IMPORTANT NOTICE

Members of the Gaseous Electronics Conference:

As you probably noted from the advance program, the present conference departs from tradition and from the wishes of the membership and, for the first time, includes 1 1/2 days of simultaneous sessions. In the view of the executive committee this is the most equitable solution for the present three day meeting. It may be that, after seeing how the present conference works out, the membership will feel that this solution to the problem of an increasing interest in the field, as evidenced by the growth in the number of contributions submitted for presentation, is the least undesirable of the various alternatives.

It would greatly assist the executive committee, if between now and the business meeting on Thursday, you will consider the possible alternatives for future conferences. Among these possibilities are the following:

(1) Increase the length of the meeting to four days.

(2) Shorten the length of time per paper for presentation and discussion.

(3) Order the executive committee to reject a sufficient number of papers to bring the program down to the necessary size.

(4) Use simultaneous sessions involving as little overlap of fields of interest as possible.

(5) Agree in advance that the next conference will not include certain of the usual subjects of the G. E. C. and rotate the choice of "de-emphasized" fields each year.

(6) Permanently redefine the scope of the G. E. C. to lessen the number of subjects included. For example, eliminate subjects that are also included by the Atomic Collisions Conference and/or the Plasma Physics Conference.

I am sure that many of you have, as I do, strong reservations about some of these alternative methods. Please aid in the selection of the best course for future conferences by attending the business meeting on Thursday.

Yours truly,

M. A. Biondi

M. A. Biondi
Deputy Chairman
Gaseous Electronics Conference

CONDENSED PROGRAM

TUESDAY OCTOBER 9	2-5 p.m.	**REGISTRATION:** Lobby, Radio Building, NBS Boulder Laboratories
	8-10 p.m.	**COCKTAILS:** Harvest House Hotel
WEDNESDAY OCTOBER 10	8 a.m.	**REGISTRATION:** Lobby, Radio Building, NBS Boulder Laboratories
	9 a.m.-12:15 p.m.	**SESSION A:** Electron Energy Distributions; Probes
	10 a.m.-12 noon	Ladies "Get-Acquainted" Coffee: Meet at Harvest House Hotel
	2:15-3:25 p.m.	**SESSION B:** Session of Invited Papers
	3:45-5:30 p.m.	**SESSION C:** Physics of the Ionosphere and Exosphere
	3:45-5:30 p.m.	**SESSION D:** Breakdown Processes
	Following Sessions C and D	**JILA Open House:** 1511 University Avenue, Boulder, Colorado
THURSDAY OCTOBER 11	9 a.m.-12:45 p.m.	**SESSION E:** Diffusion and Mobility
	10:20-11:05 a.m.	**Business Meeting**
	10:30 a.m.-3 p.m.	Ladies Gold Hill Trip
	2:45-5:45 p.m.	**SESSION F:** Collision Processes: Various
	2:45-5:45 p.m.	**SESSION G:** Plasmas I: Electromagnetic Waves in Plasmas
	6:30 p.m.	**Social Hour and Banquet:** Horizon Room, Harvest House Hotel
FRIDAY OCTOBER 12	9 a.m.-12:30 p.m.	**SESSION H:** Collision Processes: Charge Exchange and Ionization
	9 a.m.-12:30 p.m.	**SESSION I:** Plasmas II; Discharges
	2:15-5:30 p.m.	**SESSION J:** Optical Radiation

A. Dalgarno
Geophysics Corporation of America
Bedford, Mass.

15th Annual

Gaseous Electronics Conference

PROGRAM and ABSTRACTS of PAPERS

Sponsored By:

American Physical Society: Division of Electron Physics

National Bureau of Standards

CONFERENCE COMMITTEE

FIFTEENTH ANNUAL GASEOUS ELECTRONICS CONFERENCE

Program and Index to Abstracts

Tuesday, October 9

2 - 5 P.M. REGISTRATION: Lobby, Radio Building, NBS Boulder Laboratories

8 - 10 P.M. COCKTAILS: Harvest House Hotel

Wednesday, October 10

8:00 A.M. REGISTRATION: Lobby, Radio Building, NBS Boulder Laboratories

9:00 A.M. SESSION A: ELECTRON ENERGY DISTRIBUTIONS; PROBES

Chairman: C. Kenty, General Electric Lamp Research Laboratory, Cleveland, Ohio

2:15 P.M. SESSION B: SESSION OF INVITED PAPERS

Chairman: C. G. Little, National Bureau of Standards, Boulder, Colorado

3:45 P.M. SESSION C: PHYSICS OF THE IONOSPHERE AND EXOSPHERE

Chairman: C. G. Little, National Bureau of Standards, Boulder, Colorado

3:45 P.M. SESSION D: BREAKDOWN PROCESSES

Chairman: H. A. Raether, Universität Hamburg, Hamburg, Germany

Thursday, October 11

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

Chairman: M. A. Biondi, University of Pittsburgh, Pittsburgh, Pennsylvania

6:30 P.M. SOCIAL HOUR AND BANQUET: Horizon Room, Harvest House Hotel. The banquet will feature a short movie, "The House of Science," which was made for, and has been extremely popular at the Seattle Worlds Fair. The original film was shown by 7 projectors on six screens - the unique effect has been largely retained in the single-projection version.

Friday, October 12

9:00 A.M. SESSION H: COLLISION PROCESSES: CHARGE EXCHANGE AND IONIZATION

Chairman: L. M. Branscomb, Joint Institute for Laboratory Astrophysics, Boulder, Colorado

Wednesday, October 10, 9:00 A.M.

SESSION A: ELECTRON ENERGY DISTRIBUTIONS; PROBES

Chairman: C. Kenty
General Electric Lamp Research Laboratory, Cleveland, Ohio

A-1 STUDIES OF THE DYNAMIC PROPERTIES OF LANGMUIR PROBES I: METHODS*

H. J. Oskam, R. W. Carlson and T. Okuda[+]
University of Minnesota, Minneapolis, Minn.

Information about various gaseous-plasma parameters, such as electron energy, electron density etc., may be obtained by measuring the Langmuir probe curve.[1] During the past decade the dynamic probe method, in which the probe potential with respect to the plasma is changed rapidly and the resulting probe current is measured, has been employed for studies of transient plasmas as well as for the investigation of plasmas produced in probe surface contaminating gases.[2] However, unless a careful study of the transient response of the space-charge sheath surrounding the probe is made, the interpretation of the experimental data remains doubtful. An experimental method was developed which made it possible to study the phenomena associated with the dynamic Langmuir probe. It was found that the conventionally used Langmuir probes are in general not suitable for the dynamic probe method. Therefore, a shielded Langmuir probe was developed and employed during the studies. Moreover, the measuring circuit has to be designed very carefully.

*Work supported by the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

+Present address: Nagoya University, Nagoya, Japan.

1. I. Langmuir and M. Mott-Smith, G. E. Review 27, 449, 538, 616, 762, 810 (1924).

2. J. F. Waymouth, J. Appl. Phys. 30, 1404 (1959); D. G. Bill, K. B. Holt and B. T. McClure, J. Appl. Phys. 33, 29 (1962).

STUDIES OF THE DYNAMIC PROPERTIES OF LANGMUIR PROBES II: RESULTS*

H. J. Oskam, T. Okuda[+] and R. W. Carlson
University of Minnesota, Minneapolis, Minn.

The study of the current response characteristics of a metallic probe immersed in a gaseous plasma, when changing the probe potential with respect to the plasma, may give information about the quantities which determine the speed with which the space-charge sheath surrounding the probe adjusts itself to a change in sheath potential. These studies may lead to a better understanding of the dynamic behavior of plasma sheaths and, moreover, are necessary for the interpretation of dynamic Langmuir probe measurements. The probe current response characteristics were studied, using the techniques described in the preceding paper, for various plasma densities, gas pressures and types of gas. The conclusions are: (a) The delay in the current collection is due to the motion of ions and is most pronounced for final probe voltages close to plasma potential. A qualitative theory explains the delay phenomena. The magnitude of the delay decreases for increasing plasma density and increasing ion mobility; (b) The influence of the probe-sheath capacitance increases with increasing plasma density. Theoretical values of the sheath capacitance agree very well with the experimental values.

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*Work supported by the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

+Present address: Nagoya University, Nagoya, Japan.

A-2 BEHAVIOUR OF GUARDRING PROBES

G. Medicus
Wright-Patterson AFB, Ohio

A plane probe (P), 0.8 mm dia., surrounded by a plane guardring (G), 5 mm dia., is expected to approach "plane probe behavior" with increasing plasma density. The probe curves obtained in a hot cathode Hg discharge are unexpectedly complicated, as is revealed by automatic second derivative ($J''(V)$) plots. Contrary to spherical probes, $J''(V)$ of the GP show a secondary sharp peak near V=0. This effect, observed under a great variety of plasma conditions, was tentatively attributed to a sharp knee in the ion current at V=0. However, a quantitative comparison between P and G+P made such an interpretation very doubtful. A constant bias between G and P makes the guardring probe behave to some extent like Boyd's screened probe.[1] When G is biassed increasingly positive against P, the ion current to P and a secondary sharp peak near the inflection point of J(V) disappear, and with the opposite bias the ion current and the secondary sharp peak become more pronounced. In this case the above interpretation of the secondary peak seems to hold. A sharp maximum at V=0 in J(V) with P positive against G indicates space potential precisely.

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1. R. L. F. Boyd, Proc. Roy. Soc. A, 201, 329 (1950).

A-3 SOLUTION OF THE FULL PLASMA-SHEATH EQUATION*

S. A. Self and G. S. Kino
Stanford University, Stanford, Calif.

In the theory of the plasma of an arc, Tonks and Langmuir and later workers assume exact space-charge neutrality. Thus they ignore the derivative term in the full plasma-sheath equation and solve the resulting plasma integral equation, obtaining solutions applicable to the body of the plasma, but which become progressively inaccurate as the boundary is approached. A solution for the sheath region ignoring ion generation is then matched on at some point near the limit of the plasma solution. This procedure gives rise to some uncertainties since the selection of the matching point, i.e., the plasma-sheath boundary, is rather arbitrary. To overcome these uncertainties, the full plasma-sheath equation has been solved numerically for the plane symmetric discharge with long ion mean free path. Solutions are presented for various values of the discharge parameters. These solutions apply throughout the plasma and sheath regions and thus avoid the arbitrary choice of a plasma-sheath boundary.

*Work supported by Aeronautical Research Laboratory, Office of Aerospace Research, U. S. Air Force.

A-4 DIRECTIONAL ELECTRON VELOCITY DISTRIBUTIONS IN A PLASMA USING AN IMPROVED LANGMUIR PROBE*

R. H. Bond
University of Colorado, Boulder, Colo.

Previously Langmuir probes were used to determine electron velocity distributions with the assumption that the distribution was isotropic. This led to a distribution function proportional to the second derivative of probe current with respect to probe voltage.[1] An analysis based on the distribution of electron velocities normal to a planar probe leads to a distribution function proportional to the first derivative of probe current with respect to probe voltage. This new theory has two advantages: (1) Accuracy is increased by eliminating one differentiation; (2) No assumption is made concerning the velocity distribution. To use this new theory, it is necessary to construct a probe with true planar geometry. This was accomplished by using a very small planar probe (the end of a 10 mil wire) surrounded by a relatively large guard ring to eliminate edge effects. This probe was compared with a conventional planar probe in a neon glow discharge. The following were noted: (1) The probe with a guard ring exhibited constant ion saturation current over a 30-volt range; (2) A lower value of "electron temperature"; (3) A velocity distribution with a slight excess of high energy electrons.

*Work supported by National Bureau of Standards, Boulder, Colorado.

1. M. J. Druyvesteyn : Z. Physik 64, 793 (1930).

A-5 **ELECTRON DISTRIBUTION FUNCTION AND ELECTRICAL CONDUCTIVITY OF A SLIGHTLY IONIZED GAS**

D. H. Sampson and J. Enoch
General Electric Company, Philadelphia, Pa.

An expansion of a formally rigorous integral solution of the Boltzmann equation in powers of the electric field and $\frac{m}{M}$ is used to demonstrate clearly the correct expression for the conductivity of a spatially homogeneous slightly ionized gas. The conditions under which the isotropic part of the electron distribution function reduces to the Margenau distribution are determined. A discussion of the physical reasons for the possibility of negative conductivity is given.

A-6 **THE RELATIVE IMPORTANCE OF INELASTIC COLLISIONS AND ELECTRON INTERACTIONS IN DETERMINING ELECTRON ENERGY DISTRIBUTION FUNCTIONS**

L. R. Megill
National Bureau of Standards, Boulder, Colo.

J. H. Cahn
University of Illinois, Champaign, Ill.

Examples will be given of the effect of varying the concentration of electrons, ions and electrons and ions in a gas in which inelastic processes are also considered. It is found that the concentration of electrons in the ionosphere is such that none of these effects can be ignored in making calculations which consider electric fields in the ionosphere.

A-7 NEARLY HOMOGENEOUS ELECTRON ENERGY DISTRIBUTIONS

A. A. Kruithof
Technical University, Eindhoven, Netherlands

In many gas discharges a Maxwell or Druyvesteyn energy-distribution of the electrons prevails. Three types of discharges came to our attention where the electron energy-distribution at a given location is nearly homogeneous, the average energy depending on the location, however: (a) The non self-maintaining discharge in mixtures of noble gases occurring in typical apparatus for the measurement of Townsend's ionization coefficient α for low values of the reduced electric field; (b) The self-maintaining discharge in a demonstration tube for Holst-Oosterhuis layers in neon; (c) The striated positive column for low current density in noble gases.[1] Common features of these discharges are low values of the reduced electric field F/p_o and low current density. The reason for the phenomena may be a small mutual interaction between the electrons.

1. c.f. J.G.A. Hölscher. Proc. Fifth Int. Conf. on Ionization Phenomena in Gases (Münich Vol. II) (Amsterdam 1962).

A-8 KINETIC THEORY OF AN ELECTRON-PHOTON GAS *

H. Dreicer
Los Alamos Scientific Laboratory, Los Alamos, N. Mex.

In the Boltzmann equation interactions between electrons and radiation field are described through transverse electric and magnetic fields. That this leads to an incomplete description is already clear from the fact that in thermal equilibrium this equation cannot be simultaneously satisfied by a Maxwell-Boltzmann and Planck distribution. To improve the description it is necessary to introduce the particle (photon) nature of the radiation field. A step in this direction has been taken[1] by deriving photon-electron collision terms which can be simultaneously satisfied by both equilibrium distributions. In the classical limit ($\hbar\omega \ll kT$) a Fokker-Planck equation results which describes the interaction through the average force associated with the radiation field, and the rapid fluctuations about it. Speaking classically such fluctuations result from the statistical interference between wave trains of different frequencies, and give rise to electron diffusion in velocity space. Application is made to cyclotron radiation, bremsstrahlung, and Compton scattering. Of particular interest are the conditions under which the electron velocity distribution becomes power saturated by the radiation, and the cyclotron absorption coefficient becomes dependent upon the radiation intensity.

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

1. H. Dreicer, Bull. Am. Phys. Soc. 7, 358 (1962).

A-9 ELECTRON MOBILITY AT HIGH E/p

P. Walsh
American-Standard Research Laboratory, Union, N. J.

At high E/p experimental drift velocities[1,2] in many gases become linear in E/p and a true mobility exists. This occurs when the increased energy which an electron gains from the field between collisions, as E/p is raised, is dissipated by inelastic losses rather than by raising the average electron energy. The average electron energy remains clamped at some fraction of the first excitation potential and the electron energy distribution function becomes independent of E/p. Using the formulation of Allis,[3] the mobility, μ, can be put into an extremely simple form as follows:

$$\mu = (e/m)\left(\int_0^1 \nu(u)u^2\,du\right)^{-1};$$

ν is the momentum transfer collision frequency and u is the ratio of electron velocity to its velocity at the first excitation potential. The following results are found where μ is given in (cm^2/volt μ sec).

Atom:	He	Ne	A	Kr	Xe
μ_{exp}:	1.1[1]	1.2[1,2]	0.31[2]	0.22[2]	0.16[2]
μ_{calc}:	0.61	1.3	0.30	0.20	0.18

1. R. A. Nielsen, Phys. Rev. 50, 950 (1936).
2. J. C. Bowe, Phys. Rev. 117, 1411 (1960).
3. W. P. Allis, Handbuch der Physik (Springer, Berlin, 1956), Vol. 21.

SESSION B: SESSION OF INVITED PAPERS

Chairman: C. G. Little
National Bureau of Standards, Boulder, Colo.

B-1 ON THE ELECTRICAL BREAKDOWN IN GASES

H. A. Raether
Universität Hamburg, Hamburg, Germany

B-2 **STUDIES OF WEAK FLUCTUATIONS OF PLASMA DENSITY IN THE IONOSPHERE USING HIGH POWERED RADAR**

K. L. Bowles
National Bureau of Standards, Boulder, Colo.

Wednesday, October 10, 3:45 P.M.

SESSION C: PHYSICS OF THE IONOSPHERE AND EXOSPHERE

Chairman: C. G. Little
National Bureau of Standards, Boulder, Colo.

C-1 **OBSERVATIONS AT THE MAGNETIC EQUATOR OF SYNCHROTRON RADIO EMISSION RESULTING FROM THE HIGH ALTITUDE NUCLEAR EXPLOSION OF JULY 9, 1962**

G. R. Ochs, D. T. Farley, K. L. Bowles and C. G. Little
National Bureau of Standards, Boulder, Colo.

As a result of the high altitude nuclear explosion of July 9, 1962, large numbers of relativistic electrons were injected into the earth's magnetosphere. Synchrotron emission from these high energy electrons has been studied at the Jicamarca, Peru, station of the National Bureau of Standards and the Geophysical Institute of Peru. These observations are discussed in terms of the radio-frequency spectrum, polarization, Faraday rotation, and temporal variation of the radio signals. Deductions are made concerning the energy spectrum and number of the relativistic electrons involved. The degree of significance of the synchrotron emissions to communication systems and radio astronomy will be discussed.

C-2 DIURNAL VARIATION OF THE TEMPERATURE OF THE F REGION

J. V. Evans
Lincoln Laboratory,* Massachusetts Institute of Technology, Lexington, Mass.

Spectral measurements of incoherent backscatter signals from the F region are described. By comparing the observed spectra with theoretical calculations by Fejer [1961] both the electron (T_e) and ion (T_i) temperatures can be found. Results are presented for observations made on four days in spring 1962, at the Millstone Radar Station. It is found that at 200 kms height equilibrium conditions prevail at all times and the diurnal temperature change is about 30%. At 300 and 400 kms equilibrium between the electron and ion temperatures occurs only during the hours of darkness. During the daytime the electron temperature T_e exceeds the ion temperature by an amount which is greatest at about noon, when $T_e/T_i \approx 1.6$. The ion temperature T_i at these heights has a diurnal variation of 50% while the electron temperature increases by 120%.

*Operated with support from the U.S. Army, Navy and Air Force.

C-3 ELECTRON TEMPERATURES IN THE IONOSPHERE

A. Dalgarno
The Queen's University of Belfast, Belfast, North Ireland

The processes by which fast photoelectrons produced by solar ultraviolet radiation are slowed down in the atmosphere are examined and it is shown that for a given electron energy there is a critical altitude above which energy is transferred to the ambient electron gas and below which energy is transferred to the neutral particle and positive ion gases. The critical altitudes are computed as a function of energy. An estimate is made of the energy distribution of the photoelectrons and the rate of heating of the electron gas is derived. Other mechanisms of heating the electron gas are also considered and it is shown that the temperature of the electron gas during the day is much higher than that of the neutral particles and positive ions.

C-4 POSSIBLE EFFECTS OF ELECTRIC FIELDS IN THE E-REGION OF THE IONOSPHERE

N. P. Carleton
Harvard University and Smithsonian Astrophysical Observatory, Cambridge, Mass.

L. R. Megill
National Bureau of Standards, Boulder, Colo.

One knows from geomagnetic effects that currents flow in the E-region of the ionosphere and hence that there are electric fields present in this region. In a recent paper[1] we have developed a method for calculating the distribution of electron energies in a weakly ionized gas under the influence of electric and magnetic fields, including the effects of inelastic collisions. We can thus postulate a field of a given strength in the E-region and predict in detail its effects, in particular excitation of electronic states by the highest energy electrons, and dissociative attachment, which removes these high energy electrons. We can also calculate more accurately than previous workers the variation of conductivity due to the increase in the average energy of the electrons. We are interested to see whether it is possible that the airglow emissions in the 100 km region are excited by electron impact. We find that rates of excitation are very sensitive to the electric field strength chosen, so despite a lack of precise knowledge of nighttime electron densities in the E-region, we predict that the electric field which would produce the observed airglow intensities almost certainly would lie in the range 8 to 18×10^{-3} V/cm. We assume current experimental and theoretical values of excitation cross sections [1] and assume the electric field perpendicular to the geomagnetic field. This field is larger by an order of magnitude or so than one would predict from the observed magnetic effects, and also would produce a rate of dissociative attachment which seems hard to balance by other mechanisms.

1. N. P. Carleton and L. R. Megill, Phys. Rev. 126, 2089 (1962).

C-5 HELIUM IONS IN THE UPPER ATMOSPHERE

T. N. L. Patterson
Graduate Research Center of the South West, Dallas, Tex.

Reasons are given for believing that ion-atom interchange between He^+ and N_2 is strongly endothermic but that ion-atom interchange between He^+ and O_2 is exothermic. It is concluded that the former ion-atom interchange process does not occur to an appreciable extent but that the latter may be responsible for the removal of He^+ being produced by photoionization. Calculations are carried out on the steady state. In harmony with the prediction of Nicolet, He^+ is found to be abundant at great altitudes even if a high rate coefficient is assigned to the collision process leading to its removal. Attention is drawn to the possibility that dissociative recombination of HeO^+ is important in connection with the problem of the escape of neutral helium into interplanetary space.

C-6 **THE REACTION $O^+ + CO_2 \rightarrow O_2^+ + CO$**

J. F. Paulson and R. L. Mosher
Air Force Cambridge Research Laboratories, Bedford, Mass.

The production of O_2^+ in a mass spectrometer ion source containing CO_2 at relatively high pressure has been shown to be due to the ion-molecule reaction: $O^+ + CO_2 \rightarrow O_2^+ + CO$. The rate coefficient for O^+ ions having up to 0.5 eV energy is $0.5 \times 10^{-9} cm^3/sec$. The rate coefficient calculated from the theory of Eyring, Hirschfelder and Taylor,[1] for thermal ions and assuming a transmission coefficient of unity, is $1.1 \times 10^{-9} cm^3/sec$. Unlike the reactions $O^+ + O_2 \rightarrow O_2^+ + O$ and $O^+ + N_2 \rightarrow NO^+ + N$, then, the reaction $O^+ + CO_2 \rightarrow O_2^+ + CO$ appears to require no activation energy. The latter reaction is of potential interest in ionospheric physics in that it converts an abundant atomic ion, for which the electron recombination rate coefficient is low, to a molecular ion, for which the coefficient is high. The reaction thus suggests both a technique for decreasing the ionospheric electron density in a limited region and a partial explanation for the decreased electron density in a missile trail.[2]

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1. H. Eyring, J. O. Hirschfelder, and H. S. Taylor, J. Chem. Phys. 4, 479 (1936).
2. H. G. Booker, J. Geophys. Res. 66, 1073 (1961).

SESSION D: BREAKDOWN PROCESSES

Chairman: H. Raether
Universität Hamburg, Hamburg, Germany

D-1 **ELECTRON IONIZATION FREQUENCY IN HYDROGEN**

W. B. Cottingham
Bell Telephone Laboratories, Whippany, N. J.

S. J. Buchsbaum
Bell Telephone Laboratories, Murray Hill, N. J.

A direct measurement of the electron ionization frequency, ν_i, in hydrogen was made by studying the temporal growth of the electron density in a microwave discharge. Breakdown was produced by pulsed microwaves in a narrow quartz tube placed across a microwave waveguide. The optical radiation from the plasma was used to measure the rate of growth of the electron density. Experimental conditions were such that electron loss by diffusion was negligible. The use of a low-Q microwave system, of a fast photomultiplier, and of a sampling system, allowed study of breakdown e-folding times as short as 2×10^{-8} sec. Values of ν_i/p were obtained for a range of the ratio of effective electric field strength to pressure E_e/p, from 36 to 200 Volts/cm-mm Hg. There is good agreement with the dc measurements of the Townsend α-coefficient of Rose,[1] but there is some discrepancy between the present measurements at low E_e/p and similar microwave-cavity measurements of ν_i of Madan et al[2] whose work was over $20 \leq E_e/p \leq 40$ Volts/cm-mm Hg.

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1. D. J. Rose, Phys. Rev. 104, 273 (1956).
2. M. P. Madan, E. J. Gordon, S. J. Buchsbaum and S. C. Brown, Phys. Rev. 106, 839 (1957).

D-2 GROWTH RATE OF MICROWAVE AND DC AVALANCHE BREAKDOWN IN HYDROGEN

G. A. Baraff
Bell Telephone Laboratories, Murray Hill, N. J.

The theory of dc avalanche breakdown due to Gerjuoy, Stuart and Pearlstein,[1] (exact angular integration of the Boltzmann equation and a modification of the spherically symmetric part caused by finite growth rate) has been extended to include inelastic collisions, which leave the electrons at zero energy. This modification provides a more valid description of effects at intermediate values of E/p. The resulting distribution function cannot be described by only two spherical harmonics. In spite of the anisotropy of the distribution the concept of an effective electric field intensity, whose use allows direct comparison between microwave experiments and dc theory remains valid. Calculations of the growth rate in hydrogen vs. E/p have been performed using the ionization probability measured by Tate and Smith.[2] Results agree well with microwave measurements by Cottingham[3] and dc measurements by Rose.[4]

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1. E. Gerjuoy and G. W. Stuart, Phys. Fluids 3, 1008 (1960); L. D. Pearlstein and G. W. Stuart, Phys. Fluids 4, 1293 (1961).

2. J. T. Tate and P. T. Smith, Phys. Rev. 39, 270 (1932).

3. Fifteenth Annual Gaseous Electronics Conference (Paper D-1).

4. D. J. Rose, Phys. Rev. 104, 273 (1956).

D-3 CROSSED-FIELD BREAKDOWN IN HYDROGEN*

M. J. Bernstein, W. B. Kunkel and G. A. Pearson
Lawrence Radiation Laboratory, Berkeley, Calif.

The current buildup and the formative time of electric breakdown in low-pressure hydrogen across a strong magnetic field ($100 < \omega\tau < 1000$) have been measured in a cylindrical geometry described before.[1] As expected, the current was seen to rise exponentially with time in the range 10^{-6} to 10^{-2} A. The statistical fluctuations of the formative time under fixed conditions amounted to less than 20%, and the product of pressure and formative time was shown to be primarily a function of E/B. The latter is predicted theoretically if it is assumed that the breakdown goes to completion owing to space-charge effects. Precise quantitative comparison with calculated or previously measured ionization rates[1] was not possible in this investigation, however, since the electron crossing time was always less than the formative time, so that some γ effects at the cathode must have been involved in the process.

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

1. M. J. Bernstein, Phys. Rev. 127, 335 and 342 (1962).

D-4 IONIZATION, ATTACHMENT, AND BREAKDOWN STUDIES IN OXYGEN*

J. B. Freely+
New York University, New York, N.Y.

L. H. Fisher†
New York University, New York, N.Y. and General Telephone and Electronics Laboratories, Inc., Palo Alto, Calif.

Steady state uniform field prebreakdown currents have been measured in oxygen for $32 < E/p < 100$ in order to evaluate α/p, η/p, and γ. For $32 < E/p < 60$, both α/p and η/p were found to be somewhat lower than values previously published.[1] For $60 < E/p < 100$, the measurements allowed evaluations of $(\alpha - \eta)/p$ but not of α/p and η/p separately. For $E/p < 30$ (in oxygen), it is difficult to evaluate η/p from steady state prebreakdown currents because of low electron multiplication. However, it was found possible to obtain values of η/p for oxygen down to $E/p = 16$ from prebreakdown ionization currents in oxygen-helium mixtures. η/p for oxygen varies slowly with E/p for $16 < E/p < 60$ and has a broad peak at $E/p = 25$. Values of γ for oxygen were evaluated from prebreakdown currents for $46 < E/p < 60$ and from sparking potential measurements for $46 < E/p < 100$; $\gamma \cong 10^{-5}$ at $E/p = 100$ and $\gamma \cong 10^{-6}$ at $E/p = 46$.

*Supported by the Office of Naval Research and the Army Research Office (Durham).

+Now at Robert College, Istanbul, Turkey.

†Now at General Telephone and Electronics Laboratories, Inc., Palo Alto, Calif.

1. M. A. Harrison and R. Geballe, Phys. Rev. 91, 1 (1953).

D-5 INFLUENCE OF PHOTOIONIZING ABSORPTION COEFFICIENTS ON STREAMER PROPAGATION*

G. Waidmann and L. B. Loeb
University of California, Berkeley, Calif.

Continuing investigations of the streamer mechanism of the spark using the Lichtenberg figure technique reported by Nasser at the Fourteenth Gaseous Electronics Conference, the effect of changing the oxygen concentration in oxygen-nitrogen mixtures as well as the influence of water vapor and Freon on branching and streamer propagation has been studied. The striking results obtained have been observed for various point sizes. Sparking potentials under static and impulse conditions as a function of oxygen content have been investigated. These lead to rather interesting conclusions concerning photoelectric ionization and the absorption of photoionizing radiations on the propagation of streamers and the production of sparks. The results indicate the important role of the two-component nature of the gas for efficient streamer propagation, as well as the necessity of a suitable photoionizing free path relative to the ionization-producing field around the point. Spectrographic study in air indicates the blue color of the streamers to be derived primarily from the second positive bands of nitrogen.

*Supported by Research Corporation and Office of Naval Research.

D-6 CALCULATIONS OF CURRENT GROWTH AND VOLTAGE BREAKDOWN*

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

Calculations[1] of dynamic current growth in gases have been extended to simulate a variety of experimental conditions. These calculations indicate that the measurements of Menes[2] can be explained by the dependence of the ratio of the ion to photon contributions to the secondary coefficient upon the field over pressure. The effect of nanosecond ultraviolet light pulses in lowering breakdown voltages has been calculated and compared with experimental data for hydrogen by Kluckow[3] and air by Godlove.[4] The effect of diffusion upon times between current peaks will be illustrated. Calculations have also been made which agree satisfactorily with measurements of current growth in air by Bandel.[5] Finally, the versatility of the program is illustrated by calculations of negative ion current resulting from attachment, in good agreement with Morrison and Edelson.[6]

*Work supported by the U.S. Army Research Office - Durham

1. A. L. Ward, Bull. Am. Phys. Soc. Series II, 6, 390 (1961).

2. M. Menes, Phys. Rev. 116, 481 (1959).

3. R. Kluckow, Z. Physik 161, 353 (1961).

4. T. F. Godlove, J. Appl. Phys. 32, 1589 (1961).

5. H. W. Bandel, Phys, Rev. 95, 1117 (1954).

6. J. A. Morrison and D. Edelson, J. Appl. Phys. 33, 1714 (1962).

Thursday, October 11, 9:00 A.M.

SESSION E: DIFFUSION AND MOBILITY

Chairman: M. A. Biondi
University of Pittsburgh, Pittsburgh, Pa.

E-1 SIMULTANEOUS INDEPENDENT MEASUREMENT OF THE MOBILITIES AND DIFFUSION COEFFICIENTS OF IONS IN NITROGEN*

D. W. Martin, W. S. Barnes and E. W. McDaniel
Georgia Institute of Technology, Atlanta, Ga.

The mobilities and diffusion coefficients of various ions in nitrogen are measured by a time analysis method in which ion pulses are generated at one of three sources located along the axis of a tube containing nitrogen at pressures from .05 to 1.0 torr. The ions formed are drawn by a weak electric field of 1 to 4 volts/cm toward one end of the tube where they are swept into a mass spectrometer. The output of the spectrometer is time analyzed to determine the drift time and spread of each ion pulse. From an analysis of the time spectra, the mobilities and diffusion coefficients can be separately determined. Data on the primary ions N^+ and N_2^+ will be presented, and the formation and transport properties of secondary ions (N_3^+, N_4^+) produced in ion-molecule reactions will be discussed.

*This work is partially supported by a grant from the Air Force Office of Scientific Research.

E-2 MOBILITIES OF N^+, N_2^+, N_3^+ IN NITROGEN

K. B. McAfee, Jr. and D. Edelson
Bell Telephone Laboratories, Inc. Murray Hill, N. J.

Mobilities of three ions produced in a pulsed non-self sustaining discharge in nitrogen have been studied by means of an ion withdrawal technique. Mass analysis of the ions drifting through a slit in the cathode is obtained as a function of time after initiation of the pulse. The technique permits direct identification of the ion, simultaneous measurement of its mobility as well as a rough determination of the γ of the cathode surface, and the gas α. In nitrogen, our preliminary determination of the mobility of N_2^+ is in general agreement with that of Varney. N^+ mobility at very high E/p is about 30% higher than N_2^+. Over the lower range of E/p studied, the relative intensities of the ions varied considerably with N_3^+ more intense than N^+. Theoretical solutions of the drift current have been obtained and are compared with experiment.

E-3 ION MOBILITIES IN HELIUM

P. Patterson and E. C. Beaty
Joint Institute for Laboratory Astrophysics, Boulder, Colo.

A study of mobilities and other data suggests that the accepted values of the mobilities of He_2^+ and A_2^+ are incorrect because of an error in identification. Further, the new low values indicate a defect in the accepted theoretical analysis of mobility data. In helium a large number of ions were found in unpurified commercial gas. Purification by cataphoresis removed all the ions except two. The mobilities of the two are about 10.2 and 16.7 cm^2-$volt^{-1}$-sec^{-1} in good agreement with the values reported by Kerr. Semi-quantitative evidence suggests that the identities of the two ions are He^+ and He_2^+. In the pure helium it has not been possible to produce an ion with mobility about 20 cm^2-$volt^{-1}$-sec^{-1} such as was reported by Biondi and Chanin and called He_2^+. The mobility of 16.7 is lower than the best available theoretical analysis will admit is possible for any ion except He^+. An effort is being made to deduce reliable data on the reaction rate for the conversion of He^+ into He_2^+. Preliminary data indicates a value at about 7 mm-Hg which is comparable to that reported by Phelps and Brown. In argon, as supplied by a commercial source, only three ions were found. In addition to two which have mobilities and other characteristics analogous to the two found in helium, a third ion is observed which is almost certainly the same as that reported by Biondi and Chanin. The argon work has been previously reported.

E-4 EFFECT OF ELECTRON DENSITY GRADIENTS ON THE INTERPRETATION OF THE TOWNSEND TYPE D/μ MEASUREMENT *

J. H. Parker, Jr.
Westinghouse Research Laboratories, Pittsburgh, Pa.

In a Townsend type experiment for obtaining the ratio of the diffusion coefficient, D, to the mobility, μ, the electrons move under the combined action of a uniform electric field and electron density gradients. In this case it is usually assumed that the spherical part of the velocity distribution can be expressed as the electron density multiplied by the normalized distribution that would exist if the electron density were uniform. This approximation neglects the effect of electron density gradients on the normalized velocity distribution. It was the purpose of the present study to find under what conditions this approximation is adequate and to estimate the error that results for actual tube geometries. Allis and Allen[1] have set up the Boltzmann transport equation, including the terms involving the electron density gradient, for electrons undergoing elastic collisions in an electric field. We have obtained solutions of this equation for the case of a point source of electrons in an infinite, uniform field region with the electrons having either a constant collision frequency or a constant cross section. It was found that serious deviations from the approximate theory occur if: (1) the position at which the comparison is made is such that the average kinetic energy $\geq eEz$, where E is the field and z is the distance from the comparison point to the source point along the field direction, and (2) if the point of comparison is appreciably off the geometrical axis. The second condition is more important for the Townsend measurement and estimates of the errors that result for typical tube geometries have been obtained.

*This work was supported in part by the Air Force Special Weapons Center and by the Advanced Research Projects Agency through the Office of Naval Research.

1. W.P. Allis and H. W. Allen, Phys. Rev. 52, 703 (1937).

RATIO OF THE DIFFUSION COEFFICIENT TO THE MOBILITY COEFFICIENT FOR ELECTRONS IN He, A, N_2, H_2, D_2, CO, AND CO_2 AT LOW TEMPERATURES AND LOW E/p *

R. W. Warren and J. H. Parker, Jr.
Westinghouse Research Laboratories, Pittsburgh, Pa.

D/μ, the ratio of the diffusion coefficient to the mobility coefficient for electrons, has been determined as a function of E/p, the ratio of the electric field to pressure, in He, A, N_2, H_2, D_2, CO and CO_2. Special interest is centered on the low temperature, low E/p data which are essential for the determination of low energy elastic and inelastic cross sections. The lowest temperature of operation is either 77°K or the boiling point of the gas being measured, whichever is higher. The lowest E/p value is

well within the thermal range where $D/\mu = kT/e$. An analysis of the operation of the experimental tube will be presented along with a method for removing inconsistencies in the results which arise from a conventional interpretation of the data.

*Work supported in part by the Air Force Special Weapons Center and by the Advanced Research Projects Agency through the Office of Naval Research.

E-5 DRIFT VELOCITY MEASUREMENTS IN CESIUM*

L. M. Chanin
Honeywell Research Center, Hopkins, Minn.

Previously reported techniques [1] for the measurement of the mobilities of positive ions have been used to investigate ion and electron drift velocities in cesium vapor. Preliminary results indicate the presence of two ionic species over an E/p_o range from approximately 10-100 volts/cm × torr. The present data yields μ_o values between .1-.2 cm^2/volt sec at low E/p_o. These results may be compared with the values of μ_o = .066 cm^2/volt sec and μ_o = .4 cm^2/volt sec obtained respectively by Dandurand and Holt,[2] and Chen [3] using microwave techniques. Measurements of the drift velocities of electrons in cesium have also been obtained using the same experimental apparatus. Preliminary electron drift velocity values vary from 3×10^5 cm/sec for E/p_o = 2 volts/cm × torr to 9×10^5 cm/sec corresponding to an E/p_o = 100 volts/cm × torr.

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*This work has been supported by the U.S. Army Research Office (Durham) North Carolina.

1. M. A. Biondi and L. M. Chanin, Phys. Rev. 94, 910 (1954).
2. P. Dandurand and R. B. Holt, Phys. Rev. 82, 278 (1951).
3. C. L. Chen, Bull. Am. Phys. Soc. II, 7, 398 (1962).

E-6 ELECTRON TIME OF FLIGHT MEASUREMENTS OF DIFFUSION AND DRIFT VELOCITY

G. S. Hurst, L. B. O'Kelly, E. B. Wagner and J. A. Stockdale*
Oak Ridge National Laboratory,+ Oak Ridge, Tenn.

Electron swarm experiments may be arranged to satisfy the boundary conditions applicable to the one-dimensional, time-dependent, diffusion-drift equation. Under such conditions it may be shown that the distribution of the time-of-arrival of individual electrons at a point on a plane which is L cm from another plane releasing electrons at time t = 0 may be interpreted in terms of the diffusion coefficient, D, drift velocity, w, and the attachment coefficient. Results for D and w for a few gases will be presented.

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*An alien guest from the Australian Atomic Energy Research Establishment, Lucas Heights, Sydney, Australia.

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

E-7 BACK DIFFUSION OF SLOW ELECTRONS IN GASES

J. A. Dahlquist
Washington University, St. Louis, Mo.

The electron current, i_o, leaving a cathode decreases to i, the current arriving at the anode, as a result of the back diffusion of electrons in the presence of a gas. An experimental method was developed for injecting electrons in equilibrium with a field in one region into a second region where i/i_o was measured as a function of E/p, the field to pressure ratio. Data were taken for pressures ranging from 9 mm Hg up to 90 mm Hg in hydrogen, nitrogen, and argon. E/p was varied from 0 to 15 volts/(cm × mm Hg) in hydrogen, 0 to 20 in nitrogen, and from 0 to 5 in argon. Experimental results were compared with a theory developed by R. N. Varney, and good agreement was obtained in hydrogen and nitrogen in the upper pressure limit. A sharp disagreement between theory and experiment in the case of argon is apparently associated with other known peculiarities of argon in discharge phenomena and arises from the unusual distribution of electron velocities in this gas.

E-8 THE HALL EFFECT IN RARE-GAS POSITIVE COLUMNS*

J. M. Anderson
General Electric Research Laboratory, Schenectady, N. Y.

The Hall voltage due to a weak transverse magnetic field (variable to ±25 Gauss) has been observed for the plasma of the positive column established in helium, neon, or argon. Pressures in the range 0.1 - 10 mm Hg and d-c discharge currents from 0.1 to 1000 milliamperes gave easily-measured Hall potentials ~ 0.1 - 1 volt across the 1.6 cm I.D. discharge tube. The Hall voltage developed both in sense and magnitude as would be expected for electrons drifting in the axial voltage gradient, E, of the column. The electron drift velocity may then be calculated for various ratios of E/pressure. Further, a knowledge of discharge current leads to column electron density. The density thus predicted was compared, for the case of helium, with that predicted by microwave measurements and by positive ion current to the column wall. The agreement is satisfactory. Results of measured drift velocities in helium, neon and argon as a function of E/p in range 0.6 - 30 volts/cm - mm Hg will be presented.

*This research has been supported in part by a contract with Air Force Cambridge Research Laboratories.

E-9 **NON-LINEAR AMBIPOLAR DIFFUSION**

K.-B. Persson
National Bureau of Standards, Boulder, Colo.

The theory of the "Inertia Controlled Ambipolar Diffusion"[1] has, by bringing in the non-linear terms that are caused by the inertia of the ions, resolved the dilemma that is associated with the linear diffusion and the boundary conditions. Bohm's criterion - - the ion drift velocity less than or equal to the sound velocity as determined by the electron temperature and the ion mass - - is caused by a singularity in the non-linear diffusion theory. This singularity is present in all isothermal plasmas and gives rise to wall stabilized plasma configurations. The general non-linear diffusion theory that includes the heat conduction or the energy transport mechanism shows that the effect of the singularity can be cancelled by the energy transport mechanism and only by this mechanism. The play between the inertia and energy transport mechanisms will, when the energy transport is sufficiently large, give rise to artifical boundaries within the plasma (striations). The general non-linear ambipolar diffusion theory has within it the capabilities of explaining most of the various plasma configurations that are seen in the laboratory; wall stabilized plasmas at low powers, striations at medium powers and low pressures and the heat conduction controlled arc columns at high powers and high pressures.

1. Scheduled for publication in The Physics of Fluids.

SESSION F: COLLISION PROCESSES: VARIOUS

Chairman: A. Dalgarno
The Queen's University of Belfast, Belfast, N. Ireland

F-1 **AFTERGLOW AND MOBILITY STUDIES IN THE RARE GASES***

H. J. Oskam, V. R. Mittelstadt and J. M. Madson
University of Minnesota, Minneapolis, Minn.

The time variation of the density of electrons in a disintegrating plasma produced in helium, neon and argon has been measured with the microwave cavity technique over a large density range and for pressures of less than 1 mm Hg up to about 40 mm Hg. It was possible to determine the recombination coefficient in neon and argon from a 1/n(t) versus time plot which was linear over a density range of about 25 and 100 respectively. The measurements at low gas pressures can be explained when assuming the disappearance of electrons by ambipolar diffusion in the presence of atomic and/or molecular ions. The values of the mobility of these ions determined from the afterglow studies are in good agreement with values obtained with the aid of the transit time method. The dependence on the gas pressure of the efficiency of the removal of neon impurities from helium by the cataphoresis effect became very evident during the studies. This pressure dependence can easily be explained when considering the process by which neon ions are produced.

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

LIGHT EMISSION AND ABSORPTION STUDIES IN HELIUM AFTERGLOWS*

H. J. Oskam, R. A. Gerber and G. F. Sauter
University of Minnesota, Minneapolis, Minn.

The intensity of the 3889 Angstrom spectral line emitted by a disintegrating plasma produced in helium is measured for a large intensity range between pressures of 1 mm Hg and 25 mm Hg. The measurements indicate the existence of electron disappearance from the plasma by a recombination process with positive ions. The time dependence of the helium triplet metastable atom is studied by measuring the absorption intensity of the 3889 Angstrom line by the decaying plasma. The results obtained during the late afterglow are in excellent agreement with studies by Phelps.[1] However, when correcting the absorption signal for the emission signal the studies do not indicate the conversion of helium singlet metastable atoms into helium triplet metastable atoms as postulated by Phelps.

*Work sponsored by the Office of Naval Research.

1. A. V. Phelps, Phys. Rev. 99, 1304 (1955)

F-2 **ELECTRON RECOMBINATION AND RELAXATION IN HEATED NITROGEN AND DRY AIR***

M. Mentzoni, C. Montgomery, and R. Row
Sylvania Electronic Systems, Waltham, Mass.

Effective volume recombination coefficients (α_r) and electron relaxation time constants (τ) for pure nitrogen and dry air have been measured in the gas temperature and pressure ranges 300^oK - 800^oK and .5 mm Hg-6.0 mm H_g, respectively, using microwave diagnostic techniques. The value of α_r at a pressure of 1 mm H_g and room temperature agrees well with published data. However, α_r is found to increase more rapidly with pressure than reported by earlier investigators. α_r decreases strongly with gas temperature, (T_g). For example, at p = 6 mm H_g and $T_g = 725^oK$ it is found that $\alpha_r = 6.1 \times 10^{-8} cm^3 sec^{-1}$. The measured values of τ are in agreement with theoretical predictions as deduced from Gerjuoy and Stein's cross-sections for rotational excitation.

*Work supported in part by the Army Ordnance Missile Command and the the Advanced Research Projects Agency.

F-3 ATTACHMENT AND DETACHMENT OF ELECTRONS IN O_2 AND CO_2 MIXTURES*

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

Electron attachment and detachment in oxygen and carbon dioxide mixtures are studied at pressures from 5 to 700 mm Hg at temperatures from 300°K to 573°K using the techniques described previously[1] for pure O_2. In mixtures of CO_2 and O_2 at high temperatures and pressures the electrons and ions traverse the drift tube in a narrow pulse. Their velocity is found experimentally to be given by $v_- + v_e K/N_1 N_2$, where v_- and v_e are the negative ion and electron drift velocities and N_1 and N_2 are the oxygen and carbon dioxide densities. The results are consistent with the assumption that $K = N_e N_1 N_2 / N_-$ is the equilibrium constant for the reaction $e + O_2 + CO_2 \rightleftharpoons CO_4^-$ where N_e and N_- are the densities of electron and negative ions. The variation of K with temperature gives an energy of formation for CO_4^- of about 1.2 eV. Electron attachment measurements at 300°K for CO_2 pressures from 5 to 700 mm Hg yield an attachment frequency equal to $K_1 N_1^2 + K_2 N_1 N_2$, in disagreement with the interpretations of Conway.[2]

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

1. J. L. Pack and A. V. Phelps, Bull. Amer. Phys. Soc. 7, 131 (1962).

2. D. C. Conway, J. Chem. Phys. 36, 2549 (1962).

F-4 ATTACHMENT COEFFICIENT FINE STRUCTURE: SF_5^- AND SF_6^- IN SULFUR HEXAFLUORIDE

D. Edelson and K. B. McAfee, Jr.
Bell Telephone Laboratories, Inc., Murray Hill, N. J.

The two negative ions SF_6^- and SF_5^- formed by attachment of low energy electrons to SF_6 in the Townsend discharge have been observed by the drift tube mass spectrometer apparatus previously described. The intensity maximum for SF_5^- occurs at a higher value of E/p than that for SF_6^-, supporting the hypothesis that an initially formed excited $(SF_6^-)^*$ decays into different fragments depending on its excess energy. Plots of attachment coefficient determined in a pulsed Townsend Discharge experiment are found to have peaks corresponding to these maxima in ion intensity. The ion transients obtained in these experiments have previously been interpreted as indicating the presence of only one ion; this is now known to be due to the nearly equal mobilities of the two ions.

F-5 THE ONSET FORMATION OF NEGATIVE IONS IN $SbCl_3$

V. E. Grob
United Aircraft Corporation Research Laboratories, East Hartford, Conn.

The onset formation of negative ions in $SbCl_3$ by electron impact has been investigated using a modification of a Lozier tube which allows the ion species to be determined and prevents contact potentials from affecting the electron energy in the collision region. The identification of the specific reaction taking place was obtained by modifying the Lozier tube to operate as a magnetron beyond cutoff. The mass of the ion specie was then determined from an analysis of the ion current to the collector as a function of the applied axial magnetic field at a constant collector bias. The contact potentials (stray potentials) were minimized by constructing the collision chamber from a single piece of oxygen free Cu and by forming the chamber entrance and exit hole in such a manner that there was less than 0.1 per cent penetration of the accelerating field and/or the electron collector bias field into the chamber. The nonexistence of contact potentials (within experimental error) in the collision chamber was determined experimentally by plotting the ion currents to two separate cylindrical collectors placed along the collision chamber and comparing the onset energy of the ion peaks. The electron energy distribution had an effective width at half height of approximately 0.07 volts which was obtained using a modulation technique.[1] Using this apparatus the most probable ion onset reaction was found, the approximate value of the resonance dissociative capture cross section, the energy of the electron for ion onset, and the dissociation energy for the reaction $SbCl_3 \rightarrow SbCl_2 + Cl$.

1. R. E. Fox, W. M. Kickans, D. J. Grove and T. Kjeldass, Jr. "Ionization in a Mass Spectrometer by Monoenergetic Electrons," Rev. Sci. Instr. 26, 12 (Dec. 1955).

F-6 COLLISION CROSS SECTION DETERMINATIONS BY ION CYCLOTRON RESONANCE*

D. Wobschall, J. R. Graham, Jr., and D. P. Malone
Cornell Aeronautical Laboratory, Buffalo, N. Y.

Ion cyclotron resonance absorption in weakly ionized gases has been studied. A narrow band, derivative type spectrometer was used to detect the power absorption as a function of frequency. Observed absorption and dispersion line shapes fit closely the Lorentz line shape derived theoretically with the assumption of constant mean free time. From the line widths, the collision frequencies of N_2^+, 0_2^+, and Ar^+ in their parent gases were found as a function of pressure and electric field strengths. From this data, the ion-molecule collision cross sections were found at high and low E/p. These cross sections will be compared with those determined from dc mobility studies.

*Supported by U. S. Air Force Contract AF 30(602)-2077 with Rome Air Development Center.

F-7 DETERMINATION OF INELASTIC COLLISION CROSS SECTIONS IN HYDROGEN AND DEUTERIUM USING TRANSPORT COEFFICIENTS *

A. G. Engelhardt and A. V. Phelps
Westinghouse Research Laboratories, Pittsburgh, Pa.

The time independent Boltzmann equation for electrons in H_2 and D_2 is solved numerically[1] taking into account elastic and inelastic collisions for E/N varying from 1.0 to 10^{-17} to 1.5×10^{-15} volt-cm^2. We assume cross sections for momentum transfer,[1] rotational excitation,[1] and ionization[2] as given in previous work, and determine a consistent set of effective cross sections for vibration, dissociation, and excitation by comparing experimental and calculated values of transport coefficients. The final cross section for vibrational excitation of H_2 has a threshold at 0.52 eV and a peak of 7.7×10^{-17} cm^2 at 4.5 eV, whereas that of D_2 has a threshold at 0.36 eV and a peak of 6.6×10^{-17} cm^2 at 4.7 eV. The derived dissociation and excitation cross sections for H_2 and D_2 have, respectively, thresholds at 8.9 eV and 12.0 eV, and peak values of 0.45×10^{-16} cm^2 at 16.0 eV and 1.0×10^{-16} cm^2 at 33.0 eV. Excellent agreement is secured between experimental and calculated values of the drift velocity, the characteristic energy, the frequency of energy exchange collisions,[1] and the Townsend ionization coefficient.

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*Work supported in part by the Advanced Research Projects Agency.

1. L. S. Frost and A. V. Phelps, Phys. Rev. 127, (Sept. 1, 1962).

2. J. T. Tate and P. T. Smith, Phys. Rev. 39, 270 (1932).

F-8 DISSOCIATION OF MOLECULAR HYDROGEN IN ELECTRIC DISCHARGES *

S. B. J. Corrigan
University of Oklahoma, Norman, Okla.

This paper presents improved experimental values of the electron impact dissociation coefficient for molecular hydrogen in the range of reduced electric fields x/p = 12-100 V cm^{-1} (mm Hg)$^{-1}$. The measurements were made both in low current radio-frequency discharges and in uniform positive columns. The dissociation coefficients obtained in these two ways are in good mutual agreement, and as regards order of magnitude are consistent with earlier published data. Reasons are given for assuming that the electron energy distribution in this gas is closely Maxwellian; and this assumption is used to derive dissociation cross-sections consistent with the observed discharge rate coefficients. Some more tentative experimental data for dissociation rates in molecular oxygen will also be presented.

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*Supported by the Air Force Office of Scientific Research.

F-9 **ELECTRON IMPACT IONIZATION CROSS SECTIONS***

J. A. Llewellyn and R. E. Glick
The Florida State University, Tallahassee, Fla.

Several workers have measured total ionization cross sections for electron impact processes but comparable information concerning the probabilities of the individual fragmentation processes which may occur in gases of polyatomic molecules does not appear to be available. We have examined gases of known total ionization cross sections using a modified Bendix Model 14 T-O-F. Mass Spectrometer. Comparison of ionization cross sections determined in this apparatus with those obtained earlier using total ion current collection methods seem to indicate that mass discrimination does not present a problem. The difficulties associated with K. E. of fragment ions have also been considered. On this basis ionization cross sections for a number of gases have been measured over a range of electron energies up to 500 eV and the total cross sections have been analyzed into those for the various fragmentation processes which may occur with polyatomic molecules.

*Supported in part by U. S. Atomic Energy Commission and the Florida State Nuclear Program.

Thursday, October 11, 2:45 P.M.

SESSION G: PLASMAS I: ELECTROMAGNETIC WAVES IN PLASMAS

Chairman: J. M. Richardson
National Bureau of Standards, Boulder, Colo.

G-1 **EMISSION AND ABSORPTION OF MICROWAVE RADIATION BY A PULSATING PLASMA**

R. L. Moore
Moore Applied Physics Co., Los Angeles, Calif.

For a cylindrical plasma with an arbitrary internal force field, the wave equation for the velocity potential includes an extra term and is more general than the usual scalar wave equation. This theory of vibration of a plasma is applicable to plasmas with surface electric and/or magnetic fields with small or large discontinuities. The coupling mechanism is the simple harmonic motion of "surface" currents for either free or fixed boundaries. The theory explains many features of recent experiments.[1] The spectra depend on the spatial eigenvalues (m, axial; n, azimuthal; and α, radial), on the axial velocity, and on both the plasma and the electron sound speeds. The absorption line shape, at low collision frequency, is due to the change of phase of the motion well-known to be associated with driven vibrations at resonance. A plasma in a cavity may take up vibrations corresponding in frequency to the fundamental of the cavity because of the dependence of the frequency on the length. An important conclusion is that experiments done at fixed plasma parameters are much more easily interpreted than those in which the plasma properties are varied and the frequency is fixed.

1. G. Bekefi, J. D. Coccoli, E. B. Hooper, and S. J. Buchsbaum, Phys. Rev. Letters, 9, 6 (1962).

G-2 THE ABSORPTION OF ELECTROMAGNETIC WAVES IN A FULLY IONIZED PLASMA*

H. Derfler
Stanford University, Stanford, Calif.

In microwave cavity diagnostic one aims at deducing the density and collision frequency of an electron plasma from measurements of the dielectric constant $\epsilon = 1 + \omega_p^2/i\omega(i\omega + \nu_c)$. For collision free conditions $\nu_c \ll \omega_p$ one expects to see a sharp absorption peak at plasma frequency ω_p. However, this formula and conclusion are valid only for cold plasmas at rest in the laboratory frame of reference. We have extended the impedance calculations to hot drifting plasmas and predict, apart from a broadening of the peak at plasma frequency, a second resonance $\omega_c = \omega_p(1 - v^2_{drift}/v^2_{thermal})^{\frac{1}{2}}$, a frequency at which the group velocity of the excited plasma waves vanishes according to Bohm's dispersion relation. The heights of these absorption peaks are controlled respectively by the magnitude of the drift and the process of Landau damping. Hence, drift, spread (temperature) and fast electron content of the velocity distribution can be determined in principle from microwave cavity experiments.

*Work supported by the U. S. Air Force, Cambridge Research Laboratories.

G-3 PLASMA SHEATH ROTATION AND ASSOCIATED MICROWAVE RADIATION IN A PENNING DISCHARGE

W. Knauer, A. Fafarman, R. L. Poeschel and R. C. Knechtli
Hughes Research Laboratories, Malibu, Calif.

In a recent paper, one of the authors has reported results of a basic investigation of the Penning discharge.[1] This investigation has shown that at low pressures ($< 10^{-3}$ mm Hg), the potential in the discharge is depressed to near cathode potential. Near the anode, the potential rises sharply and the electrons within this sheath region execute an $E \times B$ drift around the inside diameter of the anode. This rotation has been the subject of further studies. The associated current has been found to be of the order of 0.5 amp., i. e., quite large, and independent of pressure, which supports the earlier developed hypothesis of a pressure independent plasma sheath. The rotation current has also been found to produce large quantities of microwave noise power. Measurements with a split anode configuration of 1.6 cm diameter have shown several noise bands at approximately 70, 210 and 340 Mc/s with a discharge voltage of 3000 volts and a magnetic field of 2000 gauss. These bands were interpreted as associated with the first, third and fifth harmonic of the electron rotation. The total output power exceeded 1 watt.

1. W. Knauer, J. A. P. 33, 2093 (1962).

G-4 NONLINEAR INTERACTIONS OF ELECTROMAGNETIC WAVES WITH A HELIUM PLASMA*

S. J. Tetenbaum and E. B. Barrett
General Telephone and Electronics Laboratories, Inc., Palo Alto, Calif.

An investigation is being carried out on the nonlinear interactions between electromagnetic waves and a free space helium plasma in a magnetic field. The theory is based upon the work of Whitmer and Barrett [1] on nonlinear interactions. The experiment approximates small signal plane wave propagation in a uniform plasma slab and allows the simultaneous propagation of several microwave signals in the 9 and/or 18 Gc/s regions. Incident signals of identical direction and polarization propagate normal to the magnetic field. An rf oscillator produces electron densities from 10^9 to 10^{12} cm^{-3} in a rectangular glass bottle for $10^{-3} < p < 1$ torr. The magnetic field ranges from 0 to 4000 gauss. The sum frequency of two incident X-band signals and the difference frequency of a K_u-band and an X-band signal have been detected in transmission. The field strength of the generated sum frequency wave is proportional to the product of the field strengths of the individual waves. For $p < 0.05$ torr, the sum frequency power vs. magnetic field characteristic exhibits five distinct peaks. The dependence of the positions and relative amplitudes of these peaks on the plasma parameters is compared with theory.

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*Work supported by Rome Air Development Center.

1. R. F. Whitmer and E. B. Barrett, Phys. Rev. 121, 661 (1961); Phys. Rev. 125, 1478 (1962).

G-5 WHISTLER MODE RADIATION AND PROPAGATION IN HELIUM SHOCKWAVES

K. B. Earnshaw and R. M. Gallet
National Bureau of Standards, Boulder, Colo.

Radiation and propagation of 3 cm microwaves has been observed below the gyro frequency in the dense plasmas ($N_e < 10^{14}$ cm^{-3}) associated with strong shockwaves in helium ($M \sim 80$). This radiation and propagation is associated with the class of radio emissions observed in geophysical phenomena known as whistlers in which propagation along magnetic lines of force occurs at all frequencies between a very low value and the local gyro frequency, regardless of the plasma frequency. Incoherent emission of radiation along the magnetic field ($\phi = 0$) has been observed immediately behind the shock front over a band of frequencies below the gyro frequency. with no emission being observed at or above the gyro frequency. Propagation along the magnetic field is regularly observed in the strong precursor ionization far in advance of the shock, as well as in the dense, hot plasma immediately behind the shock front. As with the emission experiments, propagation occurs only at frequencies below the gyro frequency. By using microwave interferometry, the change in index of refraction caused by the approach of the highly ionized shock front can be roughly followed up to a value of 10 or more. Details of the experimental arrangement will be given, including the production of the shockwaves, and the microwave diagnostic apparatus.

G-6 MEASUREMENTS OF WHISTLER-MODE PROPAGATION

A. N. Dellis and J. M. Weaver
Culham Laboratory, Harwell, England

A study has been made of the propagation of a 9280 Mc/s wave through the afterglow plasma of a pulsed argon discharge, with a uniform magnetic field of 1800-6800 gauss superimposed. The decaying electron density and temperature were measured with a Langmuir probe. Changes in the plasma refractive index, during the afterglow, were measured interferometrically. For magnetic fields above the electron cyclotron-resonance value, and for electron densities above 10^{13} cm^{-3}, the interferograms were in agreement (30%) with the predictions of the Appleton equation for propagation of the whistler-mode, using the densities measured by the probe. The polarization of the transmitted waves was analysed and the whistler-mode wave found to have right-hand circular polarization relative to the magnetic field direction. The poorer agreement between the probe and interferometer density measurements at densities below 10^{13} cm^{-3} is discussed and reasons given why the probe is believed to be in error. The initial rise in the amplitude of the whistler-mode signal is explained by electron-ion collisional damping.

G-7 MICROWAVE TRANSMISSION IN A MAGNETIZED PLASMA

D. W. Mahaffey
Boeing Scientific Research Laboratories, Seattle, Wash.

Measurements have been made on microwave signals propagating through a plasma parallel to the magnetic field lines. The apparatus and some earlier measurements have been described previously.[1] Transmission and attenuation characteristics have now been investigated at frequencies above and below the electron cyclotron frequency for both the "ordinary" and "extraordinary" modes, that is for both left-and right-hand circularly polarized waves. The refractive index of the plasma was measured using an X-band interferometer operating in both modes and the results indicate densities covering the range 10^{10} electrons/cc to 10^{13} electrons/cc. It was thus confirmed that the microwave signals were transmitted through the plasma at frequencies both greater than and less than the plasma frequency. This latter case, with the "extraordinary" mode and a frequency less than the electron cyclotron frequency is the atmospheric "Whistler" mode.

1. D. W. Mahaffey, Bull. Am. Phys. Soc. 6, 389 (1961).

G-8 RESONANCE PHENOMENA IN A GASEOUS DISCHARGE IN THE PRESENCE OF A MAGNETIC FIELD*

B. Beeken, R. Goldman and L. Oster
Yale University and Yale University Observatory, New Haven, Conn.

With the apparatus described previously,[1] detailed measurements of energy and frequency behavior of the e.m. radiation emitted by the discharge were made. We found: (1) A series of resonance frequencies ω_i around the gyro-frequency ω_c; (2) An emission at a frequency ω_f which increases with the magnetic field, decreases with the applied voltage; (3) A strong resonance if ω_f coincides with any of the resonances ω_i. We suggest that the frequencies ω_i are caused by the simultaneous action of the magnetic field and the electric field in the body of the discharge. The resonance described under (3) can be explained as an energy transfer from a non-radiating plasma oscillation to the e.m. mode around the frequency[2] $\omega_f^2 = \omega_p^2 + (\omega_c + cE/rH)^2$, where $\omega_p (\omega_p \ll \omega_c)$ is the plasma frequency, E the electric field in the sheath region around the anode, r the corresponding linear dimension. The implications of the observed frequency variation on the discharge parameters are discussed.

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

1. B. Beeken, R. Goldman, L. Oster, Bull. Am. Phys. Soc. 7, 132 (1962).

2. L. Oster, Rev. Mod. Phys. 32, 141 (1960); c.f. Eq. (161).

G-9 FLUCTUATIONS IN A PLASMA NOT IN THERMAL EQUILIBRIUM*

O. Buneman
Stanford University, Stanford, Calif.

Radar probing has yielded information on the exospheric plasma in encouragingly good agreement with theoretical predictions, promising that eventually all significant plasma parameters may be deduced from such measurements. There is reason to believe, however, that at times the exospheric plasma is not in perfect statistical equilibrium and the fluctuation theory had to be developed for plasmas in such a state, the case of unequalized electron and ion temperatures (T_e, T_i) being the most important. Simplifications in the general theory have enabled us to derive simple formulae for the total intensity scattered from a plasma with $T_e \neq T_i$. At long wavelengths one calculates $T_i/(T_e + T_i)$ times the power scattered by free electrons. The anticipated gyro-resonances in the spectrum become sharper the more T_e exceeds T_i. The case of an appreciable drift of the electrons against a background of a collision-dominated, slightly ionized gas (ionosphere) is under consideration: a resonance between electrons and sound waves (observed in crystals) is believed to be responsible for the enchancement of backscatter under disturbed conditions.

*Work supported by AF Contract 19 (604)-7436.

G-10 NONLINEAR STATIONARY WAVES IN RELATIVISTIC PLASMAS*

H. S. C. Wang
University of Colorado, Boulder, Colo.

Theory of nonlinear stationary longitudinal waves in relativistic plasmas is treated by solving a relativistic Boltzmann equation without linearization. It is proved that stationary waves of arbitrary amplitude can be propagated and obey a dispersion equation. If the velocity of propagation, V, is less than the velocity of light, c, there is an amplitude limitation which agrees with nonrelativistic nonlinear treatments in the limit $V \ll c$. For $V > c$, however, there is no amplitude limitation. The nonlinearity in the Boltzmann equation causes a decrease of frequency of oscillation for a given wave velocity in addition to the distortion in waveform. Detailed solutions for plasmas with a Maxwellian electron velocity distribution and relativistic electron beams are given. In the former case, a dispersion equation including nonlinear effect is derived through a series expansion to an order higher than that used in linearized theory. In the latter, a complete analytic solution in terms of elliptical integrals is given. In both cases dispersion characteristics for several parameters are computed and plotted. The agreement between these nonlinear dispersion equations in the limit of vanishing amplitudes and those of the linearized theory is indicated.

*Supported by National Bureau of Standards, Boulder, Colorado.

Friday, October 12, 9:00 A.M.

SESSION H: COLLISION PROCESSES: CHARGE EXCHANGE AND IONIZATION

Chairman: L. M. Branscomb
Joint Institute for Laboratory Astrophysics, Boulder, Colo.

H-1 CHARGE EXCHANGE BETWEEN GASEOUS IONS AND ATOMS

D. Rapp and W. E. Francis
Lockheed Missiles and Space Company, Palo Alto, Calif.

A calculation of symmetric resonant charge exchange cross-sections has been made for a selection of atoms in the velocity range where the impact parameter method is a good approximation. Cross-sections for other atoms can be estimated by interpolating in terms of their ionization potentials. The results are in fair agreement with experiment. A similar calculation has been attempted for asymmetric non-resonant charge exchange processes. The approximations used are more restrictive in this calculation, the calculations being only semi-quantitative in nature. The cross section of an asymmetric charge exchange process is determined in terms of the ΔE of the reaction and the "average" ionization potential of the two atoms. The results are qualitatively in agreement with experiment. A very brief discussion of approaches for extrapolating data to lower velocities, where the rectilinear orbit impact parameter method is a poor approximation, is given.

H-2 RESONANCE CHARGE EXCHANGE IN ATOMIC COLLISIONS

W. Lichten
University of Chicago, Chicago, Ill.

The remarkable results of Everhart et al, in observing resonance charge exchange in ion-atom collisions, are discussed in terms of the well known impact parameter method. It is shown that previous theories based on adiabatic potential curves are inconsistent with the results of He^+ - He experiments. However, experimental results are correctly predicted from a Heisenberg representation consisting of the basis set of single configuration wave functions built up from molecular orbitals. In this representation, the collision can be assumed to be adiabatic except for very short or very long collision times. The case of double charge exchange is treated, and it is shown that a three-state approximation is required. The presence of phase shifts in the equations representing the experimental results follows as a result of the breakdown of interference at zero collision time. Damping is discussed. The results include the work of previous authors and are general enough to include cases that have not been discussed. In particular, charge exchange in He^{++} - He, Li^+ - Li and Li^{++} - Li collisions is discussed and prediction of experimental results are made. A brief discussion is given of non-resonant collisions, such as H^+ - He and He^+ - H.

H-3 SOME CHARGE TRANSFER MEASUREMENTS IN ATOMIC OXYGEN*

R. F. Stebbings, A. C. H. Smith and H. B. Gilbody+
General Dynamics/General Atomic, San Diego, Calif.

Cross sections for charge transfer between oxygen atoms and some positive ions have been measured within the energy range 50 to 10,000 eV, using modulated-crossed-beam techniques. The neutral beam effused from a Pyrex tube in which an electrodeless rf discharge could be established. It was determined, by use of a mass spectrometer, that about 40% of the molecules in the beam could be dissociated. The currents of slow ions which resulted from charge transfer between the primary ion beam and both the undissociated and partially dissociated oxygen beams were measured. The atomic cross sections were then evaluated from knowledge of these currents, the dissociation, and the previously determined molecular charge-transfer cross sections.

*Research sponsored by the Defense Atomic Support Agency.

+Present address: University College London, England.

H-4 RESONANT ELECTRON EXCHANGE IN ION-ATOM COLLISIONS*

P. R. Jones, P. Costigan and G. Van Dyk
University of Massachusetts, Amherst, Mass.

Recent measurements show that resonant electron exchange plays an important part in the electronic rearrangement which accompanies single collisions of Ne^+ on Ne and Ar^+ on Ar at laboratory energies of a few keV. The apparatus causes a beam of incident ions to be scattered from a low-pressure target gas and then selects those particles scattered at a prescribed angle. The data constitute a charge analysis of the scattered incident particles at each of several scattering angles and energies, and are an extension of the data of Ziemba et al.[1] At a fixed energy the neutral fraction, interpreted as the single-collision electron capture probability, oscillates with scattering angle and thus with impact parameter. This behavior is evidently the result of resonance of the ion-atom system between the repulsive and attractive states characteristic of the homonuclear, diatomic, molecular ion, and the data are discussed in terms of this interpretation. An empirical functional dependence upon internuclear separation, R, is obtained for the energy difference $(E_r - E_a)$ between repulsive and attractive states of $(Ne_2)^+$: $(E_r - E_a) = (390\ eV)\ \exp(-R/0.22Å)$ for $0.2Å < R < 0.8Å$. The Ar^+ on Ar study is still in progress, the apparatus presently undergoing modification to permit measurements at lower energies and smaller scattering angles.

*Work supported by the National Science Foundation.

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

H-5 COLLISIONS BETWEEN He^+ AND O_2*

W. L. Fite
General Dynamics/General Atomic, San Diego, Calif.

The rearrangement collisions between He^+ and O_2 have become of considerable interest recently for interpretation of the helium balance in the upper atmosphere, and for interpretation of laboratory experiments on charge transfer between O^+ and O_2 in which helium has been used as a buffer gas. Three experiments have recently been carried out to study these collisions. The first used mass spectrometric monitoring of the afterglows in He-O_2 discharges and the second used a modulated beam gas analyzer to observe the neutral particles in the discharges. HeO^+ was not observed and it seems evident that the dissociative charge transfer process $He^+ + O_2 \rightarrow He + O^+ + O$ is the dominant process at thermal energies with a rate coefficient of about $5 \times 10^{-10}\ cm^3/sec$. The third experiment was a crossed beam experiment in which the charge transfer products were detected mass spectrometrically. Up to energies of several keV dissociative charge transfer remains the dominant process and displays the general characteristics of resonant charge transfer. Some implications of these experiments are discussed.

*Research sponsored by the Defense Atomic Support Agency.

H-6 **ENERGY DEPENDENCES OF CROSS SECTIONS FOR SOME ION-MOLECULE REACTIONS***

W. B. Maier II and C. Giese
University of Chicago, Chicago, Ill.

The apparatus for the study of ion-molecule reactions which has been described [1] has been used to measure the total cross sections for a number of reactions as functions of energy of the primary ions. A number of essential corrections to the cross sections are now being applied, including the calculation of the probability that a secondary ion will be transmitted and detected. The energy of the primary ion can be made one eV or less in favorable cases and determined to within 0.2 eV. The reactions to be discussed are $H_2^+ + H_2 \rightarrow H_3^+ + H$, $Ar^+ + D_2 \rightarrow ArD^+ + D$, $D_2^+ + Ar \rightarrow ArD^+ + D$, $N_2^+ + D_2 \rightarrow N_2D^+ + D$, $D_2^+ + N_2 \rightarrow N_2D^+ + D$, and $H_2^+ + He \rightarrow HeH^+ + H$. The comparison of these cross sections with existing theoretical predictions will be discussed.

*This research has been supported by grants from the National Science Foundation, the Louis Block Fund for Basic Research, and the Esso Education Foundation.

1. Clayton F. Giese and William B. Maier II, J. Chem. Phys. 35, 1913 (1961).

DETERMINATION OF THRESHOLDS FOR SOME ENDOTHERMIC ION-MOLECULE REACTIONS*

C. Giese and W. B. Maier II
University of Chicago, Chicago, Ill.

Cross sections for the reactions: (1) $He^+ + CO \rightarrow C^+ + O + He$; (2) $Ne^+ + CO \rightarrow C^+ + O + Ne$; (3) $Ar^+ + CO \rightarrow C^+ + O + Ar$ have been studied as functions of primary ion kinetic energy. Assuming the presently well-accepted value of 11.11 eV for the dissociation energy of CO, one expects reaction (1) to be exothermic and both (2) and (3) to be endothermic. The experimental results confirm this clearly. Further, the onsets of reactions (2) and (3) are surprisingly abrupt, with the result that the thresholds can be determined quite accurately. These thresholds are in good agreement with the calculated thresholds. The possibility of extending this technique to the study of other endothermic reactions, to determine, for example, unknown bond energies, will be discussed.

*This research has been supported by grants from the National Science Foundation, the Louis Block Fund for Basic Research, and the Esso Education Foundation.

H-7 PRODUCTION OF METASTABLE Hg ATOMS BY CHARGE EXCHANGE*

R. W. Rostron
Washington University, St. Louis, Mo.

Mercury ions have been extracted from the plasma of a mercury arc through the small aperature in a probe at high negative potential. By means of suitable electrodes, the ions were brought to any desired energy in the range 500 to 5000 eV. The ions then passed through a field-free region containing mercury vapor where part of them became neutralized by charge exchange collisions. The remaining ions were stopped by a retarding potential. The beam of neutral atoms then struck a metal target within a suitable cage for collecting ejected secondary electrons. The yield of secondary electrons was so large that it seemed unlikely that neutral atoms of mercury in their ground state could be responsible. Values of γ as high as 0.50 were noted. The only reasonable alternative seemed to be that the neutral atoms were in a metastable state. Two methods were used to test this hypothesis. The first consisted of increasing the distance of flight of the metastables giving them more time to decay in flight. The second method was to introduce small amounts of foreign gases to quench the metastables in flight. Final results of these observations confirming the metastable hypothesis will be presented.

*Supported by a research grant from Army Research Office (Durham) North Carolina.

H-8 REDUCTION OF ELECTRIC GRADIENTS BY N_2 ADMIXTURES IN THE RARE GASES AND THE LIFETIMES OF METASTABLE N_2 MOLECULES

C. Kenty
General Electric Lamp Research Laboratory, Cleveland, Ohio

A 1 ma diffuse discharge in 50-500 mm of a rare gas has a high gradient (30 V/cm in 300 mm Xe in a 2.8 cm diam. tube) due to strong production of continuous (molecular) radiation. A little N_2 (.1%) greatly reduces the gradient (8-fold in Xe), multistage ionization being produced by electrons not energetic enough to excite the rare gas. The metastable $N_2(A^3\Sigma_u^+$, 6.17 eV) at a population of 10^{11} - 10^{12} cm^{-3} is the first stage, while $N_2(^3\Delta_u$, 7-8 eV) at a population of $\sim 10^{13}$ cm^{-3} is the second. These $^3\Delta_u$'s can be ionized by electrons; or e.g., two $^3\Delta_u$'s can collide, resulting in N_2^+. Such $^3\Delta_u$'s can also account for the excitation of certain metallic spectra in the afterglow and for the energy storage and ionization in the afterglow. The afterglow duration indicates a life for $^3\Delta_u$ of $\sim$ 1 sec. The Vegard-Kaplan bands from $A^3\Sigma_u^+$ are not observed (transitions $< 10^{12}$ sec^{-1} cm^{-3}). Since, in A and N_2, $\sim 10^{14}$ transitions sec^{-1} cm^{-3} come down on $A^3\Sigma_u^+$ via the first and second positive bands, some agent must be destroying $A^3\Sigma_u^+$. This agent is probably $^3\Delta_u$. The afterglow is too strongly destroyed at the walls to be due to N atoms.

H-9 IONIZATION CROSS SECTIONS FOR He^+ IONS WITH ENERGIES FROM 0.15 TO 1.0 MEV*

J. W. Hooper, R. A. Langley, D. W. Martin, and E. W. McDaniel
Georgia Institute of Technology, Atlanta, Ga.

The apparent cross section σ_+ for the production of slow positive ions and the cross section σ_- for the production of free electrons have been measured for fast He^+ ions incident on targets of He, Ne, Ar, H_2, N_2, and CO. The incident ion energy ranged from 0.15 to 1.0 Mev. A "thin target" condenser method was used. Differences between σ_+ and σ_- are attributable to "charge-changing" collisions, in which the incident ion captures or loses an electron. Experimental difficulties arising from the production of energetic electrons at collimating slit edges by the incident beam are described and the apparatus modifications and changes in experimental technique required to obtain reliable results are discussed. Final explicit numerical results are presented and are shown to be in close agreement with the available experimental results of Fedorenko[1], et. al. for the targets He, Ne, and Ar at energies up to 0.2 Mev. Further quantitative comparison is made with the charge-changing cross sections of Pivovar,[2] et. al., for the targets He, Ar, and N_2.

*Work partially supported by the U. S. Atomic Energy Commission. The work reported here is a portion of a research program undertaken by one of us (RAL) in partial fullfillment of the requirements for the degree Doctor of Philosophy at the Georgia Institute of Technology.

1. N. V. Fedorenko, V. V. Afrosimov and D. M. Kaminker, Soviet Phys.-Tech.Phys. 1, 1872 (1956).

2. L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Soviet Phys.-JETP 14, 20 (1962).

COMPARISON OF IONIZATION BY SINGLY-CHARGED HELIUM IONS WITH PROTON IONIZATION AND THE BORN APPROXIMATION PREDICTIONS

D. S. Harmer
Georgia Institute of Technology, Atlanta, Ga.

Comparison is made of the total ionization cross-sections of He^+ ions on several target gases, as determined by J. W. Hooper, et al.,[1] with proton ionization at the same incident particle velocity in the energy range 0.15 to 1.0-Mev. Using Bethe's expression for the total ionization cross-section, derived using the Born approximation in the form: $\sigma = (Z^2 A/E) \ln BE$, in which Z and E are the incident particle charge number and energy, and A and B are parameters dependent only on the target gas and the mass of the incident particle, the ionization by singly-charged helium ions may be calculated. Values[2] of A and B determined from the corresponding proton ionization cross-sections are used in the calculation, modified by the mass ratio of the helium ion to the proton. The observed cross-sections values[1] for He^+ ions, after removal of charge transfer contributions, are significantly larger than those predicted from these scaled proton results using 1.0 as the helium-ion charge, and are smaller than those predicted similarly for alpha particles. These results are discussed in terms of an increased effective charge of the He^+ ion and numerical values will be given.

1. J. W. Hooper, et al., Bull. Am. Phys. Soc. 7, 399 (1962); and (to be published).

2. J. W. Hooper, et al., Phys. Rev. 125, 2000 (1962).

H-10 ENERGY AND ANGULAR DISTRIBUTION OF ELECTRONS EJECTED FROM HYDROGEN AND HELIUM GAS BY PROTONS*

M. E. Rudd[+] and T. Jorgensen, Jr.
University of Nebraska, Lincoln, Nebr.

Differential cross sections for ejection of secondary electrons of various energies at various angles were measured for hydrogen gas bombarded by 100 keV protons and for helium gas bombarded by 50, 100, and 150 keV protons. The range of angles investigated was 10° to 160° and the range of electron energies was 1 to 500 eV. As a function of electron energy the cross sections decrease monotonically above about 2.5 eV and are uncertain below this value. All cross sections decrease monotonically with an increase in angle but are relatively constant above about 110°. The differential cross sections have been integrated to obtain distributions over electron energy and angle, total cross section for ionization, average energies of the ejected electrons, and the stopping cross sections due to ionization. Agreement of the electron energy distribution with that predicted by the Born approximation is fair for hydrogen and good for helium.

*Supported in part by the U.S. Atomic Energy Commission.

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H-11 DISSOCIATIVE IONIZATION OF H_2—A STUDY OF ANGULAR DISTRIBUTIONS AND ENERGY PROFILES OF RESULTANT FAST PROTONS*

G. H. Dunn and L. J. Kieffer
Joint Institute for Laboratory Astrophysics, Boulder, Colo.

Protons with energies between 2 eV and 14 eV have been observed from the dissociative ionization of H_2. A 60° sector magnetic spectrometer and magnetic electron multiplier were used in the experiment as the proton energy analyzer and detector respectively. Anisotropies were observed in the angular distributions of the protons. The nature of the anisotropy was found to be energy dependent with the proton distributions forward-backward peaked at low electron energies and peaked at 90° to the electron beam at high energies. These anisotropies will be discussed in terms of the symmetries of the collision.[1] The maxima of the proton energy distributions occurred at higher proton energies than those observed by prevous workers.[2] The present results are more nearly consistent with the predictions of the Franck-Condon principle.[3]

*This research was supported in part by the Controlled Thermonuclear Branch of the Atomic Energy Commission and by A.R.P.A. as a part of Project DEFENDER.

1. Dunn, G. H. Phys. Rev. Letts. 8, 62 (1962).
2. Lozier, W. W., Phys. Rev. 36, 1285 (1930).
3. Stephenson, D. P., J. Am. Chem. Soc. 82, 5961 (1960).

Friday, October 12, 9:00 A.M.

SESSION I: PLASMAS II; DISCHARGES

Chairman: L. Tonks
General Electric Company, Schenectady, N. Y.

I-1 VHF OSCILLATIONS AND ANOMOLOUS VOLT-AMPERE CHARACTERISTIC OF A PENNING GAUGE*

F. R. Crownfield, Jr. and R. N. Dennis, Jr.
College of William and Mary, Williamsburg, Va.

VHF Oscillations have been observed in a Penning Gauge by connecting a radio receiver to the anode of the gauge. The frequencies, line widths, and amplitudes of the oscillations depend on the gas pressure, applied magnetic field, and applied voltage. The frequencies can be correlated with the slow-wave modes of a plasma-filled conducting cylinder described by Trivelpiece and Gould.[1] For given conditions of gas pressure, applied magnetic field, and applied voltage, it has been found that small changes in applied voltage may produce pronounced changes in the current drawn by the gauge. Concurrent with these changes, distinct changes in the oscillation spectrum have been observed. This seems to demonstrate a connection between conduction processes in the gauge and plasma oscillations.

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*Work supported in part by a grant from the National Aeronautics and Space Administration.

1. A. W. Trivelpiece and R. W. Gould, J. Appl. Phys. 30, 1784 (1959).

I-2 THE RADIATIVE DECAY OF METASTABLE ARGON ATOMS IN A LOW-DENSITY ARGON PLASMA STREAM

L. E. Brewer and W. K. McGregor
ARO, Inc., Arnold Air Force Station, Tenn.

A low-density, luminous, supersonic argon plasma stream about one meter in length produced by a conventional dc arc plasma generator was studied spectroscopically. The spectra consisted of neutral argon atom lines and second positive nitrogen bands. Stream enthalpy and velocity calculations rule out thermal excitation and electron-ion recombination as sources of the radiation. Radiative decay of metastable argon atoms will, however, account for the long lifetimes of the radiating argon and also for the excitation of the nitrogen, which enters the stream by mixing of the ambient test cell gas. The existence of metastable atoms and their behavior are further examined by use of additive gases. Atoms with excitation levels below the potential of the argon metastables (hydrogen and krypton) tend to quench the radiation, whereas those with higher excitation levels (helium and neon) have no effect on the argon metastables, and their presence is not spectroscopically detectable. The impact of these results on the use of the radiation from the expanded jet from arc plasma generators for measurements such as thermodynamic temperature is evident.

I-3 PROPAGATION OF ULTRASONIC WAVES IN AN IONIZED GAS

M. Surdin
Centre d'Etudes Nucleaires de Saclay, France

Ultrasonic waves launched by a piezoelectric quartz crystal are propagated in an ionized gas. Experimental results concerning the velocity of propagation and the attenuation of these waves and a simplified theory of the phenomenon are given.

I-4 **PLASMA DIAGNOSTICS WITH VACUUM ULTRAVIOLET RADIATION***

G. S. Bajwa, H. E. Blackwell and G. L. Weissler
University of Southern California, Los Angeles, Calif.

The structure of the shock front and the shocked gas in xenon, produced by a Kolb-type magnetically driven shock tube, was studied in the following manner. A pulsed beam of radiation was made to pass through the gas and then dispersed by a normal incidence vacuum monochromator. Photomultipliers mounted behind the exit slits at appropriately chosen wavelengths monitored the transmitted light intensity. From the transmitted intensity ratios the neutral atom density was measured in front and behind the shock at closely spaced time intervals, and the shock front was clearly identified by the sharp rise in density. The production of xenon ions (Xe^+) was measured by a similar procedure. The undispersed radiation from the shocked gas was monitored by another photomultiplier, in order to measure the delay time between the arrival of the shock, as determined from vacuum ultraviolet absorption data, and the time when the shocked gas becomes luminous. Studies of this time resolved radiation indicate that the intensity variation of the undispersed radiation follows the variation in xenon ion density, suggesting that bremsstrahlung is responsible for most of this visible light. The presence of xenon metastables together with other effects presumably due to precursor radiation will be discussed. Improved values of the photoionization cross sections of neutral xenon will also be presented.

*It is a pleasure to acknowledge the support of both the Office of Naval Research and the Army Research Office, Durham.

I-5 **ELECTRON-DRIVEN SHOCK WAVES AS A MEASURE OF LARGE ELECTRON TEMPERATURES***

R. G. Fowler
University of Oklahoma, Norman, Okla.

Development of the theory of electron-driven shock waves has provided the possibility of turning it around to determine large electron temperatures quantitatively from flow velocities rather than vice-versa as has been done heretofore. Examples will be given and some of the difficulties reviewed.

*This study has been supported by the U.S. Office of Naval Research.

I-6 A THEORY OF BREAKDOWN WAVE PROPAGATION*

G. W. Paxton and R. G. Fowler
University of Oklahoma, Norman, Okla.

The propagation of electrical breakdown waves in a gas is analyzed by assuming that the wave front of the breakdown wave is an electron shock wave. A simple three-fluid hydrodynamical model is used in which the partial pressure of the electron gas behind the shock zone is the primary source of the motion. A theoretical wave velocity of 2×10^7 m/sec is predicted for an applied field of 10^4 volts/m in H_2 at a pressure of .2 mm Hg. Since the propagation mechanism of the breakdown wave is mechanical, the model explains propagation equally well into either a positive or negative electric field. Qualitative agreement between theoretical and experimental breakdown wave velocities is obtained.

*This study has been supported in part by the U. S. Office of Naval Research.

I-7 IONIZATION FORMULA AND LOWERING OF THE IONIZATION ENERGY FOR A PLASMA WITH COMPONENTS OF DIFFERENT TEMPERATURES

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

In a plasma the ionization energy is decreased due to the presence of the electric microfield. After investigating this problem for a system in thermodynamical equilibrium [1] we now turn to the case of a stationary multi-component system with different temperatures of the components. By the use of irreversible thermodynamics we derive a general ionization formula for such a plasma and calculate the lowering of the ionization energy similar to a procedure developed for the treatment of the equilibrium problem. [2]

1. Bulletin of the American Physical Society 7, No. 2, 130 (1962).

2. Forschungsbericht des Landes Nordrhein-Westfalen. In print.

I-8 THEORY OF THE CONSTRICTION OF THE POSITIVE COLUMN

G. Albrecht, G. Ecker and K. G. Müller
Institut für Theoretische Physik der Universität Bonn, Germany

A general discussion of the constriction of the positive column leads to the conclusion that with increasing distance from the axis either the effective electron diffusion coefficient must increase or the production coefficient must decrease to negative values. Various physical processes can meet these requirements. The constriction caused by the presence of negative ions is evaluated from the transport equations. An eigenvalue problem of two differential equations with boundary conditions results. We use the axial ionization degree and the ratio of electric field and pressure as experimental parameters. The eigenvalues give then the product of current and pressure (pI) and the product of tube radius and pressure (pR) respectively. It is possible to reduce the twofold multiplicity of radial electron density distributions to a onefold multiplicity introducing the relative half width as a constriction parameter. This constriction parameter is given as a function of the quantities pI and pR.

I-9 APPLICATION OF A NEW METHOD OF CALCULATING CURRENT IN THE IONIC CENTRIFUGE

J. Slepian
Pittsburgh, Pa.

A recently published book[1] makes the relations between mean ion density and mean electron density in a completely ionized plasma depend also upon the mean peculiar velocities (see page 122 of the book) of ions and electrons, and gives a universal equation $\rho_1\bar{V}_1 + \rho_2\bar{V}_2 = 0$ holding for the peculiar velocities. The application of these ideas to the two types of discharge in my Ionic Centrifuge[2,3] confirm the experimentally found result of half the ions discharging to the floating cylinder in the first type of discharge, and makes the second type of discharge seem hopeful for practical nuclear fusion.

1. Ferraro and Plumpton, Magneto-Fluid Mechanics, Oxford U.P. (1961).
2. J. Slepian, Proc. N.A.S. 47, 313 (1961).
3. J. Slepian, Proc. N.A.S. 48, 913 (1962).

I-10 INTEGRAL OPERATORS IN THE THEORY OF WAVE PROPAGATION*

M. Z. v. Krzywoblocki
Michigan State University, East Lansing, Mich.

Equations for wave propagation in ionosphere, troposphere, etc., based upon the Maxwell system or the system of equations of electro-magneto-hydro-dynamics, reduce to wave equations, homogeneous or not, with variable coefficients. Classical methods of solving them (linearization, small perturbation) restrict strongly the range of vector fields (small rate of change of functions). Methods applying special functions, approximate techniques (W. K. B., etc.) furnish local solutions, which should be supplemented by the analytical continuation to give solutions "in the large" (never done in practice). Moreover, they are very complicated. The author applies the technique of integral operators to the cases of wave propagation in ionized gases, scattering and attentuation of electromagnetic waves in turbulent media, wave propagation in stratified troposphere, etc. The techniques valid often in the large refer to potential theory, Green's function (Volterra's integral), Bergman's integral operators, etc. Using Bergman's operators one obtains much broader and formally more simple class of solutions than, for instance, that of Bremmer.

*Partial sponsorship of Collins Radio Company (Messrs. Perry, Hodgin and Gerks) of this work is gratefully acknowledged.

Friday, October 12, 2:15 P.M.

SESSION J: OPTICAL RADIATION

Chairman: N. P. Carleton
Harvard University, Cambridge, Mass.

J-1 COLLISIONAL EXCITATION TRANSFER TO THE 4^1D STATE IN HELIUM*

C. C. Lin and R. M. St. John
University of Oklahoma, Norman, Okla.

The excitation function of the 4^1D state of helium has been measured at various pressures by means of an automatic processing system. The peak of the curve shifts gradually from 50 eV to 100 eV as the pressure is increased. This can be explained by the collisional transfer of excitation from the ^1P states through the multiple state mechanism. Based on this theory the calculated population of the 4^1D state agrees quite well with experiments. The observed amounts of transfer from n^1P states to 4^1D and to 4^3D are of the same order of magnitude as predicted by the theory. The effect of direct transfer from 4^1P has been examined and is found to be much weaker than that of the multiple state process.

*Supported by the Air Force Office of Scientific Research.

PRESSURE DEPENDENCE OF EXCITATION FUNCTIONS OF TRIPLET S AND P STATES IN HELIUM*

R. M. St. John and C. C. Lin
University of Oklahoma, Norman, Okla.

Electron excitation functions of low-lying ^3S and ^3P states of helium at pressures above 0.1 torr show a secondary peak at 50 eV similar in shape to the excitation function of the 4^1D state at low pressure. Low level ^1D excitation functions are greatly affected at pressures above 0.01 torr due to transfer from ^1P states to F states; the F-state atoms populate the low level ^1D states by cascade but not the upper ones to any extent. This indicates that the transfer occurs mainly through high level ^1D states to triplet states. The transfer probably is mostly from n^1D to n^3D. The spin-orbit interaction produces a small amount of singlet-triplet mixing which leads to substantial cross sections for n^1D - n^3D transfer because of the extremely close resonance. Absolute measurements of densities in low ^3S and ^3P states support this mechanism. Primary cascading from a high ^3D level to a ^3P level would be followed by secondary cascading to lower ^3S levels. The observed density of population in the 3^3P and 4^3S states can be accounted for adequately by assuming a cross section of the order 10^{-18} n^4 cm^2 for the transfer from n^1D to n^3D.

*Supported by the Air Force Office of Scientific Research.

CROSS SECTIONS FOR INELASTIC COLLISIONS UNDER NEAR-RESONANCE CONDITION—2S-2P TRANSITIONS IN He BY ELECTRON IMPACT *

N. F. Lane and C. C. Lin
University of Oklahoma, Norman, Okla.

A method for the calculation of cross sections of inelastic electron-atom collisions for the case of near-resonance is presented. By means of the standard partial wave method, the Schroedinger equation can be reduced approximately to a series of pairwise coupled differential equations which contain the matrix elements of the interaction potential of the two colliding systems (of distance R apart) between the initial (i) and final (f) state such as $U_{ii}(R)$, $U_{ff}(R)$, and $U_{if}(R)$. In this method the functions U_{ii} and U_{ff} are approximated by the form of $B(R^{-1} - R_o^{-1})$ with a cutoff distance R_o while U_{if} is replaced by AR^{-2} for $R > R_o$ and a constant for $R < R_o$. The partial cross sections for $\ell > 8$ calculated by this procedure agree quite well with those obtained from Seaton's schematic model. For smaller values of ℓ, a considerable difference in the partial cross sections is found. The total cross sections for the $2^1S \rightarrow 2^1P$, $2^3S \rightarrow 2^3P$ transitions in He have been calculated and are somewhat smaller than the corresponding values obtained by Born's approximation and by Seaton's close coupling formula.

*Supported by the Air Force Office of Scientific Research.

J-2 TRANSITION PROBABILITIES OF ARGON I AND II

H. N. Olsen*
Linde Company, Indianapolis, Ind.

In a paper presented at the Gaseous Electronics Conference in 1959 a method was described for measuring absolute transition probabilities of Argon I and II lines using the high current arc plasma as a thermal source. A comparison of the early results for Ar II lines with values obtained from Garstang's absolute line strengths showed a factor of two discrepancy. This led to a closer examination of the effects of partition function cutoff and ionization potential lowering.[1] A comparison of measured absolute intensities of Ar I and Ar II lines throughout the entire plasma, in conjunction with the corrected composition, yielded unique transition probabilities for both species only after a thorough analysis of the effect of self-absorption on measured intensities. Finally, the measured transition probabilities were in good agreement with theoretical and independently measured experimental values where they were available for comparison. A previously observed discrepancy between temperatures (± 10%) measured by means of the radiation from each species of plasma particles was completely removed and the existence of local thermodynamic equilibrium more positively demonstrated by this treatment of the self-absorption.

*Now at Lockheed-California Company.

1. H. N. Olsen, Phys. Rev. 124, 1703 (1961).

J-3 A STUDY OF RESONANCE RADIATIVE TRANSFER*

H. Mochizuki
University of Oklahoma, Norman, Okla.

Experimental investigations of mercury 2537 Å radiation transfer have been made through a slab of mercury gas at various densities, using a sinusoidally modulated (~ 10 Kc/s) radio frequency excited (50 Mc/s) source of 2537 Å radiation. Transmitted radiation has been found to gain in phase relative to the source wave, while that which is scattered at 90° loses phase. A different density dependence is observed for the two modes of observation.

*This study has been supported by the U. S. Air Force Office of Scientific Research.

J-4 ESCAPE OF RESONANCE RADIATION FROM A CYLINDRICAL DISCHARGE

B. T. Barnes
General Electric Lamp Research Laboratory, Nela Park, Ohio

The transfer of resonance radiation in a discharge with a radial variation of gas temperature will be examined in detail. Correction for radial variations of gas density and of Doppler broadening is obtained by use of a series of curves for the radial density variation of atoms emitting or absorbing monochromatic radiation. Eight curves have been selected for the present study. The least radial variation of density per unit wave-length band is required for the highest temperature difference, axis to wall, and for the core of a hfs component; the steepest, for the wings. Rates of decay of excitation have been computed for groups of atoms, excited simultaneously, to which a single value of the emission coefficient can be ascribed. Corresponding unexcited atoms would have a single absorption coefficient α. Computations made for α's ranging from 0.003 to 100 cm^{-1} will be described. Changes in the velocity distribution of excited atoms, in their radial distribution, and in the spectral distribution of the escaping radiation can be determined by successive calculations covering the decay period. Similar calculations for a dc discharge would give axial density and radial and velocity distributions, for excited atoms, and the spectral distribution of the escaping radiation.

J-5 STARK-BROADENING IN AN RF DISCHARGE*

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The Balmer-lines from H_6 to H_{16} are measured in an rf discharge. The electron density and temperature are known from the intensities of the continuum and the high lines; the density is also determined by microwaves. Former quantum-mechanical calculations[1] do not account for the observations, especially at large quantum numbers. Modifications recently proposed[2,3] lead to better approximations of the measurements. For the highest lines, where the electrons approach static behavior, good agreement with static profiles for $N_i + N_e$ is shown. The static broadening is calculated from a distribution function taking into account shielding and correlation effects. Measurements for the far wings of H_5 and H_6 can be described by $2.45\ I_H(N_e)$. This relation approximates the static law for both ions and electrons and is in reasonable agreement with the quantum-mechanical theory when recent modifications[2,3] are made.

*Supported in part by the National Science Foundation.

+ Present address: University of Texas, Austin

† Present address: National Bureau of Standards, Boulder

1. H. R. Griem, Ap. J. 132, 883 (1960).
2. M. L. Lewis, Phys. Rev. 121, 501 (1961).
3. H. R. Griem, Ap. J., in press.

J-6 METASTABLE ATOMS AND THE AURORAL AFTERGLOW OF NITROGEN

F. R. Innes and O. Oldenberg
Air Force Cambridge Research Laboratories, Bedford, Mass.

The auroral afterglow of nitrogen is attributed to N atoms in the high metastable level ^6S which in binary collisions with normal N atoms produce excited N_2^+ ions and with normal N_2 molecules excite their spectrum. This hypothesis explains, (1) the high energy of the levels emitting light, (2) the dominant instantaneous intensity of the brief duration auroral afterglow, (3) the absence of the N_2^+ bands in Kaplan's "blue afterglow", and (4) the suppression of the same bands by oxygen impurity.

J-7 THEORETICAL OSCILLATOR STRENGTHS FOR NITROGEN AND OXYGEN

B. H. Armstrong and P. S. Kelly
Lockheed Missiles and Space Co., Palo Alto, Calif.

Calculations have been made of a variety of N and O oscillator strengths of interest in, e.g., upper atmosphere and astrophysical applications. Approximate Hartree-Fock (AHF) wave functions have been employed, and for comparison we have also computed Coulomb approximation (c) values (as supplemented by the work of Burgess and Seaton). AHF wave functions employed are of two types. (1), analytic functions based on the expansion method for self-consistent field solutions to the wave equation due to C.C.J. Roothaan and collaborators. (2), Hartree-Fock-Slater functions (i.e., computed with the Slater free-electron approximation for exchange), obtained by us from a computer program devised by F. Herman et. al. Our results for three transitions of interest are:

initial state	final state	σ^2(AHF)	σ^2(c)	f(AHF)
OI $2p^4\ ^3P$	$2p^3\ ^4S3d^3D$	0.00551	$4.5\text{-}7.3 \times 10^{-3}$	0.0217
OI $2p^3\ ^4S3s^3S$	$2p^3\ ^4S4p^3P$	0.035	0.035	0.0073
NI $2p^3\ ^4S$	$2p^2\ ^3P3s^4P$	0.12	0.11-0.16	0.10

The effect of cancellation on accuracy is studied, and comparison of the first listed value with another calculation, the second[1] and third[2] with experiment is made.

1. D. E. Buttrey, following abstract.
2. C. E. Fairchild and K.C. Clark, Phys. Rev. Letters 9, 100 (1962).

J-8 MEASUREMENT OF RADIATION FROM SHOCK-HEATED OXYGEN*

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The continuum radiation observed for reflected shocks in oxygen at 12,000 to 18,000°K and $0.1\rho_o$ is attributed to the processes $O^+ + e \rightarrow O + h\nu$ and $O + e \rightarrow O^- + h\nu$. Intensities have been measured for selected wavelengths between 3250Å and 6050Å with emphasis on the determination of the shift of the ^5P and ^3P edges due to plasma effects and of the magnitude of the oxygen recombination cross sections. The O^- photodetachment cross sections of Branscomb et al. were used to compute the radiation for the secondary process. Our recombination cross sections of 12,900°K and 5.6×10^{17} ions/cm^3 agree in magnitude with Boldt's[1] for the water-stablized arc for 13,000°K and 10^{17} ions/cm^3. A somewhat greater shift in the edges is observed in our data. The Stark profiles of the 4368.3 O-I line, 4^3P - 3^3S^o are compared with theoretical profiles from H. Griem. Preliminary intensity measurements for this line yield a transition probability in reasonable agreement with the theoretical values given by Armstrong and Kelly in the preceding abstract.

*Research sponsored by Special Weapons Center, Air Force Systems Command, Contract No. AF 29 (601) - 5006.

1. G. Z. Boldt, Physik 154, 319 (1959).

J-9 DOUBLE RESONANCE EXPERIMENT IN ELECTRONICALLY EXCITED CN

R. L. Barger, A. J. Estin and H. P. Broida
National Bureau of Standards, Boulder, Colo.

Non-equilibrium populations of CN in the A $^2\Pi$ and the B $^2\Sigma^+$ states are produced in the atomic flame made by reacting electrical discharge products of nitrogen with hydrocarbons at pressures near 1 mm Hg. Rotational perturbations show that several groups of levels are separated by microwave frequencies. Microwave transitions at 9855, 9740, and 8810 megacycles/sec between pairs of these levels have been detected by the increase in light from the appropriate rotational level in the ultraviolet spectrum of the B $^2\Sigma^+$ - X $^2\Sigma^+$ electronic transition. The total width of these lines at half-intensity is about 10 megacycles/sec. Further studies of these transitions should make it possible to determine the dipole moment, the hyperfine coupling constants, and collision cross-sections for electronically excited CN.

J-10 AN ALTERNATE METHOD OF MEASUREMENT OF THE POLARIZATION OF LIGHT EMITTED BY HELIUM ATOMS EXCITED BY ENERGETIC ELECTRONS*

R. H. McFarland and E. A. Soltysik+
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Previous measurements [1, 2, 3] of the above authors on the polarization of helium light emitted by atoms excited by an electron beam have resulted from the observation of the intensity of the light at right angles to the direction of the electron beam. Polarization was determined in terms of the relative intensities of the components of this light whose electric vectors were oriented parallel to and at right angles to the direction of the electron beam. Because of the disagreement between experiment and theory, an alternate method in which the angle, θ, between the observer and electron beam could be altered was used. After correcting for the effective volume of the beam observed, the total intensity of light at a given angle is related to that observed at 90^o by the relationship, $I_\theta = I_{90} (1 - \pi \cos^2\theta)$, where π is the polarization. Results will be given to show that for λ = 4922 Å, relative changes of polarization with electron energy are similar to those observed with the previously described more sensitive method. The trend of the polarization toward zero at the onset of excitation was again observed.

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

+Presently at the University of Massachusetts.

1. R. H. McFarland and E. A. Soltysik, "On the Polarization of Light Resulting from the Excitation of Helium by Electrons," Lawrence Radiation Laboratory report UCRL-6749 (1962). (A condensed version will appear in Physical Review Sept. 15, 1962.)

2. R. H. McFarland and E. A. Soltysik, "Polarization of the λ = 5876 Å and λ = 6679 Å Lines in Helium Excited by Electrons," Lawrence Radiation Laboratory report UCRL-6929 (1962). (Accepted for publication in The Physical Review.)

3. R. H. McFarland and E. A. Soltysik, "Magnetic Field Dependence of Polarized Helium Light Excited by Electrons," Lawrence Radiation Laboratory report UCRL-6949. (Presented to the Physical Review.)

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