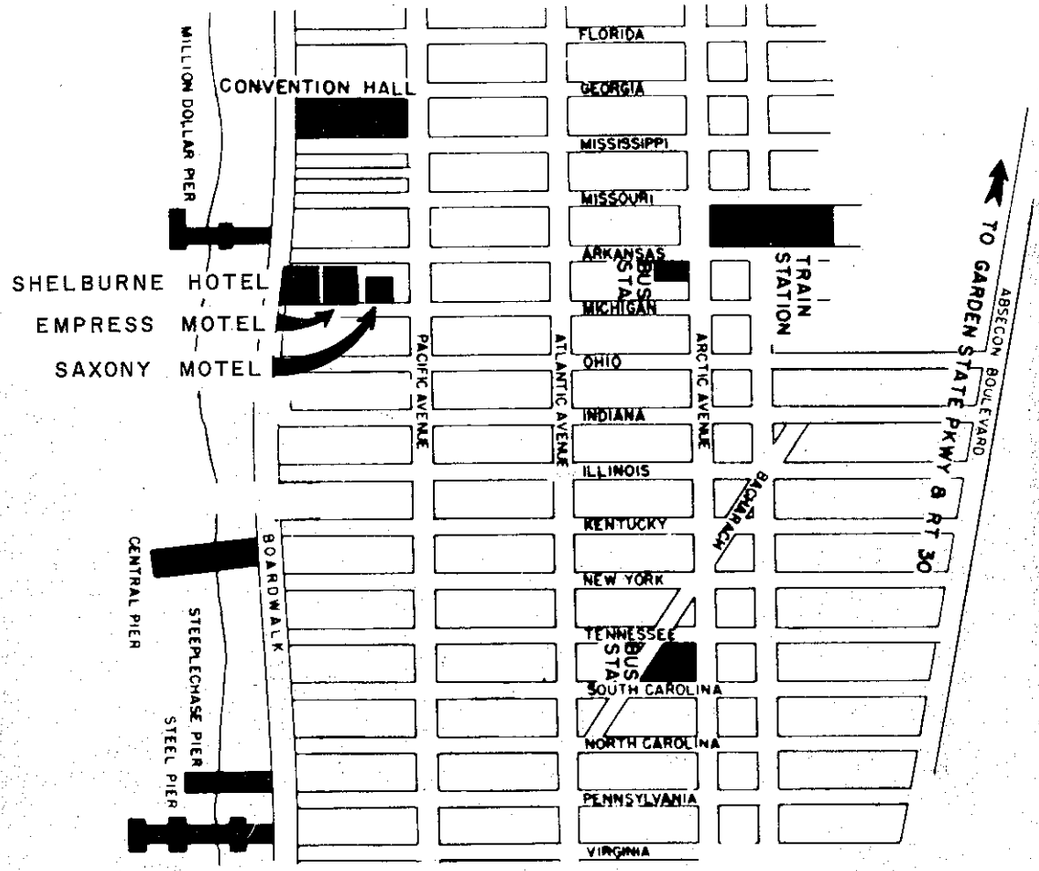

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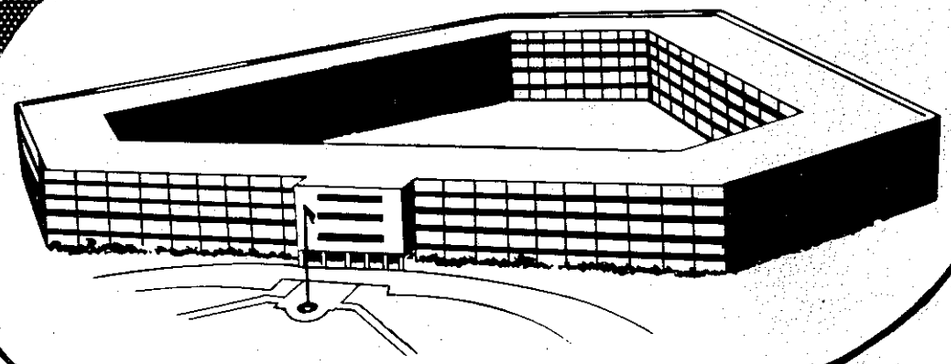

OCTOBER 1964

U. S. ARMY ELECTRONICS LABORATORIES

TOPICAL CONFERENCE OF
THE AMERICAN PHYSICAL SOCIETY

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SEVENTEENTH ANNUAL
GASEOUS ELECTRONICS CONFERENCE

PROGRAM AND ABSTRACTS OF PAPERS

October 14-16, 1964

Sponsored by

U. S. ARMY ELECTRONICS LABORATORIES

Fort Monmouth, New Jersey

Held At
Shelburne Hotel
Atlantic City, New Jersey

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SEVENTEENTH ANNUAL GASEOUS ELECTRONICS CONFERENCE

Program and Index to Abstracts

Tuesday, October 13

7:30 - 10:00 P.M. REGISTRATION: Lobby, Shelburne Hotel

COCKTAILS: Boardwalk Lounge

Wednesday, October 14

8:00 A.M. REGISTRATION: Lobby, Shelburne Hotel

9:15 A.M. SESSION A: IONIZATION

Chairman: V. A. J. Van Lint, General Atomic, San Diego, California

2:00 P. M. SESSION H: ION-MOLECULE REACTIONS

Chairman: E. C. Beaty, Joint Institute For Laboratory Astrophysics, Boulder, Colorado

6:30 P.M. SOCIAL HOUR AND BANQUET

Kerry Hall, Shelburne Hotel

A SCIENTIST IN NATO
Professor William P. Allis
Massachusetts Institute of Technology

Friday, October 16

9:00 A. M. SESSION I: BREAKDOWN; CORONA

Chairman: J. E. Creedon, U. S. Army Electronics Laboratories, Fort Monmouth, N. J.

9:00 A. M. SESSION J: MOSTLY RECOMBINATION AND AFTERGLOWS

Chairman: W. H. Kasner, Westinghouse Research and Development Center, Pittsburgh, Pa.

Wednesday, October 14, 9:15 A. M.

SESSION A: IONIZATION

Chairman: V. A. J. Van Lint
General Atomics, San Diego, California

A-1 THE PHOTOIONIZATION CROSS SECTION OF NEON

K. G. Sewell[+]
Texas Christian University, Ft. Worth, Texas

The photoionization cross section of neon has been calculated from threshold to an incident photon energy of 11.547 Rydbergs by considering transitions from the 2s and 2p shells. Hartree- Fock type functions were computed for both the initial and final states and were used to obtain the cross section. This resulted in a cross section which was in good agreement, both in magnitude and energy dependence, with recent experimental data.[1] It is shown that the agreement between the theoretical cross section and the experimental observations indicate that the free electron can be considered to move in the potential field of the neon ion. This is contrary to approximations employed in some previous calculations of photoionization cross sections.[2] However, emphasis is given to the importance of the use of accurate radial functions.

[+] Present address: LTV Research Center, Dallas, Texas

1. D. L. Ederer and D. H. Tomboulian, Phys. Rev. 113, A1525 (1964)

2. J. W. Cooper, Phys. Rev. 128, 681 (1962)

A-2 PHOTOIONIZATION THRESHOLD POTENTIAL OF O_2*

J. A. R. Samson, and R. B. Cairns
Geophysics Corporation of America, Bedford, Mass.

Photoionization of molecular oxygen has been observed at wavelengths longer than the presently accepted threshold of 1026.5 Å ± 1 Å.[1] This can be accounted for by the fact that at room temperature a high percentage of the molecules are in rotationally excited states. This fact, therefore, obscures the true onset potential for the transition $X^2\Pi_g \leftarrow X^3\Sigma_g^-$. Results will be reported for the photoionization of O_2 at liquid nitrogen temperatures where the effects of rotationally excited oxygen are absent.

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* Work supported by the National Aeronautics and Space Administration

1. K. Watanabe and F. F. Marmo, J. Chem. Phys. 25, 965 (1956).

A-3 CONCERNING ELECTRON-IMPACT AND PHOTON-IMPACT IONIZATION OF O_2*

J. W. McGowan, E. M. Clarke+, H. P. Hanson++ and R. F. Stebbings
General Dynamics/General Atomic, San Diego, Calif.

The electron impact ionization of O_2 has been studied near threshold. The results which have been obtained do not agree with recently reported electron impact studies but rather parallel those reported for photoionization. The first derivative of the ionization efficiency curve through 1.0 eV shows structure which correlates to that associated with autoionization

$$O_2 + e \rightarrow O_2' + e \quad ,$$
$$\downarrow$$
$$O_2^+ + e$$

whereas structure due to direct vibrational excitation of the ion is not pronounced. The electron distribution from the 127 deg electrostatic analyzer used as source was measured to be less than 0.06 eV. Modulated cross beam techniques were used in these experiments.

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* This research was sponsored partially by the Advanced Research Projects Agency through the Office of Naval Research and partially by the Defense Atomic Support Agency.

+ Present address: St. Francis University, Antigonish, Nova Scotia

++ Present address: University of Texas, Austin, Texas

A-4 IONIZATION PRODUCED BY COLLISIONS OF NITROGEN MOLECULES WITH NITRIC OXIDE*

N. G. Utterback
University of Denver, Denver, Col. and GM Defense Research Laboratories, Santa Barbara, Calif.

R. C. Amme
University of Denver, Denver, Col.

Ionization cross sections for nitrogen molecules impacting on NO target gas have been measured over the laboratory energy range 20 to 1000 eV. The nitrogen molecular beam was produced by electron impact ionization, electrostatic acceleration, and neutralization by resonant charge transfer. Because of the low ionizing electron energy and the resonant charge transfer behavior of N_2^+, the resulting beam was predominantly in the ground electronic state. The N_2-NO ionization cross section is presented as a function of center-of-mass energy minus the ionization potential of NO, and is compared with earlier N_2-N_2 results.[1] The cross section is observed to have the same energy dependence, with identical structure between 10 and 20 eV (excess energy). However, this structure occurs at very different beam energies in the two cases, indicating that the structure is not characteristic of the nitrogen beam. Possible reasons for the similarity of the N_2-N_2 and N_2-NO ionizing interactions will be discussed.

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* Supported by NASA

1. N. G. Utterback and G. H. Miller, Phys. Rev. 124, 1477 (1961).

A-5 ENERGY REQUIRED FOR ION PRODUCTION BY ELECTRON BOMBARDMENT IN HELIUM, ARGON AND CESIUM

R. J. Sovie and J. V. Dugan, Jr.
NASA-Lewis Research Center, Cleveland, Ohio

The energy cost for ion production has been calculated for atomic helium, argon and cesium gases by comparing the relative probabilities for the competing inelastic processes of excitation and ionization. The results are obtained for two cases: (1) a monoenergetic electron beam incident upon a cold neutral gas and (2) the interaction of a thermal electron gas with cold neutrals. Experimental excitation cross sections were used in the helium calculations. The semi-classical Gryzinski method was used to theoretically determine the cross sections needed for the argon and cesium calculations. Results obtained using theoretically determined helium cross sections are compared with those obtained using the experimental cross sections. The results are presented graphically in plots of ion production cost versus electron energy. In general this cost decreases smoothly with increasing electron energy in the thermal case and decreases irregularly with increasing electron energy in the beam case. A cursory analysis of the interaction of an electron beam with a plasma has been made from the viewpoint of determining the plasma conditions under which the results of each of the above mentioned cases may be applied.

A-6 ABSOLUTE EXPERIMENTAL CROSS SECTIONS FOR IONIZATION OF LITHIUM IONS BY ELECTRON IMPACT*

W. C. Lineberger, J. W. Hooper, and E. W. McDaniel
Georgia Institute of Technology, Atlanta, Georgia

Absolute cross sections for ionization of Li^+ ions by electron impact have been measured for electron energies over the range 300 to 700 eV. These measurements were performed at about 10^{-8} Torr under continuous beam conditions in a crossed beam facility. Monoenergetic lithium ion and electron beams intersect in a well defined collision volume and the composition of the emerging lithium beam is determined with an electrostatic analyzer.[1,2] The ion source is planar and incorporates a platinum gauze thermionic filament coated with isotopically purified β-eucryptite. The electron source is a modified 6L6 tube. With an ion current of 0.5 microampere and an electron current of 1.0 milliampere, only about four primary ions in 10^9 experience ionization by electron impact. However, spurious currents have been reduced to the level that the signal-to-noise ratio is greater than unity. Checks were performed to evaluate the possible effects of such parameters as beam intensity, chamber pressure, beam composition, signal-to-noise ratio, space charge, and beam profile.

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* Supported in part by the Controlled Thermonuclear Division of the U. S. Atomic Energy Commission.

1. G. A. Harrower, Rev. Sci. Inst. 26, 850 (1955).

2. G. D. Yarnold and H. C. Bolton, J. Sci. Instr. 26, 38 (1949).

A-7 METASTABLE-METASTABLE COLLISIONS IN NITROGEN

E. C. Zipf, Jr.+
Johns Hopkins University, Baltimore, Md.

The destruction of nitrogen molecules in the metastable $A^3\Sigma_u^+$ ($v' = 0$) state was investigated by measuring the intensity of the (0,6) Vegard-Kaplan band ($A^3\Sigma_u^+ \rightarrow X^1\Sigma_g^+$) as a function of time and pressure in the afterglow of a microwave discharge in very pure nitrogen. Early in the afterglow when the density of $A^3\Sigma_u^+$ molecules was comparatively high ($\sim 5 \times 10^{11}$ molecules/cm^3), N_2 ($A^3\Sigma_u^+$) molecules were rapidly destroyed in metastable-metastable collisions. From an analysis of the light data the ratio of the rate coefficient for this process, k, to the radiative transition probability of the (0,6) Vegard-Kaplan band, A(0,6), was determined. At 300°K $k/A(0,6) = 3 \times 10^{-9}$ cm^3. Taking the value (0.11 ± 0.04 sec^{-1}) given by Carleton and Oldenberg[1] for A(0,6), we have that $k = 3.3 \times 10^{-10}$ cm^3 sec^{-1}. The corresponding cross section for the deactivation of N_2 ($A^3\Sigma_u^+$, $v' = 0$) molecules in metastable-metastable collisions has a value of $4.9 \times 10^{-15} cm^2$.

+ Present address: University of Pittsburgh, Pittsburgh, Pa.

1. N. P. Carleton and O. Oldenberg, J. Chem. Phys. 36, 3460 (1962).

A-8 ABSORPTION OF RESONANCE RADIATION AND SUBSEQUENT IONIZATION IN CESIUM VAPOR*

D. H. Pollock and A. O. Jensen
Electro-Optical Systems, Inc., Pasadena, Calif.

The results of absorption measurements in cesium vapor near the atomic resonance lines at 8521 Å and 8943 Å and the molecular band at 7600 Å are reported. It is shown that the broadening of the resonance lines is directly proportional to the neutral cesium density. Ionization measurements are reported describing the effect of resonance radiation on the space charge limited electron current in an operating ionization cell. On the basis of these results, an ionization mechanism has been hypothesized for the production of the cesium molecular ion Cs_2^+ as the dominant ionic specie in high pressure cesium vapor plasmas. The mechanism consists of cesium atoms first being excited to the resonance levels (λ8521, λ8943) by radiation emanating from a hot cathode and subsequently combining with other excited atoms through inelastic collisions to form the molecular cesium ion. This mechanism is then compared with possible competing ionization mechanisms which have been hypothesized to exist in the cesium vapor thermionic energy converter.

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* This work was partially sponsored by the Office of Naval Research

Wednesday, October 14, 9:15 A. M.

SESSION B: TECHNIQUES; TRANSPORT

Chairman: H. J. Oskam
University of Minnesota, Minneapolis, Minnesota

B-1 A METHOD FOR MEASURING THE PLASMA POTENTIAL AT GLASS WALLS

H. Heil and R. A. Blanken
Hughes Research Laboratories, Malibu, Calif.

Modern electrometer instruments make it possible to measure the plasma potential by simply painting a conductor onto the outside of the glass wall which bounds the discharge and measuring the potential which it assumes. A glass resistance of 10^{11} Ω or less is sufficient to reduce the time constant of the instrument to seconds. In pyrex, such a resistance through the walls is obtained at about 80°C; this temperature is easily reached by a hot air blower if the discharge itself does not provide enough power. If the electrometer is used as a null instrument, no currents are drawn through the glass and the discharge plasma is left entirely undisturbed by the process of measurements. With gas laser type discharges using conducting rings around the glass tube, we measured the electric field X in the positive column as a function of the discharge parameters. At the lower pressures X is sensitively affected by variations in the shape of the envelope. A Langmuir probe has little effect on X. A pair of conducting dots at the ends of a diameter across the tube permit Hall-effect type measurements which indicate a surprisingly large drift energy of the electrons.

B-2 PERTURBATION OF A PLASMA BY A PROBE II*

J. F. Waymouth
Massachusetts Institute of Technology, Cambridge, Mass. and
Sylvania Electric Products, Inc., Salem, Mass.

The modifications that must be made to Langmuir Probe Theory when mean-free paths are short in comparison with probe size have been discussed recently by several authors. This paper discusses the opposite case, in which mean-free paths are large in comparison with the dimensions of the vessel containing the plasma. Under these conditions, d. c. electron currents drawn by the probe can appreciably depopulate large fractions of the electron energy distribution, thereby leading to erroneous results. It is shown, however, that pulsed measurements can be made in a time that is short compared with depletion time constants, so that the usual probe information can still be obtained. It is also shown that d. c. probe measurements under these conditions can yield information about the rate at which the depleted electron energy distribution is refilled by those collision processes that do occur.

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* Work supported in part by the U. S. Army, Navy and Air Force.

B-3 THE LIMITATIONS OF THE LANGMUIR PROBE THEORY AND ITS EXTENSION TO DENSE PLASMAS

G. Ecker[+] and J. J. McClure[++]
Institut Für Theoretische Physik der Universität Bochum, Germany

Deviations from Langmuir's probe theory occur if the extension of the space charge region, the density, or the temperature disturbance is larger than the mean free path of the ions. The range of experimental parameters where the deviations become important is discussed. The results of an analysis for the characteristic case of a density-limited probe are presented, which clarify the meaning of "Bohm's sheath criterion" as well as the phenomenon of probe-induced fluctuations.

[+]Present Address: Joint Institute for Laboratory Astrophysics, Boulder, Colorado

[++]Present Address: E. H. Plesset Associates, Inc., Santa Monica, Calif.

B-4 MICROWAVE COAXIAL PROBE INVESTIGATIONS OF A HELIUM DISCHARGE

B. Wieder
National Bureau of Standards, Boulder, Colorado

Recent experiments in the high frequency range have shown that if an alternating voltage is applied to a probe in a plasma a rectified direct current results, and that this current shows a resonance when the plasma frequency is near the frequency of the applied voltage. To test the technique at microwave frequencies a probe of coaxial design was inserted into a hot cathode helium discharge plasma and the direct current response was measured at several frequencies in the one to two gigaherz range as the current through the discharge was varied. At the same time a measurement was made of the microwave signal reflected from the probe. For a given frequency the reflected signal shows a clear resonance type response as the discharge current is varied; as the frequency of the signal is increased, the value of the current at resonance increases. The dc response similarly shows resonance type effects, but the response is considerably more complex and occurs at a discharge current substantially greater than the current at which the corresponding reflected signal response appears. From a plasma diagnostics viewpoint, therefore, the reflected signal is clearly more useful. A discussion of these effects, and details of the experiment will be presented.

B-5 KINETIC FORMULATION OF LOW DENSITY ELECTRON STREAMING

W. A. Janos
North American Aviation, Inc., Los Angeles, Calif.

The streaming tendency of a rarefied distribution of electrons in the presence of neutral scatterers and a unidirectional electric field is studied. Given a situation close to streaming, a linearized form of the Boltzmann equation about this collisionless solution is considered and treated as a problem in perturbation theory with the collision term as the perturbation. The assumptions made for the initial electron distribution and the distribution of neutral scatterers are that they are finite, truncated in their respective velocities, the scatterer distribution is spatially uniform and the electron distribution is too rarefied to contribute any significant self-field reaction to the external field. The basic presupposition about the collision term is the screened Coulomb version of the total scattering cross section of a form corresponding to the first Born approximation to the Fermi-Thomas scattering potential. Thus, in the language of the perturbation approach used, definition is given to maximal relationship between field magnitude and effective streaming of a class of initial electron distributions, a hypothetical prestreaming "thermalization" time in the presence of a weak external field, and critical field streaming within one collision time.

B-6 ELECTRON DRIFT VELOCITY AND HALL EFFECT IN THE LOW-PRESSURE MERCURY POSITIVE COLUMN

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

The positive column in mercury vapor from $\approx$ 1 to 500 microns pressure was examined by the Hall procedure. The average electron density in the column was measured independently by a microwave cavity, allowing separate determination of electron drift velocity, v_d. Theory relates the Hall potential, V_H, to the Hall magnetic field and column diameter, D, as $V_H = \alpha(v_d \times B)\cdot D$. The factor α was found to approach the theoretical value, $\alpha \cong 0.22$ for low pressure, "free-fall" columns and $\alpha \cong 0.5$ for medium-pressure, "diffusion-controlled" columns. At intermediate pressures this transition is not smooth and excessive discharge noise is present.

B-7 MAGNETO-PLASMA DIFFUSION WITH BIASED WALLS*

D. R. Whitehouse
Massachusetts Institute of Technology, Cambridge, Mass.

In the theory of collision-dominated, low-β, stable plasma diffusion, it is important to know what limitations the boundary conditions place on the density distribution and internal currents. For a plasma in an enclosed cavity whose walls can be biased with a variable potential, currents can be made to flow which will affect the loss rate of charges to the walls. In effect, one may vary the perpendicular and axial diffusion coefficients within certain specified limits. For an active plasma, this will control the required ionization frequency, and in an afterglow it will determine the decay rate. A sketch of the theory for three-dimensional diffusion will be presented. An experiment will be described in which a pulsed discharge generates a plasma in a rectangular cavity with biased walls, and the decay time of the afterglow is measured. Although the theory cannot predict exact functional dependence of the diffusion coefficient on applied potential, it can predict an upper and lower limit. These limits have been checked for argon plasmas from 1 to 100 microns in magnetic fields up to 1000 gauss.

* This work was supported in part by the U. S. Army, Navy and Air Force and in part by the U. S. Atomic Energy Commission

B-8 THE IONIC CENTRIFUGE IN TWO TYPES OF DISCHARGE

J. Slepian
Pittsburgh, Pennsylvania

The Ionic Centrifuge[1] may be operated in two ways. One, with large enough negative voltages on the end-plates and the cylinder floating at a constant voltage equal to $(-e/8\Pi\ c^2\ M)\ H^2\ \Gamma^2$ volts. The positive ion current received by it is one half that delivered by the central arc. The other, not as yet tried out, with the end-plates with a large enough positive voltage and the cylinder grounded. The cylinder will receive the whole positive ion current emitted by the central arc. The electron current received by the end-plates will be greatly reduced by its space charge. Three authors give for the electron current density received by the end-plates a quantity considerably less than it would be if the positive ions were not moved by the electric field in the opposite direction to the electrons.[2,3,4]

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1. J. Slepian, Proc. N.A.S. 47, 313 (1961)

2. L. Oster, Rev. Mod. Phys. 32, 141 (1960)

3. B. S. Tanenbaum, Phys. Fluids 4, 1262 (1961)

4. V. C. A. Ferraro & C. Plumpton, Magneto-Fluid Mechanics. Oxford University Press (1961)

SESSION C: EXCITATION; IONIZATION

Chairman: R. M. St. John
University of Oklahoma, Norman, Oklahoma

C-1 FRANCK-CONDON OVERLAPS AND THE DISSOCIATIVE IONIZATION OF H_2*

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

Measurements of the kinetic energy distribution of protons resulting from dissociative ionization of H_2 showed general agreement with a simple calculation.[1] Remaining discrepancies were tentatively attributed to the use of δ functions for the internuclear wave functions of the $2p\sigma_u$ state of H_2^+. Nearly exact internuclear wave functions for the continuum, $2p\sigma_u$, state of H_2^+ and ground state H_2 have been generated on a computer from the differential equation in the internuclear coordinates. The square of the overlaps, F, of these wave functions was taken as before[1] to give the energy distribution of protons. The function F was modified[2] to account for thermal motion of the H_2 gas. The resulting predicted energy distribution was then folded into the slit function for the mass spectrometer used to detect the protons.[1] The predicted relative current of protons as a function of their energy is still significantly different from the observations.

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* Supported in part by Controlled Thermonuclear Branch of the Atomic Energy Commission.

+ Staff members, National Bureau of Standards.

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

2. P. J. Chantry and G. J. Schulz, Phys. Rev. Letters 12, 449 (1964).

C-2 PHOTODISSOCIATION OF H_2^+ AND D_2^+ : THEORY*

G. H. Dunn+
Joint Institute for Laboratory Astrophysics, Boulder, Colorado

The cross sections $\sigma_{nk}(\lambda)$ for photodissociation of H_2^+ (D_2^+) from each of the 19 (27) vibrational levels n of the ion have been calculated as a function of wavelength. The electronic transition from the $1s\sigma_g$ to the $2p\sigma_u$ state is the only one considered. The calculations are considered exact within the limits of the Born-Oppenheimer approximation. The $\sigma_{nk}(\lambda)$ have been multiplied by a weight factor given by the normalized Franck-Condon factors between the ground state of H_2 (D_2) and the $1s\sigma_g$ state of H_2^+ (D_2^+), and these products were added. The resultant cross section $\sigma(\lambda)$ is expected to be characteristic of ions formed by the impact of moderate to high energy electrons with H_2 (D_2). Comparison of $\sigma(\lambda)$ with an experimental measurement[1] shows considerable discrepancy.

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* Supported in part by the Controlled Thermonuclear Branch of the Atomic Energy Commission.

+ Staff member, National Bureau of Standards

1. G. H. Dunn, Proceedings of the Third International Conference on the Physics of Electronic and Atomic Collisions (North-Holland Publishing Co, Amsterdam, 1964), p. 997.

C-3a TOTAL CROSS SECTIONS FOR DISSOCIATIVE IONIZATION OF MOLECULES BY ELECTRON IMPACT

D. Rapp, P. E. Golden, and D. D. Briglia
Lockheed Missiles and Space Company, Palo Alto, Calif.

The method of Bleakney[1] has been used to obtain approximate total cross sections for dissociative ionization of nine gases (H_2, D_2, N_2, O_2, CO, NO, CO_2, N_2O and CH_4) by electron impact from threshold to 1000 eV. The cross sections are made absolute by comparison with the total ionization cross sections. The fractions of energetic ions to total ions at 200 eV for these gases are 0.07, 0.07, 0.21, 0.36, 0.25, 0.28, 0.35, 0.28, and 0.13, respectively. Use of mass spectrometry to obtain these ratios will usually underestimate these ratios because of discrimination effects against energetic ions with various angular distributions. Evidence for ions with initial kinetic energy up to 13 eV in some gases will be presented.

---

1. W. Bleakney, Phys. Rev. 33, 1180 (1930).

C-3b TOTAL CROSS SECTIONS FOR IONIZATION OF ATOMS AND MOLECULES BY ELECTRON IMPACT

D. Rapp, P. E. Golden, and D. D. Briglia
Lockheed Missiles and Space Company, Palo Alto, Calif.

Absolute total cross sections for ionization of fourteen gases (He, Ne, Ar, Kr, Xe, H_2, D_2, N_2, O_2, CO, NO, CO_2, N_2O and CH_4) by electron impact were measured from threshold to 1000 eV. Instrument calibration was carried out with great care and attention was given to consistency checks such as total collection of ion current. The absolute values of cross sections depends on McLeod gauge measurements of low pressures and, since there has been some question of the accuracy of this method when cold traps are used, a careful assessment of a systematic effect is being made. Our data agree with those of Tate and Smith[1] to within about 5-10% whereas the differences are somewhat larger when compared to those of Asundi, Craggs and Kurepa.[2]

---

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

2. R. K. Asundi, J. D. Craggs, and M. V. Kurepa, Proc. Phys. Soc. 82, 967 (1963).

C-3c TOTAL CROSS SECTIONS FOR NEGATIVE ION FORMATION IN MOLECULES BY ELECTRON IMPACT

D. Rapp, D. D. Briglia, and R. D. Rempt
Lockheed Missiles and Space Company, Palo Alto, Calif.

Absolute cross sections for resonance dissociative attachment in seven gases (H_2, D_2, O_2, CO, NO, CO_2 and N_2O) have been measured in a Tate and Smith[1] - type apparatus. Careful attention has been paid to instrument calibration as well as consistency checks such as ion saturation. In general, the agreement with previous work[2,3] is very good, although there is some discrepancy in H_2.[4] Absolute cross sections for ion pair formation were also measured by recording negative ion formation at higher electron energies. Data were taken in O_2, CO, CO_2 and N_2O up to about 60 eV. At higher energies, energetic positive ions so vastly outnumbered the negative ions that negative ion saturation could not be reached.

---

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

2. R. K. Asundi, J. D. Craggs and M. V. Kurepa, Proc. Phys. Soc 82, 967 (1963).

3. G. Schulz, Phys. Rev. 128, 178 (1962).

4. G. Schulz, Phys. Rev. 113, 816 (1959).

C-3d DIAGNOSTIC STUDIES OF THE "RETARDING POTENTIAL DIFFERENCE" METHOD FOR IONIZATION STUDIES WITH A REDUCED ELECTRON ENERGY SPREAD

D. D. Briglia, and D. Rapp
Lockheed Missiles & Space Company, Palo Alto, Calif.

It has recently been suggested[1] that the effect of electron energy relaxation in retarded electron beams may lead to uncertainties in the significance of ionization efficiency curves taken by means of "RPD". A diagnostic study of the energy distribution of the RPD-selected electrons has been performed in a Bleakney mass spectrometer ion source[2], using A.C. modulation and double phase sensitive detection.[3] It was found that as the nominal electron energy was varied by V volts, the energy distribution remained essentially unchanged, and merely translated to a new center V volts away. This was found to be true only for weak electron currents with small A.C. modulating voltages. The energy spread has been reduced to less than 0.05 eV half width at half height as shown by retarding curves of the retarded electrons. Applications to the threshold ionization of gases are made with particular

reference to the appearance potential of H_2^+. Results are obtained indicating that the H_2^+ ionization efficiency near threshold is not in agreement with predictions made by means of simple overlap integrals between the initial and final vibrational states, as has been found in energy selector experiments.[4] This may be related to the strong autoionization recently found in photoionization of H_2.[5]

---

1. P. Marmet, 12th Ann. Conf. Mass Spect., Montreal, Canada (June 1964).

2. W. Bleakney, Phys. Rev. 33, 1180 (1930).

3. V. Grob, J. Chem. Phys. 39, 972 (1963).

4. P. Marmet and L. Kerwin, Can. J. Phys. 38, 972 (1960).

5. V. Dibeler, R. M. Reese, and M. Krauss, personal communication.

C-4 EXCITATION OF THE METASTABLE STATES OF HELIUM BY ELECTRON IMPACT*

J. L. G. Dugan, H. L. Richards, and E. E. Muschlitz, Jr.
University of Florida, Gainesville, Fla.

Excitation of helium by electron impact has been studied near threshold by observation of both the metastable atoms produced[1] and the energy losses of the electrons.[2] At higher electron energies studies of the light emitted have been made.[3] In the experiments reported here an atomic beam of helium atoms excited by electron impact in the energy range 30-140 ev is used. The ratio of 2^1S to 2^3S metastable atoms is determined by deflection measurements in an inhomogeneous magnetic field. The excited atoms are detected by secondary electron emission. Extrapolation to zero pressure is used to eliminate the effects of scattering of the atoms by the background pressure in the apparatus and imprisonment of the resonance radiation. The contribution of photons to the signal is determined by increasing the helium background pressure to the point where only the photons will reach the detector. The results are compared with those of Gabriel and Heddle.[3]

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* Research supported by the National Science Foundation.

1. G. J. Schulz and R. E. Fox, Phys. Rev. 106, 1179 (1957).

2. G. J. Schulz, Phys. Rev. 116, 1141 (1959).

3. A. H. Gabriel and D. W. O. Heddle, Proc. Roy. Soc A258, 125 (1960).

C-5 ELECTRON EXCITATION FUNCTIONS OF MERCURY*

R. J. Anderson, Chun C. Lin+ and R. M. St. John
University of Oklahoma, Norman, Oklahoma

Absolute excitation functions for some twenty mercury lines in the range of 3700-6200 Å have been measured for electron incident energies from 0 to 100 eV. Fine structures in these functions corresponding to cascade from the upper states were observed for the majority of the lines. By using the self-consistent field wave functions of mercury, we have calculated the transition probabilities of all the transitions between the various components of the 6^1P, 6^3P, 6^1D, 6^3D, 7^1S, and 7^3S states from which the apparent excitation functions of the 7^3S_1 and 6^3D_2 states were evaluated. The apparent excitation cross sections for the 7^3S_1 and 6^3D_2 states at 15 eV are 1×10^{-17} cm^2 and 4.0×10^{-17} cm^2 respectively. Comparison of the experimental excitation cross sections with the values calculated by the Born Approximation will be discussed.

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* Work supported by Kirtland AFB, U. S. Air Force Systems Command

+ Alfred P. Sloan Foundation Fellow.

C-6 TRANSFER OF EXCITATION ENERGY IN HELIUM BY ATOMIC COLLISIONS*

Tsu-Wei Nee and R. M. St. John
University of Oklahoma, Norman, Oklahoma

The multiple-state transfer process of helium has been clarified and extended through the comparison of its predictions with recent absolute measurements of helium excitation functions at several pressures. Atoms excited to an n^1P level are converted to a mixed singlet-triplet F state by an atomic collision. Low lying singlet and triplet levels are fed by the many F states thusly populated. Apparent excitation functions were computed by machine for the 3^3D, 4^3D, 3^1D, and 4^1D states and compared with experimental curves of the 3^3D, 4^3D, and 4^1D states at four pressures. The calculations were based on a variety of assumptions relating to the variation of the transfer cross section with the principal quantum number n, and to the mixed F state model. The computed functions best match the experimental curves when it is assumed that:

a) the transfer cross section for the nth set of ^1P-F states is proportional to the first power of n, and

b) the $^1F_3$ and $^3F_3$ components of the mixed state are active in the transfer-cascade processes, while the $^3F_{2,4}$ states are inactive.

The energy is primarily transferred through n^1P-nF sets of states with $n \leq 15$.

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

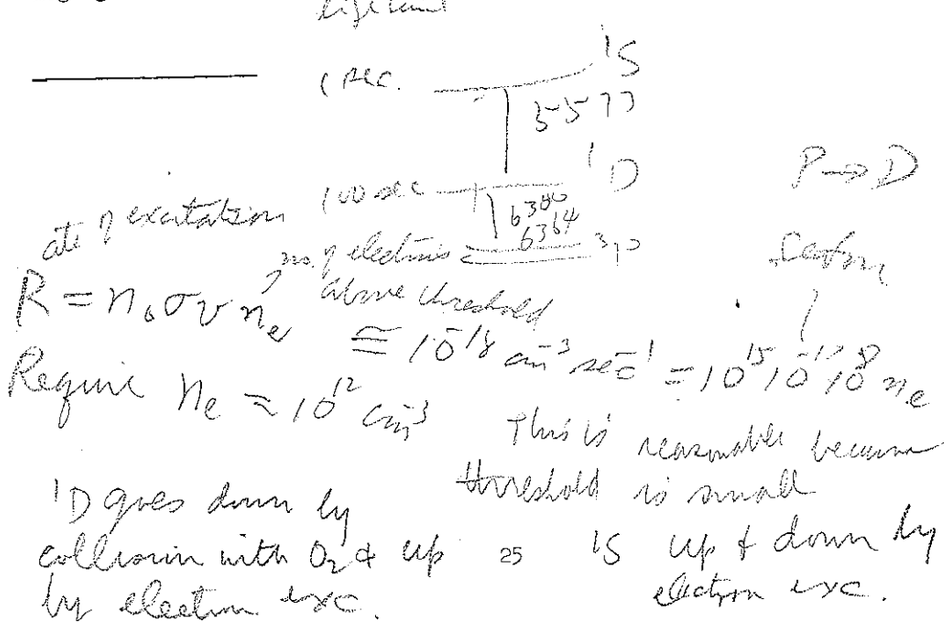
C-7 EXCITATION IN DISCHARGES OF THE FORBIDDEN OXYGEN LINES 6300-6364Å

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

F. LeBlanc
Air Force Cambridge Research Laboratories, Cambridge, Mass.

O. Oldenberg
Air Force Cambridge Research Laboratories and Harvard University, Cambridge, Mass.

The red lines of oxygen (transition ^3P - ^1D)can be generated in strong discharges through tank oxygen, in spite of the known rapid deactivation of the ^1D level by collisions with O_2 (rate coefficient, 10^{-10} cm^3sec^{-1}, determined from considerations of airglow and auroral spectra). From the lack of broadening or shifting of the lines and from their lack of sensitivity to discharge conditions we infer that there is no appreciable stimulation of emission in any collision process. Rather, we believe that the intensities observed by us (in a capillary discharge with several millimeters pressure of oxygen and tens of milliamperes current) and by others can all be readily explained by simple excitation of oxygen atoms by electron impact. A typical intensity would require, for instance, a degree of dissociation of 1%, a degree of ionization of 0.1%, with 4% of the electrons maintained above 2 ev. Under these conditions deactivation of $O(^1D)$ by electrons is slight compared to that by O_2. The population of the ^1S level of oxygen (which radiated the lines 5577Å) is, however, controlled under these conditions essentially by electron impact, all other processes being negligible.



C-8 SIMULTANEOUS EXCITATION AND IONIZATION OF HELIUM BY ELECTRON IMPACT*

E. T. P. Lee and C. C. Lin+
University of Oklahoma, Norman, Oklahoma

The cross sections for the production of He^+ ion in the 4^2S state by single-electron collisions with ground-state helium atoms have been calculated by the Born Approximation. For the wave function of the ionized electrons, the hydrogenic continuum functions given by Sommerfeld[1] were used. At an incident electron energy of 405 eV, the calculated cross section is 7.2×10^{-21} cm^2. This process is responsible for the major part of the intensity of the 4686 Å radiation ($n=4 \rightarrow n=3$ of He^+) observed in the helium discharge experiment.[2] Using the ionization-excitation cross sections of the 4^2P and 4^2D states calculated by Dalgarno and McDowell,[3] we obtain the theoretical cross section of the 4686 Å line of He^+ as 3.4×10^{-21} cm^2 at 405 eV which agrees well with the experimental value of 3.0×10^{-21} cm^2.

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

+ Alfred P. Sloan Foundation Fellow

1. A. Sommerfeld, Ann. Phys. 11, 257 (1931).

2. R. M. St. John and C. C. Lin, J. Chem. Phys. 41, 195 (1964).

3. A. Dalgarno and M. R. C. McDowell, The Airglow and Aurorae, edited by E. B. Armstrong and A. Dalgarno (Pergamon Press Inc., New York 1956) p. 340.

C-9 CALCULATION OF ELECTRON EXCITATION CROSS SECTIONS OF VIBRATION IN THE NO AND CO MOLECULES*

E. L. Breig and C. C. Lin+
University of Oklahoma, Norman, Oklahoma

The cross sections of vibrational excitation of the CO and NO molecules have been calculated by the Born Approximation over a wide range of incident electron energy. The interaction between the molecule and the colliding electron is assumed to be of the monopole-dipole type with the dipole moment of the molecule μ expanded as power series of the normal coordinate Q. The vibrational excitation cross sections depend on the quantity $(\partial\mu/\partial Q)$ which can be obtained from the measured intensities of the infrared spectra of these molecules. The cross section for the ground vibrational state of CO at 5.2 eV is obtained as 0.45×10^{-17} cm^2 in reasonable agreement with the experimental estimate of 1×10^{-17} cm^2. The corresponding calculated value for NO is 0.15×10^{-17} cm^2. The effects of the interaction of the incident electrons with the quadrupole moments of the molecules on the vibrational excitation cross sections have been examined.

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*Supported by the Air Force Cambridge Research Laboratories

+Alfred P. Sloan Foundation Fellow

C-10 A COMPARISON OF GRYZINSKI'S CLASSICAL THEORY AND THE BORN APPROXIMATION FOR EXCITATION CROSS SECTIONS OF HYDROGEN

C. F. Monnin
NASA-Lewis Research Center, Cleveland, Ohio

Using the exact wave method of Massey and Mohr[1] the Born approximation was performed to determine excitation cross sections of hydrogen from the ground state to the n = 4 level. The incoming electrons were in the energy range of threshold to 360 ev. Similar calculations were performed using the classical theory of Gryzinski;[2] in addition, the exchange cross sections of Gryzinski[3] were calculated for all transitions to S states. A comparison of the theories is given as well as a comparison with experiment for the 1S-2S and 1S-2P transitions. In comparing the theories, it is found that the Gryzinski theory yields values that are roughly half those obtained using the Born approximation. The experimental cross section for the 1S-2P transition lies between the two theoretical predictions. For the 1S-2S transition the classical exchange theory agrees well for energies less than 40 ev, but falls off rapidly after that.

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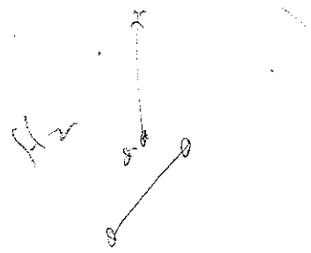
1. Massey, H. S. W. and Mohr, C. B. O., Proc. Roy. Soc. A132, 605 (1931).

2. Gryzinski, M., Phys. Rev. 115, 374 (1959).

3. Gryzinski, M., Institute of Nuclear Research - Warsaw Report No. 448/XVIII (June 1963) p. 43.



Wednesday, October 14, 2:00 P. M.

SESSION D: GLOWS, ARCS, STRIATIONS

Chairman: C. J. Gallagher, General Electric Research Laboratory, Schenectady, N. Y.

D-1a THERMAL INSTABILITY OF THE GLOW COLUMN

G. Ecker[+], W. Kröll[+] and O. Zöller
Institut Für Theoretische Physik der Universität Bochum, Germany

Instabilities of the positive column of a glow discharge have been observed in the absence of a magnetic field. We calculate such an instability which is due to thermal effects and influenced by an external ohmic resistance. Normal mode analysis and trial function methods are applied to derive a criterion for the instability onset, caused by the local coupling between temperature and charged particle density. For given discharge parameters instability occurs beyond a critical current depending on the outer resistance.

[+] Present address: Joint Institute of Laboratory Astrophysics, Boulder, Colorado

D-1b CATHODIC INSTABILITY OF THE GLOW DISCHARGE

G. Ecker[+], W. Kröll[+] and O. Zöller
Institut Für Theoretische Physik der Universität Bochum, Germany

The stability of the cathodic parts of a glow discharge with respect to local current density disturbances is investigated. The cathodic region is described by the particle and momentum balances of the charge carriers and the boundary conditions at the cathode surface and the negative glow. The latter are formulated with the help of the coefficients γ and δ. From

a first order perturbation theory of the stationary mode we derive a dispersion relation. The evaluation of this equation using Nyquist's theorem provides a criterion for the onset of the γ - δ instability.

+ Present address: Joint Institute of Laboratory Astrophysics, Boulder, Colorado

D-2 THE FORMATION OF THE ABNORMAL GLOW DISCHARGE IN HYDROGEN*

M. Nahemow and N. Wainfan
Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

The dynamics of the formation of an abnormal glow discharge in hydrogen will be described in terms of the electric field at the face of the cathode, the starting delay, and the light intensity in the discharge. The data will be compared to calculations which were made by A. L. Ward.[1] The electric field at the cathode was determined by measuring the Stark splitting of the H_β line as a function of time. The temporal resolution was better than 5 nsec. Measurements of the current as a function of time and the electric field data will be compared to define a starting delay and a formative period. The relation of the apparent propagating luminous fronts to the other data and calculations will be discussed. The agreement between the calculations, based on a one-dimensional avalanche theory, and the experimental results supports the essential features of a Townsend type avalanche theory of breakdown at large overvoltages.

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* Supported by the Office of Aerospace Research, Army Research Office - Durham, and the Office of Naval Research.

1. A. L. Ward, Proc. Fifth Int. Conf. of Ioniz. Phenom. in Gases, (Munich 1961) p. 1596.

D-3 DEPARTURES FROM THERMODYNAMIC EQUILIBRIUM IN A HELIUM DISCHARGE*

B. B. Chakraborty and L. Oster
Yale University Observatory, New Haven, Conn.

Quantitative measurements of the line spectrum of a low pressure rf discharge in helium available in the literature[1] have been used to determine relative populations of excited states. The population departs drastically from thermodynamic equilibrium in the sense that states with principal quantum number n + 1 are underpopulated with respect to states of number n. No relation with the electron "temperature" is found for the population of the available states. The measurements are reasonably well represented theoretically by assuming collisional excitation and radiative deactivation, taking the different behavior of the cross-sections for the various transitions into account.

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* Work supported by the Office of Aerospace Research

1. H. M. Crosswhite and G. H. Dieke, Am. Inst. of Phys. Handbook. McGraw-Hill (1957)

D-4 ARTIFICIALLY EXCITED MOVING STRIATIONS IN A GLOW DISCHARGE PLASMA

R. S. Cooper
Massachusetts Institute of Technology, Cambridge, Mass.

A new understanding of the phenomenon of moving striations is promised through the use of techniques to produce them artifically which have been developed in this research. Simple cold cathode, glow discharge tubes, filled with rare gases, were placed in series with a 1- 100 microsecond pulser. In certain regions of DC operation, it was found that a quasi-stable range of small signal AC operation existed in which linear, dispersive propagation of ionization waves resulted. The wave motion was detected using Langmuir probes, and an accompanying excitation wave was observed with photomultiplier tubes. Each wave packet is initiated at the cathode by a single pulse from the pulser and moves at subsonic velocity toward the anode. A structure develops in the packet within a few centimeters travel and moves through it in a direction opposite to that of the wave group itself. These waves have been produced in hydrogen and in all rare gases (except radon). Close analogies can be drawn between their behavior and that of spontaneous moving striations. A one-dimensional continuum theory has been developed which shows that the ionization wave must result from a non-equilibrium or delayed ionization in the gas.

D-5 ACOUSTIC WAVES RESULTING FROM ELECTRICAL DISCHARGES IN GASES*

J. A. Dayton, Jr., and J. A. Berlande
University of Illinois, Champaign, Ill.

When energy is deposited adiabatically and locally in a gaseous medium, pressure gradients are established. This is the process which takes place during an intense localized pulsed RF or DC breakdown of a gas, and the resulting pressure gradients are large enough to produce an acoustic wave. [1,2] This wave is detected with piezoelectric transducers or with mobility limited thermionic diodes. In a partially ionized gas the pressure wave causes perturbations in the electron and ion concentrations, affecting all processes depending on these concentrations. Therefore, these perturbations are observed as modulation of the plasma luminosity and the transmission of a microwave signal. The nature of the wave is discussed, and its effects on any study of the afterglow of a decaying plasma, produced by a pulsed electrical discharge, are emphasized. The velocity of propagation of acoustic waves is used to calculate the neutral gas temperature or the percentage composition of a mixture of two known gases.

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* Work supported in part by U. S. Army Electronics Laboratories and U. S. Air Force Systems Command, Bedford.

1. L. Goldstein, M. Roux, J. A. Dayton, Jr., Proceedings, Sixth International Conference on Ionization Phenomena in Gases, 3, 115 (1963)

2. J. Berlande, P. D. Goldan, L. Goldstein, Appl. Phys. Letters, 5 51, (1964).

D-6 ELECTRICAL CONDUCTIVITY OF XENON

B. T. McClure
Honeywell Research Center, Hopkins, Minn.

As an initial attempt to understand the properties of discharges in xenon, the conductivity is calculated as a function of temperature assuming thermal equilibrium. Temperatures up to 4 ev are considered. The densities of ion species up to Xe^{4+} are evaluated by solving Saha's equations. The effect of collisions between electrons and neutral atoms is evaluated by treating the system as a Lorentz gas. Numerical results are obtained by integrating the appropriate function of the momentum transfer cross section recently obtained by Frost and Phelps[1] over a Maxwellian distribution of electron velocities. The resistivity associated with collisions between electrons and various ion species is evaluated from Spitzer's[2] formula. Collisions between electrons and atoms or ions in excited states are not explicitly considered. The combined influence of ions and neutrals is obtained by adding the separate collision rates. For a gas density $G = 10^{25}$ meter^{-3} the conductivity increases rapidly with temperature to about 10^4 amps/(volt meter) at 1 ev and reaches about 4×10^4 amps/(volt meter) at 4 ev.

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1. L. S. Frost and A. V. Phelps, submitted for publication in Phys. Rev. (1964).

2. L. Spitzer, Jr., Physics of Fully Ionized Gases, Interscience Publishers, Inc., New York (1956) p. 84.

D-7 ATTEMPTS TO CALCULATE MOVING STRIATIONS

A. L. Ward
Harry Diamond Laboratories, Washington, D. C.

An existing computer program has been used in an attempt to understand moving striations. The large disparity between electron and ion mobilities and the steep field-gradient in the cathode-fall region, often leading to negative fields, have prevented a full test of the model. However, computations indicate that the quasi-static voltage of a low-pressure, abnormal glow-discharge is a strong function of the ion distribution in the cathode-fall region. This effect is equivalent to a negative resistance and thereby initiates low frequency oscillations. A higher frequency oscillation due to electron ionization cycles may correspond to negative striations and observed anode glow oscillations. Artificial striations introduced as initial conditions show that the striations move toward the cathode with a velocity of several times the ion velocity in the average field. This results from the higher ionization on the leading (cathode) edge of the striation. These artificial striations decay due to diffusion. Another type of calculation has been made by neglecting electron transport properties and using a sinusoidal increment in the applied voltage. These calculations confirm that the velocity of the ion maxima is much greater than the field mobility value. Further results are anticipated.

D-8 CURRENT DISTRIBUTION IN THE POSITIVE COLUMN OF A HOLLOW CATHODE DISCHARGE

J. S. Cory and J. L. McNichols
Douglas Aircraft Company, Santa Monica, Calif.

Measurement of the effect of pressure, total current and transverse magnetic field on the distribution of brightness in a positive column has provided new information on two aspects of positive column behavior. First, the location of the transition between a diffuse glow and a constricted filament is presented and compared with the results of Fowler and Jones.[1] Elimination of wall boundary conditions and introduction of total discharge current as an independent parameter indicate that a correlation based on current density governs the diffuse glow to filament transition. A second series of measurements of the diffuse mode have shown asymmetric striation patterns. The electric field distribution inferred from these striation patterns is closely related to equipotential lines derived in the theoretical model based on the Hall effect of Hurwitz.[2] The quantitative agreement obtained indicates that this model satisfactorily represents the two-dimensional distribution of current density and tensor conductivity in this discharge régime.

1. R. G. Fowler and L. W. Jones, J. Appl. Phys. 34 1401 (1963)

2. H. Hurwitz, R. W. Kilb, and G. W. Sutton, J. Appl. Phys. 32, 205 (1961)

D-9 PLASMA OSCILLATIONS IN THE SELF SUSTAINING DIPOLE DISCHARGE (S. S. D. D.) AT ONE ATMOSPHERE

N. T. Dzoanh
Illinois Institute of Technology, Chicago, Ill.

The discharge between two parallel plates can be established and self sustained even at relatively high pressure[1] if an artificial mechanism is used to provide to the system the necessary second ionization coefficient γ of Townsend. By covering two electrode surfaces with a porous insulating film and initiating the discharge with a polonium source, the coefficient γ will be supplied by the permanent microbreakdown between the charged porous insulating film and the metal. At one atmosphere, registered current wave pulses, which are proportional to the discharge current, are superimposed with high frequency damped oscillations. The latter imply that the medium contains a high current density plasma and justify the presence of very luminous ionized gas at the surface of the electrodes. Information about the nature and density of the plasma can be obtained. Similar oscillations have been observed in exploding wire experiments.[2]

---

1. N. T. Dzoanh, S.S.D.D. in Oxygen (to be published).

2. T. Korneff, et. al., Exploding Wires, edited by W. G. Chace and K. H. Moore (Plenium Press, Inc., N. Y., 1959) p. 116.

Thursday, October 15, 9:00 A. M.

SESSION E: COMPOUND STATES IN ATOMS

Chairman: R. Novick
Columbia Radiation Laboratory, New York, N.Y.

E-1 THE ROLE OF RESONANCES IN THE ELASTIC CROSS SECTION*

G. J. Schulz
Westinghouse Research Laboratories

The resonance in the elastic cross section in helium (occurring at 19.30 eV), first observed in a scattering experiment[1] was observed by Fleming and Higginson[2] in a modified Maier-Leibnitz[3] experiment. It will be shown that the resonance can be enhanced by a considerable factor in a transmission experiment in which the exit aperture is limited so that only the unscattered electron current is measured. If the total transmitted current is measured (as in the Maier-Leibnitz experiment), no enhancement results. In the present experiment, an electron beam with a half-width about 0.1 eV is transmitted through helium at a pressure around 0.3 torr. The exit conditions for the electron beam can be changed by application of suitable potentials and the enhancement of the resonance has been confirmed. This method has also been used to find a resonance in the elastic scattering by atomic hydrogen in the 9 - 10 eV range.

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

1. G. J. Schulz, Phys. Rev. Letters 10, 104 (1963).

2. R. J. Fleming and G. S. Higginson, Proc. Phys. Soc (London) 81, 974 (1963).

3. H. Maier-Leibnitz, Z. Physik 95, 499 (1935). In the original experiment, the resonance has not been observed.

E-2 HIGH RESOLUTION STUDIES OF LOW ENERGY ELECTRON SCATTERING FROM HELIUM

C. E. Kuyatt and J. A. Simpson
National Bureau of Standards, Washington, D. C.

Improvements in resolution and signal in electron beam transmission measurements have made possible the detection of 9 discrete resonances in the scattering of electrons from He. Most lie in the region between 19.3 eV and 25 eV. The first and largest of these is that discovered by Schulz at 19.3 eV which is associated with the $1s2s^2\ ^2S_{1/2}$ state of He^-. Other distinct resonances occur at 19.43, 21.5, 22.39 and 22.55 eV which are tentatively assigned to $1s2s2p\ ^2P_{3/2,1/2}$ and/or $1s2p^2\ ^2S,\ ^2P,\ ^2D$. In addition, the thresholds of 2^3S and 2^1S states of He are clearly seen and hence fix the energy scale to within ± 0.03 eV. Some of the remaining uncertainty is due to theoretical questions concerning the threshold shapes. Other resonances in the 50 eV region are observed which are associated with doubly excited states of He^-.

E-3 LOW ENERGY ELECTRONS IN HELIUM*

R. H. McFarland,
Lawrence Radiation Laboratory, Livermore, Calif.

An electron beam of about 0.25 electron volts energy spread has been scattered in a helium gas held at a few microns pressure. The absolute energy range of from 18 to 28 electron volts has been of particular interest as it includes regions of elastic resonance scattering as well as the inelastic states of the neutral helium atom. Both scattered and transmitted electron currents have been measured. Elastic resonances have been observed at 19.5 ± 0.1 and 20.3 ± 0.1 volt. Calibration of these energies has been in terms of the threshold of selected optically observed helium lines of helium ions of the production of helium metastables, and of neon lines in a helium-neon mixture.

* Supported by the U. S. Atomic Energy Commission

E-4 METASTABLE AUTOIONIZING ATOMIC ENERGY LEVELS IN CESIUM*

P. Feldman, R. Novick+, and G. Sprott
Columbia Radiation Laboratory, Columbia University, New York, N. Y.

Two metastable autoionizing atomic energy levels have been observed in a beam of cesium atoms excited by electron bombardment. The excitation energies are 8.5 (± 1.5) eV and 12 (± 1.5) eV, the latter corresponding to the $(p^5sd)^4F_{9/2}$ state previously observed in K and Rb.[1] The cross-section and lifetime for this state are also in agreement with our previous data on these alkali elements. On the other hand, a second long-lived autoionizing state (albeit with a production cross-section a factor of ten smaller) had not been observed in either K or Rb and its excitation energy does not fit into the I^b level scheme of Beutler and Guggenheimer.[2] A possible configuration for this state may arise from the excitation of a 5p electron from the $(5p^66s)^2S_{\frac{1}{2}}$ ground state to a low lying f level.

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* Work supported by the National Aeronautics & Space Administration and by the Joint Services (U. S. Army, Air Force Office of Scientific Research, and Office of Naval Research).

+ Alfred P. Sloan Fellow

1. P. Feldman and R. Novick, Phys. Rev. Letters 11, 278 (1963).

2. H. Beutler and K. Guggenheimer, Z. Physik 88, 25 (1934).

Thursday, October 15, 10:40 A. M.

SESSION F: SESSION OF INVITED PAPERS

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

F-1 RADIATION TRANSPORT AND GASEOUS ELECTRONICS PROCESSES IN THE UPPER ATMOSPHERE

T. M. Donahue
University of Pittsburgh, Pittsburgh, Pa.

F-2 CONTRIBUTION OF THE PROGRAM OF AURORAL MEASUREMENTS TO THE PHYSICS OF THE UPPER ATMOSPHERE

R. E. Meyerott
Lockheed Missiles & Space Co., Palo Alto, Calif.

Thursday, October 15, 2:00 P. M.

SESSION G: ELECTRON SCATTERING

Chairman: E. Gerjuoy, University of Pittsburgh, Pittsburgh, Pennsylvania

G-1 MOMENTUM TRANSFER CROSS SECTIONS FOR SLOW ELECTRONS IN He, Ar, Kr, AND Xe FROM TRANSPORT COEFFICIENTS*

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

Momentum transfer cross sections for electrons in He, Ar, Kr, and Xe are obtained from a comparison of theoretical and experimental values of the drift velocities and of the ratio of the diffusion coefficient to the mobility coefficient for electrons in these gases. The theoretical transport coefficients are obtained by calculating accurate electron energy distribution functions for energies below excitation using an assumed energy dependent momentum transfer cross section. The resulting theoretical values are compared with the available experimental data and adjustments made in the assumed cross sections until good agreement is obtained. The final momentum cross section for helium is $5.0 \pm 0.1 \times 10^{-16}$ cm^2 for an electron energy of 5×10^{-3} eV and rises to $6.6 \pm 0.3 \times 10^{-16}$ cm^2 for energies near 1 eV. The cross sections obtained for Ar, Kr, and Xe decrease from 6×10^{-16}, 2.6×10^{-15} and 10^{-14} cm^2, respectively, at 0.01 eV to minimum values of 1.5×10^{-17} cm^2 at 0.3 eV for Ar, 5×10^{-17} cm^2 at 0.65 eV for Kr, and 1.2×10^{-16} at 0.6 eV for Xe. The agreement of the very low energy results with the effective range theory of electron scattering is good.

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

G-2 ABSOLUTE TOTAL ELECTRON-HELIUM ATOM SCATTERING CROSS SECTIONS FOR LOW ELECTRON ENERGIES

D. E. Golden and H. W. Bandel
Lockheed Missiles and Space Company, Palo Alto, Calif.

The Ramsauer technique[1] has been used to measure the absolute total electron-helium atom scattering cross section as a function of electron energy from about 0.35 to about 24.5 eV. The electron energy spread during these measurements was about 6% of the electron energy or 0.1 eV, whichever was least. No "fine structure" has been observed at the lower electron energies studied. The variation of the cross section with energy for energies less than 3 eV is in reasonable agreement with the modified effective range formula of O'Malley.[2] The present results are about 10% higher than those of Normand[3] for energies less than 3 eV, provided his "fine structure" is neglected. As the energy is increased the present results approach those of Normand to within 3% for energies greater than 6 eV.

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1. C. Ramsauer, Annalen Der Physik 66, 545 (1921).

2. T. F. O'Malley, Phys. Rev. 130, 1020 (1963).

3. C. E. Normand, Phys. Rev 35, 1217 (1930).

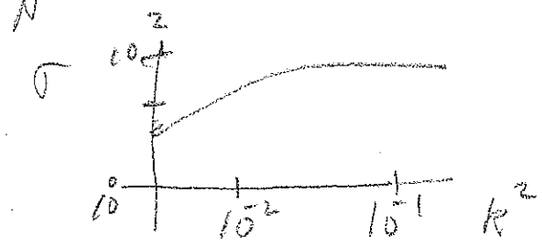
G-3 LOW ENERGY ELECTRON SCATTERING FROM ATOMS AND MOLECULES: A MODEL

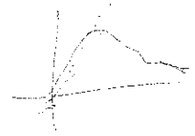
C. J. Lenander
Aerospace Corporation, Los Angeles, Calif.

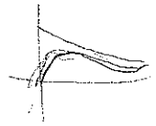
A simple model is proposed for the calculation of free electron wavefunctions for low energy electrons incident upon neutral atoms. The region of interaction of the electron with the atom may be separated into three regions of importance of potential: coulomb plus exchange; coulomb; and far-field induced polarization. The division of regions is based on mathematical and physical reasons for the characteristic behavior of wavefunctions in the scattering problem. Examples are given for the elastic scattering of electrons from Nitrogen, Oxygen and Argon. The agreement with experiment and effective range theory is good. The application of the method to predicting low energy electron scattering from homonuclear diatomic molecules is discussed.

$$\psi_p = \frac{\alpha}{2r^4}\left(1 - e^{-(r/r_0)^{24}}\right) \qquad r_0 \text{ Small}$$

$$\Sigma \simeq \int_0^{R_\Sigma} \sum_{i=1}^{N} M_i P_i^2(r)\,dr$$







G-4 ELECTRON MOMENTUM TRANSFER COLLISIONS IN OXYGEN

M. H. Mentzoni
Sylvania Electronic Systems, Waltham, Mass.

The electron collision frequency for momentun transfer, ν_m, has been determined by microwave methods in an oxygen plasma for temperatures between 300 and 900°K. It was found that the measured average electron-neutral collision frequency was consistent with ν_{em} being proportional to the square of the electron velocity when a Maxwellian velocity distribution is assumed for the electrons; i.e., $< \nu_{em} > = 3.0 \times p \times T \times 10^5$ (sec^{-1}) with p the pressure in torr as referred to 273°K and T is electron temperature in degrees Kelvin. The results also indicated that electron-ion collisions are important at the lower temperatures with the values of ν_{ei} in agreement with the ones recently reported by Chen.[1] Some measurements on the electron energy relaxation times indicated that the G-factor was much larger (by approximately an order of magnitude) than reported for nitrogen under similar conditions.

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1. C. L. Chen, Phys. Rev., 135, A627 (1964).

G-5 MICROWAVE MEASUREMENT OF THE PROBABILITY OF COLLISION OF LOW ENERGY ELECTRONS IN NITROGEN*

J. H. Noon, E. H. Holt, and J. P. Quine
Rensselaer Polytechnic Institute, Troy, New York

The probability of collision for momentum transfer (P_c) of low energy electrons (< 1 eV) in nitrogen has been experimentally determined using microwave transmission techniques. These results show agreement with those of Phelps et al[1] but disagree with those of Anderson and Goldstein.[2] A bakeable cell constructed of X-band waveguide contained the plasma. A nitrogen discharge was produced by a pulsed DC supply and the phase shift and attenuation of the microwave signal measured as a function of the time in the afterglow plasma. The change in electron temperature with time was monitored using a gated microwave radiometer. Assuming a Maxwellian velocity distribution for the electrons, P_c was calculated as a function of electron energy from the measured values of microwave conductivity and electron temperature. The radiometer measurements indicate that the electron energy distribution is not Maxwellian in the early afterglow. The relevance of this in explaining the disagreement between values of P_c calculated by earlier workers and the heating effect of nitrogen metastables in the afterglow will be discussed.

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* Work supported by the National Aeronautics and Space Administration

1. A. V. Phelps, O. T. Fundingsland, and S. C. Brown, Phys. Rev. 84, 559 (1951).

2. J. M. Anderson, and L. Goldstein, Phys. Rev. 102, 388 (1956).

G-6 LOW ENERGY POSITRON-HYDROGEN SCATTERING

P. M. Stone
Sperry Rand Research Center Sudbury, Mass.

The contribution of polarization and virtual positronium formation in positron-hydrogen scattering is still uncertain. The only conclusive result of prior calculations is that polarization of the hydrogen atom by the positron is important at low energies ($\leq$ 1 eV), generally changing the phase shifts from negative values associated with the repulsive mean static field to positive values associated with an over-all attraction. Calculations are reported here where the polarization potential is considered in a new[1] and general way. The potential is obtained by minimizing the target atom energy at each position of the positron for a class of disturbed atomic wave functions. This is justified at the low impact energies considered. The form of the disturbed wave functions is a linear combination of the unperturbed functions. Results are presented where the perturbing state is a 2p state, combinations of 2p and 2s states, and combinations of 2p and higher p states. The advantages of this method over the "coupled equations" method, and the relationship to the variational methods are discussed. The numerical results indicate a stronger effect of polarization than previous calculations.

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1. P. M. Stone and J. R. Reitz, Phys. Rev. 131, 2101 (1963).

G-7 THE CONCEPT OF COLLISION FREQUENCY IN WAVE-PLASMA INTERACTIONS

R. F. Whitmer and G. F. Herrmann
Lockheed Missiles and Space Company, Palo Alto, Calif.

An electromagnetic wave propagating through a weakly ionized gas is characterized by two parameters of the plasma, the electron density and the electron-neutral particle collision frequency. When the collision frequency is independent of the electron velocity the propagation constant of the wave can be derived in a straightforward manner. Molmud[1] has shown that in the case of a velocity dependent collision frequency an effective collision frequency can be defined and used to describe the wave characteristics. However, this concept is inconvenient to use because this effective frequency is a complex quantity. In this paper it will be shown how two real parameters, an effective collision frequency and an effective plasma frequency, can be defined which will completely describe the effects of the velocity dependence of the collision frequency on wave propagation. These two quantities involve integrals of the velocity dependent collision frequency and the electron distribution function. These integrals have been evaluated numerically for the gases He, Ne, A and N_2. At high frequencies the effective collision frequency differs from the actual collision frequency by approximately 20% in He and a factor of two in A. Such differences produce an appreciable change in the calculated attenuation coefficient. At low frequencies or near a resonance the effect can be as much as an order of magnitude. Consequently, the line shape at cyclotron resonance, particularly for Ne and A, should vary drastically from the form predicted on the basis of a velocity independent collision frequency.

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1. Molmud, P., Phys, Rev., 114, 29 (1959)

Thursday, October 15, 2:00 P. M.

SESSION H: ION-MOLECULE REACTIONS

Chairman: E. C. Beaty
Joint Institute For Laboratory Astrophysics,
Boulder, Colorado

H-1 SHOCK TUBE STUDY OF THE TEMPERATURE DEPENDENCE OF NITROGEN ATOMIC RECOMBINATION*

G. R. Carruthers
University of Illinois, Champaign, Ill.

The temperature dependence of the three-body recombination rate constant for atomic nitrogen, as studied in shock tubes in the temperature range 500 - 2,000°K, is reported. Both pure nitrogen and dilute mixtures of nitrogen in argon or helium were used. A small amount of dissociation was produced in the test gas prior to initiation of the shock wave, either by a rf discharge in conjunction with a flowing system or by a capacitor discharge along the length of the shock tube test section. The relative recombination rates ahead of and behind the shock were determined by monitoring the intensity of the Rayleigh afterglow across the shock. A 1/T dependence of the afterglow recombination rate constant was found, with the upper limit of 2,000°K being set by the appearance of impurity radiation. Evidence is presented for considering this temperature dependence to apply also to the total recombination rate constant. The change in spectral distribution of the Rayleigh afterglow across the shock was also studied.

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* Work supported in part by U. S. Air Force Systems Command, Bedford.

H-2 ISOTOPIC ABUNDANCE STUDIES OF HOMONUCLEAR AND HETERONUCLEAR MOLECULAR IONS IN RARE-GAS PLASMAS*

M. A. Mosharrafa and H. J. Oskam
University of Minnesota, Minneapolis, Minnesota

A highly sensitive quadrupole mass-spectrometer, bakeable at 350°C, has been constructed for studying plasma properties. The considerations which led to the choice of this particular type of spectrometer will be discussed. Isotope techniques applied to active plasmas produced in neon-argon and neon-krypton mixtures revealed the presence of the heteronuclear ions $(NeAr)^+$ and $(NeKr)^+$. The isotopic abundances of certain molecular ions were found to differ from the natural abundances in the gases. A theoretical explanation based on the molecular-ion production processes will be presented. The extremely small relative number densities of the heteronuclear ions explain why they have not been observed in plasmas by previous investigators.

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* Work supported by the National Science Foundation and the Advanced Research Projects Agency through the Office of Naval Research.

H-3 MEASUREMENT OF THE TEMPERATURE DEPENDENCE OF THE RATE OF CONVERSION OF He^+ INTO He_2^+ IN THE HELIUM AFTERGLOW*

F. E. Niles, C. B. Collins+ and W. W. Robertson
University of Texas, Austin, Texas

Previous work[1] yielded the rate of conversion at room temperature of He^+ into He_2^+ by the reaction $He^+ + 2He \rightarrow He_2^+ + He$ from the observed decay of the atomic and molecular emission in the early helium afterglow and the known rate of diffusion of He^+. Similar measurements have been carried out over the temperature range 77°K to 443°K. These measurements show that the temperature dependence of the rate of conversion, βp^2, goes as T^{-1} and, consequently, that the temperature dependence of β goes as T^{-3}. These results seem to be consistent with the theoretical predictions of the temperature dependence of termolecular reactions.

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* This work was supported by the U. S. Air Force Office of Scientific Research

+ Present address: Southwest Center for Advanced Studies, Dallas, Texas

1. F. E. Niles and W. W. Robertson, J. Chem. Phys. 40, 3568 (1964).

H-4 SPECTROSCOPIC INVESTIGATION OF THE HELIUM-NEON MOLECULE (ION)*

W. R. Henderson, F. A. Matsen and W. W. Robertson
The University of Texas, Austin, Texas

When a discharge is excited in a helium-neon mixture a band spectrum appears that is absent in the spectra of the separate gases. This spectrum has been attributed to the He-Ne molecule (ion).[1,2] Investigated here under high resolution, the spectrum could not be completely analyzed. However, substitution of He^3 for He^4 resulted in isotopic shifts in agreement with those calculated for the rotational structure of a diatomic He-Ne molecule. Investigation of the spatial distribution of intensity of the atomic and molecular radiation in the cathode region of a dc discharge through a helium-neon mixture and its behavior under a probing microwave field yielded a clear indication of the origin of the molecular spectrum. The He-Ne molecular ion is evidently formed in an excited state of the ion having as its dissociation limit $He^+ + Ne$ and decays to a lower state of dissociation limit $He + Ne^+$. The reaction is found to be $He^+ + Ne + X \rightarrow (HeNe^+)^* + X$. The approximate depths of the potential wells can be inferred from the appearance potential of $HeNe^+$ if the reaction is assumed to be of the Hornbeck-Molnar type.

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* This work was supported by the U. S. Air Force Office of Scientific Research.

1. N. J. Druyvesteyn, Nature (London) 128, 1076 (1931).

2. H. J. Oskam and H. M. Jongerius, Physica 24, 1092 (1958).

H-5 ENERGY ANALYSIS OF IONS PRODUCED BY COLLISIONS OF N_2^+ WITH MOLECULAR OXYGEN*

R. C. Amme
University of Denver, Denver, Colorado

N. G. Utterback
University of Denver, Denver, Colorado and General Motors Defense Research Laboratories, Santa Barbara, Calif.

Efforts to measure the non-resonant charge transfer cross section for N_2^+ ions incident on molecular oxygen have shown that the associated scattering is of great importance. Using the grid arrangement described by Utterback and Miller[1], an energy analysis of the ions produced in a charge transfer gas cell was performed. Incident ion energies studied ranged from 20 eV to 1000 eV. Grid current representing those collected ions with energies less than a few eV was found to be unaffected by increasing the ion source electron energy from 17 to 24 eV. It is concluded that the long-lived excited states thus generated in the nitrogen ion beam are not important for this process. An interpretation of the measured ion currents in terms of the charge transfer cross section will be discussed.

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* Supported by NASA.

1. N. G. Utterback and G. H. Miller, Rev. Sci. Instr. 32, 1101 (1961).

H-6 CHARGE TRANSFER CROSS SECTIONS FOR N_2^+ IN ARGON AND Ar^+ IN NITROGEN*

H. C. Hayden and R. C. Amme
University of Denver, Denver, Colorado

Charge transfer cross sections for N_2^+ in argon and Ar^+ in molecular nitrogen have been measured as functions of ion energy and of ion source electron energy. Ion energies studied were in the range of 50 eV to 1000 eV and the ion source electron energy was varied between 16 and 24 eV. For the $Ar^+ + N_2$ case, the cross section appeared to be non-resonant and was insensitive to ionizing electron energy. The slightly endothermic charge transfer for the $N_2^+ + Ar$ case also appeared to be non-resonant, but was measurably influenced by ion source electron energy. This result is attributed to the presence of long-lived excited states of N_2^+, reported earlier.[1] Evidence will be presented to show that the $(N_2^+)^*$ ions may exhibit resonant behavior in charge transfer with argon atoms. This suggests that the effect might be due to the excitation of vibrational states by ionizing electrons.

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* Supported by NASA.

1. R. C. Amme and N. G. Utterback, Proc. Third Intern. Conf. on Phys. of Electronic and Atomic Collisions, London (North Holland Publ. Co., 1964).

H-7 CONVERSION OF N_2^+ TO N_3^+ IONS AS A FUNCTION OF E/p_o*

S. B. Woo+ and R. N. Varney++
Washington University, St. Louis, Missouri

The existence of the four ions in nitrogen, N^+, N_2^+, N_3^+, and N_4^+, now commonly observed, introduces peculiar problems in drift velocity measurements of ions in nitrogen. We had used a single-shutter drift velocity tube having as ion source an electron emitter with controlled accelerating arrangement so that considerable limitation could be imposed on the type of ion produced and its possible degree of excitation. With this arrangement coupled with careful and extensive analysis of data we have been able to observe and identify the following: N^+ in a range of $8 \leq E/p_o \leq 100$, and N_2^+ in a range of $55 \leq E/p_o \leq 200$, and N_3^+ in a range of $9 \leq E/p_o \leq 40$. Also observed were the following: N^+ and N_2^+ simultaneously with no interchange from one ion type to another in a range $55 \leq E/p_o \leq 100$; N^+ and N_3^+ simultaneously with no interchange from one ion type to another in a range $10 \leq E/p_o \leq 40$. In addition, N_2^+ was observed undergoing a transition to N_3^+ for which the attachment frequency was measured as a function of E/p_o and p_o. It was found that the attachment frequency α was proportional to p_o^2 and to $\exp(-AE/p_o)$ where $A = 5.75 \times 10^{-2}$ (cm x mm Hg)/volt. Values of α ranged from 0.8 to 8×10^{-4} sec^{-1}. Finally, N_3^+ was observed changing to N_2^+ in flight, but only semiquantitative data were obtained.

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* Work supported by ARO-D

+ Present address: Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, Colorado

++ Present address: Lockheed Missiles and Space Company, Palo Alto, Calif.

H-8 MOBILITY AND MASS ANALYSIS OF IONS IN HYDROGEN*

G. Sinnott†, R. N. Varney+ and M. Saporoschenko
Washington University, St. Louis, Missouri

The mobility of ions in hydrogen has been measured over a range $0.6 \leq E/p_o \leq 110$ Volts/(cm mm Hg) with a double shutter device capable of considerable precision and using a glow discharge of minimum power (about 1 watt) as ion source. Pressures were varied from 0.5 to 5 mm Hg. The temperature was also varied covering $77^oK \leq T \leq 470^oK$. The results differ considerably from those of Chanin[1] but our agreement with his results in helium suggests that the difference is not instrumental but involves a different ion in hydrogen. Evidence will be presented supporting the hypothesis that our basic ion is H_5^+, presumably formed from $H_3^+ + H_2$ which seem to coalesce but with fairly weak binding, probably under 0.5 eV. Using a separate mass spectrographic apparatus, the ion of mass 5 has indeed been found in hydrogen. As a check, the ion of mass 10 in pure deuterium was also sought and found and its behavior as a function of pressure studied.

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* Work supported by ARO-Durham, AEC, and Research Corporation.

+ Present address: Lockheed Missiles and Space Company, Palo Alto, Calif.

1. L. M. Chanin, Phys. Rev. 123, 526 (1961)

H-9 SOME ATOMIC-HELIUM ION REACTIONS STUDIED AT THERMAL ENERGIES

F. C. Fehsenfeld, D. B. Dunkin, H. I. Schiff, and E. E. Ferguson
National Bureau of Standards, Boulder, Colorado

A number of helium ion reactions have been studied in a steady state afterglow system. These include

$$He^+ + N_2 \rightarrow He + N + N^+ \qquad (1)$$

$$He^+ + O_2 \rightarrow He + O + O^+. \qquad (2)$$

The ratio of these reaction rates is measured to be 1.2 ± 0.2. This has the important geophysical consequence that atmospheric helium ions will be lost by reaction (1) rather than by reaction (2), as currently assumed. The absolute rates are $k_1 = 1.3 \pm 0.3 \times 10^{-9}$ cc sec^{-1}, and $k_2 = 1.1 \pm 0.4 \times 10^{-9}$ cc sec^{-1}. These rates have been determined by two independent experiments, one involving measurement of ion currents as a function of N_2(or O_2) concentration with a quadrupole mass spectrometer, the other involving an optical measurement of He(2^3S) metastable concentrations as a function of N_2(or O_2) concentration. The measured Penning rates will also be reported. A number of other reaction rates (or upper limits) for thermal helium ions have been measured, including charge-transfer to the other rare gases and non-dissociating states of N_2, and will be reported.

H-10 SOME PROPERTIES OF MOLECULAR HELIUM IONS

E. E. Ferguson, F. C. Fehsenfeld, and A. L. Schmeltekopf
National Bureau of Standards, Boulder, Colorado

Significant advances in the understanding of the properties of the molecular helium ion have occured since the last Gaseous Electronics Conference. Mulliken has revised the picture of molecular helium potential curves, Takayanagi has estimated the vibrational relaxation time of He_2^+, and the collisional-radiative recombination calculations of Bates and Kingston have been extended and compared to afterglow experiments. These results will be briefly reviewed and their significance with respect to interpretation of experiments in this and other laboratories discussed. In particular, dissociative recombination appears not to be important in laboratory conditions which have been investigated and it is doubtful whether any convincing evidence for its occurrence has been reported in the literature. We have measured the rate for the ion-atom interchange reaction (1) to be $10^{-10} cm^3 sec^{-1}$.

$$He_2^+ (v = 0) + Ne \rightarrow (HeNe^+)^* + He. \qquad (1)$$

$$(HeNe^+)^* \rightarrow He + Ne^+. \qquad (2)$$

Only the disappearance of He_2^+ and the appearance of Ne^+ are observed. However, the alternative mechanism for this overall reaction, which would involve charge-transfer to the unstable He_2 ground state, is endothermic by at least 2 eV.

Friday, October 16, 9:00 A.M.

SESSION I: BREAKDOWN; CORONA

Chairman: J. E. Creedon
U. S. Army Electronics Laboratories, Ft. Monmouth, N.J.

I-1 PRESSURE DEPENDENT BREAKDOWN POTENTIALS IN PENNING MIXTURES

L. M. Chanin and G. D. Rork
Honeywell Research Center, Hopkins, Minnesota

Measurements have been made of the primary and secondary electron ionization coefficients in neon-hydrogen, helium-hydrogen, and neon-argon mixtures using the Townsend techniques. In these mixtures measurements have been conducted over a considerable range of pressures at the E/p_o value corresponding to the maximum of the Penning effect and for the optimum concentrations. Examination of the pre-breakdown current growth clearly indicates a pressure dependent breakdown potential. Measurements of the primary coefficient as a function of pressure show no significant pressure variation. Measurements of the secondary ionization coefficient, however, indicate that γ decreases with increasing pressures consistent with the observed breakdown potential variation. Limitations of the Townsend technique for studying secondary coefficients will be discussed.

I-2 ELECTRICAL BREAKDOWN PROCESSES IN SHOCK HEATED AIR

D. R. White, A. N. Greenwood, and T. H. Lee
General Electric Co., Philadelphia, Pa.

Tests, designed to study the electrical breakdown processes in air in the temperature range 1800° - 3200°K, are described. The method used was that of applying an electric field across a shock-heated gas. In tests with nitrogen previously reported, what appeared to be "thermal breakdowns" were observed at high temperature. In these tests an appreciable current was observed to flow although the voltage remained quite high. This was again seen with air. Oscillograms show tens of amperes flowing for up to 100 μsecs., before an arc was developed, with a voltage of 5-10 kV across an 8 cm gap. The density was approximately 1/8 amagat. A theory was proposed in an earlier publication which suggests that the form of the breakdowns, whether an abrupt spark breakdown or a thermal breakdown, might well depend upon the electron concentration. In an effort to test the theory the electron concentration was measured, in the tests described, by microwave attenuation and also indirectly with low voltage probes. The two methods gave better than order of magnitude correlation. Typical oscillograms are reproduced. The values observed are higher than the Saha equilibrium value, which almost certainly indicates the presence of NO.

I-3 RECENT THEORETICAL AND EXPERIMENTAL ADVANCES IN THE KNOWLEDGE OF CORONA STREAMER BREAKDOWN*

L. B. Loeb, G. A. Dawson, and W. P. Winn
University of California, Berkeley, Calif.

Studies have been made of the growth of streamer sparks in short point-to-plane gaps in atmospheric air using measurements of current and luminosity employing one or two photomultipliers, Lichtenberg figures, photographic recordings, and an image converter. Streamers were produced by both impulse potentials of nanosecond rise and fall times and by suppression of breakdown streamers with current-limiting resistors. The studies have indicated the presence of fast primary streamers propagating into the low field, secondary more conducting streamers which near breakdown carry high tip potentials across the gap, ionizing waves of potential, and indirectly the presence of return strokes as observed by Kritzinger for long gaps, bringing into sensible agreement studies of all previous observers. The work has led to development of the zero-field theory of primary streamer propagation, which is not only in excellent agreement with observation but recently has received impressive confirmation. According to the theory, the streamer tip, considered to be electrically isolated from the anode, gains energy in the high field region proportional to the applied potential and propagates in the low field until this energy is dissipated by ionization, excitation, and branching.

* Work supported in part by U. S. Office of Naval Research.

I-4 FORMATION OF LOW IMPEDANCE NANOSECOND ARC CHANNELS

H. Fischer
Air Force Cambridge Research Laboratories, Bedford, Mass.

The transition from a low current streamer into a high density arc channel of low impedance has been discussed in the past without complete agreement in regard to the mechanism of the breakdown and the priorities of participating processes.[1,2,3,4] On the other hand, it was recognized that the time scale and possibly the mechanism of the breakdown will depend upon the impedances of the current feeding circuit.[5] Formation of an extremely narrow, <0.1 mm, and apparently magnetic pinched arc channel, ≥10 A/cm^2, in 1 atmosphere air within 10^{-9} second after "zero" time recently has been demonstrated by means of a plated coaxial, ~0.5 ohm, capacitor transmission line.[6] For such a case the present model of arc channel formation needs modification as it may appear. A model is suggested in which the differential ionization by the electrons is increased within the forming channel which appears to narrow with increasing current. Short wave radiation may account for the expansion of arc channels after such breakdown has been completed. Photographs of low impedance nanosecond arc channels are shown and discussed.

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2. J. M. Meek and J. D. Craggs, Electrical Breakdown of Gases, Oxford University Press (1953).

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4. H. Raether, Ergebnisse exakt. Naturw. 33, 175 (1961).

5. R. F. Saxe, Brit. Journ. Appl. Phys. 7, 336 (1956).

6. H. Fischer, Journ. Opt. Soc. Am. 51, 543 (1961).

I-5 IONIZING RADIATIONS EXCITED IN A POSITIVE BURST PULSE CORONA IN NITROGEN, OXYGEN AND AIR

T. Tamura
Shizuoka University, Hamamatsu, Japan

The onset of a positive burst pulse corona was measured at different pressures in nitrogen, oxygen and air. From the extrapolated value of reduced field strength to indefinitely high pressure the effective absorption coefficient of the radiation active in the formation of a positive burst pulse corona was deduced using the Loeb's condition for the onset of a burst pulse corona. The estimated values of absorption coefficient for each of these gases differ according to the values of the field strength at the tip of the positive electrode. It seems that there are six or seven components for each of these gases. They are 4900, 4400, 2375, 99, 0.227, and 1.02 x 10^{-5} cm^{-1} for nitrogen and 3200, 3080, 2700, 1565, 440, 34.3 and 0.00522 cm^{-1} for oxygen and 5650, 5340, 3620, 218, 2.76, 0.01 and 7.5 x 10^{-5} cm^{-1} for air. Ratios of numbers of ionizing photons to ions in a burst forming avalanche and excitation coefficient were calculated for these components and were found to depend on the field strength at the tip of the positive electrode.

I-6 VALIDITY OF TOWNSEND'S IONIZATION FUNCTION IN NON-UNIFORM ELECTRIC FIELDS

L. H. Fisher, and D. E. Golden
Lockheed Missiles and Space Company, Palo Alto, Calif.

A number of authors[1,2,3] have concluded that experimental values of pre-breakdown ionization gas current multiplications in non-uniform electric fields are not correctly predicted by generalizing Townsend's ionization function for uniform fields to non-uniform fields. Re-analysis of the available non-uniform field data in hydrogen has been made using newer values of the first Townsend ionization coefficient.[4] It is concluded that in a number of cases where such a failure has been reported there is in fact no such failure. The reported failures in these cases are due to the use of incorrect values of the first Townsend ionization coefficient.

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1. P. L. Morton, Phys. Rev. 70, 273 (1946).

2. L. H. Fisher and G. L. Weissler, Phys. Rev 66, 95 (1944).

3. G. W. Johnson, Phys. Rev. 73, 284 (1948).

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I-7 PLASMA GENERATION BY THE LASER ILLUMINATION OF A TUNGSTEN SURFACE

A. S. Gilmour, Jr. and F. A. Giori
Cornell Aeronautical Laboratory, Inc., Buffalo, New York

The generation of a dense tungsten plasma by the illumination of a tungsten surface with a pulsed ruby laser is described. Ion-current emission densities greater than 2000 a/cm^2 and electron-current emission densities greater than 200,000 a/cm^2 have been achieved. Measurements made with a quadrupole mass spectrometer have shown that the ionization of the tungsten material leaving the emitting surface was over 99% complete and that singly-charged, single-atom ions only were generated. The average energy of the ions was found to be 15 ev under a wide range of conditions and the energy required per ionization was as low as 4000 ev. Under some circumstances, large electron and ion currents continued to be emitted from the tungsten surface for as long as 2 milliseconds after the cessation of the laser light. It is thought that this phenomenon resulted from ohmic heating of the emitting surface of the tungsten. Mechanisms that may account for the extremely efficient ionization process are discussed.

I-8 GAS BREAKDOWN BY OPTICAL FREQUENCY RADIATION

A. F. Haught and R. G. Meyerand, Jr.
United Aircraft Research Laboratories, East Hartford, Conn.

Electrical breakdown of gases by optical frequency radiation has been studied over a wide range of pressures in a number of gases. Field strengths of the order of 10^7 volts per cm from a 25 nanosecond ruby laser pulse were required for the breakdown and resulted in electron densities up to 10^{19} electrons per cm^3 within the breakdown volume. Diagnostics involving charge collection, spectroscopy, and framing camera photographs of the breakdown luminosity have been used to study the phenomena. Measurements of the attenuation of the irradiating laser beam show that the breakdown developed within 5-9 nanoseconds of the start of the optical pulse. It has been established that the energy removed from the irradiating beam is absorbed by the breakdown plasma. The rapid development of the breakdown cannot be adequately explained on the basis of existing theories of breakdown in gases. This production of a plasma by optical frequency radiation provides a unique method for the study of high density plasmas without requiring the use of electrodes or otherwise introducing possible contaminants to the plasma.

I-9 NANOSECOND PULSE MICROWAVE BREAKDOWN OF AIR AND HELIUM*

C. Buntschuh and M. Gilden
Microwave Associates, Inc., Burlington, Mass.

Microwave breakdown of air and helium was studied at a frequency of 9 Gc using pulses 11 nsec. long. The pulses were generated by discharging the energy stored in a resonant cavity. Normalized breakdown field strengths, E_{eff}/p, ranged from 70 to 1900 v/cm-torr in air, and 20 to 160 in helium. Corresponding values of $p\tau$ were 5×10^{-7} to 3×10^{-9} torr-sec in air and 5×10^{-6} to 5×10^{-8} in helium. The results agree with the video pulse breakdown measurements of Felsenthal[1] at pressures high enough for the RF effective field correction to be negligible. The effective field correction factors required to obtain agreement between microwave and video pulse data[1] at low pressures yielded the following approximate electron collision frequencies for high E_{eff}/p: for air $\nu_c = (4 \pm .012\ E_{eff}/p) \times 10^9 p$ sec^{-1}; for helium $\nu_c = 1.5\times10^9 p$ sec^{-1}. The results indicate that the effective field concept is valid for large values of E_{eff}/p and that the pulse breakdown theory of Gould and Roberts[2] may be applied to breakdown times as short as a nanosecond.

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* Supported by Rome Air Development Center.

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Friday, October 16, 9:00 A.M.

SESSION J: MOSTLY RECOMBINATION AND AFTERGLOWS

Chairman: W. H. Kasner
Westinghouse Research and Development Center
Pittsburgh, Pa.

J-1 DISSOCIATION OBSERVED IN A HELIUM AFTERGLOW*

C. B. Collins, Jr.+ and W. W. Robertson
University of Texas, Austin, Texas

Spectroscopic observations conducted on a flowing helium afterglow at an electron density of the order of $2 \times 10^{12}/cm^3$ and a temperature of 1800°K revealed the emission of the 10,830 Å ($2^3P \rightarrow 2^3S$) helium line at a higher intensity than could be expected as the result of cascading from the higher levels populated by the collisional-radiative recombination of He^+. The emission was found to be quenched upon application of a weak microwave field to the afterglow. An examination of the pressure dependence of the 10,830Å intensity and ion concentrations established that the anomalously high 2^3P population was the result of the ion electron recombination of He_2^+. The axial variation of the intensity revealed a dependence which was first order on He_2^+ concentration and first order on electron density. Mechanisms are discussed.

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* Supported by the Propulsion Division, Air Force Office of Scientific Research.

+ Present address: Southwest Center for Advanced Studies, Dallas, Texas.

J-2 IONIZATION AND RECOMBINATION IN CESIUM-SEEDED PLASMAS NEAR THERMAL EQUILIBRIUM

L. P. Harris
General Electric Research Laboratory, Schenectady, N. Y.

Measurements have been completed of electron-density relaxation in cesium-seeded plasmas perturbed from thermal equilibrium at temperatures in the 1500° to 2000°K range. The gases consisted of 0.1 to 20 Torr Cs vapor in atmospheric pressure argon or helium. Electron densities ranged over 1.9×10^{11} to 3.8×10^{13} cm $^{-3}$ and relaxation times over 30×10^{-6} to 50×10^{-3} second. The results indicate that charge production and loss are dominated by the atomic-ion process $Cs + e + 3.89$ ev $\rightleftarrows Cs^+ + 2e$ at the higher temperatures, and by the molecular-ion process $Cs + Cs + 2.82$ ev $\rightleftarrows Cs_2^+ + e$ at the lower temperatures and higher cesium pressures. At the lower temperatures and lower cesium pressures the dominant process is ambipolar diffusion. The results obtained when the atomic-ion process dominates agree well with calculations based on the equilibrium properties of the gas and recent theory for two-electron, three-body recombination. The rate of the molecular-ion process corresponds to a two-body recombination coefficient of approximately 1×10^{-8} cm^3/sec at temperatures of 1250° to 1400°C, a value small relative to that derived from earlier experiments. All evidence indicates that, despite their numerical preponderance, the argon and helium atoms play no significant roles beyond those of thermal bath and diffusion barrier.

J-3 a IONIZATION EXPERIMENTS IN ELECTRON-IRRADIATED N_2 - O_2 MIXTURES* I. ELECTRON DENSITY MEASUREMENTS

P. N. Eisner, M. N. Hirsh, and J. A. Slevin
The G. C. Dewey Corporation, New York, New York

Steady-state and afterglow measurements of electron densities have been made in O_2 - N_2 mixtures weakly ionized by a spatially uniform flux of 1.5 Mev electrons from a Van de Graaff accelerator. The plasma is contained in a large uhf resonant cavity to which mass and optical spectrometers are appended; electron densities are deduced from measured shifts in the resonant frequency of the cavity. The large cavity size minimizes wall effects, and ultra-high vacuum techniques safeguard gas purity. Measurements made over the range 0.8 to 10 Torr indicate that the predominant linear electron loss process is three-body attachment to O_2, with the coefficient $\beta = (2.1 \pm 0.4) \times 10^{-30}$ cm^6 sec^{-1}. The efficiency of N_2 relative to O_2 in stabilizing the attachment is found to be $\xi = 0.06 \pm 0.03$.

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* Supported by the Defense Atomic Support Agency through the U. S. Army Electronics Laboratories, Fort Monmouth, N. J.

J-3 b IONIZATION EXPERIMENTS IN ELECTRON-IRRADIATED N_2 - O_2 MIXTURES* II. MASS AND OPTICAL SPECTROSCOPY

M. N. Hirsh, P. N. Eisner, and J. A. Slevin
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Mass and optical spectroscopic measurements have been performed on the plasmas generated by the equipment described in the preceeding abstract. The principal positive ion found in N_2 - O_2 mixtures in the pressure range 1 to 10 Torr is O_4^+ for mixtures at least 1/3 O_2; greater concentrations of N_2 shift the predominant ion to N_2^+ in this pressure range. The general features of the positive ion spectra for various experimental conditions will be presented. Optical measurements show the First Negative System of N_2^+ to be directly excited by fast electrons from ground state neutral molecules. Cross-sections for the radiationless quenching of the $B^3 \Sigma_u^+$ state by collisions with N_2 and O_2 are found to be 1.2×10^{-14} and 4×10^{-14} cm^2, respectively. Evidence for the origin of the Second Positive System in positive ion-electron recombination will be presented.

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* Supported by the Defense Atomic Support Agency through the U. S. Army Electronics Laboratories, Fort Monmouth, N. J.

J-4 CYCLOTRON RESONANCE ABSORPTION OF SOME NEGATIVE IONS*

D. Wobschall and J. R. Graham, Jr.
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Ions were produced by passing a low energy (< 8 ev) beam of electrons through oxygen and other gases in a fixed magnetic field. Negative ions can be distinguished from positive ions by applying a transverse circularly polarized RF electric field of the proper sense at the cyclotron frequency. Techniques will be described. Also given will be observations of line inversion; that is, the detection of power emission at one set of RF electrodes caused by ions which have absorbed power from a perpendicular set. The pressure dependence of the line widths of O_2^- and O^- were measured in order to determine their collision cross sections in oxygen. These cross sections were slightly (10-30%) smaller than the cross section of O_2^+ in O_2 (200Å^2) and agree with Langevin's theory within experimental error.

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* Supported by the U. S. Army Research Office - Durham

J-5 NEW EVIDENCE FOR THE IMPORTANCE OF $N_2(^3\Delta_u)$ IN DISCHARGES AND AFTERGLOWS IN N_2 PLUS RARE GAS

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In low current discharges and afterglows in 200 mm A + .1% N_2, the 10,500 Å (0,0 first positive) N_2 band is found to be enhanced 30-fold as compared to bands originating in v'=1, v'=2, etc. of $B^3\pi_g$. This highly selective excitation of v'=0 of $B^3\pi_g$ at 7.35 eV is ascribed to collision induced, radiationless transitions between N_2 $^3\Delta_u$ and normal N_2 or A or both; and is taken as further evidence of a high population[1] of $^3\Delta_u$, at ~ 7.35 eV. Bayes and Kistiakowsky[2] using A + N_2 pressures up to 30 mm found the lowest levels of $B^3\pi_g$ (their group 3b) to be selectively excited; this could be associated with the pronounced effect found here. In Xe + N_2, bands from $B^3\pi_g$ are absent; yet there is evidence of a large population of some carrier (not $A^3\Sigma_u^+$) which greatly lowers the voltage and excites Hg, BaII, etc. Conceivably $^3\Delta_u$ forms a complex with Xe having considerable life, but not enough energy to transfer collisionally to $B(^3\pi_g)$. A new band at ~ 12,500 Å may represent transitions from such a complex to $A^3\Sigma_u^+$.

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1. C. Kenty, Proc. 3rd Int. Conf. on Phys. of Electronic and Atomic Collisions (1963) p. 1133.

2. K. D. Bayes and G. B. Kistiäkowsky, J. Chem. Phys. 32, 992 (1960).

J-6 OPTICAL DEACTIVATION OF Ne METASTABLES IN AN AFTERGLOW*

B. Pariser and T. Marshall
Plasma Laboratory, Columbia University, New York, N. Y.

A neon afterglow plasma was optically pumped with broad band radiation produced by a xenon flash lamp. The neon metastable concentration ($1S_5$) was observed by the absorption of resonance radiation transmitted through the plasma. When the plasma was exposed to a 12.5 joule xenon flash the $1S_5$ level was quenched by greater than 50%. The Einstein Radiation Laws were applied to a simplified atomic model consisting of the ground state, four 1S levels and ten 2P levels. This predicted the level populations (1S and 2P) in neon as a function of time which were in good agreement with the experimental data. A series of similar pumping experiments were conducted on a He - Ne laser. A cross modulation was observed on the laser output by optically pumping the neon metastable with selected wide band filters. Laser lines (6328Å and 1.15 μ) were quenched as a result of $1S_5 \rightarrow 2P_4$ pumping. Amplification of the 1.15 μ laser line was observed using a second set of filters. In this case the metastables were pumped to the 3P levels.

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

J-7 MEASUREMENT OF THE CONCENTRATION OF METASTABLE ATOMS IN PULSED LOW PRESSURE He DISCHARGES

R. Buser and J. Kainz
U. S. Army Electronics Laboratories, Fort Monmouth, N. J.

Preliminary space and time resolved emission and absorption measurements in the early and late afterglow of a He discharge are presented (pressure below 1 mm, fundamental diffusion length 2.9 cm, power input approximately 100 Joule in 100 μsec.). In particular, the concentration of the 2^1S metastable state of the He atom has been determined. The experimental time constants thus obtained for the He metastable decay and the line intensity decay are compared with different models for the low pressure afterglow in He.

J-8 THE DISSOCIATION OF THE HYDROGEN MOLECULAR ION BY PROTONS AND HYDROGEN ATOMS*

J. M. Peek
Sandia Laboratory, Albuquerque, New Mexico

The first Born approximation for the reactions

$$H^+ + H_2^+ \ (1s\sigma_g) = H^+ + H_2^+ \ (2p\sigma_u) \qquad (1)$$

$$H(1s) + H_2^+ \ (1s\sigma_g) = H(n\ell) + H_2^+ \ (2p\sigma_u) \qquad (2)$$

is developed for a given internuclear separation, R, of H_2^+ where the electronic states of H_2^+ are approximated by LCAO wave functions. The total cross section $Q(R)$ for (1) is found to diverge for large R as R^3. $Q(R)$ for reaction (2) is a rapidly increasing function of R for R near the equilibrium internuclear separation but the asymptotic behavior for large R is $A - B/R^2 + O(1/R^4)$ where A,B are finite positive constants for a given incident velocity. This is true for all $n\ell$. Using an approximate theory[1] to treat the internal degrees of freedom of H_2^+, the total cross section Q_ν for H_2^+ initially being in a vibrational state ν is calculated for both reactions and all bound ν. Assuming a population of vibrational states[2] which is probably typical of a laboratory source of H_2^+, the higher vibrational states, $\nu > 5$, make up the greater contribution to the cross section for (1), even though these states are individually weakly populated. Because of the different behavior of $Q(R)$ at large R for (2) these higher states are much less important and the majority of the contributions to dissociation comes from the lower vibrational states.

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

1. J. M. Peek, Phys. Rev. 134, A877 (1964).

2. J. Wm. McGowan and L. Kerwin, Can. J. Phys. 42, 972 (1964).

J-9 THE THEORY OF COLLISIONS BETWEEN IONS AND POLAR MOLECULES

J. V. Dugan, Jr.
NASA-Lewis Research Center, Cleveland, Ohio

J. L. Magee
University of Notre Dame, South Bend, Indiana

The collision between an ion and a rotating molecule with a permanent dipole moment is treated theoretically as a function of ion velocity and molecular rotational energy. Such encounters are of interest in the transport theory of ionized polar gases. A quantum mechanical approach is formulated for computing the collision cross section for low ion velocity where the scattering can be treated adiabatically as an "ion-induced Stark effect". A detailed treatment of the symmetric top target molecule demonstrates the critical effect of molecular geometry upon the collision cross section. The predictions of the theory are confirmed for high rotational and translational quantum numbers by a 7094 computer solution for a diatomic target molecule. The cross section for this classical description is calculated from a statistical assortment of cases by solution of the Lagrangian equations of motion and is discussed in terms of dimensionless time and distance parameters. The predictions of the theory are in good agreement with large experimental cross sections reported by Hamill et al[1,2] for certain ion-polar molecule systems.

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1. Theard, L. P. and Hamill, W. H., J.A.C.S., 84, 1134 (1962).

2. Moran, T. F. and Hamill, W. H., J. Chem. Phys. 39, 1413 (1963).

J-10 MEASUREMENTS OF COLLISIONAL ENERGY TRANSFER BETWEEN ROTATIONAL ENERGY LEVELS IN CN

K. M. Evenson
National Bureau of Standards, Boulder, Colorado

Although few direct measurements of the rates of collisional energy transfer between rotational energy levels have been made, they are of importance for understanding the detailed behavior of plasmas and discharges. Measurements of such rates in CN will be reported. A novel microwave-optical technique which selectively populated a single rotation level of CN and permitted the observation of the redistribution of this population was utilized. CN was formed in the $A^2\Pi$ state when CH_2Cl_2 was added to the afterglow of a nitrogen discharge. The near coincidence of the $K' = 4$, $v = 10$ level of the $A^2\Pi$ state with the $K = 4$, $v = 0$ level of the $B^2\Sigma$ state permitted microwave transitions near 10 GHz from the more populated Π level to the Σ level. The increased population in the rotational levels neighboring the $K' = 4$ level of the $B^2\Sigma$ state were detected by measuring the increased optical emission due to the $B^2\Sigma - X^2\Sigma$ transitions near 3875Å. Collisional energy transfer was measured over a pressure range from 0.1 to 5 Torr. Rates of energy transfer were measured for rotational separations as great as eight. It was shown that rotational transitions having changes in the rotation quantum number greater than unity take place with high probability, contrary to the optical selection rule. These results are in agreement with those found in NO by Broida and Carrington.[1]

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1. H. P. Broida and T. Carrington, J. Chem. Phys. 38, 136 (1963).

Friday, October 16, 1:45 P. M.

SESSION K: BRUSH DISCHARGES; RADIATION

Chairman: O. Oldenberg
Harvard University, Cambridge, Mass.

K-1 THE BRUSH CATHODE (Invited Paper)

K.-B. Persson
U. S. National Bureau of Standards, Boulder, Colorado

Results of probe, spectroscopic and microwave studies are used to describe properties of a novel cold cathode discharge. The use of a brush cathode greatly exaggerates some of the usual cold cathode mechanisms, thus determining the interesting features of the plasma produced. The cathode fall is about an order of magnitude larger than for the corresponding normal cold cathode. The brush cathode generates a uniform electron beam in the energy range 1 to 10 kilovolts and a corresponding negative glow with a longitudinal dimension (reaching distance of the beam) one to two orders of magnitude larger than for the normal cathode. The large dimensions of the negative glow and the fact that it is extremely well behaved (no instabilities and no striations) make it ideal for a whole series of investigations in plasma physics and spectroscopy. The electron density in the helium plasma is in the range 10^{10} to 10^{14} cm^{-3}, the electron temperature in the range 0.05 to 0.10 eV. The negative glow is beam generated (essentially field free) and recombination dominated making it a practically uniform plasma ideal for the study of rate and transport coefficients. Preliminary measurements of the particle balance gives a recombination rate of 5×10^{-10} cm^3 sec^{-1} at 1100°K and an electron density of 3×10^{12} cm^{-3} in excellent agreement with the collisional-radiative recombination theory developed by Bates, Kingston and McWhirter.[1] The recombination light emitted by the plasma is sufficiently strong to make spectroscopic methods very useful for measurements of the electron density and the electron temperature. Lines in the series $2s^3S\text{-}np^3P^0$ are observed up to the quantum level n=30.

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1. D. R. Bates, A. E. Kingston, and R. W. McWhirter, Proc. Roy. Soc. A267, 297 (1962).

K-2 SPECTROSCOPIC DIAGNOSIS OF A BRUSH CATHODE HELIUM PLASMA

A. L. Schmeltekopf, R. L. Barger, K. B. Persson, and E. E. Ferguson
National Bureau of Standards, Boulder, Colorado

The results of detailed spectroscopic studies of the novel plasma described elsewhere in these proceedings will be reported. As many as twenty-seven members of the $n^3P - 2^3S$ series plus the continuum were observed. Electron temperatures were determined from the frequency dependence of the continuum intensity as well as from the relative intensities of lines emitted from levels in Saha equilibrium with the electron gas. Electron densities were measured by use of the Inglis-Teller relation and by absolute intensity measurements. Extensive molecular Rydberg series have been observed, and some of the above analyses carried out on them. These measurements have been carried out at various currents and neutral helium pressures in a field free plasma region, and yield electron densities from 5×10^{11} to 10^{13} and electron temperatures ranging from 1000°K to 1500°K. Between a sharp visible boundary near the brush cathode and the cathode the electric field has been measured by the Stark splitting of the $n^3D - 2^3P$ levels where n is 4 to 7.

K-3 ULTRAVIOLET LIGHT EMISSION FROM TOWNSEND DISCHARGES IN HYDROGEN

K. J. Nygaard
Princeton University, Princeton, N. J.

The total uv radiation from Townsend discharges in hydrogen has been measured by means of a sodium salicylate wavelength shifter in front of a photomultiplier tube. Self-sustained discharges with currents from 1-10 μ amps were studied, covering a range of E/p values from 80-250 v/Torr x cm. Let the excitation coefficient δ_o/p be defined as the number of uv photons produced when one electron is drifting 1 cm against the applied electric field E in a gas with pressure p = 1 Torr. It was found that δ_o/p versus E/p passes through a maximum at 150 v/Torr x cm. This is probably a consequence of the fact that the excitation cross section for the $2^1\Pi_u$ level as a function of electron energy passes through a maximum. The pressure dependence of the radiation can be ascribed to quenching with a quenching pressure equal to 20 Torr. An attempt has been made to evaluate separately the excitation coefficient for the $2^1\Pi_u$ radiation by subtracting other uv contributions from the total light intensities observed.

K-4 TRANSITION PROBABILITIES OF TWO STRONG OXYGEN MULTIPLETS IN THE NEAR INFRARED

J. E. Solarski and W. L. Wiese
National Bureau of Standards, Washington, D. C.

The two strong oxygen multiplets at 7773 and 8446 Å were studied in a well stabilized arc which burned in nitrogen with a small admixture of oxygen (5%). The oxygen content of the plasma was kept small to avoid self-absorption of the lines. The arc was operated at atmospheric pressure at a current of 50 amperes. The radiation was observed side-on with a photoelectric spectrometer and reduced to radial intensities by an Abel inversion procedure. Temperatures were determined for several radial distances from absolute intensity measurements of a nitrogen multiplet of known transition probability and by applying the arc equilibrium and conservation equations. The transition probabilities were then obtained from intensity measurements relative to the 7157 Å multiplet whose transition probability had been measured earlier.[1] The results agree within a few percent with those of a recent shock tube experiment by Doherty[2] and are about 20% smaller than some calculated values.[3,4]

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1. J. E. Solarski and W. L. Wiese, J. Opt. Soc. Am. 52, 592 (1962).

2. L. R. Doherty, Thesis Michigan University (1963).

3. D. R. Bates and A. Damgaard, Phil. Trans. Roy. Soc. London A242, 101 (1949).

4. P. S. Kelly, private communication.

K-5 ATOMIC AND MOLECULAR EMISSION IN THE NEGATIVE GLOW OF A HELIUM DISCHARGE*

W. B. Hurt+ and W W. Robertson
University of Texas, Austin, Texas

The spatial distribution of helium atomic and molecular radiation has been investigated in the negative glow of a dc discharge. The atomic radiation peaks sharply at the cathode edge of the negative glow, the molecular radiation less sharply at a greater distance from the cathode. Microwave quenching indicates that most of the atomic and all of the molecular radiation results from electron-ion recombination processes. The decrease in atomic radiation reflects the decrease in atomic ion concentration which is controlled primarily by diffusion away from the cathode and by three-body conversion to molecular ions. The molecular ions are lost by diffusion and by collisional-radiative recombination to the neutral molecule, with collisional processes predominating. The negative glow can thus be characterized as a plasma steady in time but with a one-dimensional spatial decay away from the cathode.

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

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K-6 INTENSITY AND INTENSITY RATIOS OF THE PRINCIPAL SINGLET AND TRIPLET LINES OF MOLECULAR HYDROGEN

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NASA-Lewis Research Center, Cleveland, Ohio

The only studies available for the excitation of the singlet and triplet lines of molecular hydrogen as a function of electron energy are those by Brasefield[1] and by Kruithof and Ornstein[2]. Brasefield studied the principal singlet and triplet lines in the energy range of 19 to 220 ev. However, he did not calibrate his photographic emulsion. Kruithof and Ornstein studied the 4634 Angstrom singlet line and the 4617 Angstrom triplet line and reported their results in intensity units. With the aid of these results, a calibration curve for the photographic emulsion used by Brasefield was determined. This calibration curve was used to replot Brasefield's results in intensity units and intensity ratios. Although imprecise, the resulting excitation functions are the only ones presently available for these spectral lines, and so must serve until more precise measurements are reported. Electron energies obtained by using intensity ratios reported in this paper are consistent with data from experiments by the present author.

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1. Brasefield, C. J., Phys. Rev. 34, 431 (1929).

2. Kruithof, A. A., and Ornstein, L. S., Physica, 2, 611 (1935).

INDEX TO AUTHORS