fashion the ionization relaxation behind Mach 14 to 17 shock waves in argon. Interferograms taken simultaneously at two different optical wavelengths permit separation of the plasma contribution to the refractive index through the relatively large plasma dispersion, proportional to λ^2. The technique is limited at present to experiments in which the number of free electrons in the optical path is within an order of magnitude of 7 x 10^{17} cm^{-2}. While the method thus far has been applied only to shock heated gases, it is also applicable to the study of ionization produced by various types of discharges. Furthermore, the technique should prove useful in studying flows of ionized gases, plasma flows in a magnetic field, and kinetics of ionization and recombination.

Good agt. Measured luminosity - corresponds to onset of ioniz behind shock.

Initial p 1-3 mm Hg.

100 psi H_2+O_2 mixture

F-8

THE MICROFIELD AT NEUTRAL AND CHARGED PARTICLES IN THE PLASMA

G. Ecker and K. G. Müller
University of Bonn
Bonn, Germany

In a plasma of sufficiently high temperature and low density, Holtsmark's theory describes the microfield for neutral atoms as well as for ions. With increasing density, the effect of the interaction energy of the plasma becomes more important. This effect was calculated[1] for neutral particles on the basis of plasma polarization and shielding. The applicability of the shielding method was not determined. Also not determined was the effect of the cut-off procedure in the numerical calculation. A careful discussion that makes use of the individual and collective particle aspects shows that the Debye-Hückel theory is applicable to the plasma only when the Onsager-Kirkwood condition holds and when the particle number in the Debye sphere is sufficiently large. Within these limits, the shielding method is justified. We find that in the applicable range, the difference in the microfield distribution at the position of the neutrals as compared to that at the position of the charged particles marked only for large β . We also took account of the true Debye field without approximation, using the analog computer of the Inst. f. Instr. Math., Univ. Bonn. The new results confirm the conclusions drawn from the cut-off calculation. Quantitatively there is an increase in the influence of the Gibbs-factor for small values of δ and β .

Interaction energy → Boltzmann factor $e^{-H(p,q)/kT}$
Holtsmark neglected it. A no. of later authors used it for ions

Onsager-Kirkwood cond: $\frac{e^2}{rkT} \ll 1$ → D.H. theory fails if not met.

$\delta = \frac{(kT)^{3/2}}{19 e^2 (\sqrt{2\pi n})^{1/2}}$ – no of particles in Debye region

If $\delta \gg 1$, can average & use D.H.

$\beta = F/F_0$

1 G. Ecker, Z. F. Phys. 148, 593 (1957); Z. Naturf. 12a, 346 (1957)

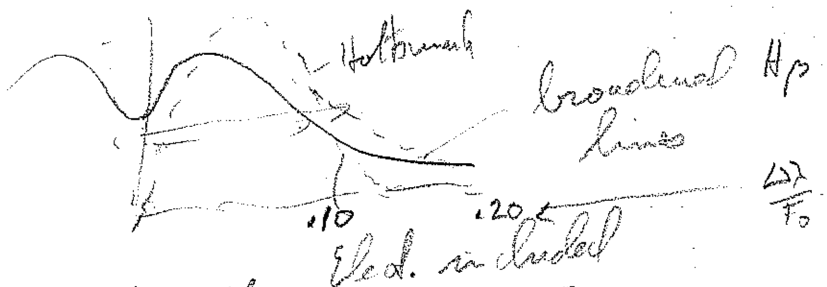
STARK EFFECT BROADENING OF HYDROGEN LINES AND ITS APPLICATIONS TO PLASMA DIAGNOSTICS

F-9

H. Griem
University of Maryland, College Park, Maryland
and
U. S. Naval Research Laboratory
Washington, D. C.

Practically all the broadening of hydrogen lines emitted from plasmas is due to interactions of the hydrogen atoms with ions and electrons. The action of the ions can be described by the well-known quasistatic theory of Holtsmark, suitably modified to take into account Debye shielding, whereas the electron contribution can be obtained by means of a recently developed impact theory for nearly degenerate quantum mechanical systems.[1] This theory takes into account both elastic and inelastic electron scattering and was used to calculate line profiles resulting from electron impacts for a given ion field strength. Observable line profiles were then obtained by folding the electron impact profiles into the ion field strength distribution function. The Holtsmark theory yields line profiles accurate within a factor of two, because electron broadening is neglected. The new theory was carried through with an accuracy of 10%. Measurements of hydrogen line profiles will therefore allow us to determine ion and electron densities with similar accuracies in high temperature experiments now in progress.[2]

Impact approx - time between coll's duration



Half-widths agree to few %

Note difference at center - not certain it's accurately this large.

1 A. C. Kolb, and H. Griem, "Theory of Line Broadening in Multiplet Spectra," Phys. Rev. (July 1958).

2 E. A. McLean, H. Griem, A. C. Kolb, J. Milligan, unpublished.

Agrees in wings with 2x Holtsmark

Agrees pretty well with exp't - Hβ at 10,000°K,
Insensitive to Temp 10-20,000°K

SESSION G
Saturday, October 25
9:00 A. M.

Chairman
Wulf B. Kunkel
University of California Radiation Laboratory

THERMONUCLEAR PROGRAM I

Invited Papers

G-4 THE IXION AND SCYLLA EXPERIMENTS
D. Nagle

G-5 THE PYROTRON PROGRAM
R. F. Post

RADIAL COMPRESSION OF DENSE PLASMAS BY PULSED MAGNETIC FIELDS

A. C. Kolb
U. S. Naval Research Laboratory
Washington, D. C.

The heating and confinement of deuterium plasmas can be accomplished by a high current electric discharge through a single turn coil with magnetic mirrors.[1, 2] With currents in the range 1 - 6 x 10^6 amperes, fields up to $\sim$ 500 kilogauss have been generated for times of the order 10 μ sec with a 285 KJ, 20 KV condenser bank.[3] Observations of the radiation emitted from the plasma, shock phenomena, the compression, electrical parameters and their theoretical interpretation will be discussed.

1 A. C. Kolb, "High Temperature Plasmas Produced by the Magnetic Compression of Shock Preheated Deuterium," International Conference on the Peaceful Uses of Atomic Energy, Geneva (1958).

2 R. F. Post, Bull. Am. Phys. Soc., Ser. II, 3, 196 (1958).

3 A. C. Kolb, Conference on Extremely High Temperatures, John Wiley and Sons (1958).

G-2

SPECTROSCOPIC MEASUREMENTS OF TEMPERATURE AND DENSITIES PRODUCED BY MAGNETICALLY DRIVEN SHOCK WAVES

E. A. McLean, C. E. Faneuff, A. C. Kolb, J. E. Milligan
U. S. Naval Research Laboratory
Washington, D. C.

H. Griem
University of Maryland, College Park, Maryland
and
U. S. Naval Research Laboratory
Washington, D. C.

The spectral radiation from helium plasmas produced by Mach 30 shock waves[1] was observed using a time-resolving (10^{-7} sec) photoelectric spectrograph. Absolute intensity measurements were made possible by calibrating the photomultipliers and the spectrograph with a tungsten ribbon-filament lamp of known radiation intensity. Total line intensities of several lines of neutral and ionized helium and continuum intensities in the visible region were monitored simultaneously. Temperatures and densities of neutral atoms, ions and electrons were calculated from these intensities assuming equilibrium conditions. Shock velocities were measured with a smear camera. For these velocities and the initial conditions, temperatures and densities behind the shock front were calculated. A comparison of these values with the corresponding spectroscopic data will be made.

Spectrograph 42,000°K   Ion density 6.3×10^{16}, theoretical $\sim10^{17}$
from vel. 24,000°K   pressure 1 mm Hg.

at 5 mm Hg, Ion dens 6.9×10^{16}
Temp. 37,300°K from spect.
23,000 " vel.

Simple shock theory cannot explain

1 A. C. Kolb, "Production of High-Energy Plasmas by Magnetically Driven Shock Waves," Phys. Rev. 107, 345 (1957).

THE DIVERTOR, A DEVICE FOR REDUCING THE IMPURITY LEVEL IN A STELLARATOR G-3

C. R. Burnett,* D. J. Grove,** R. W. Palladino,
T. H. Stix and K. E. Wakefield
Project Matterhorn, Princeton University
Princeton, New Jersey

A divertor, designed to reduce the flow of impurities from the wall into a gas discharge, has been used with a small stellarator. In the divertor, an outer shell of magnetic flux is bent away from the discharge channel into a large auxiliary chamber. Ions diffusing toward the wall tend to follow the lines of force of this outer shell into the divertor chamber. Impurities produced by wall bombardment in this chamber do not readily return to the discharge. The magnetic design of this device is described, and a phenomenological theory of its performance is outlined. The spectroscopic data with and without the divertor activated indicate that the divertor reduces the influx of impurities by a factor of two to three, while the impurity concentration at the core, or central region, may be diminished by an order of magnitude when the divertor is activated. Kinetic temperatures of positive ions determined from spectroscopic measurements of Doppler broadening increase from 40 ev without the divertor to 60 ev for He^{+} and to 130 ev for O^{++++} with use of the divertor.

* On leave from the Pennsylvania State University.
** On loan from Westinghouse Electric Corporation.

G-4 INVITED PAPER

THE IXION AND SCYLLA EXPERIMENTS

D. Nagle
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

INVITED PAPER G-5

THE PYROTRON PROGRAM

R. F. Post
University of California Radiation Laboratory
Livermore, California

G-6

MULTISTAGE MAGNETIC COMPRESSION OF HIGHLY IONIZED GAS*

F. H. Coensgen, W. F. Cummins and A. E. Sherman
University of California Radiation Laboratory
Livermore, California

An apparatus has been built for compressing and heating an ionized gas in a cylindrically symmetric magnetic field. Intense magnetic fields at the ends of the system inhibit the escape of charged particles along the magnetic field.[1] Electrically neutral plasma is injected into the large diameter end of a tapered evacuated chamber and guided through the chamber by a dc magnetic field. The magnitude of the dc field along the axis of the system is inversely proportional to the square of the chamber diameter. Pulsed magnetic fields are used to force the plasma to the small end where it is further compressed by a magnetic field of 10^5 gauss. Theoretically, both the ion density and the ion rotational kinetic energy are increased linearly as the ratio of the final magnetic field to that at the injection point. Presently their ratio is approximately 10^3. The density has been observed at three points by means of microwave techniques,[2] and found to agree with that predicted within the limits of the measurements. Preliminary ion energy measurements yield evidence of ion heating. The system can be adapted to include compression along the magnetic field lines.

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

1 R. F. Post, "The Mirror Machine," Bull. Am. Phys. Soc., May 1958.

2 C. B. Wharton and D. M. Slager, UCRL-5244, to be published.

ORTHOGONAL OR B-CENTERED PINCH*

J. W. Mather
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

A description of some early work (the "Jug" 1953) is given in which a ring discharge is formed in hydrogen gas. Using a parallel arrangement of circular coils, energy from a low voltage condenser bank is coupled to the discharge vessel. Fast smear photography is employed, showing the initial ring discharge and the subsequent radial inward motion. The dynamics of the simple ring discharge can be treated in an analogous fashion to the sheath in the ordinary pinch theory. The electric and magnetic fields (E_z - B_θ) of the ordinary pinch are replaced by an orthogonal set (E_θ - B_z). Thus, the ring discharge can be termed an orthogonal or B_z-centered[1] pinch. In a later experiment (1958), a similar discharge is initiated using an improved electrical design. The magnetic field of this discharge is recorded with a small magnetic probe as a function of time and radius. From an analysis of the magnetic field data along with Maxwell's equations, it is possible to determine the local current density and electric field, eventually obtaining the conductivity of the plasma.

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

1 Terminology used by Bostick and Levine.

SESSION H
Saturday, October 25
1:30 P.M.

Chairman

E. Frieman
Princeton University

THERMONUCLEAR PROGRAM II

Invited Papers

H-3 THE STELLARATOR PROGRAM
M. B. Gottlieb

H-4 THE DCX EXPERIMENT
P. R. Bell

COLUMBUS II*
(A HIGH POWERED LINEAR PINCH MACHINE)

A. H. Williams and J. W. Mather
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

The linear pinch machine, Columbus II, with discharge tube 30 cm long and 10 cm i. d., is designed to operate at 100 kv, 1.5 x 10^6 amperes discharge current and 2 microseconds rise time. The effect of an axial magnetic field on the production of neutrons suggests that several mechanisms are responsible for the observed neutrons. Typically 100, 500 and 4500 gauss decrease the neutron production by a factor of 3, 10, and ~100, respectively, from the zero gauss yield. Peak yields of 6 x 10^8 neutrons per burst have been measured at 40 kv (16,000 joules). The axial neutron energy measured at the cathode decreases with increasing B_z, 2.72 Mev (zero field), 2.58 Mev (100 gauss), and 2.55 Mev (500 gauss). The significance of the neutron energy shift and the high neutron yields are discussed in terms of simple pinch models.

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

H-2 DETAILED MAGNETIC PROBE MEASUREMENTS ON A STABILIZED PINCH*

L. C. Burkhardt and R. H. Lovberg
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Improved magnetic probe techniques have made possible the determination, from magnetic field plots, of current densities, electric field intensities, and electric conductivity along magnetic field lines during the first three microseconds of compression in a stabilized pinch. It is found that after two microseconds, the sum of electromagnetic and plasma energies is less than the energy extracted from the capacitor bank and that this difference continues to grow, suggesting an effective loss mechanism between the plasma and the external surroundings. It has further been found that the onset of heavy energy losses is coincident in time with the appearance of surface instabilities on the hollow cylindrical current sheath. Through the use of multiple-probe arrays, it has been determined that these instabilities appear as local turbulences which are the order of 1 cm in extent for the discharge under observation. The inertial force on the contracting plasma column has been separated from the total j x B force with the result that a mass density for the pinch has been obtained. It appears that the system mass is concentrated in a hollow shell, ("snowplow model") and that this mass is equal to the total mass of deuterium swept in by the contracting sheath.

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

THE STELLARATOR PROGRAM

M. B. Gottlieb
Project Matterhorn, Princeton University
Princeton, New Jersey

INVITED PAPER

THE DCX EXPERIMENT

P. R. Bell
Oak Ridge National Laboratory
Oak Ridge, Tennessee

THE TUBULAR PINCH ("TRIAX")

Oscar Anderson, William R. Baker, John Ise, Jr.,
Wulf B. Kunkel, Robert V. Pyle, and John M. Stone
Radiation Laboratory, University of California
Berkeley, California

Theoretical considerations indicate that a uniform current-carrying plasma sheet of infinite extent, supported by its own magnetic field, possesses positive stability for some perturbation modes and at least neutral stability for others. In the "Triax" discharge, which consists of a hollow cylindrical plasma sleeve of only modest dimensions, comparative stability without aid from auxiliary stabilizing magnetic fields is indeed observed experimentally. The plasma is formed by passing a high current (10^5 to 2×10^6 amperes) through a low-density gas (100 to 2000 μ Hg pressure) along the annular space between two coaxial cylindrical return conductors. Typical dimensions of the tubes used are 10 to 20 cm o. d. and 20 to 100 cm in length. Under suitable conditions the discharges are highly reproducible, showing no sign of instabilities and performing up to ten successive oscillations of the plasma thickness which last for about 3 μ sec. The details have been studied by means of small probe coils placed inside the discharge region. In these cases the observed plasma resistance is in agreement with estimates based on the temperature and mean compression deduced from the probe measurements. Time-resolved spectroscopic observations performed on deuterium indicate complete ionization after the second pinch and low recombination until the second current reversal about 10 μ sec later. This work was done under the auspices of the U. S. Atomic Energy Commission.

AN RF THERMONUCLEAR MACHINE CONCEPT*

J. W. Butler, A. J. Hatch and A. J. Ulrich
Argonne National Laboratory
Lemont, Illinois

Plasma-field interface instabilities tend to generate organized plasma motions which are oriented by the confining magnetic field. Rapid variation of such a field, particularly in direction, tends to destroy the coherence of the instability motions with the field. Thus we are led to the consideration of rotating rf fields as a method of confining a thermonuclear plasma.[1] Such a field is that produced by the time quadrature excitation of the TE_{110} and TE_{111} modes in a spherical cavity. A central spherical core of hot plasma in such a cavity will experience a time average containing force.[2,3] Heating of the plasma core results from skin depth penetration of the core boundary by the rf field. The core possesses stability against change of scale and against short wavelength distortions of the plasma surface. Various aspects of this concept will be discussed. A brief comparison with other rf thermonuclear machine concepts will be made.[3,4,5]

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

1 J. W. Butler, A. J. Hatch and A. J. Ulrich, "Radiofrequency Thermonuclear Machines," Geneva Conference Paper P/350 (1958).

2 H. A. H. Boot, R. B. R-S-Harvie, Nature (London) 180, 1187 (1957).

3 H. A. H. Boot, S. A. Self and R. B. R-S-Harvie, J. Electronics and Control 4, 434-453 (1958).

4 F. B. Knox, Australian J. of Phys. 10, 221-225, 565-586 (1958).

5 E. S. Weibel, "Confinement of a Plasma Column by Radiation Pressure and its Application to Fusion Power Generation," ARL-57-1026 (Ramo-Wooldridge Corp.) August 26, 1957.

ENERGY EXCHANGE BETWEEN CHARGED PARTICLES AND A ROTATING ELECTROMAGNETIC FIELD*

H-7

A. J. Ulrich
Argonne National Laboratory
Lemont, Illinois

In a cavity composed of the space between two perfectly conducting parallel planes of infinite extent in x and y, the two cutoff modes, one involving electric and magnetic fields E_x and B_y, and the other involving E_y and B_x, are excited in time quadrature. The result is a standing wave with $\underline{E}$ and $\underline{B}$ parallel or antiparallel rotating about the z direction. Energy exchange between this field and charged particles emitted from the walls and subject to the Lorentz force is investigated with the aid of a digital computer.[1] Cases with and without an additional steady magnetic field, and with a plasma as one wall are included. It is found that a constant B_z field can cause energy to flow from the particles to the electromagnetic field or vice versa, depending on the direction of B_z under resonance conditions. Possible applications are discussed.

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LIST OF CONTRIBUTORS

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