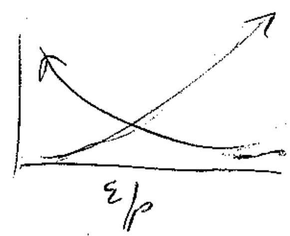
14[th] *Annual*

Gaseous Electronics Conference



Program and Abstracts of Papers

General Electric Research Laboratory and Hotel Van Curler, Schenectady, New York

Sponsored by The American Physical Society and the General Electric Research Laboratory

October 11-13, 1961

CONFERENCE COMMITTEE

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PROGRAM

Fourteenth Annual Gaseous Electronics Conference
General Electric Research Laboratory and Hotel Van Curler
Schenectady, New York ...... October 11-13, 1961

Tuesday, October 10

8:00 P.M. Advance Registration, Lobby of Hotel Van Curler

Wednesday, October 11

8:00 A.M. Registration, Lobby of Hotel Van Curler

9:00 A.M. SESSION A: COLLISION PROCESSES, ELECTRON ENERGY DISTRIBUTIONS
Location: Ballroom, Hotel Van Curler
Chairman: B. Bederson, New York University

A-1 ION ENERGIES AT THE CATHODE OF A GLOW DISCHARGE
W. D. Davis and T. A. Vanderslice, General Electric Research Laboratory

A-2 SPUTTERING YIELDS AS A FUNCTION OF ANGLE OF INCIDENCE
G. D. Magnuson, C. N. Abeyta and P. A. Harkins, General Dynamics/Convair

A-3 A TRUNCATED COULOMB CROSS SECTION
D. E. Harrison Jr., U. S. Naval Postgraduate School

A-4 ELECTRON CAPTURE AND LOSS IN ION-ATOM COLLISIONS BELOW 25 KEV
P. R. Jones and I. S. Frost, University of Massachusetts

A-5 PRELIMINARY MEASUREMENTS OF THE PHOTOIONIZATION CROSS SECTION OF SINGLY IONIZED XENON
R. B. Cairns and G. L. Weissler, University of Southern California

A-6 IONIZATION OF A GAS BY RADIATION FROM A DISCHARGE
R. E. Voshall and G. W. Penney, Carnegie Institute of Technology

A-7 REARRANGEMENT SCATTERING WITH TWO POTENTIALS
B. A. Lippmann, Lawrence Radiation Laboratory, Livermore

A-8 INELASTIC COLLISIONS OF SLOW ELECTRONS WITH MOLECULES
G. J. Schulz, Westinghouse Research Laboratories (Invited Paper)

Wednesday, October 11 (Continued)

A-9 ELECTRON ENERGY DISTRIBUTION IN SLIGHTLY IONIZED GASES UNDER THE INFLUENCE OF ELECTRIC AND MAGNETIC FIELDS
N. P. Carleton and L. R. Megill, U. S. National Bureau of Standards, Boulder

A-10 ELECTRON ENERGY DISTRIBUTIONS IN VARIOUS DISCHARGES
B. T. Barnes, General Electric

A-11 POLARIZATION OF SPECTRAL EMISSION INDUCED BY ELECTRON IMPACT ON HELIUM
R. H. Hughes, R. B. Kay and L. D. Weaver, University of Arkansas

2:30 P.M. SESSION B: EXCITATION AND IONIZATION

Location: Ballroom, Hotel Van Curler

Chairman: L. B. Loeb, University of California

B-1 CHEMIONIZATION IN GASES
C. Gatz, F. T. Smith and H. Wise, Stanford Research Institute

B-2 AUGER TRANSITIONS OCCURRING DURING CHEMISORPTION
P. M. Waters, Westinghouse Research Laboratories

B-3 LOWERING OF THE IONIZATION POTENTIAL IN A PLASMA
G. Ecker and W. Kröll, Bonn University

B-4 INTERACTION OF RADIATION AND MATTER IN A PLASMA
L. Oster, Yale University

Business Meeting (20 Minutes)

Now A-1 B-5 COHERENT OSCILLATIONS AT OPTICAL FREQUENCIES USING A GASEOUS DISCHARGE
A. Javan, Bell Telephone Laboratories (Invited Paper)

B-6 TRANSMITTANCE MEASUREMENTS IN A MERCURY DISCHARGE WITH ADDITIONS OF He OR H_2
J. T. LaTourrette and N. A. Peppers, General Electric Research Laboratory

Thursday, October 12

9:00 A.M. SESSION C: ATTACHMENT AND RECOMBINATION

Location: Ballroom, Hotel Van Curler

Chairman: L. M. Branscomb, U. S. National Bureau of Standards

C-1 CREATION AND DESTRUCTION OF CHARGED PARTICLES AND EXCITED STATES IN HELIUM AFTERGLOW
D. E. Kerr and C. S. Leffel Jr., The Johns Hopkins University

C-2 LOW ENERGY ELECTRON ATTACHMENT TO AND DETACHMENT FROM OXYGEN
D. C. Conway, Purdue University

C-3 ELECTRON CAPTURE IN GAS MIXTURES CONTAINING WATER VAPOR
L. B. O'Kelly, G. S. Hurst and T. E. Bortner, Oak Ridge National Laboratory

C-4 ELECTRON ATTACHMENT AND DETACHMENT IN O_2 AT HIGH PRESSURES
J. L. Pack and A. V. Phelps, Westinghouse Research Laboratories

C-5 ELECTRON-ION RECOMBINATION COEFFICIENTS IN NITROGEN AND IN OXYGEN
W. H. Kasner, W. A. Rogers, and M. A. Biondi, Westinghouse Research Laboratories

C-6 MASS SPECTROMETRIC STUDIES OF AFTERGLOWS
W. L. Fite, J. A. Rutherford, W. R. Snow and V. A. J. van Lint, General Atomic

C-7 ELECTRON-ION RECOMBINATION IN LOW-TEMPERATURE GASEOUS PLASMAS
J. M. Anderson, General Electric Research Laboratory (Invited Paper)

C-8 FURTHER STUDIES OF ELECTRON REMOVAL PROCESSES IN NITRIC OXIDE PLASMAS AT LOW PRESSURES
R. C. Gunton, E. C. Y. Inn and T. M. Shaw, Lockheed Missiles and Space Company

C-9 NONLINEAR AMBIPOLAR DIFFUSION - PLASMA STRIATIONS - APPARENT RECOMBINATION
K. B. Persson, General Electric Research Laboratory

C-10 THE MEASUREMENT OF PLASMA LOSS PROCESSES BY FREE SPACE MICROWAVE TECHNIQUES
R. G. Buser, U. S. Army Signal Research and Development Laboratory

Thursday, October 12 (Continued)

2:30 P.M. SESSION D: ELECTROMAGNETIC (RF) RADIATION

Location: Ballroom, Hotel Van Curler

Chairman: A. V. Phelps, Westinghouse Research Laboratories

X D-1 THERMAL RADIATION FROM A PLASMA
M. N. Rosenbluth, General Atomic (Invited Paper) ill

D-2 LORENTZ INVARIANT TREATMENT OF THE PROPAGATION OF EM WAVES IN A PLASMA WITH A DENSITY GRADIENT
G. Lanza, P. Rothwell and R. Spurr, Northeastern University

D-3 ON SOLAR RADIO OUTBURSTS AND COSMIC RADIO NOISE AS RADIATION FROM A BOUNDED PLASMA
R. L. Moore, R. L. Moore Consultants

D-4 CYCLOTRON RADIATION FROM A GASEOUS DISCHARGE
B. Beeken, R. Goldman and L. Oster, Yale University

D-5 ION CYCLOTRON RESONANCE IN HYDROGEN, HELIUM AND NEON
S. J. Buchsbaum, Bell Telephone Laboratories

D-6 ELECTRON TEMPERATURES FROM IONIC SOUND WAVES
I. Alexeff and R. V. Neidigh, Oak Ridge National Laboratory

D-7 HIGH-FREQUENCY DIELECTRIC CONSTANT OF HIGH-FREQUENCY PLASMOIDS
A. J. Hatch, Argonne National Laboratory

Thursday Evening

6:30 P.M. COCKTAILS AND BANQUET: Ballroom, Hotel Van Curler

After-Dinner Speaker: Dr. C. G. Suits, Vice President and Director of Research, General Electric Company .... "NEW RICHES FROM OLD MINES"

Friday, October 13

9:00 A.M. SESSION E: DIFFUSION AND MOBILITY

Location: Auditorium, General Electric Research Laboratory

Chairman: S. J. Buchsbaum, Bell Telephone Laboratories

E-1 DETERMINATION OF THE THREE BODY RECOMBINATION RATE CONSTANT FOR NEUTRAL NITROGEN ATOMS IN N_2 BY ELECTRON SPIN RESONANCE
T. Marshall, University of Illinois

Friday, October 13 (Continued)

E-2 TEMPERATURE DEPENDENCE OF IONIC MOBILITIES IN GAS MIXTURES
G. E. Courville and M. A. Biondi, University of Pittsburgh

E-3 ELECTRON DRIFT AND DIFFUSION MEASUREMENTS IN HYDROGEN IN A TRANSVERSE STRONG MAGNETIC FIELD
M. J. Bernstein and W. B. Kunkel, Lawrence Radiation Laboratory, Berkeley

E-4 ORTHOGONAL AMBIPOLAR DIFFUSION CURRENTS IN A MAGNETIZED PLASMA
D. R. Whitehouse and H. B. Wollman, Massachusetts Institute of Technology

E-5 PLASMA DIFFUSION IN A MAGNETIC FIELD
S. D. Rothleder and D. J. Rose, Massachusetts Institute of Technology

E-6 PLASMA GENERATION AND CONFINEMENT MECHANISMS IN THE HOLLOW CATHODE DISCHARGE
L. M. Lidsky, S. D. Rothleder, D. J. Rose and S. Yoshikawa, Massachusetts Institute of Technology

E-7 POTENTIAL DISTRIBUTION IN THE REFLEX ARC
F. F. Chen and W. L. Harries, Princeton University

E-8 GENERATION OF A SYNTHESIZED PLASMA
J. R. Fendley and K. G. Hernqvist, RCA Laboratories

E-9 NONTHERMAL IONIZATION IN MAGNETOHYDRODYNAMIC GENERATORS
S. Tamor, D. J. BenDaniel, C. M. Bishop, W. F. Westendorp, L. M. Goldman and H. Hurwitz Jr., General Electric Research Laboratory

E-10 NON-EQUILIBRIUM N_2^+ - 1st NEGATIVE BAND EMISSION BEHIND SHOCK WAVES
W. Roth, Armour Research Foundation

E-11 EXPERIMENTAL INVESTIGATION OF ELECTRICALLY DRIVEN SHOCKS
J. B. Gerardo, C. D. Hendricks Jr. and L. Goldstein, University of Illinois

Friday, October 13 (Continued)

2:30 P.M. SESSION F: BREAKDOWN; DISCHARGE PHENOMENA

Location: Auditorium, General Electric Research Laboratory

Chairman: J. D. Cobine, General Electric Research Laboratory

F-1 SOLUTION OF THE SPACE CHARGE PROBLEM FOR A PULSED TOWNSEND DISCHARGE
J. A. Morrison and D. Edelson, Bell Telephone Laboratories

F-2 PULSED TOWNSEND DISCHARGE IN ELECTRON-ATTACHING GASES
K. B. McAfee Jr. and D. Edelson, Bell Telephone Laboratories

F-3 CONTRIBUTION TO THE THEORY OF HIGH-FREQUENCY BREAKDOWN
R. E. Kell, Cornell Aeronautical Laboratory

F-4 STREAMER SPARK BREAKDOWN AS REVEALED BY LICHTENBERG FIGURES
E. Nasser and L. B. Loeb, University of California

F-5 IMPEDANCES AND ION TRANSIT TIMES IN GLOW DISCHARGE TUBES
L. G. Schneekloth and A. L. Ward, Diamond Ordnance Fuze Laboratories

F-6 IONIZATION ENHANCEMENT OF A SEEDED FLAME PLASMA BY ELECTRICAL MEANS
J. D. Cobine, M. Lapp and J. A. Rich, General Electric Research Laboratory

F-7 GRADIENTS IN MERCURY-RARE GAS DISCHARGES
P. J. Walsh, G. W. Manning and D. A. Larson, Westinghouse

F-8 ION BEAM PROBE MEASUREMENTS ON THE THREE-DIMENSIONAL POTENTIAL WELL PRODUCED BY ELECTRON MULTIPACTING
E. Clothiaux and H. B. Williams, New Mexico State University

F-9 THE USE OF CATAPHORESIS TO DETERMINE DISCHARGE PARAMETERS
W. Muller and E. F. Tubbs, General Telephone and Electronics Laboratories

F-10 A SIMPLE MEANS OF EXTRACTING ELECTRICAL ENERGY FROM HIGH-TEMPERATURE PLASMAS
J. F. Waymouth, Sylvania Lighting Products

SESSION A

WEDNESDAY, OCTOBER 11
9:00 A. M.

COLLISION PROCESSES, ELECTRON ENERGY DISTRIBUTIONS

CHAIRMAN

BENJAMIN BEDERSON
NEW YORK UNIVERSITY

A-1 ION ENERGIES AT THE CATHODE OF A GLOW DISCHARGE

W.D. Davis and T.A. Vanderslice
General Electric Research Laboratory
Schenectady, New York

The energy distribution for the various ionic species striking the cathode of a D.C. glow discharge were determined for the gases H_2, He, Ne, and A. The ions were allowed to pass through a small pinhole in the cathode, accelerated by an electric field and then analyzed for energy and mass by successive electrostatic and magnetic sector-type analyzers. Pressures in the range 0.1 to 1 or 2 mm Hg and voltages up to 800 v were used for the discharge. Results obtained ranged from spectrums that showed that only very low energy ions existed to ones that indicated that the majority of the ions reaching the cathode had the full cathode fall energy. These observations will be compared with the calculated energy distributions obtained by assuming that all the ions originate from the negative glow and that the main energy-loss mechanism is one of charge exchange.

A-2 SPUTTERING YIELDS AS A FUNCTION OF ANGLE OF INCIDENCE*

G. D. Magnuson, C. N. Abeyta, and P. A. Harkins
General Dynamics/Convair, Physics Section

Sputtering yields of polycrystalline targets of Cu and Fe bombarded by 500-volt Hg^+ ions have been measured as a function of the angle of incidence, measured from the surface normal. The yields were measured by a direct weight loss method using a quartz helical microbalance located in the vacuum system. A mercury discharge system similar to that used by Wehner was employed as the source of Hg^+ ions. Ions were extracted from the discharge at the desired accelerating potential and were then allowed to impinge on the target which was inclined at the desired angle of incidence. The samples were maintained at a temperature above 300°C during bombardment to prevent amalgamation. It was found that the sputtering yield $S(1+\gamma)$, where γ is the secondary electron coefficient, increases with increasing angle of incidence. Comparison with previous data will be made. Optical reflectivity curves of the sputtered samples will also be presented.

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*This work was supported in part by the National Aeronautics and Space Administration, Huntsville, Alabama.

A-3 A TRUNCATED COULOMB CROSS SECTION

Don E. Harrison, Jr.
U. S. Naval Postgraduate School
Monterey, California

A recent attempt to fit theoretical curves to sputtering data required a cross section which approaches hard sphere behavior at low energies and a pure coulomb interaction at high energies. A truncated coulomb potential

$$V(r) = Z_1 Z_2 e^2/r , \quad 0 \leqslant r \leqslant r_T ,$$
$$= 0 \quad , \quad r_T < r \leqslant \infty ,$$

has these properties. The orbital equations can be solved, and if a distance of closest approach, R, is defined from some interaction potential, the resulting cross section becomes hard sphere when $R = r_T$, and approaches a pure coulomb when $R \ll r_T$.

The cross section with R calculated from the Bohr potential gave unexpectedly good magnitude agreement and excellent one parameter fits of sputtering data in the energy range from 150 ev to 40 kev, with mass ratios ranging from D^+-Cu to Hg^+-W.

A-4

ELECTRON CAPTURE AND LOSS IN ION-ATOM COLLISIONS BELOW 25 Kev*

P.R. Jones and I.S. Frost
University of Massachusetts

Measurements have been made of single collisions of Ne^+ and A^+ with an A target. The incident ions ranged in energy from 20 kev to 3 kev and were analyzed at scattering angles from 3° to 20°. The scattered incident particles at each angle were found in general to be neutral, singly ionized, and doubly ionized, corresponding respectively to the processes of electron capture, scattering without change of charge, and electron loss. The probability of electron loss is found to become very small (< 0.01) for small-angle collisions at lower energies. The electron capture probability is found to oscillate both as a function of scattering angle and incident ion energy, there being also a general trend toward higher capture probabilities at smaller angles and lower energies. Measurements are still in progress, comparison being made in several cases with the previously reported data of Everhart and co-workers.(1)

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*Supported by the National Science Foundation.

(1) Ziemba, F.P., G.J. Lockwood, G.H. Morgan, and E. Everhart, Phys. Rev. 118, 1552 (1960).

A-5

PRELIMINARY MEASUREMENTS OF THE PHOTOIONIZATION CROSS SECTION OF SINGLY IONIZED XENON*

R. B. Cairns† and G. L. Weissler
Department of Physics
University of Southern California
Los Angeles 7, California

Techniques for the measurement of photo-absorption and photoionization cross sections of neutral gases are well known. This report describes an attempt to obtain corresponding quantities for ions. In order to produce high number densities of ions, a Kolb-type(1) magnetically driven shock tube was used. A pulsed beam of radiation was made to pass through the highly ionized plasma behind the shock front and was then dispersed by a windowless normal incidence vacuum monochromator. Photo multipliers, mounted behind exit slits at appropriately chosen wavelengths, monitored light intensities as a function of time. The simplicity of the absorption spectra of rare gases suggested the study of the following reactions:

$$Xe + h\nu_1 \; (> 12.13 \text{ ev}; \; \lambda_1 < 1022 \text{ A}) \xrightarrow{\sigma_1} Xe^+ + e^-; \qquad (1)$$

$$Xe^+ + h\nu_2 \; (> 21.19 \text{ ev}; \; \lambda_2 < 585 \text{ A}) \xrightarrow{\sigma_2} Xe^{++} + e^-. \qquad (2)$$

Xenon was selected because the above wavelength thresholds were within the capabilities of the monochromator and because it was reasonable to assume that Xenon absorbs more strongly than Argon. The cross sections for neutral Xe were determined to be $\sigma_1 \simeq 53$ Mb at 760 A and $\sigma_1 \simeq 32$ Mb at 555 A. With the plasma in the optical path of the probing radiation beam, no absorption was observed at 760 A, indicating nearly complete ionization behind the shock front. In contrast, there was a reduction in intensity at 555 A. This was attributed to the photoionization of Xe^+, eq. (2). On the basis of certain simplifying assumptions, the photoionization cross section of singly ionized Xenon was found to be $\sigma_2 \sim 16$ Mb at 555 A.

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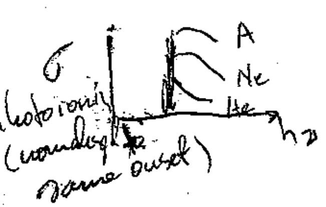
*This research has been supported by the U.S. Army Research Office (Durham), by O.N.R., and by ARPA.

† A N.A.T.O. Fellowship is hereby gratefully acknowledged.

(1) A.C. Kolb, Phys. Rev. 107, 345 (1957).



He+ requires grazing incidence
GLW's is normal incidence

A-6 IONIZATION OF A GAS BY RADIATION FROM A DISCHARGE

Roy E. Voshall and Gaylord W. Penney
Carnegie Institute of Technology

With a discharge and a movable collector both mounted in a vacuum chamber, ionization by radiation from the discharge was measured for air, oxygen, and nitrogen at pressures of 2.0 to 10 mm of Hg and at a distance of 8 to 18 cm. The source of ionizing radiation was the positive column of a normal glow discharge. Ions formed outside the chamber were excluded from the measuring section by a system of grids. Experiments at different discharge ion densities indicate that the ionizing radiation is produced primarily by collisions in the discharge rather than by electron-ion recombinations. Generalized coordinates reduce the data for oxygen to a single curve but air and nitrogen do not reduce to single curves. The behavior of air and nitrogen can be explained by an additional ionizing mechanism which does not travel in a straight line such as imprisoned radiation or metastable states. Experiments in which the collector could not "see" the discharge showed such a mechanism for air and nitrogen but not for oxygen. Application of this photoionization data to the initiation of positive corona accounts for the observed corona starting voltage.

A-7 REARRANGEMENT SCATTERING WITH TWO POTENTIALS

Bernard A. Lippmann
Lawrence Radiation Laboratory, Livermore

With the potentials $v_1' + v_2'$ and $v_1'' + v_2''$ present in the original (') and rearranged (") channels, the transition amplitude for rearrangement collisions obeys the well-known relation $T_{ba} = \langle \Phi_b'', (v_1'' + v_2'') \Psi_a^{(+)'} \rangle = \langle \Psi_b^{(-)''}, (v_1' + v_2') \Phi_a' \rangle$. Introducing $\chi_a^{(\pm)'}$ and $\chi_b^{(\pm)''}$, the exact scattering state vectors with v_1' and v_1'' respectively acting alone, we derive a new identity: T_{ba} =

$$\langle \Phi_b'', v_1'' \chi_a^{(+)'} \rangle + \langle \chi_b^{(-)'}, v_2'' \Phi_a^{(+)'} \rangle + \langle (\chi_b^{(-)''} - \Phi_b''), (v_2' - v_2'') \chi_a^{(+)'} \rangle =$$

$$\langle \chi_b^{(-)''}, v_1' \Phi_a' \rangle + \langle \Phi_b^{(-)''}, v_2' \chi_a^{(+)'} \rangle + \langle \chi_b^{(-)''}, (v_2'' - v_2') (\chi_a^{(+)'} - \Phi_a') \rangle .$$ In recent

work[1, 2, 3], only the middle term (MT) in each expression for T_{ba} has been used; the remaining terms (RT) do not appear. The discussion in Ref. 1 shows RT is zero for the case considered, but Refs. 2 and 3 fail to do this: Ref. 2 starts with MT as the transition amplitude "one finds", while Ref. 3 provides a proof of this assertion that we regard as incomplete. We feel that the absence of a convincing demonstration that RT is zero or small for the cases considered in Refs. 2 and 3 impairs the dependability of their results.

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(1) Day, Rodberg, Snow, and Sucher, Phys. Rev. 123, 1051 (1961).

(2) R.H. Bassel and E. Gerjuoy, Phys. Rev. 117, 749 (1960).

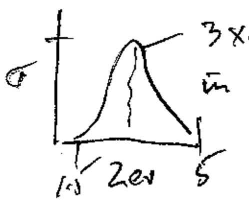
(3) M.H. Mittleman, Phys. Rev. 122, 1930 (1961).

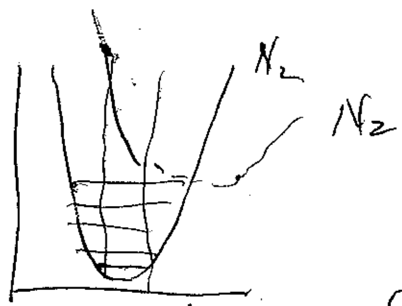
Invited Paper

A-8 INELASTIC COLLISIONS OF SLOW ELECTRONS WITH MOLECULES

George J. Schulz
Westinghouse Research Laboratories

vibrational excitation:
Theory $\frac{m}{M}$ means small σ for vibrational exc. small
Expt does not bear this out

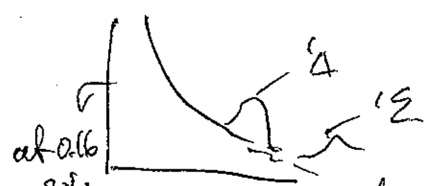




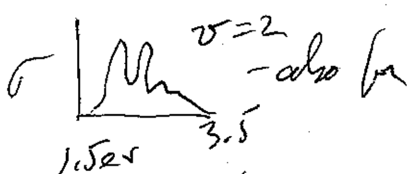
Double e.s. analyzer for electrons which measures forward scattering – now have one for 60°.

No theory yet to calculate σ's
Apply to other molecules?
O_2

Sweeps energy by [illegible] of volts at 2.6 ev – see vibrational structure



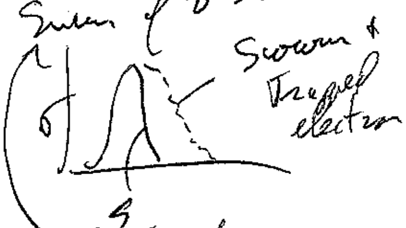
vib quant no.

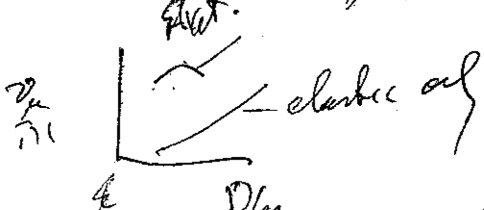


– also for v = 3 – 8

Sum of v = 2 – 8

Frost + Phelps: $\frac{v_d}{N} = \frac{E/N}{D/\mu - \frac{kT}{e}}$ w adiabatic
H_2

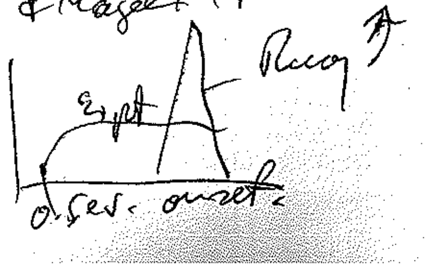




Theory seems to give a low cross section at onset of 0.5 ev. [illegible]

believes this is right – electron energy dist. much better than e.s.

Theory of Gerjuoy + Stein + Mason (Mass?) H_2

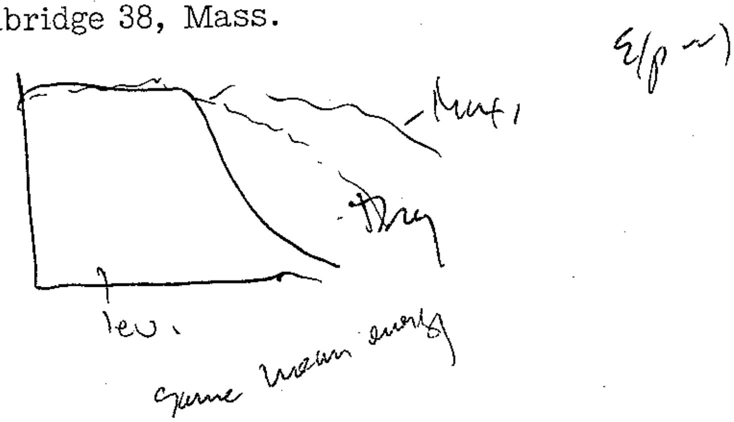


A-9 ELECTRON ENERGY DISTRIBUTION IN SLIGHTLY IONIZED GASES UNDER THE INFLUENCE OF ELECTRIC AND MAGNETIC FIELDS

Nathaniel P. Carleton* and Lawrence R. Megill
United States National Bureau of Standards
Boulder, Colorado

We obtain numerically computed solutions to the Boltzmann equation giving the electron energy distribution in weakly ionized air under the following assumptions: (1) that there are present a static magnetic field and an electric field of constant direction (perpendicular to the magnetic field) and of constant rms value; (2) that the gas is homogeneous and the fields uniform in space; (3) that the degree of ionization is weak enough so that electron-electron and electron-ion collisions are negligible; (4) that the fields are such that the average electron energy is much larger than the thermal energy of the gas molecules, and that the heating of the gas by the electrons is negligible; (5) that processes of creation and removal of free electrons are negligible; and (6) that electrons may lose energy in elastic collisions and may also excite rotational, vibrational, and electronic degrees of freedom. To describe these energy-loss processes we use experimental cross sections. We take the constituents of the air to be N_2, O_2, and O, the latter being included for upper atmosphere applications. Our results extend those of earlier authors in demonstrating that improper treatment of inelastic collisions may cause large errors in predicted distribution functions. We further show that for very high exciting frequencies the distribution function is independent of the total gas density, so that the ratio of electric field to gas density, commonly used as a parameter, is no longer useful.

*National Research Council-National Bureau of Standards Post-doctoral Research Associate, 1960-61, while on leave from Physics Department, Harvard University, Cambridge 38, Mass.



A-10 ELECTRON ENERGY DISTRIBUTIONS IN VARIOUS DISCHARGES

Bentley T. Barnes
Lamp Research Laboratory
General Electric

With tubes 34 mm i.d. at 1.4 or 1.0 amp in 7 mm Ne and 1.0 - 2.0 mm A, Kr and Xe, the distributions were Maxwellian. In the measurable range of electron current (at least three decades) the maximum electron energy U was 0.64 - 0.78 times the minimum for excitation. Extrapolated distributions were used to compute the power spent in excitation. For argon, the result was 0.96 times the value obtained by subtracting elastic and wall current losses from the input; with neon, the ratio was 4.2. Corrections for power returned to the electrons and for stepwise excitation are needed but unknown. For the argon discharge, a six-decade Maxwellian distribution is indicated. With mercury vapor (2.5 - 25μ) in argon (1.6 and 3.0 mm) the distribution f(U) measured over 3 - 4 decades of electron current was Maxwellian only at the lower gas pressure and mainly at the highest current (1.50 amp). With 0.25 per cent Kr in 6.4 mm Ne, at 0.5 amp, one obtains a pink core surrounded by a pale violet mantle. f(U) is nearly the same in these two regions for $U < 7$ ev, but it falls off much faster in the mantle for $U > 10$ ev.

A-11

POLARIZATION OF SPECTRAL EMISSION INDUCED BY ELECTRON IMPACT ON HELIUM*

R. H. Hughes, R. B. Kay, and L. D. Weaver
University of Arkansas

The polarization of several lines induced by electron impact on helium is being studied as a function of electron energy and pressure. Data has been obtained on the lines $\lambda 3889$ A ($3^3P \rightarrow 2^3S$), $\lambda 4922$ A ($4^1D \rightarrow 2^1P$), and $\lambda 4471$ A ($4^3D \rightarrow 2^3P$). The $\lambda 3889$ polarization data at low energy confirm the minimum in the polarization found by Lamb and Maiman.(1) We obtain a minimum polarization at ≈ 25.5 volts with rising polarization to about 24 volts, the lowest energy used. $\lambda 4922$ shows a peak polarization of slightly over 50 per cent (at ≈ 31 volts and $< 1\mu$ pressure). Both $\lambda 4922$ and $\lambda 4471$ exhibit a monotonic decrease in polarization with decreasing energy past the peak. In the "high" energy region, the point at which the polarization changes sign is pressure dependent for all three lines. This "cross-over" point occurs at higher energies as the pressure is decreased. The polarization is sensitive to secondary excitation processes, such as cascade and collisions of the second kind.

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*Supported by the Air Force Office of Scientific Research.

(1) W. E. Lamb and T. H. Maiman, Phys. Rev. 105, 573 (1957).

McKeown says this is important & should be done again

SESSION B

WEDNESDAY, OCTOBER 11
2:30 P. M.

EXCITATION AND IONIZATION

CHAIRMAN

LEONARD B. LOEB
UNIVERSITY OF CALIFORNIA

B-1

CHEMIONIZATION IN GASES

C. Gatz, F.T. Smith and H. Wise
Chemical Physics Division, Stanford Research Institute
Menlo Park, California

Chemionization may be an important source of charge production for plasmas in which exothermic chemical reactions can occur. Such processes have been postulated for the reaction zone of hydrocarbon flames and for the nitrogen afterglow. Several recently identified chemionization reactions are briefly reviewed. For a detailed understanding of mechanisms of chemionization, fundamental kinetic data are needed. We have used saturation current techniques to measure the total rate of charge production in a flow system containing cesium vapor and partially dissociated nitrogen. Saturation currents proportional to the square of the nitrogen atom concentration were observed. If one assumes all charges are produced by the chemionization reaction $N + N + Cs \rightarrow N_2 + Cs^+ + e$, the apparent rate constant of this reaction is 10^{-31} (atom cm^{-3})$^{-2}$ - sec^{-1}. Additional experiments are in progress to determine the contribution to charge production by other possible reactions in this system.

B-2 AUGER TRANSITIONS OCCURRING DURING CHEMISORPTION*

P.M. Waters
Westinghouse Research Laboratories
Pittsburgh 35, Pennsylvania

The emission of electrons has been observed during the adsorption of the first monolayer of oxygen on a tungsten "flash filament". The yield for this adsorption emission was determined to be 2.5×10^{-4} electrons per molecule adsorbed for coverages less than 0.3 monolayers, and to decrease for coverages greater than this. Although small, this yield is comparable with the photoelectric quantum efficiency for $h\nu \sim 5$ ev. These excited electrons are shown to arise in a process other than the photoelectric effect. It is suggested that the observed emission results from Auger transitions during chemisorption, i.e., the so-called "heat of adsorption" is transferred to one metal electron in an adsorption event. This electron subsequently has a finite probability of escaping the metal, if the energy transferred exceeds the work function of the metal. That such a process should occur for O_2 on W follows from the facts that measured heats of adsorption range from 5.3 to 8.2 ev/event and the work function of clean polycrystalline tungsten is $\sim$4.5 ev. Calculations based on this model are made in a manner similar to that employed by Hagstrum. The agreement between theory and experiment is reasonable.

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*This work was supported by the U.S. Atomic Energy Commission under Contract AT-(30-1)-2176.

B-3 LOWERING OF THE IONIZATION POTENTIAL IN A PLASMA

G. Ecker and W. Kröll
Institut für Theoretische Physik der Universität Bonn, Bonn.

In a plasma the ionization potential of a neutral atom is decreased due to the presence of the microfield. Several attempts have been made in the past to calculate this effective ionization potential. These calculations using statistical or thermodynamical procedures give quite different results. Some produce only a "polarization term", some only a "lattice-or field term". We ourselves treated the problem and found both of these terms. All results show certain quantitative differences. But apart from this there have been principal differences in opinion. Some arguments aim to remove the "lattice term" altogether. Others try to double its value. We present here a general statistical treatment describing the effective ionization potential in the whole density region above and below the so-called critical density. The results are compared with the results of all earlier calculations and the cause for the discrepancies is revealed.

B-4 INTERACTION OF RADIATION AND MATTER IN A PLASMA*

Ludwig Oster
Laboratory of Marine Physics
Yale University, and Yale University Observatory
New Haven, Connecticut

The familiar radiation laws are reviewed, showing that the phenomenological coefficients of emission, absorption and conductivity are merely variants of the same basic quantity and can be readily transformed into each other. It follows that for a specific emission and absorption mechanism the calculation of either one of the coefficients is sufficient. The atomistic coefficients of spontaneous emission, absorption and induced emission and their mutual relations are then derived from Einstein's quantum probabilities for the case of radiative transitions of free particles. In high energy plasmas the atomistic mechanisms of bremsstrahlung and cyclotron radiation are the most prominent ones. Cross sections are given for both processes, including quantum effects. Finally, emission and absorption coefficients are derived for arbitrary non-equilibrium plasmas, the energy transfer equation and its solution are discussed.

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*Supported by the Office of Naval Research.

Invited Paper

B-5

COHERENT OSCILLATIONS AT OPTICAL FREQUENCIES USING A GASEOUS DISCHARGE

Ali Javan
Bell Telephone Laboratories

B-6 TRANSMITTANCE MEASUREMENTS IN A MERCURY DISCHARGE WITH ADDITIONS OF He OR H_2

J. T. LaTourrette and N. A. Peppers
General Electric Research Laboratory
Schenectady, New York

Butaeva and Fabrikant[1] have reported achieving a transmittance greater than unity for the visible triplet of mercury (at wave lengths 5460, 4358 and 4047 A) in a mercury discharge containing He at 4 torr pressure. They employed a dc discharge with electrodes of unspecified geometry and report a range of transmittance of 1.14-1.29, 1.13-1.23 and 1.20 respectively for the above wavelengths in a cell 36 cm long. They noted that their results were difficult to understand theoretically. We have investigated mercury discharges with various added noble gases employing rf excitation with electrodes external to a quartz discharge cell 20 cm long by 4 cm diameter. The optical system is typical for transmittance measurements and is equivalent to that of Reference 1. The transmittance is taken to be $T = (I_{SC} - I_C)/I_S$, where I_S, I_C and I_{SC} are the outputs of the photomultiplier detector when the source only, the absorption cell only, and both the source and cell are excited respectively. In no case has a transmittance greater than unity been observed to date, although adding H_2 makes the discharge nearly transparent. Indeed, in the case of 4.6 torr of pure He added to Hg, transmittance of 0.20, 0.54 and 0.14 respectively were obtained. However, with the addition of some H_2, the discharge became nearly transparent with transmittance 0.99, 0.98 and 0.96 respectively. It is interesting to note that if one computes the ratio, I_{SC}/I_S, then one obtains a "pseudo-transmittance" of 1.12, 1.06 and 1.08 for the latter case. This, however, only indicates that the excitation temperature of the cell is greater than the excitation temperature of the source, a not unusual result.

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(1) R. A. Butaeva and V. A. Fabrikant, Investigations in Experimental and Theoretical Physics (in memoriam to G. S. Landsberg), USSR Academy of Sciences Press (1959), pages 62-70.

SESSION C

THURSDAY, OCTOBER 12
9:00 A. M.

ATTACHMENT AND RECOMBINATION

CHAIRMAN

LEWIS M. BRANSCOMB
NATIONAL BUREAU OF STANDARDS

C-1

CREATION AND DESTRUCTION OF CHARGED PARTICLES AND EXCITED STATES IN HELIUM AFTERGLOW*

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

We summarize consequences of measurements of magnitude and time dependence of electron concentration and of spectrally resolved atomic and molecular radiation at pressures of 0.25 to 20 mm Hg. These measurements provide better knowledge and control of gas purity, greater dynamic range, and much greater spectroscopic detail than those of previous work. Microwave cavity measurements of ambipolar diffusion loss rates infer ionic mobility at pressures below 3 mm to be that of the atomic ion, reduced by diffusion cooling, and above that of the molecular ion. The mobilities at 300°K at 10.7 and 16.2 cm^2/volt-sec. respectively, agreeing with drift-tube measurements for the atomic ion but 20 per cent lower for the molecular ion. Limits on recombination coefficient α are: for pressure about 1 mm, $\alpha > 2 \times 10^{-10}$ cm^3/sec; above 15 mm, $3 \times 10^{-10} < \alpha < 2 \times 10^{-9}$. Attempts to reconcile these and other detailed results with currently popular theories of recombination and of processes for production of radiating excited states reveal ambiguities or internal conflicts. Suggestions for additional theory and measurements are given.

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

C-2

LOW ENERGY ELECTRON ATTACHMENT TO AND DETACHMENT FROM OXYGEN

D.C. Conway
Purdue University

The experimental data on electron attachment in pure O_2 and mixtures of O_2 and other gases are reviewed. It is concluded that the Hurst and Bortner mechanism(1) should be modified. A general rate equation is derived, the rate constants calculated, and the equation shown to be in general agreement with the reaction orders which have been obtained with the exception of one of the terms which was found for CO_2-O_2 mixtures.(2) The author's interpretation of the experimental data leads to a value of 1.0×10^9 sec^{-1} for the rate constant for electron detachment from the vibrationally excited O_2^-. This is a factor of 20 larger than the previously calculated value.(1) The cause for this disagreement is examined. Further calculations indicate that the O_2^- in the experiments of Phelps and Pack(3) was in the ground state and consequently that the electron affinity of O_2 is 0.46 ev.

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(1) G.S. Hurst and T.E. Bortner, Phys. Rev. 114, 116 (1959).

(2) L.B. O'Kelly, G.S. Hurst, and T.E. Bortner, ORNL-2887 (1960).

(3) A.V. Phelps and J.L. Pack, Phys. Rev. Letters 6, 111 (1961).

Phelps ~~found~~ finds CO_4^- in a preliminary measurement - as Conway predicted

C-3

ELECTRON CAPTURE IN GAS MIXTURES CONTAINING WATER VAPOR

L.B. O'Kelly, G.S. Hurst, and T.E. Bortner
Health Physics Division
Oak Ridge National Laboratory*

Electron capture in gas mixtures containing water vapor has been studied by use of an electron swarm method. High energy electron capture was studied by mixing small amounts of water vapor with argon which was used as the gas in an ion chamber. It was found that the capture cross section (due to the formation of H^-) when integrated over energy was 7.7×10^{-18} cm^2 ev. This is consistent with the value of 6.5×10^{-18} cm^2 ev obtained in a recent electron beam experiment by Buchel'nikova.(1) The capture process was found to peak at an energy of 6.4 ev which agrees quite well with the peak energy found by Buchel'nikova, although in general it disagrees with other values obtained by mass spectroscopy. Capture at low electron energies was studied by using mixtures of water vapor with various molecular gases in the ion chamber. The capture cross section at low electron energies has been found to be very small. An exception to this occurs in carbon dioxide-water vapor mixtures where there appears to be a small pressure-dependent capture process. During the course of these studies it was necessary to measure electron drift velocity in the various gas mixtures. The addition of water vapor to argon caused a large increase in drift velocity. In nitrogen a similar effect was observed although the increase was smaller. In carbon dioxide, ethylene, and methane the drift velocity decreased with the addition of water vapor.

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*Operated by Union Carbide Corporation for the U.S. Atomic Energy Commission.

(1) I.S. Buchel'nikova, Soviet Physics JETP 35(8), 783 (1959).

Assume dissoc. capture giving H^- & that it has a δ-function σ.

For A - H_2O, a small amount of H_2O makes a large increase in drift velocity.

Don't find attach. in pure H_2O at low energy

C-4

ELECTRON ATTACHMENT AND DETACHMENT IN O_2 AT HIGH PRESSURES*

J.L. Pack and A.V. Phelps
Westinghouse Research Laboratories
Pittsburgh 35, Pennsylvania

Electron attachment and detachment in molecular oxygen are studied at pressures between 50 and 700 mm Hg at 477°K and 529°K. The rates of electron attachment and detachment are large and very nearly equal so that the electrons and ions traverse the drift tube in a narrow pulse. Their velocity is $v_- + (\nu_d v_e N/\nu_a)(1/N)$; v_- and v_e are the negative ion and electron drift velocities, ν_a and ν_d are the frequencies of electron attachment and detachment collisions, and N is the oxygen density. The results are consistent with the reaction $e + 2O_2 \rightleftharpoons O_2^- + O_2$. Combining high pressure data with improved measurements at low pressures[1] yields detachment frequencies about 30 per cent above previous values.[1] High pressure measurements at very low E/p and electron collision frequency data[2] yield an electron affinity in satisfactory agreement with previous estimates.[1] If the O_2^- ions are in an excited state, the coefficient of de-excitation in collisions with oxygen molecules is less than 10^{-18} cm^3/sec ($\sim 5 \times 10^8$ elastic collisions).

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*Supported in part by the Air Force Research and Development Command.

(1) A.V. Phelps and J.L. Pack, Phys. Rev. Letters 6, 111 (1961).

(2) V.A.J. van Lint, E.G. Wilkner, and D.L. Trueblood, Rept. No. TR59-43 (August 1959) General Atomic Division of General Dynamics Corp., San Diego, Calif. (unpublished).

EA = 0.43 ev.

ν_d ~ 30% larger than prev.; ind. of E/p

ν_a [illegible]

C-5

ELECTRON-ION RECOMBINATION COEFFICIENTS IN NITROGEN AND IN OXYGEN*

W.H. Kasner, W.A. Rogers† and M.A. Biondi**
Westinghouse Research Laboratories
Pittsburgh 35, Pennsylvania

Conventional microwave apparatus and an rf mass spectrometer have been used simultaneously to study the afterglow decay of microwave discharges in N_2-He, N_2-Ne, and O_2-Ne gas mixtures. Mass analysis shows that for nitrogen or oxygen partial pressures of less than 10^{-2}mm Hg only the diatomic ions N_2^+, or O_2^+, are significant in the afterglow, while at higher partial pressure more complex nitrogen, or oxygen, ions are observed in varying quantities. At low total gas pressure ambipolar diffusion loss of ions and electrons is observed. The approximate D_ap values obtained from these studies are 900 (N_2^+ in helium), 450 (N_2^+ in neon), and 450 (O_2^+ in neon) in units of (cm^2/sec) - (mm Hg). In the N_2-Ne and O_2-Ne mixtures, at neon partial pressures greater than ~12 mm Hg, the reciprocal electron density varies linearly with time for at least a ten-fold change in electron density, indicating that the afterglow decay mechanism is chiefly recombination of positive ions and electrons. The measured recombination coefficients for N_2^+ ions and electrons and for O_2^+ ions and electrons are (5.9 ± 1.0) x 10^{-7} cm^3/sec and (3.8 ± 1.0) x 10^{-7} cm^3/sec respectively. $N_3^+ - N_4^+ \sim 2 \times 10^{-6}$ (agree with Biondi & Brown's earlier work)

*This research has been supported in part by the Army Research Office (Durham).

† Present address: Physics Dept., Thiel College, Greenville, Pa.

** Physics Dept., University of Pittsburgh, Pittsburgh 13, Pa.

Bake at 400°C, background p ~ 10^{-8}
In pure N_2 + N_2-He, 0.1-7mm pressure found N_3^+ & N_4^+
below 10^{-2} mm, N_2^+ by far predominates.

C-6

MASS SPECTROMETRIC STUDIES OF AFTERFLOWS

W.L. Fite, J.A. Rutherford, W.R. Snow and V.A.J. van Lint
General Atomic
San Diego, California

For the study of thermal electronic and ionic collision processes in atmospheric gases and mixtures thereof, a series of experiments has been conducted in which afterglows have been examined with a fast mass spectrometer. The afterglows have been those following pulses of (1) radio-frequency discharge power and (2) high energy (20-Mev) electrons from the General Atomic Linear Accelerator. Comparison of both the positive and negative ion mass spectra in the two types of afterglows permits the assessment of some of the differences in the ion populations produced by the two methods. Examination of the growth and decay of each of the many ion species observed in the afterglows permits the identification of some of the more prominent processes occurring in the afterglows and provides estimates of the rate coefficients for certain ion clustering, charge transfer and ion exchange processes.

This research was supported by the Defense Atomic Support Agency under Contract DA-49-146-XZ-049.

John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporations.

$N_2^+ + N_2 \rightarrow N_4^+$ 1 mm 1.5×10^{-13} cm³/sec.

In air with afterglow NO^+ predominates after 3-400 μsec, lasts till > 5 msec

$O_2^+ + N_2 \rightarrow NO + NO^+$ α

$\alpha + \frac{\beta}{2000} \sim 6 \times 10^{-13}$

$O_2^+ + NO \rightarrow O_2 + NO^+$ β

Much less NO^+ in linac expt - maybe in afterglow, NO^+ is made during discharge

Mass 21.3 $O_3^- \rightarrow O_2^- + O$ on impact $\alpha \sim 10^{-14}$ very large

Finds mass 12 - maybe He_3^+

Biondi says no He_3^+ if use liq He instead of spectroscopic gas

$N_2^+ + O_2 \rightarrow N_2 + O_2^+$ 3×10^{-10}

Can't yet estimate a recomb. coeff for NO^+

61 RL 28176

Invited Paper

C-7

ELECTRON-ION RECOMBINATION IN LOW-TEMPERATURE GASEOUS PLASMAS

– mostly He

John M. Anderson – Report from GE
General Electric Research Laboratory

He_2^+ states – Buckingham + Dalgarno

Do He_2^+ exist? He_3^+

Kerr $3 \times 10^{-10} < \alpha < 2 \times 10^{-8}$

Biondi 10^{-8}

Oskam small; couldn't measure

Chen + Goldstein $\alpha \sim 10^{-9}$ (9×10^{-9}) $T^{-3/2}$

maybe another type of capture?

Stellarator group 1μ gas (lower than closed)
2 electron – 3 body decay indicated
$\alpha \sim T^{-5/2}$

– Graph summarizing all α's from H_2 to Xe

Averages seem to give $\alpha \sim M^{3/2}$
but unconvincing.

Probe measurements & pressure.

~~Molecular~~ Atmospheric gases way off

C-8

FURTHER STUDIES OF ELECTRON REMOVAL PROCESSES IN NITRIC OXIDE PLASMAS AT LOW PRESSURES

R.C. Gunton, E.C.Y. Inn and T.M. Shaw
Lockheed Missiles and Space Company

The measurement of rate coefficients of electron loss processes in nitric oxide plasmas has been continued by a method previously described.[1] Measurements below 1 mm Hg, where ambipolar diffusion is dominant, yielded a diffusion constant, $D_a p$, of about 80 cm^2 sec^{-1} mm Hg. In this same regime but at high initial electron densities, recombination appears to be emphasized relative to diffusion and a two-body recombination coefficient of about 10^{-6} cm^3 sec^{-1} was obtained from an analysis of the measured decays. As reported previously, three-body attachment of electrons occurs and becomes dominant at higher pressures. At low pressures, where diffusion is the dominant loss mechanism, an enhancement of the decay rate was observed during the later stages of decay. This may be related to the accumulation of negative ions in the plasma. The rate of decay of electron density is markedly influenced if, during the decay, the electron energy is raised by the application of low power microwave heating pulses to the plasma. In particular, an increase in electron density attributed to detachment of electrons from negative ions has been observed.

(1) R.C. Gunton and E.C.Y. Inn, Bull. Am. Phys. Soc. 6, 387 (1961).

$\alpha \sim 10^{-6}$ within a factor of 2
Biondi & Gray & Kerr error?

C-9 NONLINEAR AMBIPOLAR DIFFUSION - PLASMA STRIATIONS - APPARENT RECOMBINATION*

Karl Birger Persson
General Electric Research Laboratory

A simple solution, exact for practical purposes, of the nonlinear ambipolar diffusion equation, applicable to the steady-state plasma between infinite parallel plates, is derived and its implications are discussed. It is shown that this solution can be transferred to the two and three dimensional cases with only minor modifications insofar as the nonlinearities are concerned. The main nonlinearity in the diffusion mechanism is due to the commonly-neglected inertial forces. They set in and become important whenever Bohm's criterion for pure diffusion--diffusion drift velocity less than the average thermal velocity --is violated. The onset of the inertial forces causes a choking of the diffusion flow and essentially discontinuous changes in electron density, thereby introducing artificial boundaries within the plasma (striations). The critical dimension of the plasma contained within these artificial boundaries is approximately $\sqrt{D_a/\nu_i}$ where D_a is the ambipolar diffusion coefficient and ν_i the ionization frequency. Whenever this characteristic length is less than the diffusion length of the fundamental diffusion mode of the vessel containing the plasma, the plasma becomes strongly nonuniform and it can no longer be described by a fundamental diffusion mode but consists instead of "lumps" of plasma with dimensions approximately given by the characteristic length $\sqrt{D_a/\nu_i}$. This characteristic length decreases with increasing molecular weight and decreasing ionization potential of the parent gas. These nonlinearities are therefore particularly important in the heavy gases with low ionization potentials as is easily demonstrated experimentally. The "choking" of the diffusion flow is not limited to steady state plasmas but will also appear in the early afterglow plasma whenever the initially-generated plasma does not "fill" the discharge vessel. The decay of the electron density in the early afterglow is then governed by a nonlinear diffusion mechanism (inertia controlled) and may be interpreted, unfortunately, as a recombination process in certain cases where the average electron density is measured.

*This work was supported in part by the Air Force Cambridge Research Center, Contract No. AF 19(604)-7433.

C-10

THE MEASUREMENT OF PLASMA LOSS PROCESSES BY FREE SPACE MICROWAVE TECHNIQUES

R. G. Buser
U.S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey

A 4-mm microwave interferometer has been used to measure the decay mechanism in the afterglow of a very intense He discharge (Pressure range: 50 - 1000 micron). We first explore how the possible decay mechanisms of the electron concentration (ambipolar diffusion, volume recombination, attachment) are connected with the quantity which is measured, namely the integrated index of refraction and its change with time. We then compare our measurements with the theory. Some of the results and a number of theoretical and experimental problems are discussed.

SESSION D

THURSDAY, OCTOBER 12
2:30 P. M.

ELECTROMAGNETIC (RF) RADIATION

CHAIRMAN

ARTHUR V. PHELPS
WESTINGHOUSE RESEARCH LABORATORIES

Invited Paper

D-1

THERMAL RADIATION FROM A PLASMA

Marshall N. Rosenbluth
General Atomic

D-2

LORENTZ INVARIANT TREATMENT OF THE PROPAGATION OF EM WAVES IN A PLASMA WITH A DENSITY GRADIENT

G. Lanza, P. Rothwell, and R. Spurr
Northeastern University
Boston 15, Massachusetts

In order to obtain solutions which are Lorentz invariant, the relativistic Boltzmann equation of Clemmow and Wilson together with Maxwell's equation are applied to a plasma in a constant magnetic field, assuming a variable density in the z direction and hence, a variable collision frequency. The assumption that $E \backsim e^{i\omega t}$ gives two 4th order differential equations which are solved for the plasma and electromagnetic modes, respectively. The modified solutions of the usual dispersion relations resulting from the Lorentz form and the assumptions of variable density and collision frequency are examined for an effective density gradient and possible coupling between the different types of waves. Finally, the mode properties are examined in the inertial frame of an observer moving with relative velocity with respect to the plasma.

D-3

ON SOLAR RADIO OUTBURSTS AND COSMIC RADIO NOISE AS RADIATION FROM A BOUNDED PLASMA

Richard L. Moore
R. L. Moore Consultants

In a bounded plasma with a Gaussian radial density distribution,[1] standing internal waves such as ion or electron sound waves are coupled into the radiation field by the acceleration of the surface charge at the plasma-vacuum interface. The internal vibrations are given as solutions of a differential equation of the confluent hypergeometric type. The radiated power for a plasma of length L, radius r_o (both small compared to the wavelength of the emitted radiation), and radial standing waves of velocity, $V_r \sin\omega t$, is $9 \times 10^{-54}(N\omega V_r L r_o)^2$ watts (mks units). N, the effective surface charge density, is estimated from three alternative physical models to be proportional to either H, $T^{1/2}H^{-1}$, or $T^{5/2}H^{-1}$ (H is the vacuum magnetic field). This type of radiation coupling assumes a high dielectric constant for the plasma interior. It provides a possible explanation for the harmonic frequency relations found in astrophysical and laboratory plasmas.[2] The problems discussed by Field[3] are overcome. The coupling coefficient derived in this paper is in agreement with Field's calculation of the emitted energy for a solar radio outburst. The fluctuating induction fields of such a plasma could also function as a charged particle accelerator thus giving an explanation of the cosmic rays associated with solar noise flares.

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(1) R. L. Moore, J. Electron. Contr., to be published.

(2) F.W. Crawford, Phys.Rev. Letters, 6, 663, June 15, 1961.
R. Motley, C. Lustig, and S. Sanders, Microwave Radiation from Stellerators, Bull. Am. Phys. Soc., Ser. II, 6, 314, April 25, 1960.

(3) G.B. Field, Astrophys. J., 124, 555 (November 1956).

D-4 CYCLOTRON RADIATION FROM A GASEOUS DISCHARGE*

Basil Beeken, Robert Goldman, and Ludwig Oster
Physics Department, Yale University, and Yale University Observatory
New Haven, Connecticut

Measurement of cyclotron radiation provides a convenient basis for the determination of physical parameters in a plasma. At low pressures the line contour follows the distribution function of electron velocities along the magnetic lines of force, whereas at higher pressures additional broadening originates from collisions with heavy particles(1) for which at present no reliable theory is available. We have attempted to formulate a quantum mechanical theory from which the classical Lorentz-treatment follows as a first approximation. We consider electron-ion interactions, represented by Coulomb perturbations acting on the wave functions of free electrons in the magnetic field. Short-range interactions are treated by a random phase approximation, while the long-range encounters are approximated by an average phase change per unit length. Line contour and higher order deviations from the Lorentz shape are discussed.

We have also measured the line contour of the cyclotron line emitted by a gaseous discharge in air at pressures between 10^{-1} and 100 microns. The apparatus consists of a wave guide, one section of which is pumped out, placed between the poles of a large electromagnet, and used as the discharge chamber. The magnetic field is swept by approximately 1 per cent, and the cyclotron radiation emitted by the discharge is detected at a fixed frequency of 9375 Mc in a frequency band of 100 kc.

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*Supported by the Office of Naval Research and the Aeronautical Research Laboratory, Office of Aerospace Research, United States Air Force, Wright-Patterson Air Force Base, Ohio.

(1) J.L. Hirshfield and S.C. Brown, Phys. Rev., 122, 719 (1961).

D-5

ION CYCLOTRON RESONANCE IN HYDROGEN, HELIUM, AND NEON

S.J. Buchsbaum
Bell Telephone Laboratories, Incorporated
Murray Hill, New Jersey

Experiments on phenomena associated with ion cyclotron resonance in a plasma were performed at frequencies in the megacycle/sec band on the positive column of an arc discharge. Ion cyclotron resonance absorption and dispersion curves were obtained in hydrogen, helium, and neon at variable gas pressures and plasma densities. The shape of the curves is not Lorentzian and varies with conditions of the experiment. The values of ionic mobilities obtained from these curves will be discussed.

D-6 ELECTRON TEMPERATURES FROM IONIC SOUND WAVES

I. Alexeff and R.V. Neidigh
Oak Ridge National Laboratory*
Oak Ridge, Tennessee

The existence of ionic sound waves was first predicted by Tonks and Langmuir. In most plasmas formula for the velocity of the wave is equal to $(\gamma k T_e/M_i)^{1/2}$. In the magnetically supported column of plasma as used at ORNL standing waves are produced much the same as ordinary sound waves produce standing waves in an organ pipe. Since the physical dimensions of the apparatus and the mass of the ion, M_i, are known the electron temperature may be found. The electron temperatures of several different plasmas have been found to agree well with the temperature obtained by the Langmuir probe technique, and by a spectroscopic technique using the intensity ratio of the singlet-triplet lines in helium. Further verification is obtained from the measurement of electron pressure $(n_e k T_e)$, where the electron density, n_e, is obtained by a plasma decay technique.

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*Operated by Union Carbide Nuclear Company for the U.S. Atomic Energy Commission.

D-7

HIGH-FREQUENCY DIELECTRIC CONSTANT OF HIGH-FREQUENCY PLASMOIDS*

Albert J. Hatch
Argonne National Laboratory

The high-frequency dielectric constant κ of a high-frequency low-pressure plasmoid has been determined by two different experimental methods that yield widely divergent values. Typical results will be presented. One value, $\kappa \approx +4$, is determined by a method of circuit substitution. The other value, $\kappa \approx -9$, is determined from the ratio of the external field to the internal field as measured from an r-f field probe. These values are reconcilable from considerations of simple classical dispersion theory and the geometrical relations between the plasmoid and the exciting electrodes. The results are consistent with a mechanism in which the plasmoid is considered as a quasi-dielectric medium with an excess of positive space charge about which an electron bunch executes forced bound oscillations. The distinction between these oscillations and the Langmuir type of plasma oscillations will be discussed.

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

SESSION E

FRIDAY, OCTOBER 13
9:00 A. M.

DIFFUSION AND MOBILITY

CHAIRMAN

SOLOMON J. BUCHSBAUM
BELL TELEPHONE LABORATORIES

Disch. vessel 2 Liter to prevent buildup of N at low flow rate

Can detect 10^{12} spins

E-1 DETERMINATION OF THE THREE BODY RECOMBINATION RATE CONSTANT FOR NEUTRAL NITROGEN ATOMS IN N_2 BY ELECTRON SPIN RESONANCE*

Thomas Marshall
University of Illinois, Urbana, Illinois

Under circumstances where surface recombination is negligible for the products of a nitrogen afterglow plasma, the decay of the neutral atomic nitrogen density $N_1(t)$ by the volume process $N + N + N_2 \longrightarrow N_2^* + N_2$, is given by

$$d N_1/dt = -k N_1{}^2 N_0$$

where N_0 is the concentration of the third body, molecular nitrogen, and k is the reaction rate constant. Here, $N_1(t)$ was determined directly by observing the electron spin resonance (ESR) signal from the ground state ($^4S_{3/2}$) of the nitrogen atoms. The absolute atomic concentration was inferred by calibrating the nitrogen ESR signal against that from a known concentration of molecular oxygen in the same geometry.

Determination of k was made in a stream of flowing gas which was piped through the ESR cavity; this space resolved the time dependent decay. Nitrogen atoms were created in appreciable quantities (10^{15} cm^{-3}) by dissociation in either cw electrodeless or condensed discharges. Surface recombination was suppressed by exposing the glass walls of the vacuum tubing to the vapors of concentrated H_2SO_4, after which the data obeyed the above decay law. The trimolecular rate constant k, determined over a pressure range of two to ten millimeters, was $2.8 \pm 0.6 \times 10^{-32}$ cc^2/sec. Optical studies of the Rayleigh afterglow near 5800 A showed the ESR signal and the light decay obeyed the same form of decay for dry nitrogen.

A similar study for the reaction $O + O + O_2 \longrightarrow O_2^* + O_2$, previously undertaken by Krongelb and Strandberg, has given $k = 1.1 \pm 0.3 \times 10^{-32}$ cc^2/sec for oxygen with H_2SO_4 on the walls.

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*This research was performed under the sponsorship of Air Force Cambridge Research Center.

Continuous Flow p 0.2 – 10 mm, ESR cavity
Tenths of second in flow path – metastables, ions all gone. Assume N atoms in ground state.
$dN/dz = c(N - N_1/2)(N - N_1)N_1$
N_1 N atom conc.

Calibrate with O_2 – use $K=5$, $J=4 \to 6$, $M=1 \to 2$ line in O_2

5800A° line linear 1/N vs t
H_2SO_4 on walls

E-2

TEMPERATURE DEPENDENCE OF IONIC MOBILITIES IN GAS MIXTURES*

G. E. Courville† and Manfred A. Biondi
University of Pittsburgh, Pittsburgh 13, Pa.

An ion mobility tube[1] has been used to investigate the mobilities of various ions in helium-neon mixtures at gas temperatures of 77°, 195°, and 300°K. Using a Blanc's law plot of reciprocal mobility vs fractional concentration of the gases in the mixture, it is possible to trace the mobility of a given ion, e.g., He^+, from its parent gas (helium) value, through the mixtures, to its value in the "foreign" gas (neon). In this way we have determined the thermal energy mobilities of the various ions under conditions where the ion-atom interaction changes markedly (e.g., from predominantly charge transfer to polarization interaction). In addition, a search was made for the effects of $(HeNe)^+$, previously postulated[2] to account for deviations from Blanc's law in 300°K studies. No effects clearly attributable to $(HeNe)^+$ ions have been observed.

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*This research has been supported in part by the Army Research Office (Durham).

†Present address, American-Standard Research Division, Union, N. J.

(1) M. A. Biondi and L. M. Chanin, Phys. Rev. 94, 910 (1954).

(2) M. A. Biondi and L. M. Chanin, Phys. Rev. 122, 843 (1961).

For Ne^+ in He, falls below polarization limit at $t \to 0$

E-3

ELECTRON DRIFT AND DIFFUSION MEASUREMENTS IN HYDROGEN IN A TRANSVERSE STRONG MAGNETIC FIELD*

Melvin J. Bernstein and Wulf B. Kunkel
Lawrence Radiation Laboratory
University of California, Berkeley

When the electron cyclotron frequency is much larger than the elastic-collision frequency, expressions for the energy distribution, drift velocities, and diffusion coefficients become greatly simplified.(1) The energy distribution becomes Maxwellian with the average energy given by $ME^2/2\eta B^2$, where M is the molecular mass and η is an average-energy-loss parameter. Experiments have been performed in a strong magnetic field to measure the ratio of the perpendicular to transverse drift velocities and the coefficient for diffusion along the magnetic field. In this limit the perpendicular drift velocity is E/B. The experiments were done with coaxial electrodes whose axes were parallel to the magnetic field. Data will be shown that verifies the dependence of the transverse drift velocity and diffusion coefficient on the parameter E/B. Use of these data with the theoretical expressions has yielded the elastic-collision cross section of electrons in hydrogen. This cross section is somewhat larger in the range of 1/2 to 4 ev than that previously accepted. Values for the average energy of the electrons in hydrogen and deuterium have also been determined.

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

(1) W.P. Allis, Handbuch der Physik (Springer Verlag, Berlin 1956), Vol. XXI, p. 404.

E-4

ORTHOGONAL AMBIPOLAR DIFFUSION CURRENTS IN A MAGNETIZED PLASMA*

David R. Whitehouse and Herbert B. Wollman
Massachusetts Institute of Technology

The magnetoambipolar diffusion theory of a plasma in a conducting cavity has been derived by several authors. In this paper we show the relationship between the boundary conditions at the walls and the required ionization frequency to maintain a steady state plasma. The interesting conditions are the Simon and Allis diffusion limits, the congruence and short circuit limits, and two other limits obtained when the radial ion current or axial electron current is equal to zero. The theory is checked by measurements of the diffusion currents made in a vacuum, metal, cylindrical cavity whose end walls are insulated from the radial wall. The cavity is also fed with microwaves to produce the steady state plasma, and wall probes have been placed throughout the cavity to monitor the current distribution.

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E-5

PLASMA DIFFUSION IN A MAGNETIC FIELD*

S. D. Rothleder and D. J. Rose
Department of Nuclear Engineering and
Research Laboratory of Electronics
Massachusetts Institute of Technology

An investigation is made of the diffusion of a fully ionized plasma in a finite, cylindrically symmetric region containing a magnetic field. The plasma source is a hollow cathode argon discharge,[(1)] 0.4 cm diameter, running down the axis. The experimental region is 10 cm diameter and 16 cm long. Results of Langmuir probe measurements of the spatial variation of density, temperature, and potential are presented for various values of magnetic field. The experimental results are discussed in terms of equations derived from the first three moments of the Boltzmann equation for a fully ionized gas.

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*This work was supported in part by the U. S. Army Signal Corps, the Air Force Office of Scientific Research, and the Office of Naval Research; and in part by the National Science Foundation.

(1) C. Michelson and D. J. Rose, Bull. Am. Phys. Soc. II, 6, 385 (1961).

E-6

PLASMA GENERATION AND CONFINEMENT MECHANISMS IN THE HOLLOW CATHODE DISCHARGE*

L. M. Lidsky, S. D. Rothleder, D. J. Rose and S. Yoshikawa
Department of Nuclear Engineering and
Research Laboratory of Electronics,
Massachusetts Institute of Technology

A description of the hollow cathode discharge plasma source has previously been presented.(1) Recent experimental data confirm that the exterior plasma is generated in the interior of the hollow cathode and that ionization in the exterior region plays a small secondary role. Analysis of the cathode power balance indicates that the probability of ionization of the input gas in the cathode interior is very high. The external plasma (of characteristic density $10^{13}/cm^3$) is confined by low magnetic fields (100-500 gauss). Application of the hydromagnetic momentum conservation equations demonstrates that a hybrid confinement mechanism operates with electrons confined by the magnetic field and ions trapped in the resulting space charge field. The solution of the hydromagnetic equations in the special case of constant temperature indicates a simple scheme for independent measurement of ion temperature. Relations between the ion and electron temperatures are shown both experimentally and by analysis of the steady-state energy transfer equations.

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*This work was supported in part by the U.S. Army Signal Corps, the Air Force Office of Scientific Research, and the Office of Naval Research; and in part by the National Science Foundation.

(1) C. Michelson and D. J. Rose, Bull. Am. Phys. Soc. II 6, 385 (1961).

E-7 **POTENTIAL DISTRIBUTION IN THE REFLEX ARC**

Francis F. Chen and W. L. Harries
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Princeton, New Jersey

Reflex discharges in strong magnetic fields have been observed to have a depression in potential on the axis since electrons have difficulty crossing the magnetic field to the anode. The radial potential distribution of an idealized model of such a discharge has been computed for a case in which the field is so strong that enhanced diffusion is necessary to supply the anode current. Gradients in the axial direction are assumed to be small; however, particle currents in this direction play an important part in determining the potential profile. The shape of the potential curve is independent of the discharge current and of the diffusion coefficients, since they were assumed equal for ions and electrons, and is governed primarily by the ion transverse mobility. It is interesting that although enhanced diffusion was present in the discharge, a good fit with experiment can be obtained with a mobility which is not correspondingly enhanced.

E-8

GENERATION OF A SYNTHESIZED PLASMA*

J. R. Fendley and K. G. Hernqvist
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It is the purpose of this paper to describe theoretical and experimental studies of a method to generate a low temperature, high density "collisionless" plasma. The plasma is synthesized by bringing together electrons and ions independently generated in a diode configuration, the duo-emitter diode.

In the theoretical analysis we consider two infinitely wide parallel planes facing each other, one plane emitting electrons only and the other emitting ions only. Two solutions to the space charge problem have been found, one of which corresponds to a charge distribution where most of the interelectrode space is occupied by a plasma stabilized at the surfaces by space charge sheaths.

In the experiment, the electron emitter is a barium impregnated cathode and the ion emitter is a niobium surface. Both are heated. A low pressure cesium environment assures ion generation (due to resonance ionization) at the niobium surface. The volt-ampere characteristic demonstrates plasma synthesis in excellent agreement with the theory. The plasma density is subject to continuous electrical control from a low value to its maximum value ($\sim 10^{12}$ cm^{-3}).

*This research was sponsored by Advanced Research Project Agency, Department of Defense.

E-9

NONTHERMAL IONIZATION IN MAGNETOHYDRODYNAMIC GENERATORS

S. Tamor, D.J. BenDaniel, C.M. Bishop, W.F. Westendorp,
L.M. Goldman, and H. Hurwitz, Jr.
GE Research Laboratory, Schenectady, New York

The electric field seen in the gas frame in an MHD generator can cause the electrons to be much hotter than the gas. The degree of ionization computed from the Saha equation using the electron temperature may be appreciable even if the gas is cold. To estimate the range of validity of such quasi-equilibrium arguments, the solutions of the steady state equations for ionization and de-ionization for cesium have been examined. Since most required cross sections are poorly known rough estimates were used, and it is found that there is indeed an interesting regime of operation in which the ionization enhancement occurs. Results are also presented for an experimental study of a transient discharge in helium at atomic density $\sim 5 \times 10^{18}$ cm^{-3} seeded with 10^{-3} to 10^{-5} atomic fraction of cesium. This experiment was designed to simulate the assumed conditions in a generator and test the gross predictions of the theory. The observed conductivities are consistent with high cesium ionization.

E-10

NONEQUILIBRIUM N_2^+ - 1st NEGATIVE BAND EMISSION BEHIND SHOCK WAVES

Walter Roth
Physics Division, Armour Research Foundation
Chicago, Illinois

A study has been made of the temporal behavior of N_2^+ - 1st negative band emission behind strong shock waves in xenon containing small amounts of nitrogen. Emission from the v' = 0 and v' = 1 vibrational levels in the upper electronic state ($\beta\,^2\Sigma^+$) was found to be sequential in time with the former appearing first. This observation has suggested a mode of formation of N_2^+.

The N_2^+ - 1st negative emission intensity was found to overshoot its equilibrium value during the approach to equilibrium. The time to maximum overshoot as a function of temperature and the dependence of overshoot intensity on temperature and initial N_2 density have suggested a mechanism for the nonequilibrium production of electronically excited N_2^+. Rate constants for several of the elementary reactions involved have been deduced from the experimental data. It appears that the cross section for ionization of N_2 is much greater than that for subsequent electronic excitation of the ion.

Withdrawn

E-11

EXPERIMENTAL INVESTIGATION OF ELECTRICALLY DRIVEN SHOCKS*

J. B. Gerardo, C. D. Hendricks, Jr., and L. Goldstein
Department of Electrical Engineering
University of Illinois
Urbana, Illinois

This paper deals with some experimental results obtained in the investigation of electrically driven shocks by microwave techniques, electrical probes, and observation of visible light intensity with photomultipliers. The investigated shocks were in the mach 3 to mach 15 velocity range and were produced in both neon and air at pressures from 1 to 5 mm Hg. Under specified conditions the velocity of the shocks obtained by Doppler shift considerations of a radio frequency wave reflected from the highly ionized shock front was not in agreement with the velocity obtained by electrical probes and light methods. This consistent discrepancy is attributed in part to an electron precursor. This and other phenomena occurring in front of, as well as in, the shock front have been investigated and will be discussed.

*This research was sponsored in part by the Air Force Cambridge Research Center under Contract AF 19(604)-7411.

SESSION F

FRIDAY, OCTOBER 13
2:30 P. M.

BREAKDOWN; DISCHARGE PHENOMENA

CHAIRMAN

JAMES D. COBINE
GENERAL ELECTRIC RESEARCH LABORATORY

F-1

SOLUTION OF THE SPACE CHARGE PROBLEM FOR A PULSED TOWNSEND DISCHARGE

J.A. Morrison and D. Edelson
Bell Telephone Laboratories, Incorporated
Murray Hill, New Jersey

The pulsed Townsend discharge technique for determination of electron attachment coefficients of electro-negative gases is examined for situations where the current density is sufficiently high that space charge effects must be considered. The equations of motion for the ions are solved by integrating the third order differential equations twice to yield a first order nonlinear partial differential equation. This is solved implicitly by Charpits' method of integration, leading to a first order ordinary nonlinear differential equation for a parametric function in terms of which the current and boundary position may be expressed. For the particular case of interest, an initial ion distribution which decays exponentially from the cathode, an exact solution for the current is obtained by numerical evaluation of this function.

An experimental apparatus is described which makes use of a specially designed coaxial flash lamp yielding a very intense beam of ultraviolet light of a few tenths microsecond duration. Using a freshly activated copper photocathode, large negative ion densities have been achieved in SF_6. Comparison of experimental results with theoretical predictions shows excellent qualitative and fair quantitative agreement.

Coaxial condenser for spark source

F-2

PULSED TOWNSEND DISCHARGE IN ELECTRON-ATTACHING GASES

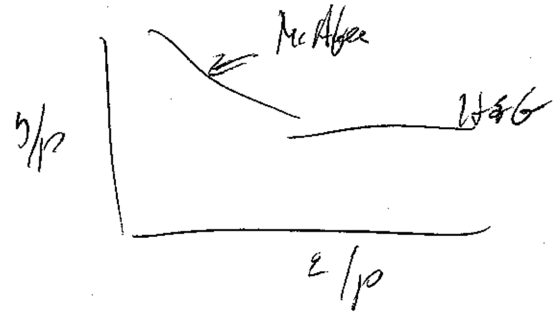
K. B. McAfee, Jr. and D. Edelson
Bell Telephone Laboratories, Incorporated
Murray Hill, New Jersey

The technique of the pulsed Townsend discharge is applied to the determination of attachment coefficients and ionic mobilities in gases having very large capture cross-sections for electrons. Very high precision in the construction of the experimental apparatus, and exact mathematical procedures in evaluating the data are required to avoid erroneous and scatterned results. It is shown that ion diffusion is a very significant factor in these experiments and that its neglect can lead to large errors and an apparent pressure dependence of η/p, in seeming violation of the principle of similitude as pressure and field strength vary.

A solution to the ion drift equation including diffusion is obtained for a model with slightly modified boundary conditions at the electrode surfaces. For the values of η and μ obtaining in the experiment, this model is an excellent approximation. A special nonlinear curve fitting procedure using a modified method of steepest descents devised by M. B. Wilk is used to evaluate these constants from the experimental data. The method also permits examination of confidence regions for the parameters, thus allowing a critical evaluation of the accuracy of the technique.

Measurements have been obtained in oxygen, SF_6, and other polyatomic molecules. The determinations are made under conditions where positive ion formation is negligible. The results in oxygen at low values of E/p agree well with those obtained by other techniques. A single ion is observed in SF_6 for drift times from 20 microseconds to several milliseconds.

SF_6^- seems to be [illegible] [illegible] to exchange with SF_6 10 μsec for loss by auto ionization



Mobility of SF_6^- = 0.5 — less than Langevin

F-3

CONTRIBUTION TO THE THEORY OF HIGH-FREQUENCY BREAKDOWN

Robert E. Kell
Cornell Aeronautical Laboratory
Buffalo, New York

The theoretical treatment of high-frequency breakdown of a gas previously given by S.C. Brown is extended to include the effects of photoionization, diffusion dependence upon electron concentration, and recombination. The inclusion of photoionization and recombination jointly accounts for nonzero steady-state electron concentration at field intensities less than the usual breakdown threshold. This steady-state concentration increases as the electric field is increased towards the breakdown value. The decrease in the diffusion coefficient which results from increase of the electron concentration within a bounded region is then shown to account for a sudden transition in electron concentration at a well-defined electric field threshold which is identified with the experimentally observed breakdown threshold. The anticipated dependence of breakdown threshold upon size of test chamber, operating frequency, and incident radiation will be discussed.

Demonstrates a hysteresis effect

F-4

STREAMER SPARK BREAKDOWN AS REVEALED BY LICHTENBERG FIGURES*

Essam Nasser and Leonard B. Loeb
University of California
Berkeley, California

Previous investigations by Nasser at the Technical University of Berlin(1) were extended using longer gaps and a variety of photographic emulsions. Branching of primary streamers, correlating well with Hudson's(2) photomultiplier observations, increases initially up to 200 as the streamer advances but decreases in long gaps as many of the streamer branches attenuate. This is caused by the statistics of the photoionization in the gas in advance of the positive anode high field streamer tip. It was possible to determine the velocity, range, branching statistics, and tip fields of streamers.(1) Their axial range reaches about 80 mm depending on voltage. Secondary streamers represent luminosity exceeding the threshold of photomultiplier sensitivity caused by ionization furnished by vigorous primary streamer branches and their velocities therefore represent an instrumental effect. The streamer branches are intensified on arrival at the cathode by fast return stroke. The primary positive Lichtenberg figure is ascribed to the photographic image of light from streamers proceeding through the air adjoining the photographic plate.(1) Streamer tip fields at the film surface create minute electron avalanches of short range.

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*Supported by Office of Naval Research.

(1) E. Nasser, Arch. Elektrotech, 44, 157, 168, 455 (1959).

(2) G.G. Hudson and L.B. Loeb, Phys. Rev. 123, 29 (1961).

F-5

IMPEDANCES AND ION TRANSIT TIMES IN GLOW DISCHARGE TUBES*

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

A relationship has been noted(1) between the transit times of ions in the glow discharge cathode fall and the frequency at which the reactance of the discharge changes from inductive to capacitive. The use of an electronic computer(2) has enabled a more exact calculation of ion transit times. In the stationary state, effective ion transit times may be calculated directly from the field and current distributions across the gap. Dynamically, a small sinusoidal increment to the applied voltage across the tube may be used to calculate the impedance of a discharge gap. The ion transit time may then be determined from the phase lag between the electron current at the anode and the ion current at the cathode. Excellent agreement for the ion transit times as calculated by the two methods is obtained. Experimental measurements of impedances of argon tubes have been made in these laboratories. Although it is difficult to obtain experimental data and calculations for the same current density range, our data does not support Chai Yeh's hypothesis.

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*Supported by the Army Research Office-Durham.

(1) Chai Yeh, J. Appl. Phys. 27, 98 (1956).

(2) A.L. Ward, Phys. Rev. 112, 1852 (1958); Bull. Am. Phys. Soc. 6, 390 (1961).

F-6 IONIZATION ENHANCEMENT OF A SEEDED FLAME PLASMA BY ELECTRICAL MEANS

J.D. Cobine, M. Lapp and J.A. Rich
General Electric Research Laboratory

As a result of the interest in obtaining appreciable conductivities in flame gases at temperatures compatible with engineering materials, a study of the enhancement of the electrical conductivity of a potassium-seeded hydrogen/oxygen flame by electrical means has been made. A seeded argon plasma has also been investigated. The flame was produced on a Meker-type burner which was designed to give a seeded cylindrical core surrounded by an unseeded shield flame. The plasma column extended from the burner to a graphite electrode inserted into the flame. The conductivities were determined from measurements of the column gradient and current density. The gradient was obtained by changing the column length; temperature, seed concentration, and column diameter were directly measured. The voltage profile along the flame was determined and the electrode voltage-drop regions identified. Plots of the seeded gas conductivity as a function of the electrical power density imposed on the flame plasma are presented.

F-7 **GRADIENTS IN MERCURY-RARE GAS DISCHARGES**

P. J. Walsh,* G. W. Manning,† D. A. Larson
Westinghouse Lamp Division
Bloomfield, New Jersey

Mercury-rare gas discharges at low mercury pressures and moderate rare gas pressures form one of the simplest mixed gas discharge systems. The mercury supplies the ionization while the rare gas controls the particle motion. The product $E\Lambda$ will depend upon $P_m\Lambda$, $P_a\Lambda$ and I/Λ^n. E is the gradient, Λ the diffusion length, P_m and P_a the mercury and rare gas pressures, respectively and n is expected to vary in the vicinity of 1 or 2. The quantity I/Λ^n is a sensitive indicator of any nonlinear ionization present. Gradient measurements made in mercury-argon discharges verify the expected dependence. The ranges covered were 0.5 to 1.1 cm, 1.0 to 75μ, 0.7 to 35 mm and 0.1 to 3.0 amps for Λ, P_m, P_a and I, respectively. At moderate and high P_a, n is unity. It becomes 2 at low P_a. This behavior is consistent with the known interpretation of the nonlinear ionization process as due to ionization of resonance atoms whose lifetimes are governed by the imprisonment of resonance radiation. At low P_a, Doppler broadening predominates yielding: n = 2. At higher P_a, collision broadening enters as well giving: n = 1. From the data in argon, gradients in other rare gas mixtures can be predicted and agreement has been found with mercury-krypton gradients.

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†Present Address: Picattiny Arsenal, Dover, New Jersey.

F-8

ION BEAM PROBE MEASUREMENTS ON THE THREE-DIMENSIONAL POTENTIAL WELL PRODUCED BY ELECTRON MULTIPACTING*

Eugene Clothiaux and H. Bartel Williams
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University Park, New Mexico

When electron multipacting (secondary electron resonance multiplication) takes place at low pressures, of the order of 10^{-5} mm Hg or less, a three-dimensional potential well for positive ions is created.(1) The conditions for obtaining a deep and "leak free" potential well are being studied. Part of this study involves the use of an ion beam as a probe to determine the magnitude of the time averaged electric field in the potential well. Though the electric field at a point cannot be uniquely determined by this method, much can be learned about the shape and depth of the potential well. Measurements have been made at various pressures and multipacting currents to determine the shape of the potential well and to determine the effect of the ion cloud collected in the potential well upon the shape of the well. It has been determined that the potential well becomes a potential hill (for positive ions) as ion density increases. The change from potential well to potential hill seems to take place with no apparent change in the basic discharge mechanism.

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*This work supported by the Army Research Office and Bureau of Naval Weapons.

(1) H. Bartel Williams, Phys. Rev. 107, No. 5, 1451 (1957).

F-9

THE USE OF CATAPHORESIS TO DETERMINE DISCHARGE PARAMETERS

Walter Muller and Eldred F. Tubbs
General Telephone and Electronics Laboratories, Inc.
Palo Alto, California

The balance between diffusion and ion migration in d-c discharges in certain mixtures of metal vapors and rare gases produces a very sharp line of demarcation between the region containing only the rare gas and the region containing metal vapor. Frequently this line can be located within $\pm$ 1 mm. If a cold spot with a well-defined location is provided near the cathode end of the positive column, the distance from the cold spot to the line of demarcation and the potential drop across the tube are very reproducible functions of cold-spot temperature. If these functions are determined, and if the neutral-molecule diffusion coefficient and positive ion mobility are known for the vapor; a simple theory yields approximate values for electron concentration, electron mobility and the ratio of ion to electron current. The application of this method to a neon-mercury mixture will be described.

F-10 A SIMPLE MEANS OF EXTRACTING ELECTRICAL ENERGY FROM HIGH-TEMPERATURE PLASMAS

John F. Waymouth
Sylvania Lighting Products
Salem, Massachusetts

As is well known, a cold Langmuir Probe immersed in a plasma will float negative with respect to plasma potential. A Langmuir Probe heated to thermionic emission temperatures can float at plasma potential if its emission is great enough. The combination of the two can supply power to an external load, with open circuit voltage about $5kT_e/e$ and short circuit current about equal to the thermionic emission of the hot probe. Theoretical analysis indicates and experimental results confirm that optimum power output and efficiency are obtained when the ratio of the areas of "cold probe" collector and hot probe emitter is as large as possible. A small experimental converter has been built to test these ideas; from an argon plasma with kT_e/e about 2 volts, it delivered 5 amperes at 5 volts into a matched load, with conversion efficiency of 35 per cent. The principal energy losses in the device proved to be the power expended in heating the hot probe, and the energy carried to the collector by the tangential components of the electron velocity distribution.

John Doering phys. chem. Diss recomb in NO] with Mike H under Koerlin
Redus Holland Oklahoma
Sid Stone - astrophysicist
read Jordan's thesis

LIST OF CONTRIBUTORS

LIST OF CONTRIBUTORS
(Continued)