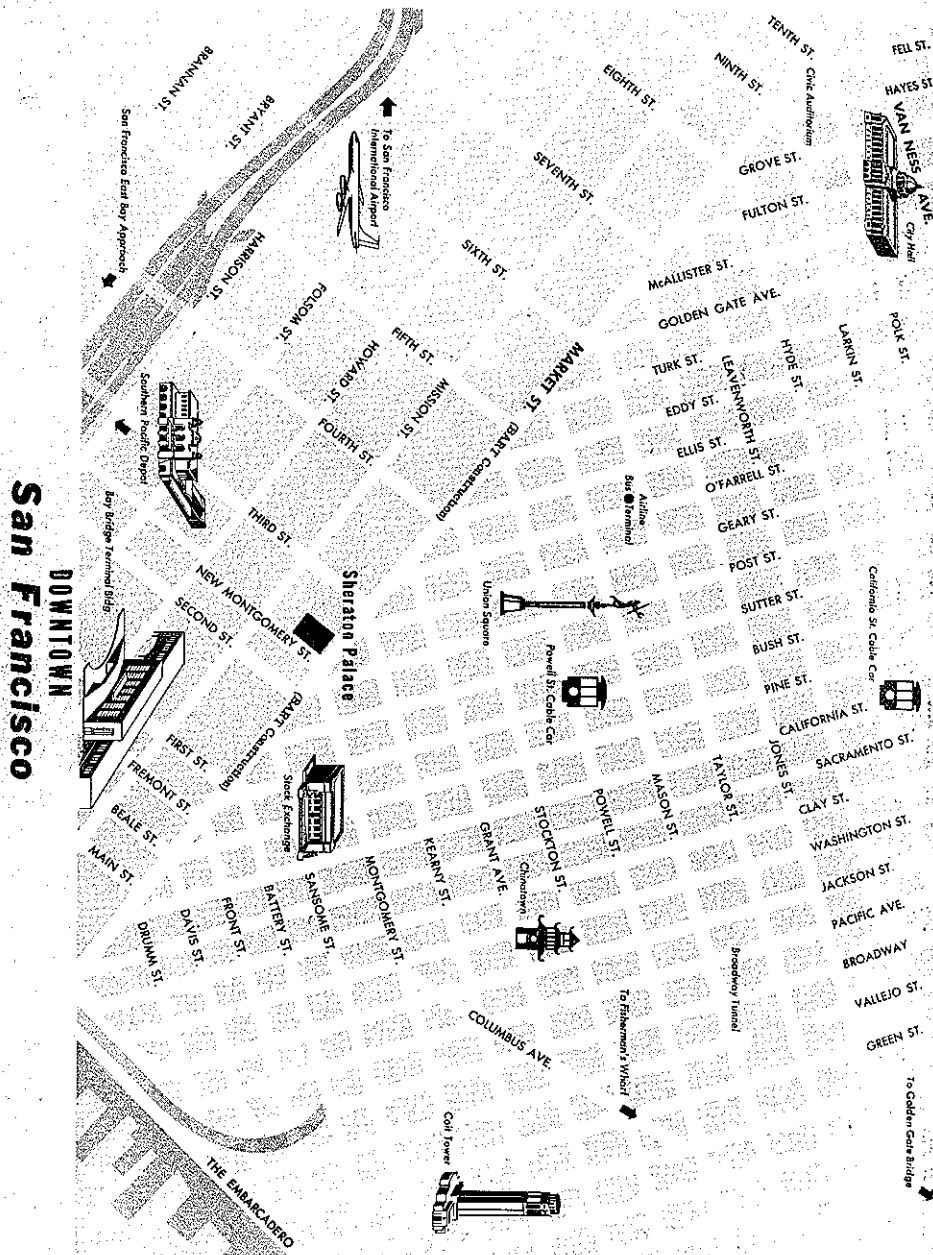**DOWNTOWN**
San Francisco

20TH
annual

GASEOUS
ELECTRONICS
CONFERENCE

TOPICAL CONFERENCE OF THE AMERICAN PHYSICAL SOCIETY

18-20 OCTOBER 1967
SAN FRANCISCO

LOCKHEED PALO ALTO RESEARCH LABORATORY
LOCKHEED MISSILES & SPACE COMPANY
PALO ALTO, CALIFORNIA

20TH ANNUAL

GASEOUS ELECTRONICS CONFERENCE

PROGRAM AND ABSTRACTS OF PAPERS

18–20 October 1967
Sheraton-Palace Hotel
San Francisco

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IN MEMORIAM

CARL KENTY

1902—1967

Distinguished worker in gaseous electronics;
sincerely admired, respected, and beloved
by all who knew him.

Twentieth Annual
GASEOUS ELECTRONICS CONFERENCE
Program and Index to Abstracts

Tuesday, October 17

7:00 –
10:00 P. M.   Registration and informal reception,
                Sheraton-Palace Hotel, Ralston Room

Wednesday, October 18

8:00 A. M.   Registration

9:00 A. M.   SESSION A: METASTABLES AND SURFACES
                Chairman: L. M. Chanin, University of
                             Minnesota, Minneapolis
                Location: Ralston Room

A-1   PHOTOEMISSION PROCESSES IN GOLD AND
                ALUMINUM IN THE EXTREME
                ULTRAVIOLET
                A. L. Morse, University of Southern
                California

A-2   PRODUCTION OF METASTABLE BEAMS
                OF H_2 AND N_2
                Robert N. Varney, Lockheed Palo Alto

A-3   INTERACTION OF METASTABLE ATOMS
                OF MERCURY WITH METAL SURFACES
                Walter L. Borst, University of California
                at Berkeley

A-4   AUGER ELECTRON EMISSION FROM Mo
                BY $O_2^+(X^2\Pi_g)$ AND $O_2^+(a^4\Pi_u)$
                BOMBARDMENT
                Dennis W. Vance, Xerox

A-5*   WORK FUNCTION EFFECTS ON AUGER
        ELECTRON EJECTION BY NOBLE GAS
        METASTABLE ATOMS
        D. A. MacLennan and T. A. Delchar,
        General Electric, Schenectady

A-6*   AUGER EJECTION OF ELECTRONS FROM
        TUNGSTEN BY OXYGEN CHEMISORPTION
        D. A. MacLennan, General Electric,
        Schenectady

Coffee Break

A-7   THE ENERGY DEPENDENCE OF THE
        DEACTIVATION CROSS SECTION FOR
        METASTABLE RARE GAS ATOMS
        Manfred Hollstein, D. C. Lorents, and
        J. R. Peterson, Stanford Research Institute

A-8   TEMPERATURE DEPENDENCE OF REAC-
        TIONS OF THE HELIUM METASTABLE
        ATOM
        C. R. Jones and W. W. Robertson,
        University of Texas

A-9   CALCULATION OF ION BOMBARDING
        ENERGY AND ITS DISTRIBUTION IN RF
        SPUTTERING
        R. T. C. Tsui, IBM

A-10   LOW TEMPERATURE DIFFUSION OF
        $He(2^3S_1)$ IN GASEOUS He^4: THE
        INTERACTION POTENTIAL AT LONG
        RANGE
        W. A. Fitzsimmons, N. F. Lane, and
        G. K. Walters, Rice University

A-11   THE EFFECTS OF CASCADING AND META-
        STABLE ATOMS ON THE DETERMINATION
        OF ELECTRON TEMPERATURE FROM
        RELATIVE LINE INTENSITIES IN A
        TENUOUS HELIUM PLASMA
        R. J. Sovie, NASA-Lewis

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*Combined papers

9:00 A.M.   SESSION B: RECOMBINATION; VACUUM
                         BREAKDOWN
             Chairman: R. C. Gunton, Lockheed
                         Palo Alto Research Laboratory,
                         Palo Alto
             Location: English/California Rooms

B-1   TEMPERATURE AND DENSITY DEPEND-
        ENCE OF THE RECOMBINATION
        COEFFICIENT OF He_2^+
        Gunthard K. Born, Ft. Monmouth

B-2   CORRECTION OF NEON RECOMBINATION
        DATA BY COMPUTER SOLUTION OF THE
        RECOMBINATION AND DIFFUSION CON-
        TROLLED CONTINUITY EQUATION
        L. Frommhold, University of Texas

B-3   ELECTRON TEMPERATURE DEPENDENCE
        OF RECOMBINATION OF Ar_2^+, Ne_2^+, AND N_2^+
        IONS AND ELECTRONS
        F. J. Mehr and Manfred A. Biondi,
        University of Pittsburgh

B-4   TEMPERATURE DEPENDENCE OF
        RECOMBINATION OF NO^+ IONS AND
        ELECTRONS
        C. S. Weller and Manfred A. Biondi,
        University of Pittsburgh

B-5   ELECTRON ENERGY RELAXATION AND
        REMOVAL IN CO
        M. H. Mentzoni and J. Donohoe, Sylvania

B-6   IONIC RECOMBINATION AND ION-
        NEUTRAL COLLISION FREQUENCIES
        IN ATMOSPHERIC GASES
        M. N. Hirsh, G. M. Halpern, and
        N. S. Wolf, Dewey Corp.

Coffee Break

B-7   RECOMBINATION OF ALKALI IONS IN A
         DENSE NEUTRAL GAS
         Milton M. Klein and A. Dalgarno, GCA
         and Queen's University, Belfast

B-8*   ELECTRODE SIZE AND PRETREATMENT
         EFFECTS ON VACUUM BREAKDOWN IN A
         TRANSVERSE MAGNETIC FIELD
         Alan Watson, Ion Physics Corp.

B-9*   FIELD ENHANCEMENT IN VACUUM
         BREAKDOWN
         Alan Watson, Ion Physics Corp.

B-10   EFFECT OF ELECTRODE TEMPERATURE
         ON VACUUM ELECTRICAL BREAKDOWN
         BETWEEN PLANE-PARALLEL COPPER
         ELECTRODES
         D. Kenneth Davies and Manfred A. Biondi,
         University of Pittsburgh

B-11   ELECTRICAL CONDUCTIVITY IN
         PARTIALLY IONIZED PLASMAS
         William L. Nighan, United Aircraft

1:45 P.M.   SESSION C: BREAKDOWN AND ELEC-
                         TRON TRANSPORT
             Chairman: J. M. Anderson, General
                         Electric Research & Develop-
                         ment Center, Schenectady
             Location: Ralston Room

C-1   DIFFUSION EFFECTS IN TOWNSEND
         DISCHARGES
         D. S. Burch and L. G. H. Huxley,
         Oregon State and Australian National
         University

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*Combined papers

C-2   THEORY OF ANOMALOUS ELECTRON
         DIFFUSION PARALLEL TO ELECTRIC
         FIELDS
         J. H. Parker Jr. and J. J. Lowke,
         Westinghouse

C-3   THERMAL ELECTRON DIFFUSION
         COEFFICIENT DETERMINATION FROM
         TIME-OF-FLIGHT SWARM STUDIES
         D. R. Nelson and F. J. Davis, Oak Ridge

C-4   THE MINIMUM EXTERNAL FIELD
         REQUIRED FOR CONTINUED STREAMER
         PROPAGATION
         E. Nasser and C. Manthiram, Iowa State
         University

C-5   EXACT NONLINEAR WAVES IN A
         COLLISIONLESS PLASMA
         W. P. Allis, M.I.T.

Coffee Break

C-6*   HIGH FREQUENCY BREAKDOWN IN NON-
         UNIFORM FIELDS
         Melvin Epstein, Aerospace Corp.

C-7*   KINETIC THEORY CALCULATIONS OF
         DATA FOR HIGH FREQUENCY BREAK-
         DOWN OF AIR
         Carl J. Lenander and Melvin Epstein,
         Aerospace Corp.

C-8   DEPENDENCE OF MICROWAVE BREAK-
         DOWN ON PREIONIZATION
         H. W. Bandel and A. D. MacDonald,
         Lockheed Palo Alto

C-9   THE TRANSITION FROM INERTIA-
         LIMITED CURRENT TO MOBILITY-
         LIMITED CURRENT
         J. H. Ingold, General Electric, Cleveland

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*Combined papers

C-10 THE THERMIONIC CATHODE IN A GAS-
FILLED DIODE
G. Ecker, University of Bonn

C-11 LASER-INDUCED BREAKDOWN IN SUPER
HIGH PRESSURE NEON
Guy Walter Haynes and Arwin A. Dougal,
University of Texas

1:45 P.M. SESSION D: HEAVY PARTICLE
EXCITATION
Chairman: N. G. Utterback, A. C.
Electronics, Santa Barbara
Location: English/California Rooms

D-1 EXCITATION OF VACUUM UV SPECTRA OF
N AND O BY keV PROTONS
William A. Brown, Lockheed Palo Alto

D-2 EXCITATION OF VACUUM UV SPECTRA
BY THE IMPACT OF 10- TO 120-keV
PROTONS AND H ATOMS ON THE MOLE-
CULES O_2, N_2O, NO, CO_2, CO, AND CH_4
D. Kent Anderson and E. A. Teppo,
Montana State University

D-3 MEASUREMENT OF AN EMISSION CROSS
SECTION FOR THE COLLISION REACTION
$H^+ + N_2(X, v = 0) \rightarrow H(3P, 3D) + N_2^+(B, v = 0)$
USING PHOTON COINCIDENCE
TECHNIQUES
J. Roger Sheridan, Stephen J. Young, and
John S. Murray, University of Alaska

D-4 ELEVATED ROTATIONAL TEMPERA-
TURES IN N_2^+ EMISSIONS EXCITED BY
ION IMPACT ON N_2
John P. Doering, Johns Hopkins University

D-5 EMISSION CROSS SECTIONS FOR LYMAN-
ALPHA RADIATION FROM H_2^+-H
COLLISIONS
T. D. Gaily and R. Geballe, University
of Washington

Coffee Break

D-6 LYMAN-ALPHA PRODUCTION AND
POLARIZATION IN He^+ COLLISIONS
WITH H AND H_2
Robin A. Young, R. F. Stebbings, and
J. William McGowan, General Atomic

D-7 OBSERVATIONS OF CHARGE TRANSFER
EXCITATION IN COLLISIONS BETWEEN
ALKALI ATOMS AND IONS
A. Salop, D. C. Lorents, and
J. R. Peterson, Stanford Research Institute

D-8 COLLISION-INDUCED DISSOCIATION OF
LOW KINETIC ENERGY IONS
T. F. Moran and J. R. Roberts, Georgia
Tech. and Bellarmine College

D-9 THE ABUNDANCE OF EXCITED IONS IN
AN NO^+ ION BEAM
R. F. Mathis, J. A. Rutherford, and
B. R. Turner, General Atomic

D-10 IONIZATION CROSS SECTION IN
COLLISION OF LIGHT ATOMS
Ira L. Karp, Florida Institute of
Technology

Thursday, October 19

8:45 A.M. SESSION E: DRIFT TUBE EXPERIMENTS
Chairman: D. S. Burch; Oregon State
University, Corvallis
Location: Ralston Room

E-1 TRANSPORT PHENOMENA OF CONVERT-
ING IONS IN DRIFT TUBES
J. H. Whealton, J. B. Giancola, and
S. B. Woo, University of Delaware

E-2   DRIFT MOBILITY TUBE/MASS SPEC-
TROMETER MEASUREMENTS OF THE
ENERGY DEPENDENCE OF ION-
MOLECULE REACTIONS
J. Heimerl, R. Johnsen, and
Manfred A. Biondi, University of
Pittsburgh

E-3*   POSITIVE ION MOBILITIES IN DRY AIR
G. Sinnott, D. E. Golden, and
R. N. Varney, Lockheed Palo Alto

E-4*   POSITIVE ION-MOLECULE REACTIONS
IN DRY AIR
D. E. Golden, G. Sinnott, and
R. N. Varney, Lockheed Palo Alto

E-5   MOBILITY OF O_2^+ AND CO_2^+ IONS IN
CO_2 GAS
M. Saporoschenko and W. W. Wisner;
Southern Illinois University

8:45 A.M.   SESSION F: EXCITED ATOMS AND
MOLECULES
Chairman: J. W. Hooper, Georgia
Institute of Technology,
Atlanta
Location: Comstock Room

F-1   THE RADIATIVE LIFETIME OF THE $sp^6\ ^2S$
STATE OF Ar II
George M. Lawrence, Douglas Advanced
Research Laboratory

F-2   AN EXPERIMENTAL DETERMINATION OF
THE RELATIVE CONTRIBUTIONS OF
RESONANT AND ELECTRON IMPACT
COLLISIONS TO THE EXCITATION OF Ne
ATOMS IN He-Ne LASER DISCHARGES
R. T. Young, Jr., C. S. Willett, and
R. T. Maupin, Harry Diamond Laboratories

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*Combined papers

F-3   IONIZATION OF ARGON AND OF OXYGEN
ON IMPACT OF 2^3S AND 2^1S HELIUM
ATOMS
J. A. Herce, K. D. Foster, and
E. E. Muschlitz Jr., University of Florida

F-4   COLLISIONAL RELAXATION OF ν_1 AND ν_3
MODES OF CO_2 BY H_2O, Xe, AND CO
P. K. Cheo, Bell Telephone Laboratories

F-5   AMBIPOLAR DIFFUSION FREQUENCY
SHIFTS IN THE HELIUM-NEON LASER
Frederick J. Mayer, Case Western Reserve
University

Coffee Break

10:30 A.M.   SESSION G: PLENARY SESSION
Chairman: L. H. Fisher, Lockheed
Palo Alto Research Laboratory,
Palo Alto
Location: Ralston Room

The Executive Committee has the privilege
of scheduling an invited paper by Professor
Leonard B. Loeb in honor of his extensive
services to the entire field of gaseous elec-
tronics, and in celebration of the 20th Gaseous
Electronics Conference.

G-1   Invited Paper: THE NEED FOR MORE
EXPERIMENTAL WORK IN GASEOUS
ELECTRONICS
Leonard B. Loeb, University of California,
Berkeley

11:30 A.M.   ANNUAL BUSINESS MEETING. Ralston
Room.

1:45 P.M.   SESSION H: ELECTRON SCATTERING
                          AND ATTACHMENT
             Chairman: G. H. Dunn, Joint Institute for
                          Laboratory Astrophysics,
                          Boulder
             Location: Comstock Room

H-1   ON ANGULAR DISTRIBUTION STUDIES OF
        LOW ENERGY ELECTRON SCATTERING
        FROM H_2, N_2, AND CO
        H. Ehrhardt, H. Langhans, F. Linder,
        and H. S. Taylor, University of Freiburg
        and University of Southern California

H-2   ANTIRESONANCE IN ELECTRON-HELIUM
        SCATTERING CALCULATION
        T. F. O'Malley, General Research Corp.

H-3   POLARIZATION DISTORTION EFFECTS IN
        LOW ENERGY ELECTRON-H_2
        SCATTERING
        Neal F. Lane and R. J. W. Henry, Rice
        University and Kitt Peak

H-4   ASYMPTOTIC EXPANSION OF FRANCK-
        CONDON OVERLAP INTEGRALS FOR
        DISSOCIATIVE IONIZATION OF DIATOMIC
        MOLECULES
        K. E. McCulloh, N.B.S.

H-5*   CALCULATION BY QUANTUM DEFECT
        METHOD OF ELECTRON SCATTERING
        BY MOLECULE-ION: H_2^+
        M. C. Weinberg and R. S. Berry,
        University of Chicago

H-6*   ELECTRON-ATOM ELECTRON-MOLECULE
        SCATTERING FUNCTIONS FROM
        PSEUDOPOTENTIALS
        B. Schneider and M. C. Weinberg,
        University of Chicago

*Combined papers

Coffee Break

H-7   ELECTRON IMPACT IONIZATION CROSS
        SECTION IN CESIUM
        K. J. Nygaard, Sperry Rand Research
        Center

H-8   LOW ENERGY ATTACHMENT IN OZONE
        J. L. Moruzzi and A. V. Phelps,
        Westinghouse

H-9   DISSOCIATIVE ATTACHMENT IN CO AND
        NO
        P. J. Chantry, Westinghouse

H-10   DISSOCIATIVE ELECTRON ATTACHMENT
        TO MOLECULES
        L. G. Christophorou and J. A. Stockdale,
        Oak Ridge

H-11   PLASMA TRANSIENT RESPONSE AND THE
        DETERMINATION OF COLLISION DATA
        R. L. Bruce, F. W. Crawford, and
        R. S. Harp, Stanford University

1:45 P.M.   SESSION I: POSITIVE COLUMNS AND
                          ARCS
             Chairman: W. W. Robertson, University
                          of Texas, Austin
             Location: Ralston Room

I-1   EFFECT OF WALL TEMPERATURE ON
        PROPERTIES OF A POSITIVE COLUMN
        Richard L. Moore and Joseph E.
        Butterworth, McDonnell Douglas Corp.

I-2   MICROWAVE RADIATION TEMPERATURES
        IN He, Ne, A, Kr, AND Xe DC DISCHARGES
        C. C. Leiby, Jr. and C. W. Rogers,
        AFCRL

Coffee Break

*L-8 and L-9 are combined papers.

L-9* COLLISION-INDUCED MIXING IN THE 2^3P LEVELS OF HELIUM
L. D. Shearer, Texas Instruments

1:45 P.M. SESSION M: AFTERGLOWS
Chairman: R. M. Hill, Lockheed Palo Alto Research Laboratory, Palo Alto
Location: Ralston Room

M-1 FREE-FALL DIFFUSION IN THE MERCURY DISCHARGE AFTERGLOW
B. C. Gregory, Trent University

M-2 MICROWAVE INVESTIGATION OF THE TRANSITION FROM AMBIPOLAR TO FREE DIFFUSION IN HELIUM AFTERGLOWS
R. J. Freiberg and L. A. Weaver, Hughes Research Laboratories and Westinghouse

M-3 OBSERVATION AND COMPUTATION OF OXYGEN AFTERGLOWS
R. C. Gunton, Lockheed Palo Alto

M-4 REACTIONS IN 4:1 MIXTURES OF N_2 AND O_2 DURING AND AFTER INTENSE IONIZATION
F. E. Niles, U.S.A. Ballistics Research Laboratories

M-5 POST-BREAKDOWN ELECTRON DENSITY DECAY IN AIR
W. Dobrov and A. D. MacDonald, Lockheed Palo Alto

M-6 ELECTRON REMOVAL IN ARGON WAKES
Wade M. Kornegay, Lincoln Laboratory

*L-8 and L-9 are combined papers.

M-7 THE PRODUCTION AND LOSS OF N_2^+ IONS IN THE NITROGEN AFTERGLOW
R. E. Lund and H. J. Oskam, University of Minnesota

M-8 ANOMALOUS EXCITATION OF THE SECOND POSITIVE SYSTEM OF NITROGEN
E. C. Zipf, University of Pittsburgh

M-9 TIME-DEPENDENT STUDY OF THE EMITTED LIGHT AND ELECTRON DENSITY IN A LOW-PRESSURE HELIUM AFTERGLOW
C. B. Collins and W. B. Hurt, Southwest Center for Advanced Studies

Session A

METASTABLES AND SURFACES

Chairman:

L. M. Chanin
University of Minnesota
Minneapolis

Wednesday, October 18
9:00 A. M.
Ralston Room

PHOTOEMISSION PROCESSES IN GOLD AND ALUMINUM IN THE EXTREME ULTRAVIOLET*

A. L. Morse
University of Southern California

Measurements of the photoelectric yield of gold and aluminum versus angle of incidence, together with electron energy distributions, have been made between 150 and 1000 Å. Below 700 Å, the peak yields will be shown to occur at large angles of incidence and to be relatively independent of the degree of polarization. This is explained in terms of the yield decreasing with the depth of absorption of the photons, due to the electrons being inelastically scattered to energies less than the work function, thus making it impossible for them to escape. The mean depth of absorption, in turn, depends on the optical properties, such that the photon free path is determined by the extinction coefficient k and the angle of refraction primarily by the index n, with both n and k calculated from reflectance data. The yield per absorbed photon was found to increase with angles of incidence until the critical angle was reached and to remain relatively constant for still greater angles. Although there was some dependence on the degree of polarization, this dependence was found to vanish if a small retarding potential was applied to reject the lowest energy photoelectrons.

PRODUCTION OF METASTABLE BEAMS OF H_2 AND N_2 *

Robert N. Varney
Lockheed Palo Alto Research Laboratory

A simple ion source has been used[1,2] differing only from a typical one for a mass spectrometer in being operated at higher pressure (about 0.05 Torr). It has been reported previously that a beam of fast, excited particles emerged from this source in addition to the ions. The ions have been deflected away to permit study of the neutral beam. Critical identification of the beam particles has been made by causing them to strike a tungsten ribbon target and searching with a quadrupole mass spectrometer for surface-ionized products, and in addition by changing the surface work function between that of freshly flashed tungsten and lightly oxidized tungsten. The respective work functions are believed to be ~ 4.5 eV and ~ 6.3 eV. H_2 particles showed no surface ionization on impact with the clean tungsten surface but showed strong surface ionization on the oxidized surface. The ions leaving the surface were H^+. For N_2 particles, there was a small amount of N_2^+ from the clean surface and relatively less from the oxidized surface, but a great deal of NO^+ emerged from the latter. No N^+ ions were produced with either surface. The results narrow the allowable energy, M, of the metastable state of H_2 to the range, $11.7 < N < 13.5$ eV. For N_2, the bookkeeping is more complicated, but the appearance of N_2^+ on clean tungsten suggests that the metastable level is above 11 eV.

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[1]R. N. Varney, 19th GEC, Atlanta, Ga., 12−14 Oct 1966; Bull. Am. Phys. Soc., 11, 12, 224 (1967).
[2]R. N. Varney, Phys. Rev., 157, 113 (1967).

INTERACTION OF METASTABLE ATOMS OF MERCURY WITH METAL SURFACES*

Walter L. Borst

University of California at Berkeley

Secondary electron emission and surface ionization due to thermal metastable Hg atoms on an air-contaminated tungsten surface were studied. An approximate metastable excitation function for the excitation by electron impact was obtained by monitoring secondary electrons liberated from the target as a function of exciting electron energy. It appears that atoms in the $^3D_3$ metastable state (9.05 eV) of Hg were most active in liberating secondary electrons and undergoing surface ionization. The cylindrical tungsten target, which surrounds the excitation chamber, was probably heavily contaminated by air since due to its large size it could not be outgassed at a high temperature. The experimental tube was baked at 300°C for 20 hr which resulted in a base pressure of about 1×10^{-9} Torr. Hg gas pressures ranged from 10^{-4} to 10^{-3} Torr. Secondary electrons ($\approx 10^{-12}$ A) and surface ions ($\approx 10^{-12}$ A) could be removed from the target by a properly biased highly transparent grid in front of the target. The electron beam of 1×10^{-7} A and 0.3 eV energy spread (FWHM) through the excitation chamber was collimated by an axial magnetic field of 100 G.

AUGER ELECTRON EMISSION FROM Mo BY $O_2^+\left(X^2\Pi_g\right)$ AND $O_2^+\left(a^4\Pi_u\right)$ BOMBARDMENT

Dennis W. Vance

Research Laboratories, Xerox Corporation

Measurements have been made of the yield, γ_i, of secondary electrons emitted upon bombardment of an "atomically clean" polycrystalline molybdenum ribbon by 30 to 400 eV O_2^+ ions at normal incidence. The yield is sensitive to the energy of the bombarding electrons used to produce O_2^+. For electron energies less than 16.0 eV, the value of γ_i is constant (for a given ion energy) and presumably is the electron yield for ground state $\left(X^2\Pi_g\right) O_2^+$. As the electron energy is increased above 16.0 eV, the value of the yield increases monotonically, attaining a constant value for electron energies above 50 eV. The increase in yield is due to the presence of O_2^+ in the metastable $a^4\Pi_u$ state (energy, 16.0 eV). Measurements of the dependence of the electron yield on ion energy at two ionizing electron energies (15.7 and 60.0 eV) permit independent determination of the absolute electron yield for the $X^2\Pi_g$ ions and the relative yield for the $a^4\Pi_u$ ions. For ground state ions, the electron yield is a strong, nearly linear function of the ion kinetic energy, increasing from 8.0×10^{-3} electrons/ion at 50 eV to 4.0×10^{-2} electrons/ion at 400 eV. The yield for excited state ions, however, is nearly constant over the entire ion energy range. If the population of excited states in the ion beam is estimated from photoionization data, then the absolute value of the excited state yield can be computed giving the value 5.95×10^{-2} electrons/ion at 400 eV.

WORK FUNCTION EFFECTS ON AUGER ELECTRON EJECTION BY NOBLE GAS METASTABLE ATOMS

D. A. MacLennan and T. A. Delchar
General Electric Research and Development Center

A tungsten single crystal cut to expose the (111) and (110) planes was employed to examine the influence of work function on electron ejection by incident helium or argon metastable atomic beams. The (111) and (110) surfaces have work functions of approximately 4.4 and 5.9 eV, respectively.[1] With incident helium metastable atoms the electron yield of the (111) surface was about 1.5% higher than that of the (110) surface. With argon, this difference was about 4%. The ejected electron energy distributions were essentially the same for both crystal faces with helium and argon, respectively. Theory[2,3] and experimental work comparing tungsten and molybdenum[3] indicate that the electron yields are greatly affected by changes in work function. A model has been constructed which resolves this discrepancy. The basic feature is that the Auger process takes place with those electrons on the vacuum side of the surface electron cloud. Ultrahigh vacuum conditions and atomically clean surfaces were used throughout.

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[1] T. A. Delchar and G. Ehrlich, J. Chem. Phys., 42, 2686 (1965).
[2] H. D. Hagstrum, Phys. Rev., 96, 336 (1954).
[3] H. D. Hagstrum, Phys. Rev., 104, 672 (1956).

AUGER EJECTION OF ELECTRONS FROM TUNGSTEN BY OXYGEN CHEMISORPTION

D. A. MacLennan
General Electric Research and Development Center

A measurement has been made of the energy distribution and approximate yield of electrons ejected from a polycrystalline tungsten ribbon during oxygen chemisorption. The distribution function, large near zero energy, falls off rapidly reaching zero near 3 eV. The total yield is 10^{-9} electrons per oxygen molecule adsorbed. A model for the chemisorption process has been constructed in terms of Franck-Condon potential energy curves for O_2 molecule-surface and O-O atom-surface interactions. An incoming molecule follows the O_2 curve which is initially below the O-O curve. If after passing the crossover point the now upper O_2 curve is followed, there exists a high probability for an Auger transition to the lower O-O curve. The energy of transition will be given to a conduction band electron which can be ejected when the separation between the potential energy curves is greater than the metal work function. The yield and energy distribution of the ejected electrons can be explained in terms of the high Auger transition probability.

THE ENERGY DEPENDENCE OF THE DEACTIVATION CROSS SECTION FOR METASTABLE RARE GAS ATOMS*

Manfred Hollstein, D. C. Lorents, and J. R. Peterson
Stanford Research Institute

Metastable rare gas atom beams with energies between 50 eV and 500 eV have been produced by charge transfer of ions passing through alkali vapor. The interaction of these beams with the gases N_2, C_2H_2, Ar, and He has been studied by measuring the attenuation of the beam by ionization and excitation transfer reactions. The beam travels down the axis of a cylindrical cavity which is divided into three separate chambers. Ions produced from a beam segment of known length by the interaction of the primary beam with target gas, are trapped and collected inside each chamber. The deactivation cross section is determined from the three ionization currents, the pressure, and the length of each chamber. The collision partners were chosen so that deactivation is predominantly due either to Penning ionization or symmetric excitation transfer. For interaction energies > 100 eV, the Penning ionization cross sections are in the 10^{-15} cm^2 range and are nearly independent of the energy. At energies < 100 eV, the cross sections increase slowly with decreasing energy. The symmetric excitation transfer cross sections for He* + He and Ar* + Ar decrease linearly with $(\ln E)^2$, as do symmetric charge exchange reactions.

TEMPERATURE DEPENDENCE OF REACTIONS OF THE HELIUM METASTABLE ATOM

C. R. Jones and W. W. Robertson
University of Texas

The temperature dependence of the cross sections of several reactions of metastable helium has been measured in a pulsed static afterglow. The three-body conversion of metastable atoms to metastable molecules $\left[\text{He}(2^3\text{S}) + 2\text{He} \rightarrow \text{He}_2\left(^3\Sigma_u^+\right) + \text{He}\right]$ shows an exponential increase in rate constant over the temperature range 193° to 400°K, indicating, as previously reported,[1,2] an activation energy of ~ 0.06 eV. The near-resonance reaction $\text{He}(2^3\text{S}) + \text{Ne} \rightarrow \text{He} + \text{Ne}(2\text{s})$, responsible in part for the population inversion in the He-Ne laser, also shows an exponential increase in cross section with gas temperature which can be interpreted in terms of a potential barrier of 0.04 eV. The cross section for the Penning reaction $\text{He}(2^3\text{S}) + \text{Ar} \rightarrow \text{He} + \text{Ar}^+ + e$ should have the $T^{-1/3}$ dependence predicted for orbiting collisions.[3] The measured cross section, from 193° to 500°K, decreases with increasing cross section, but at a rate that seems to be somewhat slower than expected.

[1]A. V. Phelps and J. P. Molnar, Phys. Rev., 89, 1202 (1953).
[2]K. H. Ludlum, L. P. Larson, and James M. Caffrey, Jr., J. Chem. Phys., 46, 127 (1967).
[3]E. E. Ferguson, Phys. Rev., 128, 210 (1962).

CALCULATION OF ION BOMBARDING ENERGY AND ITS DISTRIBUTION IN RF SPUTTERING

R. T. C. Tsui
IBM T. J. Watson Research Center

The energy distribution of bombarding ions in typical rf sputtering conditions has been calculated from first principle. The Mathieu-type equations of motion of ions and electrons in the cathode fall region are numerically integrated by computer with various initial and boundary conditions. The self-biased dc component, V_{dc}, is found to be 0.999928 of one-half the peak-to-peak rf potential applied across the cathode darkspace, which is in agreement with the value from mobility considerations. The ion energy distribution is found to depend on rf voltage and frequency, darkspace distance and e/mass ratio of the ion. Physical explanations are provided for the fact that large percentages of the ions possess energies greater than V_{dc}. The effect of high electron temperature in the plasma on ion energy distribution has been studied and found to be very small. Trajectories of both ion and electron in the cathode fall region have also been calculated.

LOW TEMPERATURE DIFFUSION OF $He\left(2^3S_1\right)$ IN GASEOUS He^4; THE INTERACTION POTENTIAL AT LONG RANGE*

W. A. Fitzsimmons,† N. F. Lane, and G. K. Walters
Rice University

Discharge afterglow techniques were used to measure the diffusion coefficient of $He^4 \left(2^3S_1\right)$ in gaseous He^4 over the temperature range from 1° to 4.2°K. The results indicate that D is a monotonically increasing function of temperature, varying only slightly from the curve that can be extrapolated from the previously available high temperature data. At 1° and 4.2°K, respectively, D is 10.5 and 24.0 cm^2/sec at a density corresponding to 1-mm Hg pressure at 300°K. Qualitatively, this behavior of the diffusion coefficient at low temperatures is to be expected because of the long range repulsive interaction between the 2^3S_1 state and 1^1S_0 ground state in He.[1,2] However, using available theoretical interaction potentials, partial wave analysis of the low energy scattering process predicts diffusion coefficients much smaller than the measured values. This suggests that the long-range repulsive interaction is being overestimated. The experimental results are used to make a better estimate of the interaction potential at long range.

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[1] R. A. Buckingham and A. Dalgarno, Proc. Roy. Soc. (London), A213, 327 (1952).
[2] F. D. Colegrove, L. D. Schearer, and G. K. Walters, Phys. Rev., 135, 2A (1964).

THE EFFECTS OF CASCADING AND METASTABLE ATOMS ON
THE DETERMINATION OF ELECTRON TEMPERATURE FROM
RELATIVE LINE INTENSITIES IN A TENUOUS HELIUM PLASMA

R. J. Sovie
NASA-Lewis Research Center

The method[1,2] for determining electron temperature from the relative intensities of helium singlet and triplet series spectral lines has been frequently discussed in the recent literature.[3-8] However, the effects of cascading and electron-metastable atom interactions on the observed line intensities have not been heretofore treated. These processes are considered and the results show that the presence of metastable atoms will have a small effect if cascading effects are accounted for experimentally. In addition, limitations on the applicability of the technique and experimentally measurable criteria for determining its validity are discussed.

[1]S. P. Cunningham, USAEC Rep WASH-289 (1955).
[2]R. J. Sovie, Phys. Fluids, 7, 13 (1964).
[3]I. M. Podgornyi and G. V. Sholin, Soviet Phys. DOKLADY, 10, 48 (1965).
[4]V. M. Strunnikov, Optics and Spectr., 20, 1 (1966).
[5]R. F. DeVries and R. Mewe, Phys. Fluids, 9, 414 (1966).
[6]V. L. Vdovin et al., Atumnaya Energiya, 20, No. 2, 148 (1966).
[7]R. Mewe, Brit. J. Appl. Phys., 17, 1239 (1966).
[8]R. W. P. McWhirier, in Plasma Diagnostic Techniques, R. H. Huddlestone and S. L. Leonard, eds. (Academic Press, New York, 1965).

Session B

RECOMBINATION; VACUUM BREAKDOWN

Chairman:

R. C. Gunton
Lockheed Palo Alto Research Laboratory
Palo Alto

Wednesday, October 18
9:00 A.M.
English/California Rooms

TEMPERATURE AND DENSITY DEPENDENCE OF THE RECOMBINATION COEFFICIENT OF He_2^+

Gunthard K. Born
Institute for Exploratory Research, Ft. Monmouth

The recombination coefficient $\alpha(N_e, T_e)$ of He_2^+ was measured in helium afterglow plasmas (12 Torr $\leq$ p $\leq$ 20 Torr; t $\gtrsim$ 1 msec) as a function of electron density and gas temperature under conditions where the temperature of the electrons equals that of the neutral gas (2.5×10^{12} cm$^{-3} \leq N_e \leq 2 \times 10^{13}$ cm^{-3}; 900°K $\leq$ T $\leq$ 2200°K). The electron density was measured with a free-space microwave interferometer (70 GHz); the gas temperature was determined from the velocity of sound waves detected with microwaves (9 GHz).[1] The decay of several lines and bands was also monitored. For the whole range of densities and temperatures, the measured α of He_2^+ was found equal to the theoretical collisional-radiative recombination rate of He^+. In spite of the high vibrational excitation of the recombining He_2^+ corresponding to the high gas temperatures in this experiment, no evidence for dissociative processes was detected. In particular, the light decay could not be reconciled with collisional-dissociative recombination, contrary to Robertson's interpretation of his experiments.[2]

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[1] G. K. Born and R. G. Buser, J. Appl. Phys., 37, 4918 (1966).
[2] W. W. Robertson, J. Chem. Phys., 42, 2064 (1965).

CORRECTION OF NEON RECOMBINATION DATA BY COMPUTER SOLUTION OF THE RECOMBINATION AND DIFFUSION CONTROLLED CONTINUITY EQUATION

L. Frommhold
University of Texas

The continuity equation for the electrons in a decaying plasma is solved in three dimensions, including ambipolar diffusion and a loss term quadratic in the electron density (i.e., recombination). The geometries investigated are the finite cylinder and rectangular parallelepiped. Some quantitative general rules are given for correction of recombination data from microwave afterglow studies following the pattern set by Gray and Kerr in their one-dimensional study.[1] For three-dimensional geometries we find two to four times smaller linear reciprocal electron density ranges (f-values) and about twofold larger corrections to the apparent recombination coefficient than given by Gray and Kerr's one-dimensional (infinite cylinder) analysis.[1] We also confirmed Gray and Kerr's predictions when we treated one-dimensional cases. We have therefore re-evaluated several existing studies of recombination in neon, applying our solution to the actual geometries and modes used in each case. We find that all of the experiments yield corrected recombination coefficients within the range $\alpha\left(Ne_2^+\right) = (1.75 \pm 0.1) \times 10^{-7}$ cm^3/sec at 300°K, indicating that this is the most accurately determined recombination coefficient today.

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[1] E. P. Gray and D. E. Kerr, Ann. Phys., 17, 276 (1959).

ELECTRON TEMPERATURE DEPENDENCE OF RECOMBINATION OF Ar_2^+, Ne_2^+, AND N_2^+ IONS AND ELECTRONS*

F. J. Mehr and Manfred A. Biondi
University of Pittsburgh

A three-mode microwave afterglow apparatus has been used to study the dependence of the recombination coefficient, α, on electron temperature over the range $300°K \leq T_e \leq 11,000°K$. The α values are determined by comparison of the observed afterglow electron density decays with computer solutions of the electron continuity equation including recombination and ambipolar diffusion losses. The room temperature ($T_e = T_+ = T_{gas} = 300°K$) values for Ar_2^+, Ne_2^+, and N_2^+ are 8.3, 1.6, and 3.6×10^{-7} cm^3/s, respectively. The observed variations with electron temperature may be represented as T_e^{-n}, where $n = 0.7$, 0.43, and 0.32 for Ar_2^+, Ne_2^+, and N_2^+ ions, respectively. The dependence for argon, $n = 0.7$, is weaker than that recently obtained[1] from shock tube studies ($n \simeq 1.5$), over the range of 1000° to 4000°K, where $T_e = T_+ = T_{gas}$. This discrepancy can arise from the changing vibrational state population of the molecular ions in the shock tube experiment. The $n = 0.43$ dependence for Ne_2^+ is in good agreement with results of Kasner,[2] who varied the gas temperature from 295° to 503°K.

[1]J. N. Fox and R. M. Hobson, Paper 1.1.5, 8th Intern. Conf. on Phenom. in Ionized Gases, Vienna, 1967.
[2]W. H. Kasner, submitted to Phys. Rev.

TEMPERATURE DEPENDENCE OF RECOMBINATION OF NO^+ IONS AND ELECTRONS*

C. S. Weller and Manfred A. Biondi
University of Pittsburgh

Photoionized plasma afterglows of NO have been studied by combined microwave and mass spectrometric techniques. Nitric oxide neon mixtures (5−65 mTorr NO, 2−7 Torr Ne) are contained in a 10-cm resonant cavity where they are ionized by a "single-pulse" of Lyman-alpha radiation. A temporal spectrum of ions diffusing to the wall is obtained by a differentially pumped mass spectrometer and multichannel analyzer. Analysis of the electron density decay curves to obtain an electron-ion recombination coefficient for NO^+ is complicated by the conversion of NO^+ to the dimer ion $(NO)_2^+$. At sufficiently low densities of nitric oxide the $(NO)_2^+$ concentration becomes negligible, and the NO^+ wall current follows the electron density decay. From comparisons of experimental electron density decay curves with computer solutions of the electron continuity equation, the values

$$\alpha(NO^+) = (7.8 \pm 1), \left(4.1 \pm \begin{matrix} 0.4 \\ 0.2 \end{matrix}\right), (3.1 \pm 0.3) \times 10^{-7} \ cm^3/sec$$

at $T = 200°$, $300°$, and $450°K$, respectively, are obtained. The electron-ion recombination coefficient exhibits an approximate T^{-1} dependence. These results are in reasonable agreement with those of Gunton and Shaw.[1]

[1]R. C. Gunton and T. M. Shaw, Phys. Rev., 140, A756 (1965).

ELECTRON ENERGY RELAXATION AND REMOVAL IN CO*

M. H. Mentzoni and J. Donohoe
Sylvania Electronic Systems

Microwave interferometry, cross modulation, and radiometer technique were used to investigate the dc discharge afterglow in carbon monoxide. The pressures ranged generally from 1 to 5 Torr. Two-body electron-ion recombination was in evidence around 1 Torr with $\alpha_r = 6.8 \pm 1.2 \times 10^{-7}$ cm^3 sec^{-1}. Cross modulation was only achieved with TWT-amplified disturbing signals ($P_{peak} = 15$ W) with fall times of 165 nsec. This, it was found, can be regarded as an upper limit for the electron energy relaxation. The Maxwellian average of the electron energy loss rate per unit number density was computed based on the published cross section[1,2] yielding a moderate decrease from the value 2.28×10^{-23} to 1.77×10^{-23} erg cm^3/sec in the interval $T_{el} = 300°$ to $2000°K$, with $T_{gas} = 300°K$. This should result in relaxation times within the experimentally determined upper limit.

[1]Kazuo Takayanagi, J. Phys. Soc. Japan, 21, 507 (1966).
[2]R. D. Hake and A. V. Phelps, Phys. Rev., 158, No. 1, 70 (1967).

IONIC RECOMBINATION AND ION-NEUTRAL COLLISION FREQUENCIES IN ATMOSPHERIC GASES*

M. N. Hirsh, G. M. Halpern, and N. S. Wolf
G. C. Dewey Corporation

Impedance probe and mass spectrometer measurements have been used to determine ion-neutral collision frequencies and ionic recombination coefficients for species of interest in the lower ionosphere. Following the removal of the ionizing electron beam from the gas at sufficiently high pressures in the experimental system described previously,[1] thermal secondary electrons rapidly attach to O_2 molecules, leaving a slowly decaying positive ion-negative ion plasma. The impedance of a large capacitor containing this plasma was measured as a function of time in the afterglow for CO_2-contaminated O_2 and airlike N_2:O_2 mixtures over the pressure range of 1 to 20 Torr. Ion species occurring in the plasma are sampled by diffusion and studied with a monopole mass filter. The dominant ions are CO_2^+ and CO_3^- in oxygen, and NO^+, NO_2^-, and NO_3^- in the airlike mixture. From the impedance measurements the dominant ion removal mechanism is two-body ionic recombination, with the coefficients $\alpha_i(O_2) = (5.9 \pm 1.2) \times 10^{-8}$ cm^3/sec, $\alpha_i(N_2:O_2) = (4.4 \pm 1.0) \times 10^{-8}$ cm^3/sec. Ion-neutral collision frequencies in these gases are $\nu_i(O_2) = (4.0 \pm 2.0) \times 10^6$ p sec^{-1}, $\nu_i(N_2:O_2) = (7.7 \pm 4.0) \times 10^6$ p sec^{-1}, where p is gas pressure in Torr. Implications of these results to the ionosphere will be discussed.

[1]M. N. Hirsh et al., Bull. Am. Phys. Soc., 11, 495 (1966).

RECOMBINATION OF ALKALI IONS IN A DENSE NEUTRAL GAS*

Milton M. Klein
GCA Corporation
and
A. Dalgarno
Queen's University, Belfast

Calculations have been made by the method of Bates and Khare[1] of the recombination coefficient α of the alkali ions Li^+, Na^+, K^+, and Rb^+ in several rare gases (He, Ne, and A) and atomic oxygen. The method of calculation has been extended to take into account the variation of the momentum transfer cross section for collisions between the incident electrons and the atom. The results show the anticipated increase of α with the density of the neutral gas and its decrease with temperature. The weak effect of density upon α at the higher temperatures is noted and discussed. Increasing the atomic weight of the ionic species yields a slow decrease in α which becomes virtually constant for the heavier species. The weak dependence of α on the ionic species is in qualitative agreement with the results of Bates, Kingston, and McWhirter.[2] The effects of parameters such as atomic weight and cross section and the strong minimum in the argon cross section upon the relative values of the recombination coefficients is discussed.

[1] D. R. Bates and S. P. Khare, Proc. Phys. Soc., 85, 231 (1965).
[2] D. R. Bates, A. E. Kingston, and R. W. P. McWhirter, Proc. Roy. Soc., A, 267, 297 (1962).

ELECTRODE SIZE AND PRETREATMENT EFFECTS ON VACUUM BREAKDOWN IN A TRANSVERSE MAGNETIC FIELD*

Alan Watson
Ion Physics Corporation

Large and small uniform field copper electrodes were initially fired at 900°C in either vacuum or hydrogen before transferring to a large vacuum test chamber for further bakeout at 400°C. A statistically designed experiment at 10^{-8} Torr in which voltage was raised 10 kV every 2 minutes showed that from 0.75 to 3.0 cm, but not below this, the breakdown voltage and prebreakdown currents were both dramatically reduced by a 250-G transverse magnetic field. Hydrogen firing and small electrodes, individually and in combination, enhanced the breakdown voltage with or without magnetic field present. An auxiliary experiment revealed that, for the same gap separation, the threshold for gas surges appearing was raised by the magnetic field. The corresponding current threshold was unaltered, but the ultimate prebreakdown current was reduced by the magnetic field. The evidence supports the theory that gas released from the anode at a critical current level accumulates according to the pumping conductance and the subsequent breakdown is facilitated by a weak transverse magnetic field.

FIELD ENHANCEMENT IN VACUUM BREAKDOWN*

Alan Watson
Ion Physics Corporation

A theoretical analysis of the surface migration of atoms at a cathode protrusion in an electric field[1] shows that the enhancement factor β will vary with voltage V and gap separation d such that:

$$\frac{V^2}{d} \doteq \frac{constant}{\beta}$$

If the breakdown voltage V_B corresponds to a critical β, then it will increase almost as the square root of gap separation, a relation which is observed experimentally. Development of the Fowler-Nordheim expression for the total current I to account for the corresponding area change of the emission site shows that the value of $1/V_B \ln \left(I/V_B^2 \right)$ should be constant at all gap separations. Experimental data are presented to confirm that this is so after some spark conditioning.

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[1]F. M. Charbonnier, et al., Proceedings of the International Symposium on Insulation of High Voltage in Vacuum (1964).

EFFECT OF ELECTRODE TEMPERATURE ON VACUUM ELECTRICAL BREAKDOWN BETWEEN PLANE-PARALLEL COPPER ELECTRODES

D. Kenneth Davies and Manfred A. Biondi*
Westinghouse Research Laboratories

Combined measurements of current-voltage, prebreakdown characteristics, and breakdown voltage have been made for plane-parallel copper electrodes in ultrahigh vacuum as a function of both cathode initial temperature and anode initial temperature, respectively. These measurements have been carried out for an electrode separation of 0.1 cm over the temperature range from 313° to 913°K. From the experimental data the temperatures of the hottest point of the cathode surface, $(T_C)_s$, and of the anode surface, $(T_A)_s$, at breakdown have been determined as a function of electrode initial temperature, Over the whole range of the investigation it is found that $(T_A)_s$ is greater than $(T_C)_s$. Moreover, the values of $(T_A)_s$ at breakdown are essentially independent of anode initial temperature and have a mean value of (1100 ± 150)°K. In contrast, the values of $(T_C)_s$ at breakdown increase with increasing values of cathode initial temperature. The results suggest that a thermal instability of a point on the anode surface leads to breakdown. A model will be presented of the steps leading to ionization by electron collisions with copper vapor in the gap.

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*Physics Department, University of Pittsburgh.

ELECTRICAL CONDUCTIVITY IN PARTIALLY IONIZED PLASMAS

William L. Nighan
United Aircraft Research Laboratories

The variational description of the plasma transport phenomena of Robinson and Bernstein[1] has been applied to the calculation of plasma electrical conductivity. The plasmas under investigation are in the partially ionized regime where consideration must be given to the effect of electron-electron as well as electron-atom and electron-ion collisions. The extremal nature of plasma transport phenomena permits a novel approach to this problem resulting in considerable simplification of numerical procedures while maintaining a high degree of accuracy. As a demonstration of the method, the electrical conductivity of an argon plasma has been calculated using the electron-argon atom momentum transfer cross section as determined by Frost and Phelps.[2] The conductivity has been calculated for electron temperatures in the 300° to 30,000°K range and for degrees of ionization ranging from the weakly to the fully ionized limit. Because of the accuracy of the electron-atom cross section used in the calculation and the exactness of the method, the resultant values of electrical conductivity for any electron temperature and degree of ionization are correct to within ±25%.

[1] B. B. Robinson and I. B. Bernstein, Ann. Phys. (N.Y.), 18, 110 (1962).
[2] L. S. Frost and A. V. Phelps, Phys. Rev., 136, A1538 (1964).

Session C

BREAKDOWN AND ELECTRON TRANSPORT

Chairman:

J. M. Anderson
General Electric Research & Development Center
Schenectady

Wednesday, October 18
1:45 P.M.
Ralston Room

DIFFUSION EFFECTS IN TOWNSEND DISCHARGES

D. S. Burch* and L. G. H. Huxley
Ion Diffusion Unit, Australian National University

Although experiments on the growth of current in a uniform electric field have generally given results in good agreement with Townsend's theory, in which diffusion was ignored, the diffusive contribution to the current density is known to be nonnegligible in some circumstances. This contradiction is resolved in the analysis to be presented and it is concluded that the experiments may be expected to verify Townsend's law in all but extreme cases. Nevertheless, the role of diffusion is not trivial; consideration of its consequences forces a reinterpretation of the primary ionization coefficient α which appears in Townsend's law.

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*On leave from Oregon State University.

THEORY OF ANOMALOUS ELECTRON DIFFUSION PARALLEL TO ELECTRIC FIELDS

James H. Parker, Jr., and John J. Lowke
Westinghouse Research Laboratories

Recent experimental results[1,2] demonstrate that the apparent rate of electron diffusion parallel to an electric field can differ significantly from that in the perpendicular direction. In the case of argon, for example, the parallel diffusion at high E/p was found to be about one-seventh of the transverse diffusion. We have explained this anomalous behavior by taking account of the effect of electron density gradients on the solution of the Boltzmann equation representing a pulse of electrons under the influence of a uniform electric field. The theory, which gives an energy distribution that is a function of position within the pulse, predicts that while the drift velocity of the pulse is given by conventional mobility formulas, the half width in the field direction is characterized by a new effective diffusion coefficient. In the limit high pressure, this new longitudinal diffusion coefficient can be expressed as integrals involving the momentum transfer cross section and the unperturbed energy distribution. Results for helium and argon are found to be within 20% of the experimental values.

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[1]E. B. Wagner, F. J. Davis, and G. S. Hurst, to be published in the J. Chem. Phys.
[2]M. T. Elford and R. W. Crompton, private communication.

THERMAL ELECTRON DIFFUSION COEFFICIENT DETERMINATION FROM TIME-OF-FLIGHT SWARM STUDIES*

D. R. Nelson and F. J. Davis
Oak Ridge National Laboratory

A dwell-drift technique for measurement of thermal electron diffusion coefficients, D_t, has been devised. The electron swarm from the photocathode is pulsed to the center of the reaction chamber where it is left to diffuse in a zero field for accurately measured periods of dwell time, T, before being pulsed to the electron multiplier detector at the anode. From the distribution in the time-of-arrival of electron swarms at the anode, the full width at $1/e$, δx, is obtained as a function of T. The thermal diffusion coefficient is then determined from the slope of the δx^2 versus T line. In the case of argon, a most interesting discontinuity occurs showing a sharp initial increase of δx^2 in the δx^2 versus T plot. This discontinuity is interpreted as being a consequence of electrons passing through the well-known Ramsauer-Townsend window during the equilibration of the swarm to a thermal energy distribution. A measure of the time of equilibration can be obtained from a study of the shape of the discontinuity in the δx^2 versus T curve. $D_t P$ values for methane and ethylene are 0.25 cm^2 Torr/μsec and 0.28 cm^2 Torr/μsec, respectively. CO_2, CO, N_2, H_2, He, and Ne are presently under investigation.

THE MINIMUM EXTERNAL FIELD REQUIRED FOR CONTINUED STREAMER PROPAGATION*

E. Nasser and C. Manthiram
Iowa State University

Positive streamers in atmospheric air were observed capable of advancing axially and laterally into low field regions approaching or reaching the plane cathode at voltages lower than spark threshold.[1] The zero-field theory explains how such ionization waves survive by continuous advance without any external field and should therefore propagate indefinitely, something which was not observed to happen. A small electric field was therefore predicted to exist. Experimental and computational studies were conducted to determine this minimum external field intensity required to assure continued ionization ahead of the streamer tip and further propagation. Using the Lichtenberg technique,[1] the distance traveled by the streamers was plotted as a function of the applied voltage with the electrode spacing as a parameter. The electric field between the electrodes was computed using a digital computer and applying the principle of charge simulation. From these data of 2% accuracy, the field intensity at the point where a streamer stops advancing was determined to be 480 to 590 V/cm for positive streamers and is independent of location and voltage.

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

EXACT NONLINEAR WAVES IN A COLLISIONLESS PLASMA*

W. P. Allis

Los Alamos Scientific Laboratory and Research Laboratory
of Electronics, M.I.T.

A potential wave of the form $\phi(x - ut)$ is assumed and the distribution function is required to be Maxwellian in the laboratory frame wherever the potential vanishes. The Liouville equation then determines the distribution f_F of free electrons everywhere. If this distribution were linearized the conventional theory would be recovered, but this is not done. Selected assumptions are made concerning the distribution f_T of trapped electrons. All integrals can then be evaluated and Poisson's equation solved exactly. It yields periodic but generally not sinusoidal waves. With the potential wells properly filled, the dispersion equation may be expanded in absolutely convergent series in powers of ϕ and u^2. These waves are undamped. The series in u^2 may be inverted to give an asymptotic expansion in powers of $1/u^2$ with a minimum error of the order of $e^{-mu^2/2kT}$. This expansion agrees exactly with linear theory but without Landau damping. It represents the undamped waves to which the perturbation theory waves lead after phase mixing of the trapped electrons. With the potential wells empty, terms in $\sqrt{\phi}$ enter as predicted by Bernstein, Green, and Kruskal. These waves disagree with linear theory.

HIGH FREQUENCY BREAKDOWN IN NONUNIFORM FIELDS

Melvin Epstein

Aerospace Corporation

Exact analytical solutions have been obtained for the breakdown condition in both planar and cylindrical geometries for a number of physically realistic electric field distributions. These solutions indicate that in many practical situations the field nonuniformities can significantly affect the field strength at which breakdown occurs. Since exact analytical solutions could be obtained only for a special set of field distributions, an approximate analytical method was developed to treat arbitrary field distributions. This method, which includes consideration of a field strength dependent diffusion coefficient, is based on a variational formulation of the breakdown problem. A Ritz method is used to solve the variational problem. Comparisons between the exact and approximate solutions showed that a one-term representation of the electron density distribution results in good agreement between the two solutions. The use of two terms to represent the electron density distribution resulted in an error of a fraction of a percent in the field strength required to produce breakdown.

KINETIC THEORY CALCULATIONS OF DATA FOR HIGH FREQUENCY BREAKDOWN OF AIR

Carl J. Lenander and Melvin Epstein
Aerospace Corporation

The computer program developed by Carleton and Megill[1] for the calculation of the electron energy distribution function was modified to include the newest, most reliable cross sections in air and effects of fields well above breakdown.[1] Ionization and attachment rates calculated using this program are in excellent agreement with values derived from breakdown experiments[2] at high pressures. At low pressures, the predicted rates are considerably higher than the values inferred from experiments. It was further found that the effective field concept did not correlate the data. Nonetheless, the use of these results together with the nonuniform field breakdown analysis of Epstein[3] resulted in very good predictions of the breakdown of air in MacDonald's cavity experiments.[2] It is concluded that the use of the effective field concept and the neglect of nonuniform field effects in the diffusion controlled regime may lead to improper inferences of ionization rates from breakdown experiments. The direct calculation of ionization rates by kinetic theory appears to provide a more rational and accurate method of generating these data.

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[1] N. P. Carleton and L. R. Megill, Phys. Rev., 126, 2089 (1962).
[2] A. D. MacDonald, P. U. Gaskell, and H. N. Gitterman, Phys. Rev., 130, 1841 (1963).
[3] M. Epstein, "High Frequency Breakdown in Nonuniform Fields," 20th GEC.

DEPENDENCE OF MICROWAVE BREAKDOWN ON PREIONIZATION

H. W. Bandel and A. D. MacDonald
Lockheed Palo Alto Research Laboratory

Microwave breakdown thresholds have been measured in a TM_{010} mode cavity ($f_0 = 3.061$ GHz, $\Lambda = 0.391$ cm) as a function of electron density in the afterglow of a previous discharge. Measurements have been made with helium, neon, and argon at pressures for which the electron density can be determined by measurement of the frequency shift of the cavity. Preionization densities ranged from about 10^6 electrons/cm^3 to about 10^9 electrons/cm^3 for each set of measurements. With increasing electron density, the predominant loss mechanism changes from free diffusion to ambipolar diffusion and breakdown field strengths decrease to a fraction of the values obtained without preionization. In general, the transition is complete for densities of about 5×10^8 electrons/cm^3. At low pressures, when the collision frequency is much less than the microwave radian frequency, the reduction in breakdown field strength is as much as 90% and occurs mainly within one order of magnitude change of electron density. However, with increasing pressure the relative change is smaller and takes place over a wider density range.

THE TRANSITION FROM INERTIA-LIMITED CURRENT TO MOBILITY-LIMITED CURRENT

J. H. Ingold
General Electric Lighting Research Laboratory

The transition from inertia-limited current to mobility-limited current is studied theoretically by taking moments of the Boltzmann equation for electrons in a gas-filled diode. It is shown that the resulting current-voltage characteristic reduces naturally to the Child-Langmuir $V^{3/2}$-law for $\nu_c/\nu_p \ll 1$, where ν_c is the frequency of elastic collisions between electrons and atoms, and ν_p is the plasma frequency for electrons, and to the high-pressure V^2-law for $(m/M)\nu_c^2/\nu_p^2 \gg 1$, where m and M are the electronic and atomic masses, respectively. For the intermediate pressure range where $(m/M)\nu_c^2/\nu_p^2 < 1 < \nu_c/\nu_p$, the current voltage characteristic is a hybrid mixture of the $V^{3/2}$-law and the V^2-law. The complete theoretical current-voltage characteristic is valid for all gas pressures. It is shown further that the Child-Langmuir law can be cast into the form of an Ohm's law, with the plasma frequency for electrons playing the role of a collision frequency.

THE THERMIONIC CATHODE IN A GAS-FILLED DIODE

G. Ecker
Institute for Theoretical Physics, University of Bonn

The work of Langmuir and his followers has provided us with a satisfactory theory of the vacuum diode which is in good agreement with the experimental observations. A sufficient theory for the gas-filled diode is not yet available. There have been attempts to interpret the observations of the gas-filled diode in analogy to Langmuir's theory of the vacuum diode. We investigated the planar gas-filled diode with a thermionic cathode. Analysis and machine solutions of the quasi-Maxwellian mode provide the (V-j) characteristic of the diode and other quantities of interest. The results show that the usual interpretation of the (V-j) characteristic in analogy to the vacuum case is misleading. Instead of the terms retarding field region, zero field point, and accelerating field region, the terms quasi-Maxwellian mode, point of mode change, and run-away mode seem to describe the physical phenomena more appropriately.

LASER-INDUCED BREAKDOWN IN SUPER HIGH PRESSURE NEON*

Guy Walter Haynes and Arwin A. Dougal
Department of Electrical Engineering and Laboratories for
Electronics and Related Science Research,
The University of Texas

Laser-induced, electrical breakdown of super high pressure neon gas is investigated experimentally and analytically to delineate mechanisms responsible for optical breakdown of gases. Electrical breakdown in Ne at pressures up to 30,000 psi is produced by focusing the optical radiation from a 30 MW, 40 nsec pulsed, giant pulse ruby laser. An experimental curve of the threshold electric field required to produce breakdown versus the gas pressure indicates a threshold electric field which decreases with increasing gas pressure and with a possible minimum at or above 30,000 psi. These experimental results are indicative of electron-impact ionization. Analytically, microwave theory is extended to optical frequencies for electrical breakdown in Ne at super high pressures. Solutions are obtained for Ne from 1,000 to 100,000 psi for a characteristic diffusion length of 10^{-4} cm. The analytical calculations indicate a threshold electric field minimum at 30,000 psi. It is concluded that electrical breakdown in Ne occurs through electron-impact ionization following energy gain by free electrons accelerated in the incident field while undergoing collisions with neutrals.

Session D

HEAVY PARTICLE EXCITATION

Chairman:

N. G. Utterback
A. C. Electronics
Santa Barbara

Wednesday, October 18
1:45 P. M.
English/California Rooms

EXCITATION OF VACUUM UV SPECTRA OF N AND O BY keV PROTONS*

William A. Brown
Lockheed Palo Alto Research Laboratory

Relative excitation efficiencies of uv atomic lines of N and O have been measured using analyzed protons of from 3 to 80 keV impacting molecular nitrogen and oxygen. Using SWR film in a uv spectrograph,[1] we observe atomic and ionic lines of nitrogen, together with members of the Lyman-Birge-Hopfield and Birge-Hopfield band systems, and Lyman-alpha due to electron capture by protons. With oxygen as the target, the only prominent spectral features in the wavelength band of 800 to 1800 Å are the resonance multiplets of O and O^+ at 1302 and 835 Å, plus, again, Lyman-alpha. A LiF window photomultiplier tube was used in the spectrometer to establish the energy dependence of the stronger spectral lines, N 1493, H 1216, and O 1302. Target gas pressures were held at about 4μ. With the exception of Lyman-alpha, the line intensities were found to be linear in pressure and proton beam intensity over more than a decade. We obtained absolute excitation cross sections by connecting our measurements to those of Van Zyl et al.[2]

EXCITATION OF VACUUM UV SPECTRA BY THE IMPACT OF 10- TO 120-keV PROTONS AND H ATOMS ON THE MOLECULES O_2, N_2O, NO, CO_2, CO, AND CH_4

D. Kent Anderson and E. A. Teppo
Montana State University

The spectra excited by the collision of protons and neutral hydrogen atoms with various molecular gases were scanned with a vacuum monochromator. The prominent lines in the spectral range of 1200 to 3000 Å are atomic lines characteristic of the atoms in the target molecule and the Lyman-alpha line of atomic hydrogen. In addition to these atomic lines, the Miescher-Baer bands of NO^+ and the first negative bands of CO^+ are strongly excited. Cross sections for the emission of Lyman-alpha and the atomic oxygen multiplet at 1304 Å were measured separately for both proton and H atoms impact on O_2 in the energy range of 10 to 120 keV. The Lyman-alpha cross sections for O_2 are similar to those reported[1] for N_2 over the same energy range.

MEASUREMENT OF AN EMISSION CROSS SECTION FOR THE COLLISION REACTION $H^+ + N_2(X, v = 0) \rightarrow H(3P, 3D) + N_2^+(B, v = 0)$ USING PHOTON COINCIDENCE TECHNIQUES

J. Roger Sheridan, Stephen J. Young, and John S. Murray
University of Alaska

In previous cross-section measurements for heavy particle collisions, the initial and final states of both colliding partners have not been specified. An experiment which includes knowledge of the initial and final states of both particles has been carried out at our laboratory for the specific case of simultaneous excitation of the 3P or 3D state of hydrogen and the $B^2\Sigma_u^+(v = 0)$ state of N_2^+ in charge exchange collisions of protons with ground state nitrogen molecules. We have measured the cross section for production of Balmer alpha radiation from the 3P or 3D state and N_2^+ first negative $(0, 0)$ radiation in the same collision. This was accomplished by counting single photons in coincidence. The emission cross sections determined in preliminary measurements are 2.6×10^{-18} cm^2 at a proton energy of 7.4 keV and 0.8×10^{-18} cm^2 at 21.2 keV. An educated estimate of the relative populations of 3P and 3D levels yields excitation cross sections for the 3P and 3D states separately. A comparison of these measured cross sections with available data for total charge exchange and charge exchange with excitation indicates that the excitations of N_2^+ and H are not correlated.

ELEVATED ROTATIONAL TEMPERATURES IN N_2^+ EMISSIONS EXCITED BY ION IMPACT ON N_2 *

John P. Doering
Johns Hopkins University

To investigate rotational excitation in ion-molecule collisions, we have measured the rotational temperature of the N_2^+ first negative $(0, 0)$ band (λ 3914Å) as a function of projectile ion velocity for several positive ions of energies 2 to 17 keV incident on N_2. The apparatus used included a duoplasmatron ion source, mass analyzer, and a specially designed 1-m Fastie-Ebert monochromator. The rotational lines of the transition were completely resolved in all cases. Projectile ions used were He^+, N_2^+, and Ar^+. We find that the rotational temperature is equal to the gas temperature at laboratory projectile ion velocities greater than 2×10^8 cm/sec. Below this velocity, however, the rotational temperature rises and reaches 650°K at 3×10^7 cm/sec (the lowest velocity used). The effect is independent of the nature of the exciting ion and appears to depend solely on its velocity.

EMISSION CROSS SECTIONS FOR LYMAN-ALPHA RADIATION FROM H_2^+-H COLLISIONS*

T. D. Gaily and R. Geballe
Department of Physics, University of Washington

Emission cross sections for Lyman-alpha radiation from the two reactions $H_2^+ + H \rightarrow H_2^+ + H*(2P)$ (target excitation) and $H_2^+ + H \rightarrow H*(2P) + H^+ + H$ (projectile breakup) have been measured for ion energies from 1.0 to 5.0 keV. In addition, the radiation polarization for the target excitation reaction has been determined over the same energy range.[1] A crossed-beam technique with an oxygen filtered photomultiplier radiation detector was used. Doppler shifted radiation from atoms moving at ion beam speeds was absorbed by the filter and allowed the simultaneous reaction signals to be separated. Observed target excitation results will be compared with both experimental and theoretical results for proton excitation of H atoms.[2] Low energy structure in the target excitation cross section reproduces that observed with proton projectiles. The cross section for projectile breakup will be compared with earlier measurements which used other target atoms.

LYMAN-ALPHA PRODUCTION AND POLARIZATION IN He^+ COLLISIONS WITH H AND H_2 *

Robin A. Young, R. F. Stebbings,† and J. Wm. McGowan
General Atomic Division of General Dynamics Corporation
John Jay Hopkins Laboratory for Pure and Applied Science

Measurements of the Lyman-alpha production from $He^+ + H(1s) \rightarrow He^+ + H(2p)$ collisions have been obtained over the energy range from 0.5 to 30 keV. At the lower ion energies the cross section remains large; this fact reflects the rotational interaction between states of the collision complex HeH^+. A similar result had been reported by Stebbings et al.[1] for the H^+-H collision system. Also presented are measurements of the total cross section for Lyman-alpha production from He^+-H_2 collisions. Some values of the polarization have been obtained for emission of Lyman-alpha from the collisions of He^+, Ne^+, and Ar^+ with atomic hydrogen.

OBSERVATIONS OF CHARGE TRANSFER EXCITATION IN COLLISIONS BETWEEN ALKALI ATOMS AND IONS*

A. Salop, D. C. Lorents, and J. R. Peterson
Stanford Research Institute

Optical excitation produced in collisions between alkali atoms and various atomic and molecular ions is being studied using a crossed-beam apparatus. Radiation emitted in the beam intersection region is observed at right angles using an optically "fast" grating spectrograph and a monochromator-photomultiplier combination. Initial studies are being made in the wavelength range of 3000 to 5000 $\overset{\circ}{A}$. For 1.5 keV He^+ on K and Rb, the spectra observed are identified primarily with excited alkali ions resulting from electron capture into the ground state of He. For most of the observed lines, the upper level corresponds to $3p^5 4p$ excitation for K^+ and $4p^5 5p$ excitation for Rb^+. The energy defects for these reactions range from -2.5 to -6.7 eV for K and from -3.0 to +1.3 eV for Rb. For 1.5 keV N_2^+ on K and Na, the predominant spectra are the bands of the second positive system in N_2 resulting from electron capture into the excited $C^3\Pi_u$ states of N_2. Measurements of the energy dependence of the emission cross section for various lines produced by charge transfer excitation are in progress.

COLLISION-INDUCED DISSOCIATION OF LOW KINETIC ENERGY IONS*

T. F. Moran
Georgia Institute of Technology
and
J. R. Roberts†
Bellarmine College

Dissociative reactions of diatomic molecule ions with various atoms and molecules have been measured for H_2^+, O_2^+, and N_2^+ ions having kinetic energies less than 20 eV. In our experimental arrangement, the initial velocity components of the reactant ions are axial to the slit system of the analyzing mass spectrometer which serves to discriminate against them but allows for effective collection of the slow reaction products. The cross sections for the production of low kinetic energy H^+, N^+, and O^+ ions in the dissociation of H_2^+, O_2^+, and NO^+ range from 0.1 to 1.0 $\overset{\circ}{A}^2$ with reasonably sharp onsets. Kinetic energy thresholds for atomic ion formation indicate a large percentage of the available relative energy is transferred into internal energy in the colliding partners. The mechanism of formation of slow atomic ions in these low velocity interactions is consistent with the occurrence of nonvertical electronic transitions[1] of the ionized species in heavy particle encounters.

[1] R. L. Champion, L. D. Doverspike, and T. L. Bailey, J. Chem. Phys., 45, 4377 (1966).

THE ABUNDANCE OF EXCITED IONS IN AN NO$^+$ ION BEAM*

R. F. Mathis, J. A. Rutherford, and B. R. Turner
General Atomic Division of General Dynamics Corporation
John Jay Hopkins Laboratory for Pure and Applied Science

Measurements have been made on a beam of NO$^+$ ions to determine the relative abundances of excited state and ground state ions. The experimental procedure involved the attenuation of the ion beam in a reaction chamber filled with a gas chosen so that different states of the ion were attenuated with different rates. The ions were formed from NO by impact of electrons with energies of 25, 50, and 100 eV. The determination was made ~ 20 μsec after the ions were formed so that only long-lived states remained in the beam. It was found that the pressure in the ion source, as well as the electron energy, influenced the abundance of excited state ions. Several gases, H_2, N_2, O_2, and A, were used in the reaction chamber to assess the importance of de-excitation processes and to reduce the possibility of error which would arise from identical loss cross sections for excited and ground states. For example, it was found that using electron energies above 50 eV and low source pressures, more than one-third of the ions in the beam are excited.

IONIZATION CROSS SECTION IN COLLISION OF LIGHT ATOMS*

Ira L. Karp
Florida Institute of Technology

For H$^-$-He collisions at 4 to 20 eV, center of gravity system, a model assuming classical dynamics for the nuclei and direct electron ejection to the continuum gives ionization cross section deviating by a possible factor of 4 from the data,[1] with satisfactory energy dependence, but correspondingly for He-He collisions at 10^3 to 10^4 eV, gives ionization cross section two orders of magnitude lower than data.[2] A second model of He-He collisions uses the Landau-Zener formula,[3] describing, in terms of potential energy curve constants, the feeding of nuclear motion energy into the ground $1s^2 2s^2$ electronic shell, which jumps to the $1s^2 2p^2$ state, going into the continuum at large internuclear distances to a final ionized state, giving satisfactory energy dependence but large errors due both to uncertainties in potential constants and the dynamical models.

[1] E. E. Muschlitz, Jr., Phys. Rev., 95, 635 (1954).
[2] A. Rostagni, Nuovo Cimento, II, 621 (1934).
[3] Massey and Burhop, Electronic and Ionic Impact Phenomena (Oxford-Clarendon Press), 2nd ed., pp. 445−450; 513−540.

Session E

DRIFT TUBE EXPERIMENTS

Chairman:

D. S. Burch
Oregon State University
Corvallis

Thursday, October 19
8:45 A.M.
Ralston Room

TRANSPORT PHENOMENA OF CONVERTING IONS IN DRIFT TUBES*

J. H. Whealton, J. B. Giancola, and S. B. Woo
University of Delaware

The transport and diffusion phenomena in drift tubes of two charged species, A and B, where A converts to B, are analyzed. Contrary to Beaty's[1] complete absorber model, asserting that

$$I_{collector} = D[\partial\rho/\partial x]_{collector}$$

we employ an open shutter model for the collector, having

$$I = -v\rho + D[\partial\rho/\partial x]$$

I, ρ, v, and D are current, ion density, drift velocity, and diffusion coefficient, respectively. The effect on the computed values of mobility, μ, diffusion coefficient, D, and reaction rate, α, from the same experimental data, using either model is discussed. Our solution is obtained without assuming that the ion temperatures of reacting species are equal, as was assumed in Beaty's case. Therefore it will more accurately determine μ, D, and α at any E/p_0 where the ion temperatures become significantly different. Analysis is also done on the transport phenomena of two interconverting charged species, assuming a spatial distribution of finite width initially for each species. This solution is discussed in connection with the collisional detachment of O^- phenomena in drift tubes.

[1]E. C. Beaty and P. Patterson, Phys. Rev., 137, A346 (1965).

DRIFT MOBILITY TUBE/MASS SPECTROMETER MEASUREMENTS OF THE ENERGY DEPENDENCE OF ION-MOLECULE REACTIONS*

J. Heimerl, R. Johnsen, and Manfred A. Biondi
University of Pittsburgh

Ions generated in a pulsed discharge are admitted to a drive region where an applied electric field controls their transit time and energy. Various gases are added to the drift region to permit the parent ion to undergo ion-molecule reactions. The ions arriving at the collector are sampled by a differentially pumped quadrupole mass spectrometer. Two methods of determining reaction rates are used; one depends upon analysis of the arrival time spectrum of the product ions. The second method varies the parent ions' total transit time by reversing or interrupting the drift field for various time intervals. The decay of this ion signal is measured as a function of the additional transit time to determine the reaction rate. Reaction rates determined by the two methods are in agreement. The values for the reactions $He^+ + N_2$ and $He^+ + O_2$ at 300°K agree with results of other investigations,[1] and the 2-body reaction rate appears to be independent of ion energy over the measured range, $300 \leq "T_+" \leq 1200°K$.

[1]See, for example, F. C. Fehsenfeld, A. L. Schmeltekopf, P. D. Goldan, H. I. Schiff, and E. E. Ferguson, J. Chem. Phys., 44, 4087 (1966).

POSITIVE ION MOBILITIES IN DRY AIR*

G. Sinnott, D. E. Golden, and R. N. Varney
Lockheed Palo Alto Research Laboratory

Mobilities of mass identified positive ions in dry air have been measured for a range of E/N between 20 and 2000 Townsends. The measured zero field mobilities were 1.6 for N_2^+, 3.5 for NO^+, and 2.5 for O_2^+ in air. The high E/N data yield average momentum transfer cross sections in air of 110, 21, and 30 $\mathring{A}^2$, respectively, for N_2^+, NO^+, and O_2^+.

POSITIVE ION-MOLECULE REACTIONS IN DRY AIR*

D. E. Golden, G. Sinnott, and R. N. Varney
Lockheed Palo Alto Research Laboratory

A drift tube and differentially pumped, quadrupole, ion mass spectrometer combination was used to measure the reaction rate constants for N^+, O^+, and N_2^+ in air as a function of E/N (electric field strength/density). In this work the density ranged from 7×10^{14} to 4.2×10^{15} cm^{-3} and E/N ranged from 7×10^{-16} to 1.4×10^{-14} (V-cm^2). This range of E/N corresponds to an average energy range in the center of mass system of about 0.05 to 1 eV for N_2^+ and of about 0.3 to 5 eV for the atomic ions. The various observable ion molecule reactions starting with the above ions lead ultimately to the production of O_2^+ and NO^+ and are discussed. For the disappearance of N_2^+ by charge exchange with O_2, the rate constant has been found to be approximately constant over the range of E/N studied with a value of 8.5×10^{-11} cm^3 sec^{-1}. Possible mechanisms for the disappearance of N^+ and O^+ are discussed together with experimental values of the rate constants.

MOBILITY OF O_2^+ AND CO_2^+ IONS IN CO_2 GAS

M. Saporoschenko and W. W. Wisner*
Southern Illinois University

The most abundant ions observed in this experiment using the glow discharge ion source with the CO_2 gas pressure between 0.5 to 1.6 Torr are the O_2^+ ions at low values of E/p_0 and the CO_2^+ ions at high E/p_0. Other positive ions observed in considerably smaller abundance are: C^+, CO^+, $C_2O_2^+$, $C_3O_2^+$, and CO_4^+. The mobility of O_2^+ ions has been measured for values of E/p_0 between 20 and 250 V/cm-Torr and of CO_2^+ ions between 75 and 250. The reduced mobility of O_2^+ ion varies with E/p_0 going through a maximum value of 1.56 cm^2/V-sec at E/p_0 of about 120. The mobility of O_2^+ ions has been observed to be pressure dependent for $E/p_0 > 80$. The processes of formation of some secondary ions will be discussed.

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*Present address: Allis-Chalmers Co., Milwaukee, Wis.

Session F

EXCITED ATOMS AND MOLECULES

Chairman:

J. W. Hooper
Georgia Institute of Technology
Atlanta

Thursday, October 19
8:45 A.M.
Comstock Room

THE RADIATIVE LIFETIME OF THE $sp^6\,{}^2S$ STATE OF Ar II

George M. Lawrence
Douglas Advanced Research Laboratories

The decay of 919.8 and 932.0 Å radiation following a 6 nsec wide pulse of electrons (40 to 80 eV) in argon (~ 0.02 Torr) was observed using a time-to-height analyzer. The mean lifetime observed is 4.80 ± 0.1 nsec, which is to be compared with the (central field) calculation by Varsavsky[1] of 0.1 nsec. The system uses 100 Mhz nuclear counting modules and exhibits a "prompt" decay constant of 0.7 nsec. An exponential decay is observed for four decades before background and secondary processes become dominant. The measured lifetime is independent of Ar pressure, electron current, electron voltage, and repetition rate. About 10^8 decay photons were timed. The quoted error is an estimate of the calibration error.

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[1] C. M. Varsavsky, Astrophys. J. Suppl. Ser., 6, 75 (1961).

AN EXPERIMENTAL DETERMINATION OF THE RELATIVE CONTRIBUTIONS OF RESONANT AND ELECTRON IMPACT COLLISIONS TO THE EXCITATION OF Ne ATOMS IN He-Ne LASER DISCHARGES

R. T. Young, Jr., C. S. Willett, and R. T. Maupin
Harry Diamond Laboratories

A new technique has been developed to differentiate between the excitation of Ne by resonant energy transfer from excited He atoms and excitation by electron impact. Comparisons are made of spontaneous emission intensities of Ne lines in pure Ne discharges and in He-Ne discharges with pD values chosen to keep the electron temperature constant. For a 5:1 He:Ne mixture at a pD of 4 Torr-mm in a 10-mm diameter tube, the ratio of the number of Ne atoms excited to the $3s_2$ level (Paschen notation) by He 2^1S metastables to the number excited by electrons varies from 65 (at 150-mA discharge current) to 90 (at 40 mA). For the Ne $3s_2$ and $3s_4$ levels the ratio is 4 and 7 independent of current. For the $3s_5$ level the ratio varies from 7 to 9, with a current dependence similar to that for the $3s_2$ level. Measurements made on the Ne 492.8-nm ($5s_2$-$2p_4$) line also show that a strong enhancement of this line occurs. This implies that there is a resonant reaction: He 2^1P + Ne $\rightarrow$ He + Ne $5s_2$ - ΔE (197 cm^{-1}), with a cross section of approximately 10^{-16} cm^2.

IONIZATION OF ARGON AND OF OXYGEN ON IMPACT OF 2^3S AND 2^1S HELIUM ATOMS*

J. A. Herce, K. D. Foster, and E. E. Muschlitz, Jr.
University of Florida

Measurements of cross sections for the ionization of molecules on impact of excited atoms have been made using an improved apparatus. The ions formed are extracted from the collision region at right angles to an incident beam of metastable helium atoms excited by electron impact. Long-lived states of higher excitation are removed from the beam by a quenching field. Measurements of the relative ion abundances as a function of the exciting electron energy, thereby changing the 2^1S to 2^3S ratio in the beam,[1] yield abundances for each metastable species. Using the known total ionization cross sections,[2] separate cross sections may then be calculated. Cross sections in $\mathring{A}^2$ for formation of the indicated ions in the two gases investigated are:

Beam \ Product	Ar^+	$HeAr^+$	O^+	O_2^+
2^3S He	6.6	1.0	0.9	13
2^1S He	7.0	0.6	2.0	12

Further measurements are in progress on associative versus Penning ionization in the rare gases.

[1]J. L. G. Dugan, H. L. Richards, and E. E. Muschlitz, Jr., J. Chem. Phys., 46, 346 (1967).
[2]W. P. Sholette and E. E. Muschlitz, Jr., J. Chem. Phys., 36, 3368 (1962).

COLLISIONAL RELAXATION OF ν_1 AND ν_3 MODES OF CO_2 BY H_2O, Xe, AND CO

P. K. Cheo
Bell Telephone Laboratories

Studies have been made of the effective lifetimes, τ, of the ν_1 (10°0) and ν_3 (00°1) modes of CO_2 as a function of the concentration of H_2O, Xe, and CO additives using an afterglow gain technique in a pulsed 10.6μ CO_2 laser amplifier previously described.[1] This technique yielded a relaxation cross section $\sigma_{\nu 3}$ for CO_2-H_2O collisions of $\simeq 3.6 \times 10^{-17}$ cm^2, as computed from the linear slope of the plot of $1/\tau_{\nu 3}$ versus P_{H_2O} (0 to 0.3 Torr range). This value is more than two orders of magnitude higher than those obtained for CO_2-CO_2 collisions. Risetime data, interpreted in terms of relaxation of the ν_1 asymmetric mode of CO_2 by CO_2-H_2O collisions, indicate that $\tau_{\nu 1}$ is less than 10 μsec at about 0.3 Torr of H_2O pressure. Values of $\tau_{\nu 1}$ and $\tau_{\nu 3}$ obtained in CO_2-Xe mixtures both increase slightly with increasing P_{Xe}. No *any very small* measurable change in the lifetime of ν_1 and ν_3 modes of CO_2 was observed upon addition of CO for a CO pressure range from 0 to 6 Torr. Data on pressure dependence will be presented and possible mechanisms discussed.

[1]P. K. Cheo, J. Appl. Phys., 38, 3563 (Aug 1967).

AMBIPOLAR DIFFUSION FREQUENCY SHIFTS IN THE
HELIUM-NEON LASER

Frederick J. Mayer
Plasma Research Laboratory, Case Western Reserve University

Simple charged particle diffusion theory of the positive column of a gas discharge predicts the establishment of a radial electric field, which by the second-order Stark effect produces a shift of the atomic line center in a single frequency helium-neon laser. These frequency shifts are estimated with a simple theory. The results are that (1) the atomic line center is a function of radial position in the discharge tube, (2) the magnitude of the frequency shift is proportional to $(T_e/R)^2$ (where T_e is the electron temperature and R is the tube radius), (3) the pressure dependence of the shift is via changes in T_e, and (4) the frequency shifts are independent of discharge current.

Session G

PLENARY SESSION

Chairman:

L. H. Fisher
Lockheed Palo Alto Research Laboratory
Palo Alto

The Executive Committee has the privilege of presenting an invited paper by Professor Leonard B. Loeb, University of California at Berkeley, in honor of his extensive services to the entire field of gaseous electronics and in celebration of the 20th Gaseous Electronics Conference.

"The Critical Need for More Experimental Work in Gaseous Electronics"

Thursday, October 19
10:30 A.M.
Ralston Room

Session H

ELECTRON SCATTERING AND ATTACHMENT

Chairman:

G. H. Dunn
Joint Institute for Laboratory Astrophysics
Boulder

Thursday, October 19
1:45 P. M.
Comstock Room

ON ANGULAR DISTRIBUTION STUDIES OF LOW ENERGY ELECTRON SCATTERING FROM H_2, N_2, AND CO

H. Ehrhardt, H. Langhans, F. Linder
Department of Physics, University of Freiburg
and
H. S. Taylor
Department of Chemistry, University of Southern California

Data on the angular dependence of low energy (0 to 10 eV) electron-molecule elastic and inelastic (vibrational excitation) scattering are presented. It is shown how the single particle shape resonance model[1] was capable of predicting the experimental results. The theoretically expected and experimentally measured different angular dependence of the low energy N_2 and CO resonances are shown. The use of angular distribution studies to detect resonances that do not show up as distinctive changes in the cross section as a function of energy is demonstrated. It is shown that without angular studies, one cannot say anything definitive about the absence of resonances. The angular dependence studies of inelastic scattering to the $v = 1$ channel of H_2 show up clearly the existence of a single particle $^2\Sigma_u^+$ resonance of H_2 at about to 8 eV. These same studies detected the presence of the repulsive $^2\Sigma_g \sigma_g 1s(\sigma_u 1s)^2$ resonance of H_2 above the 8 eV region.

[1]H. S. Taylor, G. Nazeroff, and A. Golobiewski, J. Chem. Phys., 45, 2872 (1966).

ANTIRESONANCE IN ELECTRON-HELIUM SCATTERING CALCULATION*

T. F. O'Malley
General Research Corporation

Several suggestions have been made that there may exist a strange new kind of resonance related to the exclusion principle.[1,2] This paper reports a calculation in the pseudopotential formalism[3] of e-He scattering, which clearly shows such a remarkable resonance (an antiresonance) in the S wave. Its parameters are $E_r = 37.5$ eV, $\Gamma = -2.5$ eV. Unlike Herzenberg and Lau's calculation, the position (but not the width) is quite insensitive to the strength of the polarization potential in the pseudopotential formalism. The antiresonance occurs for S wave electrons with kinetic energy just equal to that of the bound electrons. The negative width corresponds to a decreasing phase shift and hence a time advance. This is consistent with a very strong long-ranged, energy-dependent repulsion, which reaches out to exclude the incident electron from the forbidden region of space occupied by the bound electron with identical energy. If this phenomenon is not spurious, experiments should show a broad 70% dip in the total cross section.

[1]A. Herzenberg and H. S. M. Lau, Proc. Fifth Atomic Collisions Conf. (Nauka, Leningrad, 1967); also private communication.
[2]M. R. C. McDowell, private communication.
[3]N. R. Kestner, J. Jortner, M. Cohen, and S. Rice, Phys. Rev., 140, A56 (1965).

POLARIZATION DISTORTION EFFECTS IN LOW ENERGY ELECTRON-H_2 SCATTERING*

Neal F. Lane
Rice University
and
R. J. W. Henry
Kitt Peak National Observatory†

A variational treatment of the electron-H_2 system has been employed to obtain an adiabatic polarization potential for use in low-energy electron-H_2 scattering calculations, where polarization distortion effects are important. Elastic and rotational excitation cross sections have been calculated using this potential; the resulting cross sections are somewhat smaller than those obtained using a semi-empirical polarization potential.[1] The polarization potential (in atomic units) may be represented as

$$- V(r,\theta) = V_o(r) + V_2(r)P_2(\hat{r} \cdot \hat{R})$$

where $\hat{r}$ and $\hat{R}$ refer to the position of the electron and the orientation of the molecular axis, respectively. Illustrative values of the radial coefficients are: $V_o = 0.065,\ 0.022,\ 0.0085,\ 0.0037,$ and $V_2 = 0.023,\ 0.0054,\ 0.0017,\ 0.00068$ a.u. for $r = 2.0,\ 3.0,$ $4.0,$ and $5.0\ a_o$, respectively. The asymptotic behavior is given by $r^4 V_o \sim 2.44,$ and $r^4 V_2 \sim 0.39$.

[1]N. F. Lane and S. Geltman, Phys. Rev. (to be published).

ASYMPTOTIC EXPANSION OF FRANCK-CONDON OVERLAP INTEGRALS FOR DISSOCIATIVE IONIZATION OF DIATOMIC MOLECULES

K. E. McCulloh
National Bureau of Standards

Franck-Condon overlap integrals for certain bound-continuum transitions of diatomic molecules are expanded as an asymptotic series in powers of a small parameter. A reflection approximation is derived from the leading term in the series. For a number of cases of dissociative ionization of diatomic molecules, the initial semiconvergence of the expansion is sufficiently rapid to provide a convenient basis for computing the kinetic energy distribution of the resulting atomic ions. Computed distributions are presented for three modes of dissociative ionization of H_2, including double ionization, single ionization involving the repulsive $2p\sigma_u$ state of H_2^+, and single ionization into the dissociation continuum of the $1s\sigma_g$ state of H_2^+.

CALCULATION BY QUANTUM DEFECT METHOD OF ELECTRON SCATTERING BY MOLECULE-ION: H_2^+

M. C. Weinberg and R. S. Berry
Department of Chemistry and James Franck Institute,
University of Chicago

A quantum defect method has been developed from which phase shifts can be computed for electron scattering by axially symmetric molecules. The method is applied to calculation of low-energy elastic scattering cross sections e-H_2^+ scattering. These results, semi-empirical in nature, are compared with the recent nonempirical calculations of Temkin and Vasavada. The comparison suggests that the Temkin-Vasavada calculations give reasonably accurate phase shifts. Furthermore, as one might expect, the quantum defect method is significantly better when it is based on a small number of accurately known bound state energies than when based on a larger number of less accurate bound state energies.

ELECTRON-ATOM ELECTRON-MOLECULE SCATTERING FUNCTIONS FROM PSEUDOPOTENTIALS

B. Schneider and M. C. Weinberg
Department of Chemistry and James Franck Institute,
University of Chicago

With the ultimate goal of elucidating inelastic electron molecule processes, we have developed a pseudopotential method by which one can compute the wavefunctions for electron scattering states around molecules and molecular ions. The method is carried out as follows: The phase shift is assumed known, e.g., from scattering experiments or from quantum defect calculations.[1] A parameterized model potential is chosen and from it a wavefunction is determined which satisfies the boundary conditions. Parameters of the potential are chosen to give the correct phase shift. Then the pseudopotential is developed from the model wavefunction and from known bound state functions of the electrons in the scatterer. As a first example the method is applied to photodetachment of electrons from O^-.

[1] M. C. Weinberg and R. S. Berry, "Calculation by Quantum Defect Method of Electron Scattering by Molecule-Ion: H_2^+," 20th GEC.

ELECTRON IMPACT IONIZATION CROSS SECTION IN CESIUM*

K. J. Nygaard
Sperry Rand Research Center

The total ionization due to the passage of an electron beam in cesium vapor has been measured with a Tate and Smith-type apparatus. The retarding potential difference method was used in the electron gun to obtain energy resolution better than 0.1 eV. The density of Cs atoms was determined from the Taylor and Langmuir tables and also measured with a surface ionization detector. The two methods give the same density to within ±3% when the apparatus is in thermodynamic equilibrium with the Cs reservoir. The cross section for production of Cs^+ has been determined from threshold to 100 eV. For energies above 50 eV, the results agree closely with those of McFarland and Kinney.[1] In the threshold region our results are higher than those of Heil and Scott.[2] From the fine structure on the ionization curve we estimate the cross section for autoionization to be about 1.5×10^{-16} cm^2.

[1] R. H. McFarland and J. D. Kinney, Phys. Rev., 137, A1058 (1965).
[2] H. Heil and B. Scott, Phys. Rev., 145, 279 (1966).

LOW ENERGY ATTACHMENT IN OZONE*

J. L. Moruzzi and A. V. Phelps
Westinghouse Research Laboratories

The attachment of low energy electrons to ozone has been studied in N_2-O_3 mixtures using drift tube techniques.[1] The current waveform is recorded using a multichannel analyzer to improve the signal-to-noise ratio. Using estimated characteristic electron energies and electron drift velocities for the various N_2-O_3 mixtures, the rate coefficient for attachment has been determined from the slope of the ion current waveform for characteristic electron energies between 0.05 and 0.8 eV. At energies near 0.15 eV, the concentration of O_3 in the mixtures was varied from 0.5 to 3.5 Torr for total pressures of 50 Torr. The results are consistent with a two-body attachment process, presumably dissociative attachment.[2] At 0.8 eV the attachment rate coefficient is 1.8×10^{-10} cm^3 sec^{-1} and extrapolates to $1.2 \pm 0.5 \times 10^{-12}$ cm^3 sec^{-1} at thermal energies (300°K).

[1] L. M. Chanin, A. V. Phelps, and M. A. Biondi, Phys. Rev., 128, 219 (1962).
[2] R. K. Curran, J. Chem. Phys., 35, 1849 (1961).

DISSOCIATIVE ATTACHMENT IN CO AND NO*

P. J. Chantry
Westinghouse Research Laboratories

The production of O^- by dissociative attachment has been studied in CO and NO by monoenergetic electron beam techniques and direct measurement of the kinetic energy distributions of the ions using a crossed electric and magnetic field filter and mass analysis.[1] It has been shown that in CO the single peak in the dissociative attachment cross section arises predominantly from the production of O^- and ground state carbon atoms (^3P). At electron energies above 10.9 eV a second peak appears in the ion kinetic energy distribution, arising from the production of O^- and carbon atoms in their first excited state (^1D). In NO it has been shown that dissociative attachment proceeds exclusively through the reaction $e + NO \rightarrow O^- + N^*$ where N^* is the first excited state of nitrogen (^2D). No O^- ions have been observed corresponding to the production of ground state N. Nor is there any evidence for the production of the second excited state of nitrogen, $N(^2P)$, postulated by Dorman[2] to account for the second hump in the attachment cross section.

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[1] P. J. Chantry and G. J. Schulz, Phys. Rev., 156, 134 (1967).
[2] F. H. Dorman, J. Chem. Phys., 44, 3856 (1966).

DISSOCIATIVE ELECTRON ATTACHMENT TO MOLECULES*

L. G. Christophorou and J. A. Stockdale
Oak Ridge National Laboratory

Dissociative electron attachment cross sections (some unpublished) for 30 molecules are summarized, evaluated, and discussed within the framework of the resonance scattering theory. The dissociative attachment peak cross section, $\sigma_c(\epsilon_{max})$, is found to be a strong function of the peak (resonance) energy, ϵ_{max}, with a break in this dependence at the energy where electronic excitation of the neutral molecule begins to occur. Based on the experimental data, three groups of molecules have been distinguished: (1) those where ϵ_{max} is less than the energy, ϵ_N, associated with known electronic states of the neutral molecule, and the negative ion state is purely repulsive in the Franck-Condon region; (2) those where $\epsilon_{max} \geq \epsilon_N$; and (3) those with exceptionally small $\sigma_c(\epsilon_{max})$ for which $\epsilon_{max} < \epsilon_N$ but a vertical onset occurs. For the molecules in group (1), $\sigma_c(\epsilon_{max})$ varies almost as $(\epsilon_{max})^{-1}$, while for group (2), $\sigma_c(\epsilon_{max})$ is a much stronger decreasing function of the resonance energy ϵ_{max}. For group (1) the effect of autoionization on $\sigma_c(\epsilon_{max})$ is small and isotopic effects on $\sigma_c(\epsilon_{max})$ are contained within the square root of the inverse ratio of the reduced masses of the products. For group (2) and especially for group (3) the effect of autoionization on $\sigma_c(\epsilon_{max})$ is large and so are the isotopic effects on $\sigma_c(\epsilon_{max})$.

PLASMA TRANSIENT RESPONSE AND THE DETERMINATION OF COLLISION DATA*

R. L. Bruce, F. W. Crawford, and R. S. Harp
Stanford University

If a plasma column in an axial magnetic field is subjected to a short pulse applied with the electric field vector perpendicular to the discharge axis, the electrons are stimulated into motion about the magnetic field lines. The rate at which they dephase, and the rate at which the transient response decreases toward zero, depend on collisions, magnetic field inhomogeneity, and collective plasma effects. With appropriate control of the magnetic field homogeneity and plasma parameters, any one of these effects can consequently be made to dominate. Experiments will be described in which the pulse response of a plasma has been examined, first over a wide range of conditions, and then for the special case of low electron density and high magnetic field uniformity, so that electron/neutral collision frequencies can be determined from the transient response. Data are presented near the Ramsauer minimum in argon which compare well with results obtained by alternative techniques, and the paper discusses the potentiality of the method for studying collisions at energies of the order of 1 V.

Session I

POSITIVE COLUMNS AND ARCS

Chairman:

W. W. Robertson
University of Texas
Austin

Thursday, October 19
1:45 P.M.
Ralston Room

EFFECT OF WALL TEMPERATURE ON PROPERTIES OF A POSITIVE COLUMN

Richard L. Moore and Joseph E. Butterworth
McDonnell Douglas Corporation

Free-space scattering experiments, which use coolants of various dielectric constants and temperatures in a jacket surrounding the positive column, show: (1) that the Tonks-Dattner resonances are independent of the dielectric constant of the envelope of the column and (2) that at fixed currents the resonant frequency is proportional to coolant temperature. Concurrent observation of column dc resistance shows it to increase with coolant temperature and to be much greater than predicted by the electron-neutral collision frequency. Similarly, cavity measurements find the ac resistance is too great. Variation of mercury reservoir temperature has little effect on these parameters. These results are consistent with viscous loss of momentum to the column wall as calculated from Knudsen flow of the electrons (with a radial variation in density). The radial standard deviation of density is estimated from previously reported column radar cross-sections. The resonance frequency and its dependence on wall temperature is consistent with the theory of a visco-thermal standing radial wave in a nonuniform medium with no "adjustable" parameters. Values of electron viscosity inferred from three independent experiments (dc resistivity, ac resistivity, and resonant frequency) are in reasonable agreement. The observed rapid increase in damping of higher resonances is in qualitative agreement with predictions of visco-thermal theory.

MICROWAVE RADIATION TEMPERATURES IN He, Ne, A, Kr, AND Xe DC DISCHARGES

C. C. Leiby, Jr., and C. W. Rogers
Air Force Cambridge Research Laboratories

Microwave radiation temperatures T_r have been measured over the pressure range $p_o = 0.04$ to 30 Torr at three discharge currents ($i = 60$, 140, and 220 mA). The discharge tube (radius $R = 0.3$ cm) was in the form of a racetrack (perimeter 155 cm) with the active discharge occupying one straightaway (52 cm). This geometry reduced electrophoretically induced axial pressure gradients by providing a return path for discharge generated gas flows. Discharge tube wall temperatures T_w (35° to 350°C) and electric fields in the positive column were also measured. T_w is a function of the current i, the reduced gas pressure p_o, and the identity of the gas. T_w was used as an estimate of the gas temperature in the active discharge region. The data for He, Ne, and A (whose rates of change of ionization cross-section with electron energy — at onset — α_i are known) agree with Druyvesteyn's theory for electron temperature T_e as a function of $p_o R$. Assuming that $T_r \approx T_e$, this theory yields values for $\alpha_i = 0.60 \pm 0.30$ and 1.0 ± 0.4 ($\overset{\circ}{A}{}^2$/V) for Kr and Xe, respectively. Large variations in emitted noise power were observed at the lowest gas pressures in all the gases except He. These "resonances" correlate with the measured microwave insertion losses of the plasmas.

MICROWAVE-DC PROBE MEASUREMENTS OF THE PLASMA SHEATH

Maurice Weiner and Robert M. True
Electron Tubes Division, Electronic Components Laboratory,
U. S. Army Electronics Command

A microwave-dc probe is investigated for its potential as a diagnostic tool for the measurement of various plasma parameters, such as electron temperature, density, and collision frequency. The probe is connected directly to a 50-ohm coaxial transmission line through which the microwave signal is coupled to the sheath. Using the same probe, both microwave and dc measurements are carried out separately and the results compared. Results are obtained for a xenon discharge with and without a magnetic field. Microwave nonlinear effects and frequency absorption bands are observed in the plasma sheath surrounding the antenna probe. The nonlinear effects include mixing, frequency doubling, and current rectification of a microwave signal. Strong microwave nonlinear interaction is observed when the probe is dc biased at a point in the exponential region of the electrostatic curve. The nonlinear interaction occurs largely inside the microwave absorption band found in the 1.0 to 2.0 GHz range. The center frequency of the absorption band corresponds to the resonant frequency of the sheath-plasma system and is somewhat lower than the plasma frequency.[1]

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[1]R. S. Harp and F. W. Crawford, "Characteristics of the Plasma Resonance Probe," J. Appl. Phys., 35, 3435 (1964).

Abstract withdrawn

CAUSE OF THE DARK-SHEATH IN RF PLASMOIDAL DISCHARGES*

M. D. Kregel and A. Miller
New Mexico State University

The spatial variation in the intensities of emission lines of excited neutral atoms and molecular ions have been measured for a spherical dark-sheath rf plasmoid formed in oxygen. The two profiles are generally similar, but exhibit discrepancies in the vicinity of the dark-sheath. Analysis of the data has led to a simple and satisfying explanation for the occurrence of the dark-sheath.

A THEORY OF ARC STARVATION*

J. E. Faulkner and A. A. Ware
San Ramon Research Operation, Aerojet-General Corporation

The simplest discharge tube geometry for arc starvation, which avoids the complication of electrode effects, is a cylindrical tube with a short constriction at one point along its length. The conditions in such a constriction are similar to those in a plasma diode, except that electron and positive ion injection occurs from the anode end as well as from the cathode end. It is proposed that the arc starvation (i.e., current chopping) occurring in such a discharge constriction at low pressures results from a space charge instability similar to that observed in the plasma diode. To test this hypothesis, a code has been prepared for a one-dimensional computer experiment to simulate the constriction; the motion of up to 10^4 sheets of electrons and ions are followed. The results show a large amplitude space charge instability, similar to the plasma diode instability, except that the frequency is of the order of the electron transit time and not the ion transit time. This is due to the electron injection from the anode end which is absent in a plasma diode. The mechanism by which this instability causes the current chopping is discussed.

DEPLETION EFFECTS IN CESIUM-ARGON DISCHARGES

J. H. Waszink, R. Bleekrode, and J. Polman

Philips Research Laboratories, Eindhoven, The Netherlands

In the axially homogeneous positive column in cesium-argon discharges $\left(p_{Cs} \ 10^{-4} \text{ to } 10^{-3} \text{ Torr}, p_{Ar} \ 5 \text{ Torr}\right)$, a sudden change in the column parameters occurs as the discharge current I is raised to above a critical value I_c.[1] This effect takes place when the cesium ground state concentration has been depleted[2] by ionic pumping in radial direction. The electron density n_e, the electron temperature T_e, and the cesium $6^2S_{1/2}$ concentration n_{Cs} have been determined by a microwave interferometer,[3] by Langmuir probes, and by optical absorption, as a function of I and the radial coordinate r. $n_{Cs}(r)$ has a minimum value at $r = 0$, which decreases with increasing I and is about 3% of the concentration at the tube wall, $n_{Cs}(R)$, for $I = I_c$. As I is increased further, this profile becomes flat over a range $0 < r < R/2$. $n_e(r = 0)$ as a function of I shows a dip at $I = I_0$. For $I < I_c$, we find

$$n_e(r)/n_e(0) > J_0(2.40 \, r/R)$$

where J_0 is the zero-order Bessel function.

[1] H. J. G. Meyer, G. Ahsmann, and J. W. van der Laarse, App. Phys. Letters, 10, 124 (1967).

[2] M. A. Cayless, Brit. J. App. Phys., 14, 863 (1963).

[3] J. Polman, Rev. Sci. Inst., 1967, to be published.

MEASUREMENTS OF THE LONGITUDINAL PRESSURE GRADIENT IN DC DISCHARGES*

R. Bergman and L. M. Chanin

University of Minnesota

Measurements have been made of the longitudinal pressure gradient in dc discharges of helium and neon. The anode cathode pressure differential has been measured as a function of current density and gas pressure. Other variables investigated included gas temperature, electric field, temperature gradients, and tube geometry. Previous[1] theoretical explanations of the effect when compared with experimental results underestimate the magnitude of the phenomena by as much as two orders of magnitude. Satisfactory order of magnitude agreement is obtained when the present data are compared with the recent theory[2] of the volume force contribution to the effect.

[1] M. J. Druyvesteyn, Physica, 2, 255 (1935).

[2] C. C. Leiby, Jr., and H. J. Oskam, Phys. Fluids (to be published).

PHASE SHIFT BETWEEN THE VARIATIONS OF PLASMA PARAMETERS IN SLOW MOVING STRIATIONS

M. Sicha,* M. G. Drouet, and G. G. Cloutier
Plasma Physics Laboratory, University of Montreal

The methods[1,2] recently described for direct oscillographic display of the time variations of electron density, electron temperature, and axial electric field in a positive column have been used to study the propagation and amplification of moving striations. For small harmonic variations of these plasma parameters, the phase shift between these variations have been measured. The experimental results obtained have been compared with existing theories.[3,4,5] The phase shift between electron density and electron temperature variations is larger than predicted by Pekarek's calculations. For example, in neon the measured phase shift is about 180 deg while the theory predicts that this angle should be smaller than 90 deg. The phase shift between the electric field and the electron temperature is of opposite sign to that predicted by the theory of Pekarek and Krejci which is generally accepted[4] for the interpretation of the amplification of striations. It will be shown that the experimental results can be interpreted by taking into account the metastable atoms as suggested by Gentle[5] and by using a general equation of conservation of energy for the electrons.

*On leave from Charles University, Prague, Czechoslovakia.
[1] M. Sicha and G. G. Cloutier, Bull. Am. Phys. Soc., 12, 713 (1967).
[2] M. Drouet and G. G. Cloutier, Bull. Am. Phys. Soc., 12, 695 (1967).
[3] L. Pekarek, Czech J. Phys., 12, 439 (1962).
[4] D. A. Lee, P. Bletzinger, and A. Garscadden, J. Appl. Phys., 37, 377 (1966).
[5] K. W. Gentle, Phys. of Fluids, 9, 2203 (1966).

RELAXATION METHOD OF CALCULATING ARC TEMPERATURE PROFILES

J. J. Lowke
Westinghouse Research Laboratories

A relaxation method based on the time dependent energy balance equation has been used to derive the steady state characteristics of arcs, where account is taken of energy transfer due to thermal conduction, radiation, and self-absorption of radiation. An initial incorrect temperature profile is successively modified until the steady state solution is obtained. Use is made of the integration procedure developed by Swanson[1] to calculate the radiation flux density as a function of radius for a given temperature profile. Calculations have been made of the characteristics of discharges in sodium[2] vapor where radiation other than from the D lines can be neglected in a first approximation. Results are presented for a pressure of 250 Torr giving (1) temperature profiles; (2) radiation efficiency as a function of electric current, tube radius, and wall temperature; (3) a characteristic line profile of the emitted radiation; and (4) the E-I characteristics of the discharge for tube radii of 3.5 and 5 mm for currents ranging from 2 to 10 A.

[1] C. H. Church, R. G. Schlecht, I. Liberman, and B. W. Swanson, AIAA, 4, 1947 (1966).
[2] The input material functions (thermal conductivity, electrical conductivity, and spectral absorptivity) as a function of temperature were calculated by Teh-Sen Jen, who also assisted in some of the computations.

IMPURITIES, GRADIENTS, RADIATION TRAPPING,
ANOMALOUS HEAT CONDUCTIVITY, AND METASTABLES
IN A LABORATORY PLASMA*

Ray Hefferlin
Southern Missionary College†

A mass of temperature, density, and enthalpy data, obtained spec-
troscopically for various points in a certain plasma, are subjected
to interpretation in the light of the six plasma models. The source
was an argon high-enthalpy plasma jet, exhausting into air, with a
metal solution seeded into the argon. The plasma models are: (1)
The optically-thin, local-thermodynamic-equilibrium model; dis-
crepancies exist such that densities calculated from the model are
too high by a factor of 2. These discrepancies serve to motivate
further interpretations. (2) The entrainment of impurities; found to
be unimportant. (3) Gradients; the easily ionized component of the
mixture was found to radiate in a cool zone unsuspected earlier
because not all data were Abel inverted. (4) Radiation trapping;
shown by several tests to be practically absent. (5) Overpopulation
of metastable and higher levels in argon-like species; evidence in-
dicates that this process does occur. (6) Low heat conductivity of
argon; results in spread of temperatures downstream.

Session J

ION-MOLECULE REACTIONS

Chairman:

R. H. Neynaber
General Dynamics/Convair
San Diego

Friday, October 20
8:45 A.M.
Gold Ballroom

METAL ION REACTION RATE MEASUREMENTS IN A FLOWING AFTERGLOW SYSTEM

F. C. Fehsenfeld, A. L. Schmeltekopf, and E. E. Ferguson
Environmental Science Services Administration

Reaction rates between metal ions and neutral molecules (including O_3) are currently being studied in the ESSA flowing afterglow system. The metal ions are presently being produced by reactions between metastable argon atoms and the metal vapor which is evaporated from a furnace. Thus far, the reaction $Mg^+ + O_3 \rightarrow MgO^+ + O_2$ has been measured, yielding a tentative rate constant $k \cong 10^{-10} cm^3/sec$. In addition, the three-body reaction $Mg^+ + O_2 + M \rightarrow MgO_2^+ + M$, where M is a neutral third-body (in this case Ar), has been observed to have a rate constant of the order $k \cong 10^{-30} cm^6/sec$. In addition to MgO^+ and MgO_2^+, ions at mass 72 (probably MgO_3^+) and mass 96 (probably $Mg_2O_3^+$) were also detected indicating the formation of these products by reactions involving Mg^+, MgO^+, and MgO_2^+ and the neutral reactants. Magnesium ions have been observed to be major ions at certain altitudes and times in the earth's lower ionosphere. The first reaction may well be the major Mg^+ loss process in some regions of the ionosphere. Some implications of the rate constant measurements for the meteor ion chemistry of the earth's upper atmosphere will be discussed.

ION-MOLECULE REACTION RATE CONSTANT MEASUREMENTS IN THE NEAR THERMAL RANGE*

E. E. Ferguson, D. B. Dunkin, F. C. Fehsenfeld, and
A. L. Schmeltekopf
Environmental Science Services Administration

A flowing afterglow system has been constructed so that the gas temperature can be maintained at temperatures from 77° to 700°K while ion-molecule reaction rate constants are measured. Because of the large gas flows and wide temperature ranges, careful attention was given to the heat exchange problem in the equipment design in order to avoid temperature gradients in the reaction zone. The experimental details of the heated system will be briefly presented. Reactions which have been measured so far and for which data will be presented include O^+ reactions with O_2, N_2, and CO_2; He^+ reactions with O_2 and N_2; and the reaction of N^+ with O_2. The present data will be compared to other available data on the energy dependence of these reaction rates and some theoretical considerations will be proposed. The reaction rate constants to be reported will include corrections to previously reported values which have resulted from a detailed computer analysis of the hydrodynamics of the flowing afterglow experiment.

SPECTROSCOPIC INVESTIGATION OF THE ION-MOLECULE REACTION OF He^+ AND N_2 *

D. L. Albritton, A. L. Schmeltekopf, and E. E. Ferguson
Environmental Science Services Administration

Spectroscopic investigations have been made of the reaction of He^+ and N_2 in the visible and vacuum ultraviolet wavelengths as a function of the vibrational temperature of N_2. The inverse predissociation mechanism which has been commonly evoked by spectroscopists to explain the vibrational populations of the $C^2\Sigma_u^+$ state of N_2 can be excluded on the basis of these afterglow studies. When the vibrational temperature of the N_2 was elevated, the populations of the vibrational levels $v' = 4$, 5, and 6 of the $C^2\Sigma_u^+$ state increased, while that of the $v' = 3$ level decreased. This is interpreted as meaning that the predissociation of the N_2^+ $C^2\Sigma_u^+$ state cannot entirely occur at $v' = 3$, since it has been previously determined in this laboratory that the ratio of N^+ to N_2^+ produced by the He^+ reaction with N_2 increases with N_2 vibrational temperature. Emissions from the $B^2\Sigma_u^+$ state of N_2^+ have also been observed in the afterglow and show anomalous vibrational and rotational populations.

ASSOCIATIVE IONIZATION IN A NITROGEN AFTERGLOW

Walter L. Starr*
Lockheed Palo Alto Research Laboratory

In studies with nitrogen afterglows, we observed that ionization is produced by addition of NO to the afterglow. Since the dissociation energy of N_2 is greater than the ionization potential of NO, ionization of NO by association of N atoms is energetically possible. From mobility measurements, Gatz et al.[1] identified NO^+ as the product ion of this reaction. In a related study,[2] electron-irradiated N_2 was reacted with NO and the product ion mass spectrometrically identified as N_2NO^+. To make a direct determination of the ion produced by the $NO-N_2$ afterglow reaction, we used a quadrupole mass spectrometer and a flowing afterglow. NO is introduced between an electrodeless discharge and the mass spectrometer. For all flow conditions used, only NO^+ appears as a product ion. Usually N_2^+, N_3^+, and NO^+ are in the primary flow; however, NO^+ is also produced when primary flow ionization is absent. Mass 58 is not observed. By adding N_2 in place of NO it was determined that the ionization could not be attributed to a pressure effect.

[1] C. R. Gatz, F. T. Smith, and H. Wise, J. Chem. Phys., 40, 3743 (1964).
[2] V. Čermák, J. Chem. Phys., 43, 4527 (1965).

ION-MOLECULE REACTIONS IN COLLISIONS OF O^- AND O_2^- WITH H_2 AND D_2*
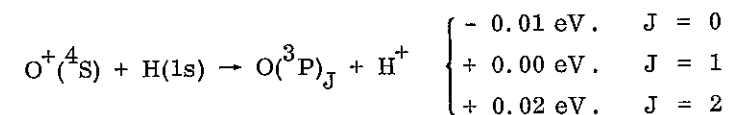
J. D. Martin and T. L. Bailey
University of Florida

Total cross sections for the negative ion-molecule reactions, $O^- + D_2 = OD^- + D$, and $O^- + H_2 = OH^- + H$, have been measured using a fixed-angle tandem mass spectrometer. The experiments were performed for primary ion energies from a few eV to 69 eV for the $O^- + D_2$ system and to 119 eV for the $O^- + H_2$ system. In both reactions the cross sections rise rapidly with increasing energy in the region near threshold, peak at approximately 10 eV, and then decrease monotonically thereafter. A pronounced isotope effect was observed: the maximum value of the cross section for OD^- formation was approximately 2.8 times the maximum for OH^- formation. From the observed onset for each reaction and simple energy considerations, it appears that the OD^- and OH^- product ions are both formed (at low collision energies) in their ground electronic states, with vibrational/rotational excitation energies of about 0.65 eV. The reactions $O^- + D_2 = D^- + OD$, $O^- + H_2 = H^- + OH$, and $O_2^- + H_2 = O^- + H_2O$ have also been observed, but cross sections for these have not yet been measured.

LOW ENERGY COLLISIONS BETWEEN $O^+(^4S)$ AND $H(1s)$ *

B. R. Turner, R. F. Stebbings, and J. A. Rutherford
General Atomic Division of General Dynamics Corporation
John Jay Hopkins Laboratory for Pure and Applied Science

The cross section for the accidentally resonant charge transfer process

$$O^+(^4S) + H(1s) \rightarrow O(^3P)_J + H^+ \begin{cases} -\ 0.01\ eV. & J = 0 \\ +\ 0.00\ eV. & J = 1 \\ +\ 0.02\ eV. & J = 2 \end{cases}$$

has been measured by use of a crossed-beam method, within the energy range of 0.6 to 25 eV in the center of mass coordinate system. These data were extrapolated to lower energies using the method recently developed by Wolf and Turner[1] and large thermal energy cross sections were obtained. The implications of the large cross sections, $2-4 \times 10^{-15}\ cm^2$ at interaction energies appropriate to a temperature of $\sim 1200°K$, to the formation of the protonosphere are discussed.
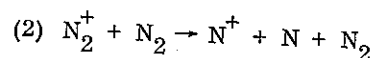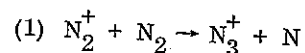
REACTIONS OF N_2^+ WITH N_2 *

William B. Maier II
Los Alamos Scientific Laboratory

Experimental cross sections for the reactions

(1) $N_2^+ + N_2 \rightarrow N_3^+ + N$

(2) $N_2^+ + N_2 \rightarrow N^+ + N + N_2$

are given for primary ion kinetic energies between 1 and 45 eV. The primary ions are produced by electron bombardment and mass analyzed prior to reaction. The electron bombarding energy is varied from 18 to 60 eV, and the effects of excited, metastable states of N_2^+ upon the cross sections are studied. With an electron bombarding energy of 18 eV, reactions (1) and (2) exhibit thresholds at primary ion kinetic energies E of about 9 and 15 eV, respectively, and have maximum cross sections $\approx 10^{-17}$ cm^2 and $\approx 10^{-16}$ cm^2, respectively. With an electron bombarding energy of 60 eV, for example, the cross section for reaction (1) is $\sim 10^{-17}$ cm^2 at $E \approx 1$ eV, due to the presence of excited, metastable N_2^+ in the primary ion beam.

ON THE REACTION $H_2^+ + H_2 \rightarrow H_3^+ + H$, EVIDENCE OF RESONANCE FORCES*

F. A. Wolf
San Diego State College

Previous theories of ion molecule reactions indicated that the maximum cross section obtainable never exceeded the result predicted by Gioumousis and Stevenson (GS) using the Langevin capture theory. Measurements of the cross section by Giese for this reaction yielded results in excess of the GS result by 20% or more in the barycentric energy range $0.1 < E \leq 2$ eV. Neynaber's recent merging beams measurements of relative values (which compare well with relative values using Giese's data) indicate that for $0.03 \gtrsim E \leq 5$ eV the cross section deviates from the GS result both in the high and low energy region. We have calculated the cross section for the above reaction using a phase space theory modified to study 4-body reactions by making them into equivalent 3-body reactions. Most important is that our calculation uses a resonance potential of the form $\sim aR \exp(-bR)$ in which a and b may be directly calculated in terms of experimental electron scattering lengths. Our results compare extremely well with the experimental data indicating that for interparticle separations ~ 5 Å, attractive resonance forces lead to a cross section larger than the GS result and that for $E \gtrsim 3$ eV the cross section is less than the GS result because of phase space competition with dissociation. The experimental results are displayed together with the GS and the resonance-phase space theoretical results.

ANALYSIS OF ION MOLECULE REACTION EXPERIMENTS WITH PRIMARY ION BEAM DEPLETION*

George Gioumousis
Lockheed Palo Alto Research Laboratory

It is possible to perform mass spectrometer ion molecule reaction experiments under sufficiently high pressures that the analysis is complicated by depletion of the primary ions. On the assumption of zero electron beam thickness and zero initial primary ion velocity, it is possible to base the analysis on the concept of ion flux as a function of position, with no restriction as to the functional form (with respect to energy ϵ) of the microscopic reaction cross section $\sigma(\epsilon)$. For a single reaction the result is

$$\log\left(\frac{i_p}{i_p + i_s}\right) = -n_2 \int_0^\ell \sigma(\mu eEz/m_1)\, dz$$

where i_p and i_s are primary and secondary ion currents, n_2 is the number density of neutrals, ℓ is the reaction length, μ is the reduced mass of primaries and neutrals, e is the charge of the primaries, E is the electric field, z is the distance parallel to the field, and m_1 is the mass of the primaries. The analysis can be generalized to systems of competing and consecutive reactions, and has been worked out for several such systems.

CALCULATIONS OF CAPTURE CROSS SECTIONS FOR ION-POLAR MOLECULE CAPTURE COLLISIONS INVOLVING CH_3CN

John V. Dugan, Jr., and James H. Rice
NASA-Lewis Research Center
and
John L. Magee
University of Notre Dame

The cross sections for capture collisions between the symmetric top molecule CH_3CN and several molecular ions are calculated by a numerical approach previously used to study collisions between ions and linear polar molecules.[1] These ion-molecule reactions with CH_3CN targets have been studied in the mass spectrometer and have large experimental cross sections.[2] Calculations are also done for symmetric tops which have relatively large moments of inertia about their symmetry axes. This was done to study the role of the added degree of rotational freedom by comparing results for the top with those for linear molecules. The numerical cross sections σ_c for the tops at rotational temperature T_R are less than experimental reaction cross sections for all ion energies ϵ_1. However, these σ_c values are much larger than predicted by the Langevin theory.[3] The $\epsilon_1^{-1/2}$ slopes for the σ_c plots are in disagreement with the reported ϵ_1^{-1} experimental behavior although they agree with predictions of a Stark effect approximation.[3]

[1] J. V. Dugan, Jr., and J. L. Magee, J. Chem. Phys. (to be published).
[2] T. F. Moran and W. H. Hamill, J. Chem. Phys., 39, 1413 (1963).
[3] J. V. Dugan, Jr., and J. L. Magee, NASA TN D-3229 (Feb 1966).

DYNAMICS OF THE N_2^+-CH_4 REACTION

E. A. Gislason, Bruce H. Mahan, and Chi-wing Tsao
Department of Chemistry and Inorganic Materials Research
Division of the Lawrence Radiation Laboratory

An apparatus has been constructed which allows mass, energy, and angular analysis of the products of ion-molecule reactions which occur when a momentum analyzed beam of ions impinges on a target gas. This apparatus has been used to study the dynamics of the reaction

$$N_2^+ + CH_4 \rightarrow N_2H^+ + CH_3$$
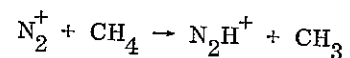
For several initial energies of N_2^+ in the range from 16 to 130 eV, we find the most probable reactive process corresponds to scattering of N_2H^+ through only small angles with respect to the N_2^+ beam direction. The greatest intensity of N_2H^+ occurs at velocities near those calculated for an ideal stripping process in which no momentum is transferred to CH_3. Other less intense features show that in some collisions CH_3 as well as N_2H^+ is formed with considerable internal excitation energy.

Session K

ELECTRON IMPACT IONIZATION

Chairman:

R. H. McFarland
Lawrence Radiation Laboratory
Livermore

Friday, October 20
8:45 A. M.
Ralston Room

CROSS SECTION AND POLARIZATION OF THE H_α LINE BY ELECTRON IMPACT EXCITATION*

H. Kleinpoppen,† and E. Kraiss

Department of Physics, University of Tübingen

The cross section $\sigma(H_\alpha)$ for the excitation of Balmer-α radiation from ground state hydrogen atoms has been determined by means of the modulated cross-beam techniques

$$\sigma(H_\alpha) = \sigma(1S, 3S) + \chi_{2S}^{3P} \sigma(1S, 3P) + \sigma(1S, 3D)$$

where χ_{2S}^{3P} is the branching ratio for the optical transition from the 3P state to the 2S state. The measured excitation function has been normalized to the Born approximation above 300 eV. The $\sigma(H_\alpha)$ cross section has a narrow peak with a value of $(0.058 \pm 0.015) \pi a_0^2$, located about 2 eV above the excitation threshold. There is good agreement with the theoretically determined $\sigma(H_\alpha)$ cross section of Morrison and Rudge[1] in the energy range from 50 to 350 eV. In addition, the polarization of the H_α has been measured in the energy range from about 15 up to 45 eV. The polarization drops abruptly in the energy range from 25 eV down to the threshold. The reported H_α cross section has been corrected for cascade and polarization effects.

[1]D. Y. T. Morrison, and M. R. H. Rudge, Proceedings of the Physical Society, London, Vol. 89, Part 1, No. 563, 1966.

THRESHOLD BEHAVIOR OF ELECTRON EXCITATION FUNCTIONS IN ATOMIC HYDROGEN*

J. F. Williams, E. K. Curley, and J. Wm. McGowan

General Atomic Division of General Dynamics Corporation

John Jay Hopkins Laboratory for Pure and Applied Science

The excitation function, for electron impact, of the (1s – 2p) transition in atomic hydrogen appears to be finite at the threshold. When electron energy distribution functions of from 240 to 100 meV (FWHM) are unfolded from the observed Lyman-alpha radiation versus electron energy curve, it appears that the excitation function reaches a significant value within several tens of meV of the threshold and then drops sharply to about 60% of its peak threshold value. A report is given of attempts made to observe the resonance in the 2p excitation function, which is predicted by Burke et al.[1] to appear just below the n = 3 level.

[1]P. G. Burke, S. Ormonde, and W. Whitaker, Phys. Rev. Letters, 17, 800 (1966).

CLOSE-COUPLING CALCULATIONS OF ELECTRON EXCITATION CROSS SECTIONS OF HELIUM*

S. Chung and Chun C. Lin
University of Oklahoma

Using Born's approximation one finds that the electron excitation cross sections of the n^1P states of helium are over 40 times larger than those of n^1D which are 10^2 times the n^1F cross sections. Because of the strong coupling between n^1P, n^1D, and n^1F, the cross sections of n^1D and n^1F may be much larger than the Born values. By including all the channels associated with the 1^1S, 3^1S, 3^1P, and 3^1D states, we have performed a close-coupling calculation of the excitation cross sections. The scattering equations are solved numerically. Similar calculations have been made for the $n = 4$ states. At 100 eV, the calculated cross sections of 3^1P, 3^1D, 4^1P, 4^1D, and 4^1F are 282, 22, 115, 10.6, and 0.54 ($\times 10^{-20}$ cm^2), respectively, as compared to the corresponding Born values of 270, 4.4, 109, 2.5, and 0.014. The 3^1D and 4^1D cross sections agree well with experiment. Because of the singlet-triplet mixing of the F states, a substantial part of the observed excitation population of 3^3D at low pressure may be ascribed to cascading from the F states.

STUDY OF 100-eV ELECTRON IMPACT EXCITATION OF THE $3^{1,3}D$ LEVELS OF HELIUM USING TIME-RESOLVED SPECTROSCOPY*

Richard J. Anderson and R. H. Hughes
University of Arkansas

The relative contributions of direct electron excitation and cascade transitions to the $3^{1,3}D$ states are being investigated by time-resolved spectroscopy[1] using an electron impact apparatus designed to minimize gas-kinetic collisional transfer effects. The observations are made via $3^3D \rightarrow 2^3P(\lambda5876\text{Å})$, and $3^1D \rightarrow 2^1P(\lambda6678\text{Å})$ transitions in the pressure range 10^{-3} to 10^{-2} Torr. Measurements at $\sim 10^{-3}$ Torr indicate that approximately 34% of the 3^3D and more than 90% of the 3^1D population results from direct electron excitation. Approximately 10% of 3^3D population results from 4F cascade. Normalizing to the absolute $3^3D \rightarrow 2^3P$ and $3^1D \rightarrow 2^1P$ cross section measurements of St. John et al.[2] at 100 eV one obtains in units of 10^{-20} cm^2; $Q(3^1D) \approx 22$, $Q(3^3D) \approx 1.5$, and $0.4 < Q(4F) < 1.6$, where $Q(4F)$ is the total 4F cross section. Direct $1^1S \rightarrow 4F$ electron excitation as predicted by Born theory, and collisional $4^1P \rightarrow 4F$ transfer can account for less than 10% of the observed 4F excitation.

[1]W. R. Pendleton and R. H. Hughes, Phys. Rev., 138, A683 (1965).
[2]R. M. St. John, F. L. Miller, and C. C. Lin, Phys. Rev., 134, A888 (1964).

THE ANGULAR DEPENDENCE OF THE ELECTRON IMPACT EXCITATION CROSS SECTION OF THE $X^1\Sigma_g^+ \to b^3\Sigma_u^+$ TRANSITION IN H_2

S. Trajmar
Jet Propulsion Laboratory, California Institute of Technology
and
D. C. Cartwright, J. K. Rice, and A. Kuppermann
Department of Chemistry, California Institute of Technology

The differential cross section for the electron impact excitation of the $X^1\Sigma_g^+ \to b^3\Sigma_u^+$ transition in H_2 has been measured in the 10 to 80 deg region at 25, 35, 40, and 50 eV impact energies. Using the Ochkur-Rudge approximation (which has proved very successful in treating electron exchange scattering), the differential cross section for this excitation has been calculated. A comparison is made between the theoretically calculated and the relative experimental values. It is found that the theory and experiment agree well at 50 and 40 eV impact energies. At 35 and 25 eV energies, the theory predicts rather pronounced maxima in the differential cross section at around 40 deg while the experiments show nearly isotropic distributions.

ELECTRON IMPACT EXCITATION OF THE $\underline{c}\ ^3\Pi_u$ STATES OF H_2 AND D_2 BY A TRAPPED ELECTRON METHOD*

J. T. Dowell and T. E. Sharp
Lockheed Palo Alto Research Laboratory

Electron impact excitation of H_2 and D_2 within 0.05 eV of threshold is studied with a trapped electron method. An ac RPD technique is used to achieve energy resolution better than 0.1 eV. A series of trapped electron peaks is resolved in the 11.7 to 13.5 eV range. These are identified as vibrational levels of the $\underline{c}\ ^3\Pi_u$ state. In this energy range, excitation of other states (both singlet and triplet) near threshold is found to be weak by comparison. Several peaks observed in the 13.8 to 15.4 eV range could not be assigned to excitation of vibrational levels of a single electronic state.

ISOTOPE EFFECT IN THE DISSOCIATIVE EXCITATION OF H_2 (D_2)

Keith M. Burrows* and Gordon H. Dunn
Joint Institute for Laboratory Astrophysics†

Cross sections for dissociative excitation of H_2 and D_2 by electron impact have been measured by detecting the first three atomic Balmer emission lines of the dissociated atoms. Structure in the curves shows that dissociative excitation arises from: (1) excitation to a bound molecular state above the dissociation limit; (2) excitation to purely repulsive states yielding an excited atom and a ground state atom; (3) excitation to repulsive states yielding two excited atoms; and (4) excitation to an excited repulsive state of the ion yielding an excited atom and a proton. Comparison of magnitudes of the cross section for H_2 and D_2 for the first type of excitation allows one to tell the internuclear separation at which the bound molecular curve crosses the dissociation limit. States involved in the second and third type of excitation lie in the ionization continuum, and may autoionize. Comparison of cross section magnitude for the two isotopes allows one to put limits on the auto-ionization lifetime.

*Visiting Fellow for 1966−67 at JILA. On leave from the University of New South Wales, Sydney, Australia.
†Of the National Bureau of Standards and the University of Colorado, Boulder, Colo.

ELECTRON EXCITATION CROSS SECTIONS OF THE FIRST POSITIVE SYSTEM OF N_2*

Paul N. Stanton and Robert M. St. John
University of Oklahoma

The apparent excitation functions for the excitation of the first positive $\left(B^3\Pi_g - A^3\Sigma_u^+\right)$ system of nitrogen by electrons with energy from 0 to 50 eV have been measured for v' values of 2 through 7. The curves are characterized by two sharp peaks. The first peak at about 11 V is due to direct electron excitation from the ground state, and the second peak at about 15 V is caused by cascade from the $C^3\Pi_u$ state (second positive system). The maximum absolute apparent cross sections have been determined for 25 bands. The absolute apparent cross sections for the second positive system have been measured previously.[1] Using these cross sections, the cascade contributions of the $C^3\Pi_u$ states have been subtracted from the apparent excitation function of the v = 4 vibrational level of the $B^3\Pi_g$ state. The maximum cross section for the (v' = 4, v'' = 2) band was found to be 5.8×10^{-18} cm^2. Relative values of apparent cross sections of bands with the same upper vibrational level are compared with the corresponding relative values calculated from Franck–Condon factors.[2]

[1]J. D. Jobe, F. A. Sharpton, and R. M. St. John, J. Opt. Soc. Am., 57, 106 (1967).
[2]R. N. Zare, E. O. Larsson, and R. A. Berg, J. Mol. Spectry., 15, 124 (1965).

EXCITATION OF N_2^+ IONS BY ELECTRONS AT NEAR-THRESHOLD ENERGIES

A. R. Lee and N. P. Carleton
Harvard University and Smithsonian Astrophysical Observatory

Absolute cross sections have been measured for the excitation of the first negative system of N_2^+ $\left(X^2\Sigma_g^+, v = 0 \rightarrow B^2\Sigma_u^+, v' = 0 \right)$ by electron impact upon N_2^+ ions over the energy range of 8 to 30 eV. The crossed-beam technique was used, with a modulated electron-beam and a continuous ion beam. 3914 Å photons resulting from the interaction were detected by a photomultiplier after passage through an f/2 lens system and an interference filter. Two-channel pulse counting was used, in which the count difference in the two channels corresponds to the interaction being studied. The over-all quantum efficiency of the detection system was determined in terms of the known cross section for the process:

$$e + N_2 \rightarrow \left(N_2^+ \right)^* \rightarrow h\nu \ (3914 \ \text{Å})$$
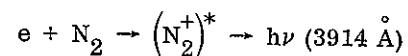
which has been measured by a number of workers, although there are some discrepancies among the existing data. For our calibration we have taken a value of $8.5 \times 10^{-18} \ \text{cm}^2$ for the cross section at 60 eV from a recent remeasurement by Holland, O'Neil, and Carleton. For the process under investigation, the cross section was found to decrease monotonically from a value of 50×10^{-16} cm^2 at 8 eV to a value of $4.5 \times 10^{-16} \ \text{cm}^2$ at 30 eV.

COMPLEX POTENTIAL ENERGY CURVES FOR THE $^2\Sigma_u^+$ AND $^2\Sigma_g^+$ STATES OF H_2^- *

Joseph C. Y. Chen and Jerry L. Peacher
University of California at San Diego

The complex potential energy curves for the $^2\Sigma_u^+$ and $^2\Sigma_g^+$ resonant states of H_2^- are obtained by a semi-empirical method in which the observed isotope effect in dissociative attachment is utilized. The adopted functional forms for the potential curves used in the semi-empirical method were suggested by the calculation carried out by Bardsley et al.[1] Significant differences from previous results are found for these curves. In particular, the imaginary parts of the potential are found to be smaller than that obtained by Bardsley et al. Assuming that the generalized analyticity and unitarity for S matrix in potential scattering holds also for the (e, H_2) multichannel system, one can show[2] that if the real part of the $^2\Sigma_g^+$ state crosses the $^3\Sigma_u^+$ state of H_2, the imaginary part of the $^2\Sigma_g^+$ state must dip to zero at the crossing. Investigation which allows for such a dip at the crossing is carried out.

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[1] J. N. Bardsley, A. Herzenberg, and F. Mandl, Proc. Phys. Soc. (London), 89, 305 (1966).
[2] P. G. Burke (private communication).

Session L

CHARGE AND EXCITATION TRANSFER

Chairman:

D. C. Lorents
Stanford Research Institute
Menlo Park

Friday, October 20
1:45 P. M.
Gold Ballroom

SINGLE CHARGE TRANSFER BETWEEN Ar^{++} AND Ar *

R. L. Champion† and L. D. Doverspike†
University of Florida

Doubly differential scattering measurements have been made on the Ar^{++} and Ar (20/11) reaction at a collision energy (laboratory) of 200 eV. Product ion kinetic energy distributions measured at various scattering angles show two distinct maxima, one lying above and the other several eV below 200 eV. If the unobserved slow Ar^{+} products are assumed to be in the ground state, then the fast Ar^{+} products are shown to be in highly excited states, ranging from the $3s\,3p^6$ level up to the ionization limit. By varying the electron bombardment energy in the ion source, it is demonstrated that the Ar^{+} corresponding to the high kinetic energy maximum in the product ion kinetic energy profiles are due to exothermic (20/11) reactions which involve highly excited metastable levels of Ar^{++}, while the slower group of observed Ar^{+} are due to endothermic (20/11) reactions involving only the $3s^2\,3p^4$ configuration. The angular distribution for the product ions, when Ar^{++} is in the $3s^2\,3p^4$ configuration, increases rapidly from 0 deg to a maximum at about 4 deg and decreases thereafter. The Ar^{+} product ions associated with highly excited Ar^{++} primaries are found to be sharply forward collimated.

CROSS SECTIONS FOR PRODUCTION AND LOSS OF H$_2$O^{+} *

J. A. Rutherford and B. R. Turner
General Atomic Division of General Dynamics Corporation
John Jay Hopkins Laboratory for Pure and Applied Science

Charge transfer cross sections resulting in either the production or loss of H$_2$O^{+} were studied within the energy range of 2 to 400 eV using the crossed ion and neutral beam technique and employing mass analysis of the primary and product ions. Ions incident on H$_2$O neutral beams were N^{+}, O^{+}, N$_2^{+}$, NO^{+}, O$_2^{+}$, and Ar^{+}; the H$_2$O^{+} ion beams were incident on neutral beams of O$_2$, NO, and H$_2$O. One rearrangement collision H$_2$O^{+} + H$_2$O → H$_3$O^{+} + OH was included. Effects on the cross sections due to the presence of excited ions in the incident beam were also investigated.

ENERGY DEPENDENCE OF CHARGE-TRANSFER REACTIONS IN THE THERMAL AND LOW eV REGION*

F. A. Wolf† and B. R. Turner
General Atomic Division of General Dynamics Corporation
John Jay Hopkins Laboratory for Pure and Applied Science

A method is presented for extrapolating to lower energies charge-transfer cross sections which have been measured by beam techniques for kinetic energies greater than 1 eV. The method combines the Rapp and Francis resonance charge-transfer theory with the Langevin capturing model, and is based upon a simple superposition of the "resonance" and "capture" probabilities resulting in charge transfer. The method also incorporates the effects of non-rectilinear orbits in the Rapp and Francis model. The theory has been applied to the negative ion charge-transfer reactions O^-, O_2^-, O_3^-, and OH^- with NO_2; the positive ion charge-transfer reactions O^+, O_2^+, N^+, and N_2^+ with NO; and N^+ and N_2^+ with O_2; and comparisons with existing experimental data are made. The method is valid provided that the relative abundances of the various products emerging from the capture-formed complex in the charge-transfer state are independent of the relative kinetic energy of the reactants.

RELATIVE CHARGE TRANSFER EFFICIENCIES OF $^2P_{3/2}$ AND $^2P_{1/2}$ XENON IONS IN Xe AND IN O_2 *

Robert C. Amme and Paul O. Haugsjaa
University of Denver

We have shown that the concentration of Xe^+ $^2P_{3/2}$ ions formed in an electron-impact ion source may be monitored by utilizing near-resonant charge transfer of Xe^+ beams with molecular oxygen. This measurement provides a means of assaying the fraction of excited ions in the Xe^+ beam and affords a technique for studying the effects of fine structure on the symmetric charge transfer process: $Xe^+ + Xe \rightarrow Xe + Xe^+$. With 25-eV electrons we find that the Xe^+ beam is about 80% $^2P_{3/2}$ state, while the remaining 20% appears to be principally $^2P_{1/2}$. The charge transfer cross section for the excited component in xenon was found to be 1.0 ± 0.15 relative to that of the $^2P_{3/2}$ ion, over a large range of incident ion energy. The results for Xe^+ in Xe are reported for the energy interval of 50 to 1000 eV. The cross sections are somewhat higher than those predicted by the Firsov formula, but agree within 20% at all energies studied.

CHARGE TRANSFER CROSS SECTIONS OF THE $^2P_{3/2}$ AND $^2P_{1/2}$ STATE ARGON AND KRYPTON IONS

J. F. Williams*
Laval University

The ionization cross section of argon and krypton atoms within 1 eV of threshold has been studied for electron impact with an average electron energy distribution of 35 meV (FWHM). In krypton, several abrupt changes in the ionization cross section occur at electron energies close to those observed spectroscopically for autoionization levels between the $^2P_{3/2}$ and $^2P_{1/2}$ levels. In argon, similar structure is observed above the $^2P_{1/2}$ level. Ions which have been formed in the above manner are then used as primary ions in charge-transfer reactions. For both Kr^+ on Kr and Ar^+ on Ar, the energy dependence of the single electron capture cross section from 500 to 1500 eV appears to be in agreement with the predictions of the adiabatic maximum criterion. From the shape and energy dependence of those cross sections it appears that for both $^2P_{3/2}$ and $^2P_{1/2}$ state primary ions the reaction has taken place such that the slow secondary ion is formed preferentially in the $^2P_{3/2}$ state. Those primary ions which originate from the structure in ionization efficiency curve between the $^2P_{3/2}$ and $^2P_{1/2}$ states have a cross section value approximately the same as the $^2P_{3/2}$ state ions.

'Present address: General Atomic Division of General Dynamics Corporation, San Diego, Calif.

IONIZATION AND ELECTRON TRANSFER IN COLLISIONS OF TWO H ATOMS: 1.25−117 keV*

G. W. McClure
Sandia Laboratory

Cross sections for electron loss and electron capture by H atoms in encounters with H target atoms are measured in the energy range 1.25 to 117 keV. The electron loss process is measured for H on H_2 as a check on the method. Three methods of processing the excited state distribution of the H atom beam are investigated in the energy range 25 to 100 keV. One method achieves a nearly pure (1s) state beam. Results are compared with theoretical Born approximation calculations of Bates and Griffing showing the theoretical cross section for the ionization process to be about 0.5 times the experimental value at 20 keV and equal to the experimental value at ~80 to 100 keV. The experimental values of the electron capture cross section are a factor of 5 to 6 below Mapleton's Born calculations. The quantum number dependence of the ionization cross section is deduced from a comparison of cross section measurements obtained with the different beam preparation methods. If the ionization cross section is assumed to vary as n^{α} where n is the quantum number of the excited projectile atom and α is a constant, it is found that α lies between 0 and 1 with most probable values < 0.36 for H on H_2 and < 0.77 for H on H.
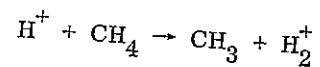
MEASUREMENT OF DIFFERENTIAL SCATTERING CROSS SECTIONS USING AN AXIALLY SYMMETRIC MAGNETIC FIELD

T. O. Bush and O. Heinz
Naval Postgraduate School
and
C. J. Cook
Stanford Research Institute

The focusing properties of an axially symmetric magnetic field are used in the study of large angle ($\theta > 32$ deg, lab) differential scattering of ions from atoms and molecules. The scattering cell is placed on the magnetic axis. All ions in the momentum interval $|\Delta p|$ at $|p|$ which are scattered into a conical shell $\Delta\theta$ at θ from the axially aligned incident beam are counted by a detector placed on the magnetic axis a distance L from the scattering cell. The solid angle is increased greatly over conventional scattering techniques of comparable angular resolution. The scattering angle θ can be swept either by moving the detector along the axis keeping the magnetic field constant or by varying the magnetic field and keeping the detector fixed. Trajectories determined by current-carrying wires agree with computer calculations. Ignoring incident beam particle orbiting, typical values of angular and energy resolution are a few tenths of a degree and a few eV, respectively. Orbiting decreases the resolution. The apparatus was designed to measure cross sections for proton capture reactions such as

$$H^+ + CH_4 \rightarrow CH_3 + H_2^+$$

Measurements of the differential scattering cross section of He^+ on He at angles above 32 deg show essential agreement with the measurements of Lorents and Aberth.[1]

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[1]D. C. Lorents and W. M. Aberth, Phys. Rev., 139, A1017 (1965).

DEPOLARIZATION OF LIGHT SCATTERED BY ALIGNED 2^3S AND 2^3P HELIUM ATOMS AT RESONANCE

L. D. Schearer
Texas Instruments Incorporated

The 2^3S_1 metastable and $2^3P_{1,2}$ excited state atoms of He^4 are aligned by an unpolarized beam of resonance radiation. The alignment is detected by the depolarization of the resonance fluorescence at $1\,\mu$ which occurs when either the 2^3S_1 or $2^3P_{1,2}$ levels are saturated by an rf magnetic field at the Zeeman frequency. The observed signals are several orders of magnitude larger than the corresponding signals observed by monitoring intensity changes in the transmitted beam. Considerably smaller signals are observed even in the absence of the pumping beam. Expressions for the intensity of the π and σ components of the scattered radiation are derived in terms of the alignment and density of the metastable atoms. The alignment of the 2^3S_1 (F = 3/2) and the 2^3P_2 (F = 5/2) levels of He^3 is also observed. The excited state linewidth as a function of pressure leads to a radiative decay time of $\tau \approx 0.96 \times 10^{-7}$ sec and a mixing cross section of 53×10^{-16} cm^2. The alignment of the 3^3P level of He^4 is also observed by monitoring polarization changes of the 3889 Å line.

COLLISION-INDUCED MIXING IN THE 2^3P LEVELS OF HELIUM

L. D. Schearer
Texas Instruments Incorporated

The cross section for the transfer of excitation from the 2^3P_0 level of helium to the 2^3P_1 and 2^3P_2 levels as a result of collisions with the ground state helium atom (1^1S_0) has been measured with a conventional resonance fluorescence technique. A He^4 source excited the $2^3S_1 - 2^3P_0$ in a He^3 absorption cell. The scattered light was examined with a high resolution grating spectrometer and the ratio of the $2^3P_0 \to 2^3S_1$ to the $2^3P_{1,2} \to 2^3S_1$ intensities measured as a function of cell pressure from 0.05 to 10 Torr. The cross section for collision-induced transitions out of the 2^3P_0 level is found to be $(68 \pm 3) \times 10^{-16}$ cm^2 at room temperature.

Session M

AFTERGLOWS

Chairman:

R. M. Hill
Lockheed Palo Alto Research Laboratory
Palo Alto

Friday, October 20
1:45 P.M.
Ralston Room

FREE-FALL DIFFUSION IN THE MERCURY DISCHARGE AFTERGLOW

B. C. Gregory

Trent University, Peterborough, Canada

Measurements of the decay of the average electron number density in the afterglow of a pulsed mercury vapor hot-cathode discharge are described. The pressure of the mercury vapor is such that the ratio of electron-atom mean free path to discharge tube radius is considerably greater than one. The decay profile of the electron number density is nonexponential under these conditions. The number density is measured using two microwave cavities, one in the TM_{010} mode and another in the plasma dipole mode. Two discharge tubes of different radii are used for the measurements, in which discharge pulse current, pulse length, and neutral particle pressure are varied. Along with these experiments the first three moment equations have been solved approximately,[1] giving approximate agreement with the measurements. A more exact solution is being attempted presently, as well as radiometer measurements of the electron temperature decay in the afterglow.

[1]B. C. Gregory, Can. J. Physics, 44, 2615 (1966).

MICROWAVE INVESTIGATION OF THE TRANSITION FROM AMBIPOLAR TO FREE DIFFUSION IN HELIUM AFTERGLOWS*

R. J. Freiberg† and L. A. Weaver‡

University of Illinois

The afterglow of helium plasmas has been investigated by incorporating microwave diagnostics and synchronous detection. Data are presented for electron densities ranging from 10^{11} down to 2×10^4 cm^{-3} where free diffusion predominates. Early in the afterglow space charge effects are important and the electron decay rate is characterized by the ambipolar diffusion coefficient D_a. At a pressure of 4.0 Torr the positive ion involved is He$_2^+$ ($D_a = 194$ cm^2/sec) whereas at 0.4 Torr He$^+$ ($D_a = 1230$ cm^2/sec) is the dominant ion. These values of D_a are consistent with the helium afterglow measurements of Kerr et al.[1] When the ratio of Debye length/tube diameter $> 10^{-2}$, the transition to free diffusion is observed. At lower electron densities when the Debye length equals the characteristic diffusion length, the effective diffusion coefficient increases to $\sim 5 D_a$ which is in accordance with the theoretical treatment of Allis and Rose.[2]

[1]C. S. Leffel, M. N. Hirsh, and D. E. Kerr (to be published).
[2]W. P. Allis and D. J. Rose, Phys. Rev., 93, 84 (1954).

OBSERVATION AND COMPUTATION OF OXYGEN AFTERGLOWS*

R. C. Gunton

Lockheed Palo Alto Research Laboratory

In oxygen afterglows at pressures near 1 Torr, time dependences of the major ions O_2^+, O^-, O_2^-, O_3^-, NO_2^-, and CO_3^- were observed with a mass spectrometer. The gas was ionized by rf pulses (10 to 1000 μsec) in an X-band microwave cavity and electron decay was monitored with a microwave signal and a wall probe. A computer program was written to describe the afterglow taking into account electrons, ions, and the neutrals O, O_2, and O_3. Diffusion of the various species was computed for the cylindrical geometry of the cavity using a space charge field formulation for the charged particles. Some 17 reactions among the species were included considering electron-ion and ion-ion recombination, attachment, associative detachment, charge exchange, and association of neutrals and charged particles. Initial species densities were chosen to match the measured microwave frequency shifts and the observed charged particle signal magnitudes. Agreement between measured and computed time dependences has been obtained. Also, using a simple, saturated plane probe theory, some agreement has been obtained between computed and measured probe currents of positive ions and negative particles. An initial O_3 density which seems too large was required to account for the observed O_3^- signal magnitude.

REACTIONS IN 4:1 MIXTURES OF N_2 AND O_2 DURING AND AFTER INTENSE IONIZATION

F. E. Niles

U.S.A. Ballistic Research Laboratories

Computer solutions have been obtained for 15 simultaneous differential equations which describe the time rate of change of electrons, NO_2^-, O^-, O_2^-, O_3^-, N_2^+, NO^+, O^+, O_2^+, N, NO, N_2O, NO_2, O, and O_3 during and after intense ionization. Initially 139 reactions involving these 15 species plus N_2 and O_2 were considered by the computer code. The number of reactions was reduced to 35 without appreciably changing the solutions. Further reduction to 15 reactions gave orders of magnitude changes in the solutions. The solutions were obtained for a rate of ionization of (1.61×10^9) p ion pairs cm^{-3} sec^{-1} where p, the pressure in Torr, ranged from 3 to 20 Torr. For continuous ionization, the solutions yield the fact that the NO^+ and NO_2^- number densities become the largest for positive ions and negative ions, respectively. The reaction sequences which lead to this result have been determined. These sequences, along with the neutral formation sequence, have been represented by schematic diagrams.

POST-BREAKDOWN ELECTRON DENSITY DECAY IN AIR

W. Dobrov and A. D. MacDonald
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A microwave technique has been developed for measurement of electron density decay following a single discharge event. The method depends on a rapid periodic sweep of the measuring frequency and selection of a desired number of sweeps for recording cavity shift versus time. This technique was applied to measurements of the decay of the electron densities produced by 9.5 GHz discharges in air at pressures 0.1 to 15.0 Torr. At most pressures in this range the decay may be represented by two decay rates which were observed to vary between a few microseconds and approximately 200 microseconds. The faster rate is interpreted as due to recombination and the slower one as due to a combination of diffusion and attachment processes. Since the diffusion rate increases and the attachment rate decreases with decreasing pressure, the resultant decay rate is expected to exhibit a minimum. This was observed at about 1 Torr for the slower rate. Separation of electron losses due to diffusion and attachment yielded:

$$D_a p = 115 \pm 15 \left[\frac{cm^2}{sec} \cdot Torr \right]$$

and

$$h\nu_c = (4.9 \pm 0.7 \cdot 10^3) \, p \, [sec^{-1}]$$

where D_a is the ambipolar diffusion coefficient, p is the pressure in Torr, h is the attachment efficiency, and ν_c is the electron collision frequency. Repeated as well as single discharges were studied and some differences between the two modes were observed.

REACTIONS IN 4:1 MIXTURES OF N_2 AND O_2 DURING AND AFTER INTENSE IONIZATION

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Computer solutions have been obtained for 15 simultaneous differential equations which describe the time rate of change of electrons, NO_2^-, O^-, O_2^-, O_3^-, N_2^+, NO^+, O^+, O_2^+, N, NO, N_2O, NO_2, O, and O_3 during and after intense ionization. Initially 139 reactions involving these 15 species plus N_2 and O_2 were considered by the computer code. The number of reactions was reduced to 35 without appreciably changing the solutions. Further reduction to 15 reactions gave orders of magnitude changes in the solutions. The solutions were obtained for a rate of ionization of (1.61×10^9) p ion pairs cm^{-3} sec^{-1} where p, the pressure in Torr, ranged from 3 to 20 Torr. For continuous ionization, the solutions yield the fact that the NO^+ and NO_2^- number densities become the largest for positive ions and negative ions, respectively. The reaction sequences which lead to this result have been determined. These sequences, along with the neutral formation sequence, have been represented by schematic diagrams.

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ELECTRON REMOVAL IN ARGON WAKES

Wade M. Kornegay
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Microwave absorption techniques have been used to measure the recombination between electrons and positive ions in the laminar wakes of hypervelocity tungsten spheres traveling 5.5 to 5.7 km/sec in high purity argon at pressures of 10 and 20 Torr. The electron density was measured over a two-order-of-magnitude range and plots of the reciprocal electron density versus time were found to be linear over the complete density range. The recombination coefficient (α_r) reduced from these data is 6×10^{-7} cm^3 sec^{-1} at 10 Torr and 3×10^{-7} cm^3 sec^{-1} at 20 Torr. Since a mass spectrometer was not employed in this investigation, one cannot state positively which type of ion the above measurements refer to. However, the magnitude of the rate constant suggests that deionization occurs by the very fast process of dissociative recombination. The value of α_r agrees well with published data for dissociative recombination of Ar_2^+ at room temperature, although the temperature in the wake is well above room temperature. This probably means that α_r is not very sensitive to temperature.

THE PRODUCTION AND LOSS OF N_2^+ IONS IN THE NITROGEN AFTERGLOW*

R. E. Lund† and H. J. Oskam
University of Minnesota

The time dependence of the number density of N^+, N_2^+, N_3^+, and N_4^+ ions was studied in the pressure range of about 0.1 to 1.7 Torr by means of mass spectrometric probing of decaying nitrogen plasmas. The results obtained from analogous studies of the emitted light intensity were used in the interpretation of N_2^+ data. The analysis of the N_2^+ decay curves showed that N_2^+ ions are produced in the afterglow by collisions between metastable nitrogen molecules, which are produced in the afterglow as a consequence of the atomic volume recombination process. Energy level and radiative lifetime considerations indicate that one of the metastable molecules is in the $a'\,^1\Sigma_u^-$ state, while the other metastable molecule may be in the same state or in the $A\,^3\Sigma_u^+$ or $^3\Delta_u$ state. The surface catalytic efficiency for de-excitation of the metastable molecules involved upon striking the molybdenum covered plasma container walls was estimated to be smaller than 2×10^{-3} at a pressure of 0.09 Torr. If both interacting metastable molecules are in the $a'\,^1\Sigma_u^-$ state, the measurements result in a value of 1.3×10^{-18} cm^2 for the cross section for destruction of this state by collisions with ground state nitrogen molecules.

ANOMALOUS EXCITATION OF THE SECOND POSITIVE SYSTEM OF NITROGEN

E. C. Zipf
University of Pittsburgh

Simultaneous measurements of the average electron density and the absolute intensity of selected bands of the second positive system of nitrogen $\left(C^3\Pi_u \to B^3\Pi_g\right)$ were made as a function of time, gas pressure, and discharge-cell geometry in the afterglow of a microwave discharge in highly purified nitrogen. The time-dependent measurements show that all five vibrational levels of the $C^3\Pi_u$ state were excited in the afterglow by the same mechanism and that they decayed with a lifetime characteristic of the long-lived excitation process. The first and second vibrational levels are preferentially populated to a marked degree. On the basis of these studies we can exclude the following excitation mechanisms: (1) electron-ion recombination, (2) electron-impact excitation, (3) three-body atomic nitrogen recombination, and (4) binary collisions between metastable nitrogen atoms or molecules with ground-state nitrogen molecules in the lowest vibrational level. The temporal behavior, the pseudo-resonant character of the excitation process, and the absolute volume emission rate of the second positive system in the afterglow can be explained quantitatively by an excitation mechanism involving inelastic metastable-metastable collisions.

TIME-DEPENDENT STUDY OF THE EMITTED LIGHT AND ELECTRON DENSITY IN A LOW-PRESSURE HELIUM AFTERGLOW

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Southwest Center for Advanced Studies

The relationship between the emitted light and decay of electron density in a pulsed helium afterglow at 1 Torr has been studied using a 0.75-m tandem monochromator and 36 Gc microwave interferometer. Substantial signal-to-noise enhancement was obtained with an automatic data processing system enabling populations of the n^3D levels ($n \leq 25$) to be measured as a function of time to 10 msec in the afterglow. In addition, the populations of low quantum levels and the free electron concentration were measured to 20 msec. It was found that the time-dependent behavior of the levels divided them naturally into three groups, only the lowest lying of which had been measured in previous afterglow experiments. The levels of this lowest group were found to decay exponentially with the same lifetime for better than three orders of magnitude. Levels of the middle group were found to decay exponentially for 2.5 decades, the lifetimes increasing monotonically with quantum number. Levels of the third group were identified to be in Saha equilibrium with the free electrons and uniformly had lifetimes equal to the sum of the calculated atomic and experimentally measured electron lifetimes.

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