18th ANNUAL

GASEOUS ELECTRONICS CONFERENCE

Program and Abstracts of Papers

October 20-22, 1965

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Held at

Leamington Hotel
Minneapolis, Minnesota

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18th ANNUAL GASEOUS ELECTRONICS CONFERENCE

Topical Conference
American Physical Society

HOTEL LEAMINGTON
OCTOBER 20-22, 1965
MINNEAPOLIS, MINNESOTA

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EIGHTEENTH ANNUAL

GASEOUS ELECTRONICS CONFERENCE

Program and Index to Abstracts

Tuesday, October 19

7:30 - 10:00 p.m. Registration: Lobby, Leamington Hotel

Cocktails: Conference Hospitality Rooms, Mezzanine - Leamington Hotel

Wednesday, October 20

8:00 a.m. Registration: Lobby, Leamington Hotel

9:15 a.m. Session A: RECOMBINATION

Chairman: P. J. Chantry, Westinghouse Research and Development Center, Pittsburgh, Penna.

*Combined papers

Wednesday, October 20 (Continued)

2:00 p.m. Session B: ATTACHMENT-DETACHMENT; ELECTRON SCATTERING

Chairman: L. M. Chanin, University of Minnesota, Minneapolis, Minnesota

*Combined papers

Wednesday, October 20 (Continued)

2:00 p.m. Session C: GLOWS AND ARCS

Chairman: J. F. Waymouth, Sylvania Electric Products, Salem, Massachusetts

Thursday, October 21

9:00 a.m. Session D: DIFFUSION-MOBILITY

Chairman: D. W. Martin, Georgia Institute of Technology, Atlanta, Georgia

11:15 a.m. Business meeting

Chairman: A. V. Phelps

*Combined papers

Proposed Amendment to the Constitution of the Gaseous Electronics Conference:

In accordance with the articles of the constitution, the Secretary has received, prior to the deadline for the submission of abstracts this year, a written Amendment endorsed by the proper number of signatures of members of the Conference. The purpose of this Amendment is to provide a greater degree of continuity to the office of the Chairman of the Executive Committee. This would be accomplished by arranging for the Chairman-Elect to serve on the Executive Committee one year prior to assuming the office of Chairman. The Chairman will place the following Amendment before the business session at the 1965 meeting.

Amendment

The General Committee will elect, by majority vote, the Chairman of the Executive Committee one year prior to the date on which he assumes office. During this year preceding his assumption of office, the Chairman-Elect will serve as one of the five general members of the Executive Committee. In the event that the Chairman-Elect is unable to assume office, the General Committee will elect a Chairman as provided in the original Constitution.

Thursday, October 22 (Continued)

2:00 p.m.

Session E: IONIZATION-EXCITATION

Chairman: E. C. Zipf, Jr., University of Pittsburgh, Pittsburgh, Pennsylvania

*Combined papers

Thursday, October 21 (Continued)

2:00 p.m. Session F: BREAKDOWN, CORONA, SPARKS

Chairman: L. H. Fisher, Lockheed Missiles and Space Company, Palo Alto, California

6:30 p.m. Social Hour, Hall of States, Leamington Hotel

7:30 p.m. Banquet, Hall of States, Leamington Hotel

LITTLE SCIENCE; LITTLE MONEY
Dr. L. M. Branscomb, Joint Institute for Laboratory Astrophysics

Friday, October 22

9:00 a.m. Session G: METASTABLES AND EXCITED ATOMS

Chairman: E. E. Muschlitz, University of Florida, Gainesville, Florida

*Combined papers

Friday, October 22 (Continued)

9:00 a.m. Session H: SURFACES AND DISCHARGES

Chairman: S. Schneider, U. S. Army Electronics Laboratories, Fort Monmouth, New Jersey

Friday, October 22 (Continued)

1:15 p.m. Session I: ION-MOLECULE INTERACTIONS

Chairman: E. E. Ferguson, National Bureau of Standards, Boulder, Colorado

SESSION A

Wednesday, October 20

9:15 a.m.

RECOMBINATION

Chairman: P. J. Chantry, Westinghouse Research and Development Center, Pittsburgh, Pennsylvania

A1 DISSOCIATIVE RECOMBINATION IN NEON AND ARGON.*

L. FROMMHOLD and M. A. BIONDI, University of Pittsburgh, Pittsburgh, Pennsylvania, U.S.A.

Atomic line shapes are studied, mainly from the strong 2p-1s transitions, during the discharge and afterglow phases of a microwave discharge in Ne and in Ar. During the discharge the lines studied appear to be determined by the thermal Doppler effect at low pressures. During the afterglow, however, the lines evidently are composed of a narrow core, emitted by thermal atoms, superimposed on a broad line, emitted by atoms moving 2 to 5 times faster, depending on the line studied. These fast atoms are evidently produced by the dissociative recombination process, $Ne_2^+ + e \rightarrow Ne + Ne^* + energy^1$. Determinations of the dissociation kinetic energy E_D of the radiating fast atoms from the line widths yield values for the binding energy of the ion, $D(Ne_2^+)$. Different values of D are obtained for line transitions with different upper atomic levels--a fact that indicates the molecular ions must be in different vibrationally or electronically excited states. Some confirmation for this conclusion is given by the just detectable additional structure of the broadened afterglow lines, which also indicates more than one value of E_D. An analysis of all resolvable structure in neon gives about 15 different D values between 0 and 2.5 eV. Similar results seem to hold in argon.

*This research was supported, in part, by the Office of Naval Research.

(1) T. R. Connor and M. A. Biondi, Bull. Am. Phys. Soc. 11, 184 (1964) and Phys. Rev., to be published.

A2 STUDY OF THE TEMPERATURE DEPENDENCE OF ELECTRON-ION RECOMBINATION IN NITROGEN.*

W. H. KASNER, Westinghouse Research Laboratories.

Combined microwave and mass spectrometric techniques[1] have been used to study the temperature dependence of the afterglow decay of electrons and ions from microwave discharges in N_2-Ne gas mixtures under conditions where N_2^+ is the only significant afterglow ion specie, i.e., at nitrogen pressures less than 1×10^{-3} Torr. For the neon pressures used, 15 to 30 Torr, the afterglow is controlled by the recombination of N_2^+ ions and electrons. Over the temperature range studied, 205 to 455°K, the recombination coefficients exhibit no observable temperature dependence, ($<1\%$), and yield results in agreement with our published value,[1] $\alpha(N_2^+) = 2.9 \times 10^{-7}$ cm³/sec. At any given temperature the results show no systematic dependence on the nitrogen or neon pressures over the ranges indicated. Temporal mass analysis indicates similar decay rates for the N_2^+ ions and for the electrons over the major portion of the afterglow.

*This research has been supported in part by the Air Force Weapons Laboratory.

1. W. H. Kasner and Manfred A. Biondi, Phys. Rev. 137, A317 (1965).

A3 TIME-DEPENDENCE OF POSITIVE ION WALL CURRENTS IN AN IONIZED GAS*.

R. C. GUNTON, Lockheed Palo Alto Research Laboratories.

In some recent experiments[1,2] the time-dependence of the wall current of positive ions has been compared with the time dependence of the average electron density determined from the frequency shift in a microwave cavity enclosing the ionized gas. In recombination-dominated afterglows in N_2-Ne[1] and O_2-Ne[2] mixtures Kasner and Biondi found good agreement in the N_2^+ case but not for O_2^+. A numerical analysis has been made of combined recombination and ambipolar diffusion of positive ions and electrons. The results obtained suggest that good agreement may be obtained in some cases but that in general the two time-dependences do not agree exactly for a significant time interval in the afterglow.

*Supported by the Lockheed Independent Research Program.

1. W. H. Kasner and M. A. Biondi, Phys. Rev. 137, A317 (1965).
2. W. H. Kasner and M. A. Biondi in Air Force Weapons Laboratory and Westinghouse Report AFWL TR-64-178, July 1965.

A4 ON THE MEASUREMENT OF RECOMBINATION RADIATION IN THE AFTERGLOW.*

E. C. ZIPF, University of Pittsburgh.

The intensity of the allowed radiation emitted by atoms excited in a 2-body electron-ion recombination process varies as the square of the electron density in a plasma with only one species of positive ions and no negative ions. This relationship has been used experimentally as a test for recombination radiation, and to evaluate the volume recombination coefficient α from afterglow data. In these studies the average emission rate per unit volume is usually inferred from a surface brightness measurement, while the average electron density is obtained by microwave methods. Because these measurements are affected differently by changes in the spatial distribution of the charged particles and excited atoms as the plasma decays, neither the measured intensity nor the average emission rate need vary as the square of the average electron density. To assess the magnitude of this effect, a numerical solution was obtained to the conservation equation with a quadratic loss term. From these results the average electron density, the intensity, and the average emission rate per unit volume of the recombination radiation were calculated and compared. It is found that the intensity of the recombination radiation may be related to the average electron density by an expression of the form:

$$I(t) = k\langle n_e(t)\rangle^2 + \epsilon(t) .$$

The magnitude of the time-dependent function $\epsilon(t)$ and the conditions under which it approaches zero will be discussed.

*This work was supported by the National Aeronautics and Space Administration.

A5 COLLISIONAL DISSOCIATIVE RECOMBINATION OF MOLECULAR IONS.* C. B. COLLINS, Southwest Center for Advanced Studies.

The recombination rate of electrons in a hypothetical plasma containing ions of a molecule having both repulsive and bound neutral states is calculated for electron densities between 10^{10} and $10^{14}/cm^3$ and temperatures ranging from $250^{\circ}K$ to $2000^{\circ}K$. It is found that if the molecule has a dissociative state located sufficiently close in energy to the molecular ion, values are obtained considerably in excess of the collisional-radiative recombination rate for systems possessing only bound states.

*This research was supported by the National Aeronautics and Space Administration.

A6 RADIATIVE RECOMBINATION TO DISCRETE STATES OF CESIUM. DAVID W. NORCROSS and PHILIP M. STONE, Sperry Rand Research Center.

The cross section for radiative recombination of slow electrons (≤ 1 eV) with cesium ions has been calculated, using an adjusted form of the Quantum Defect Method (QDM).[1] Values have been obtained for recombination to the ten lowest levels of neutral cesium. The QDM has been empirically adjusted so that oscillator strengths for transitions to high bound states agree with the carefully calculated f-values previously attained for cesium.[2] The adjustment of the QDM is discussed and the calculated recombination cross sections are presented. Deviations from the experimental results of Mohler[3] for the 6S and 6P levels are observed. Recombination rates versus temperature below $3000^{\circ}K$ are also shown.

1. A. Burgess and M. J. Seaton, Mon. Not. Roy. Astron. Soc. 120, 121 (1959).
2. P. M. Stone, Phys. Rev. 127, 1151 (1962).
3. F. L. Mohler, J. Res. Natl. Bur. Std. 17, 849 (1936) and 19, 447 (1937).

A7 ELECTRON-ELECTRON-ION COLLISIONAL RECOMBINATION COEFFICIENT.* ROBERT C. STABLER, RCA Laboratories.

The collisional recombination coefficient, defined by $C(T_e) = \lim(N_e \to \infty) N_e^{-1} \alpha(N_e, T_e)$ where α is rate of collisional-radiative decay, has been calculated approximately using the dipole cross sections of Seraph[1] and including only the $\Delta n=1$ transitions, where n is the principal quantum number of a hydrogenic atom. In the low temperature limit we find $C_1(T_e) = 7 \times 10^{-21}(250^{\circ}K/T_e)^{3.625} cm^6/sec$. This compares with the result obtained by Bates and Kingston[2] using the impulse approximation cross sections of Gryzinski and including all inelastic collisions of $C(T_e)=3\times10^{-19} (250^{\circ}K/T_e)^{4.83} cm^6/sec$. If account is taken just of the $\Delta n=1$ contribution to the cascade process this latter result is reduced to $C_1(T_e) \cong 1.5 \times 10^{-19} (250^{\circ}K/T_e)^{4.33} cm^6/sec$ for $T_e < 250^{\circ}K$, which may be compared to C_1 given above. The large reduction of this coefficient for temperatures below several thousand degrees and the change in temperature dependence arises from the fact that for large values of n, the dipole cross sections do not peak as close to threshold as do those of the impulse approximation. The dipole cross sections are probably preferable due to the failure of the impulse approximation to take adequate account of screening for inelastic collisions involving small energy transfers.

*Work sponsored by N.A.S.A.

1. H. E. Seraph, Proc. Phys. Soc. 83, 763 (1964).
2. D. R. Bates and A. E. Kingston, Proc. Phys. Soc. 83, 43 (1964).

A8 TIME DEPENDENCE OF IONIC SPECIES IN DECAYING PLASMAS PRODUCED IN HELIUM AND NEON.* G. F. SAUTER, R. A. GERBER and H. J. OSKAM, University of Minnesota.

The time dependence of ions effusing through a small hole in the plasma container was measured by means of a quadrupole mass spectrometer (length of mass analyzing field 10 cm). Precautions had to be taken in order that the measurements gave the proper information about the ion properties. The time dependence of the number density of He^+ was determined at pressures from 1 Torr to 4 Torr, while this dependence was measured for He_2^+ in the range from 1 Torr to 21 Torr. These studies resulted in ambipolar diffusion coefficients which led to mobility values of He^+ and He_2^+ in helium of 10.4 cm^2/volt sec and 16.6 cm^2/volt sec. These values are in excellent agreement with both ion-transit time and microwave cavity measurements.[1,2] At a gas temperature of 345°Kelvin, the conversion frequency for $He^+ + 2He \rightarrow He_2^+ + He$ was found to be $\nu_{conv} = 78\, p_o^2\, sec^{-1}$, where p_o is the pressure reduced to 273°Kelvin. Analogous studies in neon will be presented. Also the influence of impurities on the measurements will be discussed.

*Supported by the Advanced Research Project Agency through the Office of Naval Research and by the Air Force Cambridge Research Laboratories.

1. E. P. Beaty and P. L. Patterson, Phys. Rev. 137, A346 (1965).
2. H. J. Oskam and V. R. Mittelstadt, Phys. Rev. 132, 1435 (1963).

Combined with paper A9.

A9 TIME DEPENDENCE OF LIGHT EMITTED BY DECAYING PLASMAS PRODUCED IN HELIUM AND NEON.* R. A. GERBER, G. F. SAUTER and H. J. OSKAM, University of Minnesota.

A comparison of the time dependence of the intensity of spectral lines emitted during the decay period of a plasma produced in helium with that of the number density of He^+ and He_2^+, which was measured simultaneously, strongly indicates that the three-body recombination process $He^+ + 2e \rightarrow He^* + e \rightarrow He + e + h\nu$ is responsible for the emission of these spectral lines. The time dependence of the spectral line intensity followed very closely that of the product of the number density of He^+ and the square of the electron density. Comparison of the time dependence of the spectral band at 4650 Å and that of He^+ and He_2^+ revealed that the origin of this band is not a consequence of the process $He_2^+ + e \rightarrow He_2^* \rightarrow 2He + h\nu$. The data indicates that the molecular bands may be due to a three-body recombination process involving an He_2^+ ion, an electron and a third particle which is as yet unspecified but is not a helium atom in the ground state. The present results will be compared with those reported previously. Analogous studies in neon resulted in (a) the absence of spectral bands between 3000 Å and 7000 Å and (b) two groups of spectral lines each having its own time constant.

*Supported by the Advanced Research Project Agency through the Office of Naval Research and by the Air Force Cambridge Research Laboratories.

Combined with paper A8.

A10 EFFECT OF IONIC RECOMBINATION OF AMBIPOLAR DIFFUSION IN O_2.* M. HIRSH, P. EISNER, J. SLEVIN, and G. HALPERN, The G. C. Dewey Corporation.

Electron removal in weakly ionized oxygen has been studied at pressures from 25 to 300 microns at 300°K. In the experiment, neutral oxygen is irradiated either continuously or in periodically repeated pulses by a diffuse beam of 1.5 Mev electrons.[1] The dominant electron loss processes at these pressures and ionization levels are 3-body attachment[1] and diffusion under the combined space-charge field of both positive and negative ions. From the observed non-linear variation of steady-state electron density with irradiating flux, negative ion removal is shown to be due to recombination with positive ions, with an apparent rate coefficient of about 10^{-7} cm^3/sec. Mass spectrometer studies identify O_2^+ and O_2^- as the only significant ions at these pressures. A machine calculation has been made for the pulsed-beam experiment, using only the removal mechanisms and rate coefficients deduced from the steady-state data. The results, in excellent agreement with the transient measurements, show an initial electron density overshoot followed by a slow decay to equilibrium density in-beam, and a non-exponential afterglow decay. Observed duty-cycle effects confirm the predicted long lifetimes for negative ions in the afterglow ($\sim$1 sec).

*Work supported by Defense Atomic Support Agency through U. S. Army Signal Research Laboratories, Ft. Monmouth, New Jersey.

1. M. N. Hirsh, P. N. Eisner and J. A. Slevin, Bull. Amer. Phys. Soc. 10, 189 (1965).

SESSION B

Wednesday, October 20

2:00 p.m.

ATTACHMENT-DETACHMENT; ELECTRON SCATTERING

Chairman: L. M. Chanin, University of Minnesota,
Minneapolis, Minnesota

B1 AMBIPOLAR DIFFUSION, ELECTRON ATTACHMENT, AND ELECTRON-ION RECOMBINATION IN NITRIC OXIDE*. C. S. WELLER and M. A. BIONDI, University of Pittsburgh.

The nitric oxide afterglow produced by photoionization has been studied by microwave techniques. Nitric oxide in the pressure range of 0.1 to 5 torr was contained in a 10 cm. resonant cavity where it was ionized by a "single" pulse of radiation in the region of 1216Å. Measurements of the rates of ambipolar diffusion and electron attachment yield the values $D_a p = 142 \pm 10$ cm^2 sec^{-1} torr and K = (3.1 ± .3) x 10^{-31} cm^6 sec^{-1}, respectively. These coefficients are in agreement with the results of Gunton and Shaw[1] over the appropriate pressure ranges. Under conditions of attachment and recombination control, a recombination coefficient of $(4.0 \pm ^{2.8}_{1.8})$ x 10^{-7} cm^3 sec^{-1} has been measured, in agreement with those reported by Gunton and Shaw[1] and Doering and Mahan[2]. All measurements are at 300°K.

*This research was supported, in part, by the Army Research Office (Durham).

1. R. C. Gunton and T. M Shaw, Phys. Rev. to be published.
2. J. P. Doering and B. H. Mahan, J. Chem. Phys. 36, 669 (1962).

B2 ELECTRON ATTACHMENT TO ATOMIC FLUORINE IN THERMALLY IONIZED AIR.* R. EARL GOOD, Mithras, Inc.

The three body reaction, $F + e^- + X \rightleftharpoons F^- + X$, was studied with a shock tube exhausting through a wedge nozzle.[1] The nominal test conditions behind the shock were temperatures between 2400 and 3800 degrees K at one atmosphere pressure. Microwave interferometer measurements for the electron density were made to observe the progress of the reaction as the mixture of ionized air and fluorine atoms expanded and cooled in the nozzle. The expected exponential temperature dependence was observed as the electron density was significantly reduced only after the temperature cooled below 3000 degrees K. Measurements made with and without fluorine additive were used to determine the rate coefficient as a function of temperature. An Arrenhius law was fitted to the measurements to yield the following three-body attachment coefficient,

$$ka = 1.5 \times 10^{-37} e^{(84 \pm 4)\text{kcal}/RT} \text{ cc}^2/\text{s}$$

*This research was supported by the Fluid Physics Program of NASA Headquarters.

1. R. Earl Good, MITHRAS, Inc., Report MC 64-82-R1, June 1965.

B3 THE PHOTODETACHMENT CROSS SECTION FOR O^-. W. R. GARRETT, University of Alabama Research Institute; and H. T. JACKSON, United States Army Missile Command.

The theoretical photodetachment cross section for the negative atomic oxygen ion has been calculated for the three transitions; $O^{-2}P$ to O^3P, O^1D, and O^1S. Results are compared with the experiments of Smith[1] and Branscomb, Smith and Tisone[2] giving excellent low energy agreement. Calculations differ from previous models of Klein and Brueckner,[3] and Cooper and Martin[4] by developing the polarization potential from first order perturbation theory in conjunction with the adiabatic approximation. A modified Hartree-Fock treatment utilizing the Slater approximation for exchange is used to compute the bound state radial functions for the neutral atom and negative ion. In addition, the scattering cross section for neutral oxygen, the polarizability, the attachment cross section and attachment coefficient for electron capture by neutral oxygen were also determined. The scattering cross section is compared with experimental data.

1. S. J. Smith, Proc. Fourth Int'l. Conf. on Ionization Phenomena in Gases, Uppsala, 1959, (North-Holland Publishing Co., Amsterdam, 1960), p. 219.
2. L. M. Branscomb, S. J. Smith, and G. Tisone, J. Chem. Phys. (to be published) (1965).
3. M. M. Klein and K. A. Brueckner, Phys. Rev. 111, 1115 (1958).
4. J. W. Cooper and J. B. Martin, Phys. Rev. 123, 1402 (1962).

B4 RESONANCES IN THE ELASTIC AND INELASTIC ELECTRON SCATTERING FROM N_2. H. G. M. HEIDEMAN, C. E. KUYATT, and G. E. CHAMBERLAIN, National Bureau of Standards, Washington, D. C.

A sharp and isolated resonance of the "helium window" type has been discovered in electron transmission measurements in N_2 at 11.48 eV (believed accurate to within 0.05 eV). This resonance should be very useful in calibration of electron energy scales. Additional resonance structure is observed at 11.75 and 11.87 eV. Energy loss spectra show two triplet states of N_2, the $C^3\Pi_u$ and $E^3\Sigma_g^+$ states. The $E^3\Sigma_g^+$ threshold is coincident in energy with the 11.87 eV resonance structure and is found to exhibit an excitation probability sharply peaked near threshold. Since no other state in this energy region was found to have such a sharply-peaked excitation function, the $E^3\Sigma_g^+$ is probably responsible for the resonant production of metastable N_2 observed by Cermak. The series of resonances, previously known to exist between 1.8 and 3.5 eV as a consequence of an N_2^- state with vibrational structure, has been studied with improved resolution and by different procedures.

Combined with paper B5.

B5 INELASTIC ELECTRON SCATTERING FROM H_2.
H. G. M. HEIDEMAN, C. E. KUYATT, and G. E. CHAMBERLAIN, National Bureau of Standards, Washington, D. C.

Energy loss spectra have been measured for 13.7 to 50.7 eV electrons in H_2. For incident energies below about 16 eV, energy loss peaks are observed which are believed due to either or both of the $a^3\Sigma_g^+$ and $c^3\Pi_u$ states of H_2. The excitation cross section of the v = 0 and v = 1 vibrational levels of the $B^1\Sigma_u^+$ state show sharp and large resonances, corresponding closely in energy with resonances in the total scattering which we have previously reported. We have also recalibrated the absolute electron energy scale in H_2 to an estimated accuracy of 0.1 eV.

Combined with paper B4.

B6 ELECTRON COLLISION PROBABILITY IN NITRIC OXIDE.*
M. H. MENTZONI and J. DONOHOE, Sylvania Electronic Systems.

The conductivity ratio, ρ, together with the electron radiation temperatures, T_e, were measured in an NO afterglow using the microwave waveguide diagnostic method and noise sampling technique respectively. The normalized values of ρ are plotted versus T_e in the electron radiation temperature interval 1200 - 12000°K for pressures ranging from .25 to 4.0 Torr. Assuming the electrons to be maxwellianized the effective total collision probability has been computed yielding a value, $P_c = 13.6$ cm^{-1} Torr^{-1} at T_e = 1200°K increasing to a maximum, $P_e = 14.8$ cm^{-1} Torr^{-1}, at about T_e = 2000°K decreasing slowly thereafter to $P_e = 13.0$ at T_e = 12000°K. Extrapolating to T_e = 300°K yields a value $P_e = 6.4$ cm^{-1} Torr^{-1} and an approximate $T_e^{1/2}$ dependence of P_e from 300 to 1200°K.

*This work was partly supported by the Air Force Systems Command, U. S. Air Force.

B7 MEASUREMENTS OF THE ELECTRON COLLISION FREQUENCY FOR MOMENTUM TRANSFER IN OXYGEN.*
G. E. VEATCH,+ J. T. VERDEYEN, and J. H. CAHN, Gaseous Electronics Laboratory, University of Illinois.

The electron collision frequency for momentum transfer at thermal energies has been measured and its energy dependence determined at 300°K by two methods which do not involve measurement of the electron density or variation of the parent gas temperature. The two methods used were the microwave cross-modulation technique[1] and the cyclotron resonance line width (and shape). These two techniques combined with the theoretical work of Shkarofsky[2] yield the velocity dependence of the collision frequency. Helium was used as a test gas of the technique and excellent agreement was obtained with the published results. These measurements have yielded a collision frequency in oxygen at 300°K which is $\nu_m(u) = 4.6 \times 10^{-8} N(O_2) u$ where u is the electron energy in electron volts and $N(O_2)$ is the number density of oxygen molecules. This result is in agreement with the phase shift and attenuation measurements of Mentzoni.[3]

*This research was supported by the Air Force Cambridge Research Center, Office of Aerospace Research
+Present address University of Minnesota.
1. K. V. N. Rao, J. T. Verdeyen, and L. Goldstein, Proc. IRE, 49, 1877 (1961).
2. I. P. Shkarofsky, Can. J. Phys. 39, 1619 (1961).
3. M. H. Mentzoni, Radio Science, 69D, 213 (1965).

B8 ELECTRON SCATTERING CROSS-SECTIONS OF N_2, Ar, O_2, AND O.*
J. W. DAIBER and H. F. WALDRON, Cornell Aeronautical Laboratory, Inc.

The electron scattering cross-sections for momentum transfer in an equilibrium plasma generated by the incident shock wave in a shock tube have been measured using microwave interferometry. The cross sections of the nitrogen molecule and argon atom were measured from 2000 to 4000°K and from 1800 to 5500°K, respectively. The results agree with previous monoenergetic measurements when the cross sections are suitably averaged over a Maxwellian distribution of electron velocities with an electron temperature equal to the plasma temperature. The oxygen molecule cross-section was measured from 2000 to 3000°K and was found to be the order of 10^{-15} cm^2. Above 3000°K the oxygen molecule dissociates and the oxygen atom cross-section can be measured. From 3000 to 4000°K this atomic cross-section is approximately 1.2×10^{-15} cm^2. Using these data the electron collision frequency in an air plasma produced in a hypersonic nozzle is predicted and compared with experimental measurements. The data indicate that the free electron temperature in an expanding flow may be much higher than the local translational temperature of the neutrals and ions.

*This research is a part of Project DEFENDER under jount sponsorship of the Advanced Research Projects Agency, Department of Defense, and the Office of Naval Research.

B9 ELECTRON-ATOM COLLISION CROSS-SECTION MEASUREMENTS IN THE AFTERGLOW OF A PULSED CESIUM PLASMA.*

J. C. INGRAHAM, Massachusetts Institute of Technology, Research Laboratory of Electronics.

A gated microwave detector is used to determine the electron-atom collision cross section in the afterglow of a repetitively-pulsed dc discharge in cesium as a function of electron temperature. The detector measures the electron cyclotron absorption resonance and the electron temperature. The width and shape of the resonance are related to the electron-atom collision cross section. Data are presented for a range of electron temperatures from 550°K to 6000°K. The measured cross section is about 3×10^{-14} cm^2 at 3100°K and is higher for all lower temperatures studied, showing no Ramsauer minimum. A computer analysis is used to obtain the collision cross section as a function of electron velocity.

*This work was supported in part by the Joint Services Electronics Program.

B10 CYCLOTRON ECHO*. R. M. HILL and D. E. KAPLAN, Lockheed Palo Alto Research Laboratory, Palo Alto, California.

In cyclotron echo,[1] energy stored "coherently" in the electron cyclotron motion at time 0 is caused to reradiate at time 2τ by a microwave pulse at time τ. The process is called an "echo" in analogy to the spin echo process.[2] The amplitude of the radiated echo depends on the "coherence" memory of the electrons and is therefore sensitive to any momentum relaxation process experienced by the electrons. The application of a third pulse at time $T > 2\tau$ usually produces another echo whose amplitude dependence as a function of T should depend on the energy relaxation of the electrons. These echoes have been observed at 10 Gc/sec in A and Ne from $< 10^{-3}$ to 10^{-1} Torr and at electron densities from 10^{7} to 10^{11}/cm^3. The echo amplitudes and decay constants are found to depend on gas pressure and particularly on electron density. These results will be presented and discussed in relation to possible echo producing processes as well as the various energy and momentum relaxation mechanisms which affect the plasma electrons.

*Work supported in part by the Office of Naval Research and the Lockheed Independent Research Fund.

1. R. M. Hill and D. E. Kaplan, Phys. Rev. Letters, 14, 1062 (1965)
2. E. L. Hahn, Phys. Rev., 80, 580 (1950)

SESSION C

Wednesday, October 20

2:00 p.m.

GLOWS AND ARCS

Chairman: J. F. Waymouth, Sylvania Electric Products,
Salem, Massachusetts

C1 CATAPHORESIS INDUCED EFFECTS IN A GLOW DISCHARGE, A. GARSCADDEN and P. BLETZINGER, Aerospace Research Laboratories, U.S.A.F.

Measurements have been made on the properties of a glow discharge in gas mixtures. It is shown that cataphoresis exerts a strong influence on the discharge properties. In particular the waves of ionization have been studied and the experimental results show that after an equilibrium time of approximately 300 secs the waves of ionization in a helium-neon tube (6mm i.d., He:Ne; 4:1) exist in different modes whose properties indicate the partial pressure gradients. The radio-frequency observations are substantiated by spectroscopic measurements of the light output along the discharge axis. For these gases, in each mode the wave of ionization travels in the direction cathode to anode, creating striations which propagate in the direction anode to cathode. These effects are shown to influence the lasing properties of a He-Ne mixture.

C2 STUDY OF THE MERCURY-THALLIUM GLOW DISCHARGE. JOHN MC INALLY, Xerox Research Division.

The characteristics of an AC glow discharge with controlled mercury and thallium vapor pressures were studied both for the pure case and with the addition of nitrogen and argon. A system was designed so that Tl pressures could be maintained by immersing the quartz discharge tube in a large oven while Hg vapor pressure was controlled by means of an externally heated Hg reservoir. Hg pressure was varied between 10^{-3} and 100 Torr and Tl pressure from zero to 10^{-1} Torr at current densities from one to 6 a/m^2 in the glow mode to very high values for the constricted discharge mode. The Tl spectrum was strongly dependent on Hg pressure and current density. Increased Hg pressure led to increased Tl line intensities in the glow mode but the Hg spectrum became more prominent as the discharge became constricted. Peak Tl intensities occurred at Hg pressures between 2 and 20 Torr and a Tl pressure of 8×10^{-3} Torr. A study of the spectra indicates an enhancement of the $\lambda\lambda$ 3776, 5350Å Tl lines at low current densities. This is interpreted as being due to second kind collisions between excited Hg 6^3P_1 and Tl $8^2S_{1/2}$, which are in close energy resonance. The addition of 5 and 20 Torr N_2 to the discharge quenched the Hg 6^3P_1 by depopulating this level to the metastable 6^3P_0 state. This led to a quenching of the Tl spectrum. Thus, while the line intensities are strongly current dependent, second kind collisions are also a factor. Adding 5 Torr argon produced a slight quenching, which will also be discussed.

C3 THE HOLLOW CATHODE DISCHARGE. D. J. STURGES* and H. J. OSKAM, University of Minnesota.

Properties of a discharge maintained between a planar anode and a cathode consisting of two parallel electrodes has been studied in helium, neon, hydrogen, and helium-argon mixtures at pressures between 2 Torr and 25 Torr. The dependence of the efficiency of the discharge on pressure, current and separation between cathode electrodes was determined. When disturbing influences on discharge parameters of effects associated with gas impurities, cathode temperature variations, and anode fall development were eliminated, the analysis of the data led to the following conclusions: (1) The enhancement of the discharge efficiency by the Hollow Cathode Effect (H.C.E.) does not vary widely between the gases tested and the presence of metastable excited atoms is not essential for a pronounced H.C.E. to occur. (2) The dependence of the H.C.E. on discharge parameters appears simpler than expected and the principal features of the medium pressure H.C.E. can be explained in terms of four groups of phenomena, i.e., (a) changing collection efficiency of non-charged particles, (b) space-charge effects, (c) constriction of the discharge, and (d) non-uniformities in the negative glow region. Each of these groups of phenomena dominates for a different set of discharge conditions.

*Present address: University of Birmingham, England.

C4 A STUDY OF CAPILLARY DISCHARGES IN NOBLE GASES AT HIGH CURRENT DENSITIES. E. F. LABUDA, C. E. WEBB, R. C. MILLER and E. I. GORDON, Bell Telephone Laboratories, Incorporated.

A study of the excitation mechanism of the argon ion laser has yielded a wealth of data on many parameters of argon discharges in capillaries ranging in diameter from 0.5 to 10.0 mm and current densities ranging from 0.1 to 6.0 amps/mm^2. A similar but less extensive study has been made on krypton discharges.

Over the pressure range of the experiments ($p = 0.2$ to 20 Torr) the electron temperature is essentially independent of discharge current I and the electron density is proportional to $I \cdot p$. At low current densities, electron temperature and density measurements were made with probes, and at higher current densities the electron density was measured by Stark broadening experiments. In addition the variation of ionic spontaneous emission and ionic metastable populations on current have been used to infer the dependence of temperature and density on current.

The populations of many ArI and ArII levels, including a number of metastables, have been measured by the Ladenburg-Reiche technique. These results together with the behavior of ionic spontaneous emission lead to the conclusion that the excitation of Ar II occurs by direct electron impact on the ion ground state or on ionic metastable states.

The experiments also provide measurements of the ion and gas temperatures and the ion drift velocities.

C5 SOME COMPARATIVE PROPERTIES OF BRUSH AND PLANAR CATHODE DISCHARGES. T.D.ROBERTS, National Bureau of Standards, Boulder, Colorado

The beam-excited helium plasma has been studied in a discharge tube 1.5 meters long using carefully-constructed planar cathodes, and brush cathodes, Longitudinal electron density measurements made with a V-band (35 GHz) microwave interferometer reveal striking similarities between the density profiles at pressures of 1 torr or less. There is an increasing dissimilarity in the plasma produced by brush and planar cathodes with increasing pressure; the brush cathode produces a more dense plasma in the cathode region, the planar cathode creates a less dense, extended negative glow. Families of potential vs. discharge current curves for each configuration are qualitatively similiar, the brush cathode producing more current at any given pressure and potential. In both cases, plasmas produced are generally stable and striation free.

C6 EXPERIMENTAL STUDIES OF THE PRESSURE CONSTRICTED AND THE STRIATED POSITIVE COLUMN. G. E. COPELAND AND R. G. FOWLER, University of Oklahoma.

Substantial progress has been made in development of pulsed glow discharge equipment which permits study of the structure of positive column with observation times and initiation times each as short as 10^{-4} seconds. Onset of pressure constriction has been found in helium at ap = 28±5 cm. mm. Hg (a = 3.25 cm.) in neon at ap = 1.6±.3 cm. mm. Hg, in argon at 6.9±.3 cm. mm. Hg, and in nitrogen at 0.3±.1 cm. mm. Hg, (a = 1.6 cm.). No similarity law was found in argon. Constriction is shown to be a function of current in all gases tested. The domain of the striated positive column was found to follow the law $Ip \leq S$, where S is 8.0±.1 amp. mm. Hg for neon and 2.8±.1 amps. mm. Hg for argon. This relation was found to be independent of tube size.

C7 ENERGY DISTRIBUTION OF SPUTTERED AG ATOMS BY DOPPLER SHIFT MEASUREMENTS.* R. V. STUART, Applied Science Division, Litton Systems, Inc.

Energy distributions of sputtered Ag atoms have been determined by a time-of-flight method[1,2] and verified by measuring the Doppler shift of light emitted by sputtered atoms traveling in the direction of observation. Doppler shifts are measured with a Fabry-Perot interferometer which has a spectral range of 0.1 Å and a resolving power of 400,000. During the measurement of the Doppler shift, the observation window is kept free of sputtered deposits by rf sputtering techniques.[3] The Doppler shift method of determining ejection energies has not been successful for target materials other than Ag. Some target materials do not have an emission line of sufficient intensity for Fabry-Perot measurements. Emission lines for a number of target materials have a hyperfine structure which prevents interpretation of Doppler shift data. Average ejection energy for Ag atoms sputtered by 200 eV Ar ions is found to be 6 eV.

*This work was partly supported by Office of Naval Research.

1. R. V. Stuart, K. Brower and W. Mayer, Rev. Sci. Instr. 34, 425-429 (1963).
2. R. V. Stuart and G. K. Wehner, J. Appl. Phys. 35 1819-1824 (1964).
3. G. S. Anderson, W. N. Mayer and G. K. Wehner, J. Appl. Phys. 33, 2991-2992 (1962).

C8 A SIMILARITY PRINCIPLE FOR MULTIPACTING DISCHARGES.* R. WOO, Jet Propulsion Laboratories and A. ISHIMARU, University of Washington.

A similarity principle is introduced for multipacting discharges in geometrically-similar electrode configurations. For phase similar breakdowns, it is shown that the rf and dc voltages are proportional to $(fl)^2$ while the electron velocity and the steady magnetic field are proportional to fl, where f is the frequency of the rf voltage and l is the characteristic length for similar configurations. If the electron kinetic energy is to be similar also, fl must be invariant. These similarity relations are applied to previous work in parallel plates[1-4] and it is shown that the results of the different multipacting cases can be unified under the similarity principle. A physical explanation is also rendered for the success of the constant v_f/v_i assumption,[1,2] where v_i and v_f are the respective emission and impact electron velocities. When applied to geometries other than parallel plates, the similarity principle yields important scaling information and allows prediction of the breakdown behavior where analytical solutions are otherwise not available.

*Work done at JPL/CIT under NASA contract.

1. E. W. B. Gill and A. von Engel, Proc. Roy. Soc. (London) A192, 446 (1948).
2. A. J. Hatch and H. B. Williams, J. Appl. Phys. 25, 417 (1954); Phys. Rev. 112, 681 (1958).
3. E. F. Vance, J. Appl. Phys. 34, 3237 (1963).
4. B. A. Zager and V. G. Tishin, Zh. Techn. Fiz. 34, 297 (1964).

C9 ARC SPOTS AS MAGNETIC BOTTLES OF PLASMA WITH ELECTRICAL AND MECHANICAL STOPPERS. J. ROTHSTEIN, Laboratory For Electronics, Inc.

Mercury arc spots require astronomical current densities, and pose the puzzle of retrograde motion in a magnetic field. The dense plasma model(1) accounts for both. Spot excitation is via incident ion bombardment and ohmic dissipation (convergent electron flow in the cathode). Sidewise plasma containment is by self-magnetic pinch of the current, with stoppering of the "bottle" by ionic pumping on one side and the cathode bulk on the other; the chief energy drain is electron "evaporation". Magnetic fields parallel to the cathode surface weaken containment on one side, resulting local plasma expansion cools it (additional energy sink). The current redistributes to minimize dissipation, implying spot motion toward the high field region (retrograde motion) where containment is more efficient. Earlier mechanisms (e.g. field emission) require conditions under which a microplasma is sure to generate; its properties would then dominate the phenomenon.

[1]J. Rothstein: a) prelim. notes: P.R. 73, 1214 (1948) (L), erratum 74, 228 (1948); J.A.P. 19, 1181 (1948) (L); P.R. 75, 1323, 1335, 1336 (1949), 78, 331 (1950). b) plasma at focused laser spot: N.E.C. Proceedings, Vol. 19, pp. 554-563 (Chicago, 1963). c) analogy with exploding wires: Exploding Wires, Vol. III, pp. 115-123, Plenum Press (New York, 1964). d) ohmic dissipation at spot: Proc. Electron and Laser Beam Sympos., 1965; Ed: A. B. El-Kareh. (Penn. State U., Univ. Park, Pa.) pp. 133-161.

SESSION D

Thursday, October 21

9:00 a.m.

DIFFUSION-MOBILITY

Chairman: D. W. Martin, George Institute of Technology,
Atlanta, Georgia

D1 TIME-OF-FLIGHT MEASUREMENTS OF DIFFUSION COEFFICIENTS AND DRIFT VELOCITIES IN ELECTRON SWARMS.* G. S. HURST and J. E. PARKS, Health Physics Division, Oak Ridge National Laboratory.

The method described earlier[1] for the determination of electron diffusion coefficients (D) and drift velocities (W) from time-of-flight studies of individual electron motion in gases has been improved in two essential ways. First, an accurate method of measuring all fluctuation in the time-of-flight distribution except that due to the diffusion process itself has been developed. Second, a data analysis procedure has been worked out in which the effects of instrumental fluctuations are removed and accurate values of the parameters D and W are found from a generalized least squares procedure making use of a digital computer. Application of the improved method has been made to ethylene and ethylene-water vapor mixtures over the range of E/P from 0.01 to 1.0 (volt cm^{-1} $Torr^{-1}$). Independent measurements of the quantities D and W were made; the ratio D/W were compared with theory in the region of thermal electron energies. The ratio of the momentum transfer cross sections for H_2O compared to ethylene was the same whether use was made of D(E/P) or W(E/P) data in the region of thermal energies.

*Research sponsored by the U. S. Atomic Energy Commission under contract with Union Carbide Corp.

1. G. S. Hurst, L. B. O'Kelly, E. B. Wagner, and J. A. Stockdale, J. Chem. Phys. 39, 1341 (1963).

Combined with papers D2 and D3.

D2 TIME-OF-FLIGHT MEASUREMENTS OF DIFFUSION COEFFICIENTS AND DRIFT VELOCITIES IN ELECTRON SWARMS (DIFFERENTIAL PUMPING METHOD).* F. J. DAVIS and E. B. WAGNER, Oak Ridge National Laboratory.

An experimental apparatus using differential pumping and an electron multiplier detector was developed to make time-of-flight studies in gases not suitable for use in Geiger-Muller counters. The apparatus contains three pressure regions: 1) the swarm region at pressure up to 10-50 Torr depending on the gas, 2) an intermediate region maintained at a pressure of the order of 10^{-3}Torr and 3) the detector region at a pressure of the order of 10^{-6}Torr. Electrons are released from a photocathode by a light pulse with a duration of a fraction of a microsecond. One electron out of ten light pulses may be transmitted through the length of the swarm region and be detected by the multiplier at the exit hole of the chamber. The method of analysis has been published earlier.[1] The drift velocity and diffusion coefficients have been measured for H_2, CO_2, C_2H_4, N_2, He, A, and Ne. Considerable divergence of values (up to 50%) from published values by the Townsend-Huxley method have been noted, indicating a fundamental difference in the two types of experiments.

*Research sponsored by the United States Atomic Energy Commission under contract with Union Carbide Corporation.

1. G. S. Hurst, L. B. O'Kelly, E. B. Wagner, and J. A. Stockdale, J. Chem. Phys. 39, 1341 (1963).

Combined with papers D1 and D3.

D3 INTERACTION OF THERMAL ELECTRONS WITH POLARIZABLE AND POLAR MOLECULES.* L. G. CHRISTOPHOROU,** G. S. HURST and A. HADJIANTONIOU, Health Physics Division, Oak Ridge National Laboratory.

Drift velocities, w, were measured for thermal electron swarms traveling through gases and gas mixtures. The w data are used to calculate the cross section for momentum transfer, σ, which is assumed to have a v^{-1} and a v^{-2} dependence for nonpolar and polar molecules, respectively. An effort is made to correlate the experimental values of σ with the molecular polarizabilities and/or the molecular dipole moments. The theoretically predicted correlations are discussed and compared with experiment. Simple theories of long range forces agree well with the experimental data, while there is a disagreement between the experiment and the theory of short range inductive forces. Various factors proposed to account for the observed differences are discussed.

*Research sponsored by the United States Atomic Energy Commission under contract with Union Carbide Corporation.

**Department of Physics, University of Tennessee, and Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Combined with papers D1 and D2.

D4 ION MOBILITY STUDIES IN HELIUM.* J. M. MADSON, H. J. OSKAM and L. M. CHANIN, University of Minnesota.

The mobility of ions in Helium has been studied by means of the pulsed ion-transit-time method. The mobility tube was analogous to that used by Biondi and Chanin.[1] The ions, however, were simultaneously identified by a quadrupole mass spectrometer (analyzing field length 20 cm). Preliminary studies revealed the presence of two ions of mass eight having different mobilities. The first ion has, within the experimental error, the same mobility as that reported by Biondi and Chanin.[1] The second ion mobility value agreed, within the experimental error, with the value obtained from afterglow studies and recent ion-transit-time measurements.[2-5] The results will be discussed and possible reasons for the previous discrepancies between the various measurements will be given.

*Supported by the Advanced Project Agency through the Office of Naval Research and by the Air Force Cambridge Research Laboratories.

1. M. A. Biondi and L. M. Chanin, Phys. Rev. 94, 910 (1954).
2. D. E. Kerr and C. S. Leffel, Bull. Am. Phys. Soc. 7, 131 (1962).
3. H. J. Oskam and V. R. Mittelstadt, Phys. Rev. 132, 1435 (1963).
4. E. C. Beaty and P. L. Patterson, Phys. Rev. 137, A346 (1965).
5. J. M. Madson and H. J. Oskam, Bull. Am. Phys. Soc. 7, 636 (1962).

D5 LOW FIELD MOBILITY AND REACTIONS OF NITROGEN IONS IN NITROGEN. L. G. McKNIGHT, K. B. McAFEE, JR. & D. P. SIPLER, Bell Telephone Laboratories, Inc.

The investigation of the drift velocities and reactions of ions in nitrogen has been extended to values of E/P_0 from 6 to 66. This work completes the determination of ion velocities from $E/P_0 = 6$ to approximately 900. At values of E/P_0 higher than 30, the drift velocities of N^+ and N_3^+ are the same within the measurement error of a few per cent at one Torr. Above E/P_0 of 50, N_2^+ and N_4^+ have equal velocities forming a smooth and overlapping curve with previous data up to an E/P_0 of about 900.

To make the measurements ions were produced by a glow discharge and introduced into the drift cell using a Tyndall double grid gate. After drifting through the cell, the ions were withdrawn through a slit and their mass and intensity simultaneous determined as a function of time using the time-of-flight technique.

The shapes of the ion transients observed for the $N_2^+ - N_4^+$ system clearly show the effects of interconversion of the ions. Interconversion in the $N^+ - N_3^+$ system is indicated by the shapes of the ion transients at low E/P_0, their equal drift velocities at $E/P_0 > 30$ and their intensity dependence.

D6 A STUDY OF INELASTIC COLLISIONS BY DRIFTING IONS. Y. KANEKO*, L. R. MEGILL**, J. B. HASTED, University College London.

A series of experiments have been performed in which a mass-analysed ion beam is injected into a drift tube containing gas. The ions drift through the tube under the action of a uniform electric field and they undergo inelastic processes. The product ions are mass-analysed upon exit. The energy of the drifting ions is controlled by the magnitude of the drift field.

We have measured the low energy cross section for $Ne^+ + Ar \longrightarrow Ar^+ + Ne$, and find the cross section at reduced field 40 volts cm^{-1} $torr^{-1}$ to be $\sim 4 \times 10^{-19}$ cm^2, rising steeply with energy. We have also studied the reverse reaction $Ar^+ + Ne \longrightarrow Ar + Ne^+$ and a number of other reactions involving oxygen ions of which a fraction are excited. The mobility of a number of ions in various gases has been measured.

* On leave from Tokyo Metropolitan University, Tokyo, Japan.

** On leave from Nat.Bur.Stds. Boulder, Colorado.

D7 DRIFT VELOCITY OF D^+, D_3^+, AND D_5^+ IONS IN DEUTERIUM GAS.* M. SAPOROSCHENKO, Southern Illinois University, Carbondale, Illinois.

Drift velocity measurements as a function of E/p_0, the ratio of electric field intensity to normalized gas pressure, have been obtained for positive ions D^+, D_3^+, and D_5^+ in deuterium gas using the "four-gauze" electrical shutter method of Tyndall, et al. The ions have been identified mass spectrometrically. Measurements were made over a range of E/p_0 from 8-100 volts per cm x mm Hg. The predominant ion is D_3^+. An appreciable number of the D_5^+ ions are present at low E/p_0. The D_5^+ ion current decreases rapidly with increasing E/p_0 in the drift space. Presence of common impurities (H_2O, N_2, CO) depletes amount of the D_5^+ ion current. The mobility μ_0 corrected to 0^oC for the D^+ ions was 11.2 cm^2 per volt per second, for the D_3^+ ions 7.9 and for the D_5^+ ions 7.65 at $E/p_0 = 15$. With increasing E/p_0, the mobility of the D^+ ions decreases, that of the D_3^+ ions is constant for $E/p_0 < 17$ then increases above $E/p_0 = 17$ to a maximum of 11.5 at $E/p_0 = 55$ then again decreases, and that of the D_5^+ ions increases with raising E/p_0. Results of this experiment on drift velocity of the D_3^+ ions are in agreement with Rose's results.[1]

*Supported by a grant from the Atomic Energy Commission.

1. D. J. Rose, Jour. of Appl. Phys. 31, 643 (1960).

BUSINESS MEETING

Chairman: A. V. Phelps, Westinghouse Research and Development Center, Pittsburgh, Penna.

Proposed Amendment to the Constitution of the Gaseous Electronics Conference:

In accordance with the articles of the constitution, the Secretary has received, prior to the deadline for the submission of abstracts this year, a written Amendment endorsed by the proper number of signatures of members of the Conference. The purpose of this Amendment is to provide a greater degree of continuity to the office of the Chairman of the Executive Committee. This would be accomplished by arranging for the Chairman-Elect to serve on the Executive Committee one year prior to assuming the office of Chairman. The Chairman will place the following Amendment before the business session at the 1965 meeting.

Amendment

The General Committee will elect, by majority vote, the Chairman of the Executive Committee one year prior to the date on which he assumes office. During this year preceding his assumption of office, the Chairman-Elect will serve as one of the five general members of the Executive Committee. In the event that the Chairman-Elect is unable to assume office, the General Committee will elect a Chairman as provided in the original Constitution.

D8 <u>COLLISIONAL PHENOMENA RELATED TO THE ELECTRONIC HEAT TRANSFER IN PLASMAS</u>.* KAARE J. NYGAARD, Sperry Rand Research Center, Sudbury, Massachusetts.

We have measured the electron thermal diffusivity D_T in He and Ne afterglows (using Tonks-Dattner electro-acoustic resonances to determine electron temperature). When $\nu_{ei} \gg \nu_{en}$, the values we have found for D_T agree well with the theory of Spitzer and Härm.[1] From the experimental values of the diffusivity in the limit of the weakly ionized plasma, i.e., $\nu_{ei} \ll \nu_{en}$, we have deduced average values of the cross section for electron-atom momentum transfer. The present method covers the transition region between the weakly and the fully ionized plasma limits without any assumptions about the nature of the energy loss processes. Finally, we have compared these measurements with others using the recombination light quenching method.[2] The method of afterglow quenching is applicable only in the early stages of the afterglow when recombination is predominant, whereas the Tonks-Dattner resonance method is of particular value at later times when the plasma density is lower and controlled by ambipolar diffusion. Agreement between the two methods has been found for narrow ranges of density in which both are applicable.

*The research reported in this paper was sponsored in part by the Air Force Cambridge Research Laboratories, Office of Aerospace Research.

1. L. Spitzer, Jr. and R. Härm, Phys. Rev. 89, 977 (1953).
2. T. Sekiguchi and R. C. Herndon, Phys. Rev. 112, 1 (1958).

D9 <u>DIRECTED ELECTRON VELOCITY DISTRIBUTIONS IN RARE GAS DISCHARGES USING GUARD RING PROBES</u>.* R. H. BOND,+ Caltech.

An experimental technique for determining detailed properties of anisotropic electron velocity distributions is described. For a planar Langmuir probe it is shown that $g(V_z) = \frac{m}{e^2} \frac{\partial J_p}{\partial V_p}$ where $V_z = \sqrt{2 \frac{e}{m} V_p}$ and $g(V_z)$ gives the density of electrons with velocities normal to the probe in the range v_z to $v_z + dv_z$. This expression is valid for any distribution function making it possible to study anisotropies merely by changing the orientation of the probe. If the distribution function is isotropic the above expression is valid for cylindrical and small spherical probes as well. This technique is applied to the measurement of the directional properties of electron velocity distributions in the positive column of neon and helium hot cathode discharges. The necessary planar probe consists of a 0.01 inch diameter circular probe surrounded by a 0.090 inch square guardring. The measured distributions were Druyvesteyn in form except that all electrons were shifted in energy by an amount proportional to $E\lambda$. Here E is the magnitude of the external electric field and λ the electron mean free path as a function of v_z.

*Work supported by Office of Naval Research.
+Present address: Virginia Polytechnic Institute, Blacksburg, Virginia.

SESSION E

Thursday, October 21

2:00 p.m.

IONIZATION-EXCITATION

Chairman: E. C. Zipf, Jr., University of Pittsburgh,
Pittsburgh, Pennsylvania

E1 THE ENERGIES OF N^+ IONS FROM THE DISSOCIATIVE IONIZATION OF N_2.† L. J. KIEFFER and R. J. VAN BRUNT, The Joint Institute for Laboratory Astrophysics.††

Using an apparatus previously described in the literature,[1] the energy distribution and angular distribution of energetic N^+ ions from the dissociative ionization of N_2 by electron impact have been observed. The data are not consistent with the measurements of Tate and Lozier.[2] Ions were observed with energies from 1.0 eV to 17.0 eV. One interesting feature of these data is that there are two well defined groups of ions. The angular distribution data does not indicate any significant anistropy as observed previously for H_2.[1]

†Work supported by the Advanced Research Projects Agency (Project Defender), through the Army Research Office, as well as by the National Bureau of Standards.

††Of the National Bureau of Standards and the University of Colorado.

1. G. H. Dunn and L. J. Kieffer, Phys. Rev., 132, 2109 (1963).
2. J. T. Tate and W. W. Lozier, Phys. Rev., 39, 254 (1932).

E2 ABSOLUTE CESIUM IONIZATION CROSS SECTION* B. W. SCOTT and H. HEIL, Hughes Research Laboratories.

The ionization cross section, σ, recently measured for the first time at 50 eV and above[1] has been measured down to threshold in a Tate and Smith type apparatus. The density in the collision space was determined by a surface ionization detector allowing an overall accuracy on the cross section of 10%. We found: 1) $\sigma = 5.3 \times 10^{-16}$ cm^2 at 50 eV, smaller than (1) by a factor 1.8. The same factor is needed to bring Li cross sections[1] into agreement with computations by McDowell et al[2], 2) The recording near threshold indicates a linear range over 0.8 eV with a slope of 2.2×10^{-16} cm^2 eV^{-1}. Above 0.8 eV it rises less than linearly. 3) Above 12 eV excitation to the autoionizing states is seen and above 18 eV an additional contribution to the total cross section begins. The latter is due to ionization to an excited ion. Cross sections for these two processes have been separated. The autoionization is resonant in character with a maximum of 0.5×10^{-16} cm^2. The cross section for the second process has a maximum at high energies with a value of 1.5×10^{-16} cm^2.

*Work sponsored by Air Force Cambridge Research Laboratories

1. R. H. McFarland, J. D. Kinney, Phys. Rev. 137, A1058 (1965)
2. M. R. C. McDowell, V. P. Myerscough, G. Peach, Proc. Phys. Soc. 85, 703 (1965)

E3 A STUDY OF THE ENERGY SHAPE OF THE CROSS-SECTION FOR THE IONIZATION OF ARGON BY ELECTRON IMPACT. MICHAEL L. SEMAN, Xerox Research Division.

Measurements were made of the energy dependence of the total ionization cross-section for electron impact on argon. A retarding potential electron energy analysis together with a deconvolution process revealed the structure in the ionization probability curves reported by Fox,[1] and more recently by Stuber.[2] The structure is thought to result from the ionizing events which leave the argon ion in the $3s3p^6$ configuration as well as the usual $3s^23p^5$ configuration. Similar types of structure have been observed for the ionization of the alkalis. Arguments which lead to the above conclusion together with details of the structure are presented.

1. R. E. Fox, J. Chem. Phys. 33, 200 (1960).
2. F. A. Stuber, J. Chem. Phys. 42, 2639 (1965).

E4 CROSS SECTION FOR D^+ PRODUCED IN DISSOCIATIVE IONIZING COLLISIONS OF ELECTRONS IN DEUTERIUM. R. D. REMPT* and D. D. BRIGLIA, Lockheed Palo Alto Research Laboratory.

The cross section for production of deuterons formed as a result of electron collisions has been determined by measuring both the total ionization cross-section and the mass analyzed D_2^+ cross section in a single apparatus. Direct measurements of the D^+ cross section by means of conventional mass spectrometry are rendered inaccurate both in the magnitude and in the dependence on electron energy due to discrimination caused by the initial kinetic energies and anisotropies in angular distributions[1] of the deuterons. However, in measurements of total ionization it is possible to saturate both D_2^+ and the energetic D^+ ions to the ion collector. Also, the relative cross section for D_2^+ can be determined by mass analysis. The D_2^+ cross section can be normalized to the total cross section since below 30 eV only deuterons from the $^2\Sigma_g^+$ are produced and these constitute less than 0.5% of the total ionization. The cross section for deuteron production has been obtained by taking the difference between the total ionization cross section and the mass analyzed D_2^+ cross section measured in a combination Tate and Smith-Bleakney apparatus. The resulting cross sections are somewhat larger than previous estimates which required corrections due to solid angle factors.

*Permanent Address: Physics Department, University of California, Los Angeles, California.

1. G. H. Dunn and L. J. Kieffer, Phys. Rev. 132, 2109 (1963).

Combined with paper E5.

E5 FORMATION OF D_3^+ IN ION-NEUTRAL AND NEUTRAL METASTABLE-NEUTRAL COLLISIONS. DONALD D. BRIGLIA, Lockheed Palo Alto Research Laboratory.

Ionization efficiencies for production of D_2^+ and D_3^+ as a result of electron collisions in low pressure deuterium have been measured from threshold to 160 eV. The observed mass-analyzed ion current vs. electron energy curves possess a broad maximum at 60 eV for both D_2^+ and D_3^+ and have approximately the same form. However, a detailed study of the threshold region reveals that the appearance potential of D_3^+ is 14.9 ± 0.1 eV, i.e., approximately 0.5 eV below that of D_2^+. Thus D_3^+ is formed at threshold by collisions of neutral metastable molecules, $D_2^* + D_2 \rightarrow D_3^+ + D + e^-$. Both ion-neutral and thermal neutral-neutral collisions contribute to the yield of D_3^+. The present results provide evidence for the existence of metastable states of the deuterium molecule which are excited to within ~ 0.5 eV of the ionization limit. Similar results were obtained in hydrogen. For electron energies above threshold, higher vibrational states of D_2^* are produced which, however, pre-ionize when the imparted energy exceeds 15.46 eV. These pre-ionizing molecules are undoubtedly the source of the strong auto-ionization which dominates the direct ionization at threshold in hydrogen and deuterium.[1,2]

1. D. D. Briglia and D. Rapp, Phys. Rev. Letters, 14, 245 (1965) and J. Chem. Phys., 42, 3201 (1965).
2. J. W. McGowan and M. A. Fineman, Paper RB4, Fourth International Conference on the Physics of Electronic and Atomic Collisions, Quebec, Canada, August 1965.

Combined with paper E4.

E6 MEASUREMENT OF IONIZATION COEFFICIENT IN CESIUM-HELIUM MIXTURES.* J. F. NOLAN, Westinghouse Research Laboratories.

The Townsend α coefficient has been measured in cesium-helium mixtures as a function of E/p, the ratio of electric field to total pressure, and N_{Cs}/N_{He}, the ratio of cesium to helium density. For low density ratios ($N_{Cs}/N_{He} \sim 10^{-5}$) the dominant ionization mechanism is a Penning reaction between helium metastables and cesium atoms. At higher density ratios direct electron ionization of cesium predominates at low values of E/p. By comparing the observed α with that obtained from a numerical solution of the Boltzmann equation using an assumed cesium excitation cross section, one arrives at a cross section consistent with these measurements and with previous measurements of the cesium ionization cross section.[1-3] An excitation cross section with a peak value of 1.15×10^{-14} cm^2 at 8 eV gives good agreement with experiment. This total excitation cross section is compared with recent calculations and measurements of the cross section for 6S-6P resonance excitation in cesium.

***Work supported by the National Aeronautics and Space Administration, Lewis Research Center.**

1. J. T. Tate and P. T. Smith, Phys. Rev. 46, 773 (1934).
2. G. O. Brink, Phys. Rev. 134, A345 (1964).
3. R. H. McFarland and J. D. Kinney, Phys. Rev. 137, A1058 (1965).

E7 CALCULATIONS OF THE ELECTRON EXCITATION CROSS SECTIONS OF NEON AND ARGON*. FREDRIC E. FAJEN† AND CHUN C. LIN‡, University of Oklahoma.

The electron excitation cross sections of the $3s_5\,[(2p)^5(5s)]$ state of neon and $3s_5\,[(3p)^5(6s)]$ of argon have been calculated by the Born approximation for incident electron energies of 30-250 eV. Analytic Hartree-Fock wave functions are used for the ground states of the atoms and the wave functions of the excited states are constructed by applying Js coupling to the $(2p)^5(5s)$ and $(3p)^5(6s)$ configurations using Hartree-Fock-Slater type functions. The excitation cross sections of the 6182 Å line of neon and the 6416 Å line of argon have been computed and comparisons with experimental data are discussed.

*Work supported in part by the U. S. Air Force Office of Scientific Research.
†Part of the work was done at the Los Alamos Scientific Laboratory.
‡Alfred P. Sloan Foundation Fellow.

E8 ELECTRON EXCITATION CROSS SECTIONS OF TRANSITIONS BETWEEN THE SPIN-MULTIPLETS OF THE GROUND STATE OF OXYGEN*. EDWARD L. BREIG† AND CHUN C. LIN‡, University of Oklahoma.

Recent studies of the effect of submillimeter radiation on the cooling of interstellar media have indicated the importance of electron-excitation transitions between the three spin-multiplet J=0,1,2 of the $[(1s)^2(2s)^2(2p)^4]\ ^3P$ ground state of OI. The calculation of these cross sections has been performed using the continuous-state Hartree-Fock formulation with partial wave analysis in a coupled representation characteristic of the total angular momentum. For the s- and p-waves, the system of scattering equations associated with the $^3P_{0,1,2}$ manifold of the oxygen atom can be decoupled under an exact-resonance approximation, and the solutions obtained by numerical iteration. Here the exchange coupling is the principal interaction. Partial cross sections for the d-wave are found to be of minor importance and may be obtained by the Born approximation. Calculations have been made for energies in the range of 100° to 10,000° K and curves are presented for the individual partial and total cross sections. The calculated cross sections are in reasonable agreement with the rough estimates used in previous energy transfer analyses.

*Work supported by the U. S. Air Force Cambridge Research Laboratories.
†North American Aviation Fellow.
‡Alfred P. Sloan Foundation Fellow.

E9 EXCITATION OF MERCURY BY ELECTRON IMPACT*. RICHARD J. ANDERSON, EDWARD T. P. LEE, AND CHUN C. LIN†, University of Oklahoma.

The electron excitation cross sections of the 4047 Å, 4358 Å, 5461 Å ($7^3S_1 \rightarrow 6^3P_{0,1,2}$), and 4078 Å ($7^1S_0 \rightarrow 6^3P_1$) lines have been measured over the range of incident electron energy of 0-100 eV. From the excitation functions of the series of the $n^1P \rightarrow 7^3S$, $n^3P \rightarrow 7^3S$, and $n^1P \rightarrow 7^1S$ transitions, the populations of the 7^3S and 7^1S states due to cascade from these higher states are determined. By using the transition probabilities calculated from the self-consistent field wave functions of mercury, the direct excitation functions have been obtained. Typical values of the excitation cross sections are 5×10^{-18} cm^2 and 2×10^{-18} cm^2 for the 7^1S and 7^3S states respectively at 50 eV. Similar analysis has been made for the excitation function of the 6^3D_2 state yielding an estimate of the cross section at 50 eV as 1×10^{-18} cm^2. Theoretical cross sections have been calculated by the Born approximation and Born-Oppenheimer approximation and the results are compared with the experimental data.

*Work supported by Kirtland AFB, U. S. Air Force Systems Command and by the U. S. Air Force Office of Scientific Research.
†Alfred P. Sloan Foundation Fellow.

E10 MEASUREMENTS OF THE EXCITATION FUNCTIONS FOR METASTABLE STATES IN THE RARE GASES BY ELECTRON IMPACT*. J. T. DOWELL, University of California, Lawrence Radiation Laboratory, Livermore, California.

Excitation functions for metastables in He, Ne, A, Kr and Xe have been measured for onset to ionization potential with an apparatus similar to that of Schulz and Fox.[1] The RPD method was used to obtain a nearly monoenergetic (0.1 eV half width) electron beam. Results in He, Ne, A and Kr are consistent with those of other investigators.[1,2] Particular attention was paid to threshold behavior and threshold laws will be discussed. Data in each gas exhibit two major peaks in addition to other structure. In Xe these peaks may be interpreted as belonging to the excitation function of the lowest metastable state.

*Work performed under the auspices of the U. S. Atomic Energy Commission. Preliminary phases supported by the Office of Naval Research.

1. G. J. Schulz and R. E. Fox, Phys. Rev. 106, 1179 (1957).
2. J. Olmsted, III, A. S. Newton and K. Street, Jr., J. Chem. Phys. 42, 2321 (1965).

E11 EXCITATION PROCESSES IN ALPHA IRRADIATION OF ARGON. R. E. GLICK, Florida State University and G. S. HURST, Oak Ridge National Laboratory.

In a recent study,[1] we reported an analysis for total energy dissipation of 5 meV α particles in argon. A further detailed analysis of this problem is to be presented which employs, 1) experimental ionization cross sections[2]; 2) various experimental estimates of the average energy of the ejected electron; and 3) our previous experimental measurements.[1] A mean excitation cross section for ground→ excited atom states is found to be 0.71×10^{-16} cm^2. These results are compared with our previous experimental determination. This excitation cross section is combined with those for ion forming processes and an estimate of the f number for argon atom-atom excited states is determined to be 4.1. Other complicating processes of lesser importance are indexed and discussed.

1. G. S. Hurst, T. E. Bortner and R. E. Glick, J. Chem. Phys. 42, 713 (1965).
2. U. Fano, Phys. Rev., 70, 44 (1946); see also A. Dalgarno and G. W. Griffing, Proc. Roy. Soc. A248, 415 (1958).

SESSION F

Thursday, October 21

2:00 p.m.

BREAKDOWN, CORONA, SPARKS

Chairman: L. H. Fisher, Lockheed Missiles and Space Company, Palo Alto, California

F1 BREAKDOWN MINIMUM IN SUPER HIGH PRESSURE HELIUM IRRADIATED BY A FOCUSED GIANT-PULSE LASER.*

DENNIS H. GILL, JOHN H. MCELROY and ARWIN A. DOUGAL, The University of Texas.

A minimum has been observed in the curve of threshold peak power versus pressure for ionization of super high pressure helium using a focused giant-pulse ruby laser. The minimum is quite broad compared to that predicted by an extension of microwave breakdown theory. Threshold peak power decreases rapidly from 1 MW at 500 psi to 80 KW at 4000 psi, remains between 80 and 100 KW as pressure increases to 25,000 psi, then rapidly rises to 350 KW at 29,000 psi. Breakdown is produced in ultrahigh purity He at pressures up to 30,000 psi by focusing an attenuated 30 MW giant-pulse ruby laser beam within a specially designed cell having three quartz windows and capable of withstanding 60,000 psi. Minimum focal diameter is about 200 microns. Ionization is detected by monitoring with a photomultiplier filtered so as to receive no 6943 Å ruby light. The ionization trace rises in about 20 nanoseconds, then decays in several hundred nanoseconds. Peak power of the laser pulse is detected by a calibrated fast rise-time photodiode.

*This research was supported by the National Science Foundation.
Texas Instruments, Inc., Graduate Research Fellow.

F2 FORMATIVE TIME LAGS IN LASER BREAKDOWN OF GASES.*

A. V. PHELPS, Westinghouse Research Laboratories, Pittsburgh, R. W. WAYNANT and J. H. RAMSEY, Westinghouse Defense and Space Center, Baltimore.

Experimental and theoretical studies have been made of the formative time lags which occur when an intense laser beam is used to breakdown helium, argon, nitrogen, and air. The experimental results are consistent with an electron avalanche growth of ionization in which the initiating electron is readily produced by photoionization of impurities. Theoretical calculations of electron energy distribution functions and of the rates of excitation and ionization assuming optical photon absorption by electrons in free-free transitions yield ionization coefficients in good agreement with extrapolations from microwave results. A comparison of theoretical and experimental formative time lags suggests that some of the ionization results from photoionization of atoms and molecules excited by electron impact.

*This work was partially supported by the Rome Air Development Center.

F3 TEMPORAL GROWTH OF PLASMA IN A HIGH FREQUENCY DISCHARGE. MELVIN EPSTEIN, Aerospace Corporation.

The classical method of predicting electrical breakdown of a gas subjected to a high frequency electromagnetic field yields only the initial rate of production of electrons. It supplies no information regarding the ultimate electron density or the time history of electron density produced by a field of given strength. The temporal growth of the plasma is determined by the various electron loss mechanisms which may be operative and by the fact that as the electron density grows, the field strength in the plasma drops off. In this way, the ionization rate decreases until it equals the loss rate at which time the plasma reaches its steady state. This behavior has been analyzed by solving the electron production equation simultaneously with Maxwell's equations. In this way, the time history of the field strength transmitted through an initially uniform plasma slab has been calculated. The results indicate that the final level of transmitted power decreases as the incident power level is increased above the level required to initiate breakdown. Such predicted behavior is in agreement with experimental observations.

F4 THE TIME LAG IN THE INITIATION OF THE SELF SUSTAINING DIPOLE DISCHARGE AT HIGH PRESSURE

N. T. DZOANH, Illinois Institute of Technology.

It has already been shown that [1] if the surfaces of two parallel electrodes are covered by a porous insulating film and Polonium is used as an exciting source, a glow discharge could be created and self sustained even at high pressure (one atmosphere or more). This discharge was called a Self Sustaining Dipole Discharge (S.S.D.D.). It is believed that the secondary ionization coefficient γ of Townsend, which is well known to be necessary for maintaining the discharge, is supplied in this case by the mechanism of microdisruptive discharge at the electrode surface. In this work, a simple model of microcondensers is used as a basic hypothesis for evaluating the initiation time lag of the S.S.D.D. as a function of the applied voltage, pressure and electrode distance. Experimental data [2] seems to justify the above hypothetical assumption and to fit pretty well the theoretical relation despite an experimental device - dependent constant which is left undetermined.

1. N.T. Dzoanh Self Sustained Dipole Discharge in oxygen, Final report O.A.R. October, 1964; Journal of Applied Physics (In Press)
2. Part of the experimental work was done at Indiana University under the O.A.R. Contract.

F5 SPARK TRANSITION WITH HIGHLY STRESSED CATHODE IN ASYMMETRICAL GEOMETRY IN FREE ELECTRON GASES*.
LEONARD B. LOEB AND ABBASS HASSOUN, University of California, Berkeley.

Observations of Weissler and Miller led Loeb in 1949 to infer the inherent instability of highly stressed cathodes in gases where inhibitory negative ion space charges do not occur. Thus at threshold corona does not precede direct breakdown to a transient arc. Experimental study was not possible before vacuum and electronic techniques became adequate. Pure He was studied in a point-to-plane gap with flashed W cathode from 50 to 200 Torr and steady potential by current and photomultiplier. Breakdown to a transient arc initiates at the cathode and the luminous front measured at 20% of peak above background at 100 Torr advances at 4×10^6 cm/sec near the cathode and 10^6 cm/sec near the anode. Current and luminous duration lie in the microseconds to tens of microsecond range depending on external circuit constants and pressure. The transition is a Townsend breakdown with ion γ leading to the Morton-Johnson regime by positive ion space charge. This projects a space charge cloud of energetic electrons at the velocities indicated, slowing on crossing the gap creating the arc channel, circuit constants permitting.

*This research was supported by the Office of Naval Research.

F6 THE CATHODE FIELD EMISSION IN A POSITIVE POINT-TO-PLANE DISCHARGE. E. NASSER, Iowa State University.

Streamers originating from a point anode under a voltage pulse proceed far into the lowfield region at high velocities and under continuous branching.[1] It was found that electron liberation from the cathode occurs under the effect of the high field between the streamer tips and the cathode just before impact. Photographic evidence by means of paper films placed on the cathode with sensitive emulsion facing it, showed that at the points where strong streamers tips struck the back side of the film, great concentrations of minute dots appeared. These dots are produced by those electrons liberated from the cathode which were accelerated towards the tip and formed electron avalanches. The liberation of electrons must be due to high field intensities at the tips since radiation cannot penetrate the paper. To confirm this, the back side of the paper was blackened at spots with no change in pictures. To confirm furthermore that electron liberation was caused by field effects, a thin metallic layer was placed at the back of the paper. No electrons were liberated and no dots appeared opposite the metallic layer because no high fields can exist between it and cathode. The avalanches between film and cathode became diffuse when the air gap was increased to about 3 mm since they grew in each other. An increase to 5 mm caused only few avalanches to be produced of which some formed negative streamers and at their impact on the film caused distinct negative Lichtenberg figures.

1. L. B. Loeb and E. Nasser, J. Appl. Physics, 34 3340 (1963).

F7 CALCULATIONS OF RELAXATION OSCILLATIONS IN HELIUM AT SEVERAL ATMOSPHERES PRESSURE
A. L. WARD, Harry Diamond Laboratories.

Leycuras[1] reported measuring voltage oscillations of amplitude $\Delta V \approx 500$-3000 V and periods $\tau \approx 4$-20 μsec for applied voltages $V_A \approx 1700$-9000 V in helium at pressures from 4-8 atmospheres and a gap of 0.1 cm. Leycuras used a series resistance of 2.1 MΩ and measured a capacitance C of 8.5×10^{-11} F. Calculations of relaxation oscillations have been made with a computer program for these same parameters, except that negative fields preclude $C > 2 \times 10^{-12}$ F. Agreement of the calculated and measured variation of ΔV with V_A is quite good. Calculated qualitative variation of τ with V_A is in good agreement with the measured variation but the measured values are ~2 to 4 times the calculated ones. The calculations indicate $\tau \propto C^{1/2}$. An extrapolation of calculated values of τ to that for $C \approx 1.5 \times 10^{-11}$ F would give agreement with the measured values of τ. It is believed impossible for Leycuras to have measured an ~1500 V voltage excursion with $\tau \sim 20$ μsec for V_A under 2000 V, if her circuit time constant was truly 178 μsec. No recombination was included in the computer program formulation, even though Leycuras claimed to calculate recombination coefficients from her measurements. The calculated motion of ionization fronts will be presented in contour level drawings which simulate photographs made with a rotating mirror.

1. Yvonne Leycuras, Proc. 6th Int. Conf. Ionization Phenomena in Gases (SERMA Paris, 1963) Vol. I, p. 457.

F8 ELECTRICAL INTERACTION BETWEEN A CHARGED AEROSOL AND A CORONA FIELD.* E. BARRETO and K. MARTINOT, Curtiss-Wright Corporation, Wood-Ridge, New Jersey.

The condensation of one of the components in a gas mixture expanding through a nozzle which incorporates a corona discharge has been shown to produce an aerosol with a very high charge density (0.01 Coul/m^3). This aerosol is able to induce a multiply branched corona discharge on a nearby grounded electrode.[1] It will be shown that the charge liberated in the vicinity of the neutralizing electrode has a value in excess of the charge in the aerosol cloud. This extra charge results in a measurable current ranging from one to eight microamperes and its appearance can be correlated to visual changes in the induced corona. The energy required for the extra ionization is believed to be supplied by the mechanical flow energy through interaction with stationary corona space charge. The possibility of producing electrical interaction between two oppositely charged aerosol clouds will be discussed based on experimental evidence.

*This work is being supported by the Office of Naval Research.

1. E. Barreto and M. J. Mulcahy, Jour. Geoph. Res. 70, 1303-1309 (1965).

F9 PRESSURE AND APPLIED FIELD STRENGTH DEPENDENCE OF ELECTRODE TO WALL VOLTAGES IN RF PLASMOID DISCHARGES. A. MILLER, Physics Dept., New Mexico State University, University Park, New Mexico.

A metallic discharge chamber containing floating, internal electrodes has been used to measure the voltage developed between the walls and the electrode system in rf plasmoid discharges. This voltage is strongly dependent on the peak applied rf voltage, and shows considerable pressure dependence in spite of electron mean free paths which exceed the chamber dimensions by factors of 50 or more. Contrary to some previous speculations, it was found that the existence of (low-pressure type) rf plasmoids is not strongly influenced by either the sign or the magnitude of the wall to electrode voltage. Measurements were performed at 30 Mc/sec with a 10 cm electrode separation. Data obtained for CO_2 and N_2 (in which rf plasmoids were observed) will be compared to results obtained using He (in which no rf plasmoids were visible).

*This research was supported in part by the Office of Naval Research.

SESSION G

Friday, October 22

9:00 a.m.

METASTABLES AND EXCITED ATOMS

Chairman: E. E. Muschlitz, University of Florida, Gainesville, Florida

G1 THE EFFECTS OF METASTABLE ATOMS ON VOLUME ION PRODUCTION IN A TENUOUS HELIUM PLASMA. R. J. SOVIE and J. V. DUGAN, JR., NASA--Lewis Research Center.

The semi-classical Gryzinski method has been used to theoretically calculate the excitation and ionization cross sections for interactions between electrons and the metastable 2^1S and 2^3S states of helium. These cross sections have been used to calculate the effect of electron-metastable atom interactions on volume ion production processes in a tenuous helium plasma that has a Maxwellian distribution of free electron energies. The effects of ground state atom-metastable atom collisions have also been considered. Including the electron-metastable atom interactions in the volume ion production cost calculations yield the surprising result that these interactions do not appreciably reduce the ion production cost. The ion production cost is actually increased by these interactions for electron temperatures above 20 ev. The volume ion production cost, ion production rate, and power consumed in ion production are presented as functions of electron kinetic temperature.

G2 THE CONTROL OF METASTABLE POPULATION IN THE AFTERGLOW BY MICROWAVE HEATING AND OPTICAL PUMPING TECHNIQUES.* BERTRAM PARISER and THOMAS C. MARSHALL, Plasma Laboratory, Columbia University.

The population of neon metastable states in an afterglow can be decreased or increased by collisions with electrons heated by microwaves to ~ 2 eV. The depopulation which results is similar to that reported[1] where metastables are depopulated by optical pumping. Further heating increases the metastable population. This is due to hot electrons colliding with neutral neon atoms, exciting them to the metastable state. The theory of Biondi[2] on metastable-metastable collisions may be examined by controlling the metastable population in the afterglow. When the metastables are depopulated by optical pumping the electron density in the afterglow is found to decrease. These results indicate that the metastable-metastable collisions are an important ionization process in the afterglow.

*Supported by Advance Research Projects Agency through the Office of Naval Research.

1. B. Pariser and T. C. Marshall, Bull. of the Amer. Phys. Soc., 10, 190 (1965).
2. Manfred A. Biondi, Phys. Rev. 82, 453 (1951).

G3 MEASUREMENT OF THE HELIUM TRIPLET METASTABLE CONCENTRATION IN A FLOWING HELIUM AFTERGLOW*. J. H. CAHN and R. W. HUGGINS, University of Illinois, Urbana, Illinois

The concentration of the helium triplet metastable state $He(2^3S)$ in a flowing helium afterglow has been measured by introducing either nitrogen or argon downstream from the discharge and measuring the electron density produced by the Penning reactions

$$He^M + N_2 \rightarrow N_2^{+*} + e + He$$

and $$He^M + A \rightarrow A^+ + e + He \, .$$

The cavity method[1] is used to measure the electron density and the spacial distribution of the electrons is found experimentally by assuming that the electron density is proportional to the intensity of the first negative bands of nitrogen.

In order to properly account for diffusion and volume losses in a flowing system, we have found that a parabolic profile must be assumed and a solution of the continuity equation must be obtained.[2] Preliminary data indicate that the lowest eigenvalue solution is appropriate. A peak metastable density of $2 \times 10^{12}/cm^3$ is found at 6 mm. Hg. pressure and 1 millisecond in the afterglow.

*Work supported in part by the U.S. Air Force.
1. M.A. Biondi,S.C.Brown,Phys Rev. 75,1700,(1949).
2. Sellers,Treibus and Klein,Trans.ASME 78,441(1956).

G4 POPULATION DENSITY OF EXCITED STATES IN THE HELIUM POSITIVE COLUMN*. F. E. NILES**, MICHAEL TETER AND W. W. ROBERTSON, University of Texas.

The population densities of excited states in the helium positive column have been determined from spectral measurements for a range of pressures and currents. Electron excitation rates have been calculated using classical methods. The observed populations are compared to the calculated values. The 2^3S metastable level is populated primarily by electron collisions from the ground state and depopulated by diffusion to the wall and by electron collisions to higher levels, the latter loss being dominate for pressures above 5 Torr. The terms for $n>3$ are primarily populated by at least a two-step electron collision process and collisionally depopulated. At 7.5 Torr and 10 mA the population densities of the 2^3P-n^3D series goes as $n^{-4.7}$ and similarly for the other series. The ratio of population density to statistical weight is approximately equal for a particular L value with the ratio for the S level being the greatest.

*Work supported by the U. S. Air Force Office of Scientific Research and the University Research Institute.
**Present address: U. S. Army Ballistic Research Laboratories.

Combined with paper G5.

G5 HORNBECK-MOLNAR CROSS-SECTIONS FOR THE N = 3 STATES OF HELIUM.* M. P. TETER, F. E. NILES and W. W. ROBERTSON, University of Texas.

Analysis of the atomic light originating from energy levels of principal quantum number n = 3 in the helium positive column shows that a pressure dependent loss process exists for states other than the S-states. The loss mechanism is identified as the Hornbeck-Molnar process

$$He^* + He \rightarrow He_2^+ + e$$

by observing the effects of varying the atomic populations when the positive column is irradiated with intense atomic light. Comparison of the pressure dependent loss rate with the radiation loss rate from a particular state yields the Hornbeck-Molnar cross-section. An independent measurement relating the increase in the molecular ion concentration to the increase in the 3^3D population yields a separate value for the 3^3D cross-section which agrees quite well with that measured by the previous method. These results are consistent with those of Dahler, Franklin, Munson and Field[1] who measure the product of a reaction rate with the lifetime of the excited state involved.

*This work was supported by the Propulsion Division, Air Force Office of Scientific Research.

1. J. S. Dahler, J. L. Franklin, M. S. B. Munson, and F. H. Field, J. Chem. Phys. 36, 3332 (1962).

Combined with paper G4.

G6 RADIATIVE DECAY PATTERNS AND COLLISIONAL PROCESSES IN A HE-NE DISCHARGE.* L. A. WEAVER and R. J. FREIBERG, University of Illinois.

An idealized theoretical model is proposed to describe radiative cascade patterns in a noble gas. Using the Coulomb approximation for excited state wave functions, branching ratios for spontaneous decay are computed assuming a pure jl coupling of angular momenta. Experiments with He-Ne lasers demonstrate that oscillation depletes the upper laser level population and enhances the lower, providing a selective perturbation of excited state populations. The subsequent radiative decay of this perturbation is observed spectroscopically for the 3.39μ, 6328 A° and 1.15μ laser transitions in neon, and good agreement with predicted decay patterns is found. Observed deviations from the jl coupling behavior reveal that collisional mixing of excited neon levels substantially alters population distributions. In addition, electron impact with $Ne(3s_2)$ atoms is shown to be an important excitation mechanism for high lying neon levels, which are quenched by up to 3% due to lasering. When collisional effects within the gas are considered, the jl coupling model adequately explains observed changes in line intensity. It is suggested that noble gas laser transitions of doubtful term assignment can be identified accurately by observing laser-induced decay patterns.

*This work was sponsored by the U. S. Air Force Cambridge Research Laboratory.

G7 CONTINUUM RADIATION IN AN ARGON POSITIVE COLUMN.* J. F. PRINCE and W. W. ROBERTSON, University of Texas.

A weak continuum with a maximum near 3100Å is radiated from the positive column of an argon normal glow discharge. The intensity distribution of this continuum (observed here from 2900Å to 7000Å) does not correspond to a free-free, free-bound recombination spectrum. The continuum intensity, the $^3P_2$ metastable population, and the relative populations of more energetic atomic states are examined as functions of pressure (5-30 Torr) at constant currents and as functions of current (0.45-5 mA) at constant pressures. It is shown that the continuum is best represented as radiation emitted in transitions from weakly bound molecular states to dissociative molecular states. Examination of the pressure and electron density dependence of the continuum and the observed atomic states indicates that the proposed upper molecular states are populated by excitation from a molecule, presumably metastable, formed in a three-body process involving the $^3P_2$ atomic metastable state.

*This research was supported by the Propulsion Division, Air Force Office of Scientific Research.

G8 **EXCITATION AND DEEXCITATION OF METASTABLE O ATOMS.** **N. P. CARLETON, Smithsonian Observatory, F. J. LE BLANC and O. OLDENBERG, A. F. Cambridge Research Laboratories.**

We have studied excitation and deexcitation of the ^1D and ^1S levels of O atoms in a dc discharge through flowing oxygen, at pressures of a few torr with currents of 50 - 100 mA and a tube diameter of 6mm. We measure also: 1) the potential gradient in the positive column; 2) the absolute intensities of the lines 6300, 6364, 5577, and 2972 A°, connecting ^1S, ^1D and ground levels; 3) the density of O atoms by titration. We calculate the energy distribution of the electrons and their density, typically 10^{11} cm^{-3}, with an average energy of nearly 2 eV.* Then we calculate the excitation rates of ^1D and ^1S, and knowing their absolute populations find the rates of deactivation which balance excitation. The bulk of deactivation must be due to reactions with neutral molecules or atoms in the discharge, collisions with electrons and with the walls being negligible. We express only the upper limits that result from supposing that all the reactions are with O_2. The resulting values for the two body rate coefficients are $k(^1D, O_2) \leq 5 \times 10^{-12}$ cm^3 sec^{-1} and $k(^1S, O_2) \leq 1.5 \times 10^{-11}$ cm^3 sec^{-1}. By adding up to 10% N_2 to our O_2, we find a value for the rate of deactivation of ^1D by N_2: $k(^1D, N_2) \cong 2 \times 10^{-11}$ cm^3 sec^{-1}.

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

G9 ATOMIC DENSITY MEASUREMENTS IN NITROGEN, OXYGEN, AND HYDROGEN AFTERGLOW PLASMAS.* E. A. McLENNAN,+

Gaseous Electronics Laboratory, University of Illinois, Champaign, Illinois.

Densities of ground-state neutral atoms, formed by molecular dissociation in dc and rf discharges, have been measured over the range 10^{10} to 10^{16} cm^{-3}. Sensitive and unambiguous determinations were made using atomic resonance line absorption calibrated against atomic densities of 10^{13} to 10^{16} cm^{-3} by electron spin resonance and gas titration techniques accurate to 20%. This calibration was necessary since N and O resonance line oscillator strengths and N, O, and H source line shapes were unknown in the experiments reported. The measurement range was extended to densities below 10^{10} cm^{-3} in a 2.5 cm absorption path by time-sampling techniques with 50% accuracy at the lowest densities. In the case of nitrogen at 3 Torr, even though electron density has fallen below 10^{8} cm^{-3} within 300 μsec after cessation of the discharge, the atomic density is shown to be greater than 10^{10} cm^{-3} up to 10 sec. This provides a large and long-lived energy source in the afterglow.

*This research was supported in part by the Electronic Systems Division, U. S. Air Force Systems Command.

+Present address: Litton Industries Space Sciences Laboratory, Beverly Hills, California.

SESSION H

Friday, October 22

9:00 a.m.

SURFACES AND DISCHARGES

Chairman: S. Schneider, U. S. Army Electronics Laboratories, Fort Monmouth, New Jersey

H1 MECHANISMS OF PARTICLE EMISSION PRODUCED BY THE INTERACTION OF HIGH POWER LASER RADIATION WITH TUNGSTEN SURFACES*. J. F. READY, L. P. LEVINE, AND E. BERNAL G., Honeywell Research Center.

Production of plasma in the interaction of ruby laser radiation with tungsten surfaces in a vacuum of 10^{-8} torr has been studied using mass spectrometric techniques. The 30 nanosecond duration laser pulse delivers 30 to 100 megawatts/cm^2. The neutral particle emission consists largely of adsorbed surface gases and appears to have a thermal origin[1]. The positive ions consist of ions of surface gases, alkali metals and tungsten and appear in numbers too large to be thermal. High energy positive ions are also produced[2]. A hypothesis has been advanced for intense heating of the vaporized material by absorption of laser radiation in free-free transitions of the electrons in the plasma[3]. This would account for many of the observed features of the emission. A numerical analysis based on this model has been carried out. The results indicate that this mechanism may provide heating of a laser produced plasma if a critical electron density is reached. It appears unlikely that the necessary conditions are met in our experiments. Thus this mechanism fails to explain the observed results.

*This work was supported by the Ballistic Research Laboratories, Aberdeen Proving Ground.

1. J. F. Ready, L. P. Levine, and E. Bernal G., Bull. Am. Phys. Soc. 10, 596 (1965).
2. W. I. Linlor, Appl. Phys. Lett. 3, 210 (1963).
3. J. M. Dawson, Phys. Fluids 7, 981 (1964).

H2 ELECTRON EJECTION FROM AN ATOMICALLY CLEAN TUNGSTEN SURFACE BY HELIUM AND NEON METASTABLE ATOMS*. D. A. MacLennan, University of California, Berkeley.

The absolute secondary electron emission coefficient γ^m of helium and neon metastable atoms incident on an atomically clean tungsten surface has been determined. γ^m for helium is 0.306 ± 0.032 and γ^m for neon is 0.215 ± 0.020. The procedure was that of Stebbings[1] and Hasted,[2] using Penning ionized argon to measure the metastable beam intensity. (Argon is ionized by the metastable helium or neon, and every ion collected represents the loss of one metastable.) The atomically clean state of the surface is insured by the production of ultra-high vacuum (less than 3 x 10^{-10} Torr), the use of cataphoresis, and degassing of the tungsten surface at 2200°K with frequent flashings to 2200°K. Hagstrum[3] has predicted that the secondary electron emission coefficients of both metastables and ions of noble gases on atomically clean metal surfaces should be the same. The above coefficients are consistent with this prediction.

*This research was supported by the Office of Naval Research.

1. R. F. Stebbings, Proc. Phys. Soc. (London) A241, 270 (1957).
2. J. B. Hasted, J. Appl. Phys. 30, 22 (1959).
3. H. D. Hagstrum, Phys. Rev. 96, 366 (1954).

H3 VACUUM ELECTRICAL BREAKDOWN BETWEEN PLANE PARALLEL COPPER ELECTRODES. D. KENNETH DAVIES AND MANFRED A. BIONDI*, Westinghouse Research Laboratories.

Measurements have been made of pre-breakdown currents between thoroughly outgassed plane parallel copper electrodes in ultra-high vacuum, for electrode separations in the range 0.03 to 0.2 cm. These currents were found to be in good agreement with the Fowler-Nordheim theory of field emission from the pure metal surface. From combined measurements of pre-breakdown current and breakdown voltage at different electrode separations it is deduced that the microscopic cathode field at breakdown is constant and of magnitude $(6 \pm 1)\ 10^7$ V/cm.

Spectroscopic measurements of both resonance line absorption and line fluorescence have revealed that $\lesssim 10^{-6}$ torr pressure of neutral copper vapor is present in the interelectrode space during the application of electric fields only fractionally (< 1%) less than the breakdown field.

From the measurements it is concluded that particle exchange mechanisms and mechanisms involving the amplification of field emission current in electrode vapor produced by steady evaporation from either the anode or the cathode do not explain the electrical breakdown of vacuum between extended copper surfaces.

*Department of Physics, University of Pittsburgh.

H4 ANALYSIS OF THE ELECTRODE PRODUCTS EMITTED RADIALLY BY A DC VACUUM ARC. W. D. DAVIS and H. C. MILLER, General Electric Research Laboratory.

We have examined the particles emitted radially by dc copper arcs drawn in vacuum. Pressures while arcing were $\sim 10^{-6}$ Torr. The arc cathode was grounded, anode potential being about 20 volts during arcing. The products emitted radially by the arc were passed through a 90° electrostatic energy analyzer and then allowed to enter a 90° magnetic sector mass spectrometer. Significant emission of $Cu^{+1,2,3}$ was observed, while $Cu^{+4,5}$ were also seen. The yield rate of neutral copper was linear with current over the range 35-350A. The dependence of yield upon arc current was less for the ions, decreasing with increasing degree of ionization until it became negative for $Cu^{+3,4,5}$. The energy distribution peaked at zero electron volts for Cu^0 and at about 40-60 electron volts per unit charge for the ions. If one expressed the ion energy in electron volts/unit charge, then the energy distribution curves for the various ions were found to be very similar. The ion energy distribution peak shifted to lower energies with increasing arc current, the width of the peak also decreasing.

H5 MICRODISCHARGE PHENOMENA IN VACUUM GAPS.* A. WATSON, A. S. DENHOLM and M. J. MULCAHY, Ion Physics Corporation.

An experiment is described wherein the microdischarge prebreakdown current pulses were examined as the voltage across 8 inch diameter plane electrodes was raised in steps to breakdown: the pressure range was 10^{-4} - 10^{-6} Torr. A threshold potential existed for the appearance of these microdischarges; they were accompanied by bursts of X-radiation and for clean unbaked electrodes by a release of gas from the electrode surfaces. For large values of these transient pressure increases, complete gap breakdowns were observed. Resulting from this, a technique was evolved for conditioning unbaked clean electrode surfaces and for observing the onset of surface roughening. Finally, a series of breakdown measurements were carried out and for unbaked clean conditioned electrodes they were consistent to within 8% of a mean value. This compares favorably with the spread in the breakdown voltage reported by other workers.

*Sponsored by Advanced Research Projects Agency.

H6 THE DENSITY OF IONIZATION OF HYDROGEN BY FOUR APPROXIMATIONS.* R. E. BRUCE, F. C. TODD and W. M. ALEXANDER,† Oklahoma State University.

The variation in the lowering of the ionization potential is a basic requirement for a study of the expansion of an initially high pressure and temperature plasma, such as results from hypervelocity impact. With an assumption of thermodynamic equilibrium, the density of ionization for all ionic species is obtained from the effective ionization potential and the electronic partition functions. The effective ionization potential may be found from the excess Helmholtz free energy that represents the energy in the microfields.[1] In order to compare with published results, the density of ionization for hydrogen is compared over a wide range of densities when it is calculated in the following ways.

1. Simple Debye-Huckel fields
2. Ecker and Kröll approximation by mean fields[1]
3. Schroedinger equation with Yukawa potential[2]
4. Cluster integral evaluation of the two body interaction for the fields

The distance of closest approach parameter is considered.

*This research was supported by NASA
†Goddard Space Flight Center, NASA

1. G. Ecker and W. Kröll, Phys. Fluids 6, 62 (1963)
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H7 SIMPLIFIED THEORETICAL MODEL FOR THE CONDENSED RADIO FREQUENCY ARC. MARK P. FREEMAN, Central Research Division, Stamford, Connecticut.

The governing relationships for the atmospheric-pressure H-type radio-frequency discharge (the condensed arc used in the radio-frequency plasma jet[1]) are presented. They are then adapted to the "channel model," a simplified arc model known to quantitatively account for the electrical characteristics of a dc arc, and solved analytically using the minimum principle of Steenbeck as generalized by Peters.[2] Numerical examples calculated for argon and nitrogen plasmas using empirical and where necessary calculated material functions are presented. The calculated electrical characteristics for argon are seen to be in good agreement with some crudely determined argon plasma jet characteristics, while those for nitrogen correspond as well as might be expected to observed oxygen behavior. Other parameters of interest as well as the predicted scaling behavior of such a discharge are also discussed.

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SESSION I

Friday, October 22

2:00 p.m.

ION-MOLECULE INTERACTIONS

Chairman: E. E. Ferguson, National Bureau of Standards, Boulder, Colorado

I1 CHARGE TRANSFER CROSS-SECTION MEASUREMENTS IN THE eV ENERGY RANGE. P. MAHADEVAN, C. E. CARLSTON and G. D. MAGNUSON, General Dynamics, Convair Division, San Diego, California.

The total inelastic collision cross-sections for He^+ in He and N_2 have been measured in the energy range 1 eV to 200 eV using a simple dc technique. The low energy primary ion beams are obtained by floating the entire collision chamber at a variable potential above ground. By this method, it is possible to get reasonably large ion currents in the eV region with simple focusing. The measurement involves slow charge collection by a conventional parallel plate condenser. The width at half maximum of the energy distribution of the ion beam is determined to be 0.35 ± 0.15 eV using a parallel plate analyzer designed by Hutchinson.[1] The cross sections tend to increase rather rapidly as the beam energy decreases below about 40 eV. For a 2 eV ion beam, the cross section for He^+ in He is about 40 Å^2 and for He^+ in N_2 about 50 Å^2. Cross sections at thermal energies obtained by extrapolation are compared with data from afterglow measurements. The $He^+ + N_2$ reaction appears to be more probable at low energies than the symmetric resonant reaction $He^+ + He$. Some preliminary measurements of cross sections for NO^+ in atmospheric gases will be presented.

1. D. A. Hutchinson, 2nd Conference on Electronic and Atomic Collisions-Boulder, 1961.

I2 STUDY OF ION-MOLECULE REACTIONS BY A PHOTO-IONIZATION-MASS SPECTROMETER TECHNIQUE*. P. WARNECK and W. P. POSCHENRIEDER, GCA Corporation.

Rate constants for the following reactions

$H_2^+ + H_2 \rightarrow H_3^+ + H$	$k = 1.8 \times 10^{-9}$ cc/molecule sec
$N_2^+ + O_2 \rightarrow O_2^+ + N_2$	$k = 1.7 \times 10^{-10}$ cc/molecule sec
$N_2^+ + O_2 \rightarrow NO^+ + NO$	$k \leq 0.7 \times 10^{-13}$ cc/molecule sec
$A^+ + O_2 \rightarrow O_2^+ + A$	$k = 1.7 \times 10^{-10}$ cc/molecule sec

have been measured. A new experimental technique was employed using a photoionization mass spectrometer coupled to a ½ meter Seya uv monochromator for photon energy selection near the ionization onsets. Differential pumping permitted ion source pressures in the 0-200 micron range. These high pressures necessitated the experimental determination of ion source residence times which was accomplished by a pulse method. The present results are discussed and compared with similar data obtained from electron impact and afterglow studies.

*With partial support by the National Aeronautics and Space Administration.

I3 REACTION OF ATOMIC OXYGEN IONS WITH VIBRATIONALLY EXCITED NITROGEN MOLECULES. A. L. SCHMELTEKOPF, F. C. FEHSENFELD, G. I. GILMAN, AND E. E. FERGUSON, Central Radio Propagation Laboratory, Boulder, Colorado

The flowing afterglow reaction device in our laboratory has now been extended to measure reactions involving vibrationally excited N_2. The vibrational temperature of the ground electronic state of N_2 has been analyzed in a unique way by employing the $He(2^3S)$ metastable as an excitation source and observing the radiation from the 1st negative system of N_2^+. The reaction

$$He(2^3S) + N_2(v) \rightarrow N_2^+B^2\Sigma_u^+(v) + He + e \quad (1)$$

has been found to follow the Franck-Condon factors which have been calculated using the RKR method.

By using the vibrational distribution measured by the above method, reaction rate measurements involving known vibrational temperatures can be made. The atom-ion interchange reaction

$$O^+ + N_2(v) \rightarrow NO^+ + N \quad (2)$$

has a larger rate constant when the N_2 is vibrationally excited. For a Boltzmann distribution of N_2 vibrational states such that $T_{vib} \approx 4000°K$, the rate constant for (2) is increased by a factor of about twenty over the rate constant for the ground vibrational state of N_2

I4 SOME RECENTLY MEASURED THERMAL ENERGY ION-NEUTRAL REACTION RATES. F. C. FEHSENFELD, A. L. SCHMELTEKOPF, G. I. GILMAN, L. G. PULS, and E. E. FERGUSON, Central Radio Propagation Laboratory, Boulder, Colorado.

Measurements of several previously unreported rate constants measured in a pulsed discharge-flowing afterglow reaction tube will be reported. The results include some 300°K rates for charge-transfer of argon ions with O_2, N_2, CO, and NO, and the reactions,

$$C^+ + CO_2 \rightarrow CO^+ + CO,$$

$$N_2^+ + H_2 \rightarrow N_2H^+ + H, \qquad \text{and others.}$$

In addition, the system has been extended to the measurements of negative ion reaction rate constants and this work will be described and rates for some reactions, including

$$H^- + O_2 \rightarrow OH^- + O \qquad \text{will be given.}$$

I5 LOW ENERGY COLLISIONS BETWEEN SOME ATMOSPHERIC IONS AND NEUTRAL PARTICLES.* B. R. TURNER, J. A. RUTHERFORD and R. F. STEBBINGS, General Dynamics/General Atomic.

Collisions between some positive ions and neutrals which are present in the earth's atmosphere have been studied in a crossed beam experiment within the energy range 2 eV to 200 eV. Secondary ions produced in the reactions were analyzed in a magnetic mass spectrometer and absolute cross sections for their production were determined. The dependence of these measured cross sections upon the energy of the electrons producing the primary ions was also investigated in some detail. From these measurements the states of the reactants and the products may, in many cases, be inferred. The relationship between the beam measurements and those at thermal energies will be discussed for the following pairs of reactants: $O^+ + O_2$, $O^+ + N_2$, $O_2^+ + N_2$, $N^+ + NO$, $O^+ + NO$, $N_2^+ + NO$, and $O_2^+ + NO$.

*Research sponsored by the Defense Atomic Support Agency.

I6 ELECTRON MOLECULE AND ION MOLECULE INTERACTIONS IN NITROGEN.* R. K. ASUNDI and G. J. SCHULZ, Westinghouse Research Laboratories.

Ion molecule interactions of N_2^+ ions in N_2 up to pressures of 0.4 Torr in which N_3^+ and N_4^+ ions are formed,[1] have been studied in a mass spectrometer. The N_4^+ ion has an appearance potential of 15.1 ± 0.1 eV and exhibits a quadratic dependence on pressure near its onset. The formation of N_4^+ near onset is therefore consistent with the reaction $N_2^* + N_2 \rightarrow N_4^+ + e$. However, at electron energies above the appearance potential of N_2^+ (15.6 eV) the N_4^+ ion exhibits a cubic dependence on pressure and hence it is formed predominantly through the reaction $N_2^+ + 2N_2 \rightarrow N_4^+ + N_2$. The present observations of the appearance potential of N_3^+ (21.1 ± 0.1 eV), the shape of ionization efficiency curve, and its quadratic dependence on pressure supports the reaction scheme $N_2^+(^4\Sigma_u^+) + N_2 \rightarrow N_3^+ + N$ suggested by Cermak.[2] The dissociation of N_4^+ ions with kinetic energy, by the process $N_4^+ + N_2 \rightarrow N_2^+ + 2\ N_2$ has been observed.

*This research was supported in part by the Advanced Research Projects Agency through the Office of Naval Research.

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R. K. Curran, Jour. Chem. Phys. 38, 2974 (1963).
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I7 NEGATIVE ION MASS SPECTRUM OF O_2 AND CO_2-O_2 MIXTURES AT HIGH PRESSURES*. J. L. MORUZZI, and A. V. PHELPS, Westinghouse Research Laboratories.

Using a r.f. mass spectrometer coupled to a high pressure ion source, the negative ion mass spectra of O_2 and O_2-CO_2 mixtures have been studied at pressures between 0.5 and 5.0 Torr for E/p's from 0.1 to 70 V. cm^{-1} $Torr^{-1}$. Electrons were produced by a hot filament located on an equipotential or by a thin gold photocathode. In pure O_2 at $E/p < 2$, O_2^- formation by three-body collisions is the process observed.[1] At higher E/p's, O^- is formed by dissociative attachment and O_2^- is then formed from O^- when the O^- has sufficient kinetic energy.[2] O_3^- ions are formed via a three-body reaction[3] involving O^- and neutral oxygen with a coefficient of 1.5×10^{-31} cm^6 sec^{-1}. At low E/p's in CO_2-O_2 mixtures CO_4^- is formed by a collision between O_2^-, CO_2 and a third body. A similar reaction occurs at high E/p producing CO_3^- from O^-. The observed rate coefficients for the formation CO_4^- and CO_3^- are 1.3×10^{-29} and 1.3×10^{-28} cm^6 sec^{-1}, respectively.

* This research was supported in part by the Air Force Weapons Laboratory.

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I8 DISSOCIATION OF MOLECULAR IONS IN THE CATHODE REGION OF A GLOW DISCHARGE. M. M. SHAHIN, Xerox Research Division.

Studies made to establish the relative contribution of various ionic species to the current at the cathode of a glow discharge in molecular gases, have shown a strong dependence of the specific ionic currents on the cathode fall potential. The phenomenon responsible for the change in the relative currents appears to involve dissociative collisions of molecular ions when the latter have gained sufficient energy from the field. Processes, such as $N_2^+ + O_2 \rightarrow O^+ + O + N_2$ and $N_2^+ + N_2 \rightarrow N^+ + N + N_2$ and $N_2 + Ar^+ \rightarrow N^+ + N + Ar$ have been found to be responsible for the production of the majority of the atomic ions in the abnormal glow discharges of nitrogen and its mixtures with oxygen and argon. It is shown that when allowance is made for the charge exchange processes which modify the energy of the ions within the cathode dark space, the data can be treated to yield reasonable rate constants for these dissociative reactions.

I9 ION CYCLOTRON RESONANCE LINE BROADENING AT HIGH E/P.* DAROLD C. WOBSCHALL and JOHN R. GRAHAM, JR., Cornell Aeronautical Laboratory, Inc.

The shapes and widths of ion cyclotron resonance absorption lines were determined experimentally[1] for effective values of E/P up to 500V - cm^{-1} - $Torr^{-1}$. It was found that as the rf electric field on the detection electrodes is raised, the line shape deviates increasingly from a Lorentz shape, often to the point where it has an unsymmetrical, distorted appearance clearly unsuitable for quantitative studies. An alternative method utilizes a longitudinal dc electric field to heat the ions while the much weaker transverse rf field is used as a probe. In this case, symmetrical lines (approximately Lorentzian) are produced. From line width data the "hard sphere" or charge exchange cross sections were calculated. They agree substantially with cross sections reported from high E/P dc mobility studies. In another experimental method, a second oscillator fixed at the cyclotron frequency and connected to a transverse set of electrodes was used to heat the ions. The detection oscillator was swept over the line except for a narrow band close to the heating oscillator frequency. The resulting line shape is similar to that obtained with longitudinal heating except that there is a large dip in the center of the resonance line. The dip is associated with the correlation of the collision frequency between the heating and detection rf fields.

*Supported by the U.S. Army Res. Office (Durham).
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