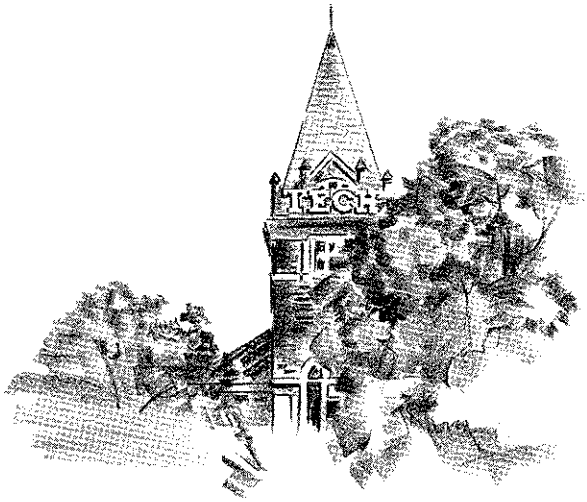
Programs and Abstracts of papers



Topical Conference
AMERICAN PHYSICAL SOCIETY

19th Annual

GASEOUS ELECTRONICS CONFERENCE

October 12-14, 1966

Georgia Institute of Technology

Atlanta, Georgia

Assisted by

Georgia Institute of Technology and Georgia Power Company

GASEOUS ELECTRONICS CONFERENCE COMMITTEE

A. V. Phelps (Chairman)

Westinghouse Research and Development Center

J. M. Anderson

General Electric Research and Development Center

L. M. Chanin

University of Minnesota

E. E. Ferguson

Environmental Science Services Administration

L. H. Fisher

Lockheed Missiles and Space Company

R. N. Varney

Lockheed Missiles and Space Company

J. F. Waymouth

Sylvania Electric Products

E. C. Zipf, Jr.

University of Pittsburgh

J. W. Hooper (Co-Secretary)

Georgia Institute of Technology

E. W. McDaniel (Co-Secretary)

Georgia Institute of Technology

Local Committee

E. W. Thomas

D. W. Martin

and
Georgia Tech
Continuing Education Department

NINETEENTH ANNUAL

GASEOUS ELECTRONICS CONFERENCE

Program and Index to Abstracts

Tuesday, October 11

7:30 - 10:00 p.m. Final Registration for those who have Pre-registered: Lobby, Americana Hotel

Cocktails: Conference Hospitality Rooms Mezzanine - Americana Hotel

Wednesday, October 12

8:00 a.m. Registration: Lobby, Electrical Engineering Building Georgia Institute of Technology

9:00 a.m. Session A: AFTERGLOWS

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

A-1 CHANGES IN THE ELECTRON VELOCITY DISTRIBUTION OF A NITROGEN PLASMA DUE TO A SMALL ADMIXTURE OF CO_2 AND O_2

J. H. Noon, P. R. Blaszuk and E. H. Holt /2

A-2 A THEORY OF THE SHORT DURATION AFTERGLOW OF NITROGEN

O. Oldenberg /2

A-3 ELECTRON TEMPERATURE DEPENDENCE OF DISSOCIATIVE RECOMBINATION OF Ne_2^+ AND N_2^+ IONS

L. Frommhold and Manfred A. Biondi /2

A-4 ELECTRON REMOVAL IN NO AND NO-Ne MIXTURES

M. H. Mentzoni and J. Donohoe /2

Coffee Break

A-5 THE RECOMBINATION COEFFICIENT OF NO^+ WITH e

Robert A. Young and Gilbert St. John /3

A-6 CHARGED PARTICLE PROCESSES IN AIRLIKE N_2:O_2 MIXTURES IRRADIATED BY 1.5 MEV ELECTRONS

M. N. Hirsh, G. Halpern, N. S. Wolf and J. Sleven /3

Wednesday, October 12 (Continued)

Wednesday, October 12 (Continued)

9:00 a.m. Session B: ARCS AND RADIATION TRAPPING

Chairman: Wulf B. Kunkel, Lawrence Radiation Laboratory, University of California Berkeley, California

Coffee Break

Wednesday, October 12 (Continued)

2:00 p.m. Session C. ELECTRON SCATTERING

Chairman: Arnold Russek, University of Connecticut
Storrs, Connecticut

C-1 SWARM DETERMINATION OF THE CROSS SECTION FOR MOMENTUM TRANSFER IN ETHYLENE AND IN ETHYLENE MIXTURES

L. G. Christophorou, G. S. Hurst, and W. G. Hendrick /10

C-2 ARGON TOTAL CROSS SECTION FOR ELECTRONS AT ENERGIES BELOW 1 VOLT

G. C. Baldwin /10

C-3 ABSOLUTE TOTAL e^- - N_2 SCATTERING CROSS SECTIONS FOR ENERGIES OF 0.3 to 25 eV

D. E. Golden /10

C-4 LOW-ENERGY SCATTERING OF ELECTRONS FROM MOLECULES--APPLICATION TO H_2

Neal F. Lane and S. Geltman /10

C-5 STRUCTURE OF RESONANCES IN ELASTIC e-H SCATTERING

Joseph C. Y. Chen /11

Coffee Break

C-6 QUALITATIVE ASPECTS OF RESONANCES IN ELECTRON-ATOM AND ELECTRON-MOLECULE SCATTERING, EXCITATION AND REACTIONS

H. S. Taylor, G. V Nazaroff and A. Golebiewski /11

C-7 A GENERAL ADIABATIC APPROXIMATION FOR ELECTRON SCATTERING

Philip M. Stone and P. de A. P. Martins /11

C-8 TREATMENT OF EXCHANGE IN ELECTRON-ATOM AND ELECTRON-DIATOMIC MOLECULE SCATTERING AT LOW ENERGIES

J. C. Tully and R. Stephen Berry /11

C-9 ELECTRON SCATTERING FROM $1s^2 2s^2 2p^q$ ATOMIC SYSTEMS

W. R. Garrett /12

C-10 TRAJECTORIES OF MAGNETICALLY CONFINED ELECTRONS IN GASEOUS COLLISIONS

D. D. Briglia /12

Wednesday, October 12 (Continued)

2:00 p.m. Session D: METASTABLE AND EXCITED STATES

Chairman: A. L. Schmeltekopf, Environmental Science Services Administration, Boulder, Colorado

Coffee Break

*Combined papers

Thursday, October 13

9:00 a.m. Session E: BREAKDOWN

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

E-1 VACUUM BREAKDOWN AS A FUNCTION OF GAP SEPARATION

A. Watson and M. J. Mulcahy /18

E-2 FURTHER CALCULATIONS OF MIDGAP BREAKDOWN IN GASES

A. L. Ward /18

E-3 THE MECHANISM OF THE ELECTRICAL BREAKDOWN OF GASES AT HIGH VOLTAGES

J. Dutton and W. T. Morris /18

E-4 THE COURSE OF NEGATIVE POINT-TO-PLANE BREAKDOWN IN FREE ELECTRON GASES

Abbass Hassoun /18

Coffee Break

E-5 POSITIVE STREAMER SPARK BREAKDOWN AT LOW PRESSURES IN AIR

T. Oshige /19

E-6 CROSSED-FIELD BREAKDOWN IN HYDROGEN

Wulf B. Kunkel and Arthur R. Sherwood /19

E-7 MECHANISMS FOR LASER-INDUCED BREAKDOWN OF SUPERHIGH PRESSURE GASES

Arwin A. Dougal and Dennis H. Gill /19

11:30 a.m. BUSINESS MEETING

Chairman: A. V. Phelps

Thursday, October 13 (Continued)

9:00 a.m. Session F: MOBILITY AND DIFFUSION

Chairman: Ronald Geballe, University of Washington, Seattle, Washington

F-1 ANALYSIS OF ION SWARM EXPERIMENTS BY MEANS OF MAXIMUM LIKELIHOOD ESTIMATORS

/18 W. S. Barnes /21

F-2 IMPROVED ION CYCLOTRON RESONANCE CROSS SECTIONS

/18 D. Wobschall, R. Fluegge, and J. R. Graham, Jr. /21

F-3 MEASUREMENT OF THE TEMPERATURE DEPENDENCE OF HELIUM ION MOBILITIES IN HELIUM

/18 P. L. Patterson /21

F-4 MOBILITIES OF H_1^+ AND H_3^+ IONS IN HYDROGEN GAS

/18 D L Albritton, T. M. Miller, J T. Moseley, D. W. Martin and E. W. McDaniel /21

Coffee Break

F-5 MOBILITY OF CO^+, CO_2^+, AND $C_2\ O_2^+$ IONS IN CARBON MONOXIDE GAS

/19 M. Saporoschenko and G. W. Bielar /22

F-6 DRIFT AND DIFFUSION OF OXYGEN IONS IN OXYGEN

/19 J. Dutton and P. Howells /22

F-7 DRIFT VELOCITIES OF NEGATIVE OXYGEN IONS IN OXYGEN

/19 L. G. McKnight /22

11:30 a.m. BUSINESS MEETING

Chairman: A. V. Phelps

Proposed Amendment to the Constitution of the Gaseous Electronics Conference

In accordance with the articles of the Constitution, the Secretary has received, prior to the deadline for the submission of abstracts this year, a written Amendment endorsed by the proper number of signatures of members of the Conference. The purpose of this Amendment is to honor Professor W. P. Allis for his outstanding contributions to the Gaseous Electronics Conference. The Chairman will place the following Amendment before the business session at the 1966 meeting.

Amendment

Professor W. P. Allis is appointed Honorary Chairman of the Gaseous Electronics Conference for his outstanding contributions to the success of this Conference. In this capacity he is appointed a permanent member of the General Committee so that the Conference may benefit from his long experience and wise counsel.

Thursday, October 13 (Continued)

2:00 p.m. Session G: HIGH ENERGY ATOMIC COLLISIONS

Chairman: E. W. Thomas, Georgia Institute of Technology, Atlanta, Georgia

G-1 DIFFERENTIAL CROSS SECTIONS FOR 2^3S AND HIGHER STATE EXCITATION IN He^+ + He COLLISIONS

D. C. Lorents, W. Aberth and V. W. Hesterman /24

G-2 OPTICAL EXCITATION OF HELIUM ATOMS BY LOW ENERGY HELIUM IONS

S. H. Dworetsky, R. Novick, W. W. Smith and N. Tolk /24

G-3 RELATIVE PRODUCTION OF SINGLY AND DOUBLY CHARGES IONS IN HELIUM BY FAST PROTONS IN THE ENERGY RANGE 0.15 - 1.00 MEV

L. J. Puckett, G. O. Taylor, and D. W. Martin /24

G-4 DEDUCTION OF POTENTIALS AND INTERACTIONS FROM THE DIFFERENTIAL SCATTERING OF He^+ BY RARE GASES

Felix T. Smith and R. P. Marchi /24

G-5 EXCITATION OF HELIUM AND NITROGEN BY FAST PROTONS

E. W. Thomas, G. D. Bent, and J. L. Edwards /25

Coffee Break

G-6 THE MEASUREMENT OF CHARGE TRANSFER CROSS SECTIONS FOR 0.25 TO 2.5 MeV PROTONS AND HYDROGEN ATOMS INCIDENT UPON HYDROGEN AND HELIUM GASES

James Francis Williams /25

G-7 ELECTRON CAPTURE BY PROTONS IN HYDROGEN AND EFFECT OF AN ELECTRIC FIELD

K. Omidvar /25

G-8 EXCITATION OF THE FIRST NEGATIVE SYSTEM OF N_2^+ BY HYDROGEN-ATOM IMPACT

D. A. Dahlberg, I. E. Dayton, and D. K. Anderson /25

G-9 THE STUDY OF LONG-LIVED EXCITED STATES IN ION BEAMS

B. R. Turner, J. A. Rutherford, D. M. J. Compton /26

G-10* CHARGE TRANSFER CROSS SECTIONS FOR NEGATIVE IONS INCIDENT ON ATMOSPHERIC GASES

R. D. Rundel, W. R. Snow, and R. Geballe /26

G-11* NEGATIVE ION CHARGE TRANSFER WITH ATOMIC TARGETS

W. R. Snow, R. Geballe and J. S. Risley /26

*Combined papers

Thursday, October 13 (Continued)

2:00 p.m. Session H: ELECTRON TRANSPORT AND DISTRIBUTION FUNCTIONS

Chairman: W. P. Allis, Massachusetts Institute of Technology, Cambridge, Massachusetts

H-1 MEASUREMENT OF THE ENERGY DISTRIBUTION OF SECONDARY ELECTRONS IN AN AURORA
John P. Doering and William G. Fastie /28

H-2 EXCHANGE OF ENERGY BETWEEN CHARGED PARTICLES
N. P. Carleton /28

H-3 THEORY OF ELECTRON COLLISION EXPERIMENTS AT INTERMEDIATE AND HIGH GAS DENSITIES
P. J. Chantry, A. V. Phelps and G. J. Schulz /28

H-4 TIME-DEPENDENT TRANSPORT COEFFICIENTS FOR ELECTRONS IN DRY AIR
A. G. Englehardt /28

Coffee Break

H-5 DRIFT VELOCITY AND THE ELASTIC COLLISION CROSS SECTION FOR ELECTRONS IN HELIUM
J. C. Bowe and R. K. Langs /29

H-6 ANOMALOUS ELECTRON DIFFUSION PARALLEL AND PERPENDICULAR TO ELECTRIC FIELDS
F. J. Davis and J. E. Parks /29

H-7 ENERGY ANTICORRELATION OF ELECTRONS EMITTED IN ELECTRON IMPACT IONIZATION OF ATOMS
A. Temkin /29

H-8 SINGLET-TRIPLET EXCITATION OF THE HYDROGEN MOLECULE BY ELECTRON IMPACT
S. P. Khare /29

H-9 VIBRATIONAL AND ELECTRONIC EXCITATION OF CO_2 BY ELECTRON IMPACT
R. D. Hake, Jr. and A. V. Phelps /30

H-10 DIRECT MEASUREMENTS OF THE ELECTRON ENERGY DISTRIBUTION FUNCTION IN A UNIFORM D. C. ELECTRIC FIELD IN HYDROGEN FOR LOW VALUES OF E/p
D. E. Golden and H. Nakano /30

6:30 p.m. Social Hour, Mezzanine - Americana Hotel

7:30 p.m. Banquet, Banquet Hall - Americana Hotel

Friday, October 14

9:00 a.m. Session I: EXCITATION, IONIZATION, AND DISSOCIATION BY ELECTRONS

Chairman: Felix T. Smith, Stanford Research Institute, Menlo Park, California

Coffee Break

Friday, October 14 (Continued)

9:00 a.m. Session J: ION-MOLECULE REACTIONS

Chairman: C. F. Barnett, Oak Ridge National Laboratory, Oak Ridge, Tennessee

J-1 USE OF CORONA DISCHARGES FOR STUDIES OF ION-MOLECULE REACTIONS
M. M. Shahin /36

J-2* ON THE POSSIBLE EXISTENCE OF H_4^+
P. Marmet /36

J-3* A FIRST APPROACH TO THE STRUCTURE DETERMINATION OF H_4^+
J. Lefaivre and P. Marmet /36

J-4 CHARGE TRANSFER REACTIONS OF ARGON IONS AT NEAR THERMAL ENERGIES
P. Warneck /36

J-5 IONIC COLLISION PROCESSES AS STUDIED WITH A TANDEM ISOTOPE SEPARATOR-MASS SPECTROMETER COMBINATION
T. F. Moran, J. J. Leventhal and L. Freidman /37

J-6 THE FLOWING AFTERGLOW EXPERIMENT FOR THERMAL ENERGY ION-MOLECULE REACTION STUDIES
A. L. Schmeltekopf, F. C. Fehsenfeld, and E. E. Ferguson /37

J-7 THERMAL ENERGY NEGATIVE ION REACTIONS
F. C. Fehsenfeld, A. L. Schmeltekopf, and E. E. Ferguson /37

J-8 THERMAL ENERGY NEGATIVE ION REACTION MECHANISMS AND APPLICATIONS
E. E. Ferguson, F. C. Fehsenfeld, and A. L. Schmeltefopf /37

Coffee Break

J-9 ENERGETIC STUDIES OF REACTIVE COLLISIONS FOR THE SYSTEMS $D_2^+ + D_2$ AND $D_2^+ + H_2$
L. D. Doverspike and R. L. Champion /38

J-10 A MERGING BEAMS EXPERIMENT
S. M. Trujillo, R. H. Neynaber, and Erhard W. Rothe /38

J-11 CROSS SECTIONS FOR INWARDLY-SPIRALLING ION-MOLECULE COLLISIONS
G. Gioumousis /38

*Combined papers

Friday, October 14 (Continued)

2:00 p.m. Session K: NEGATIVE IONS AND PHOTOIONIZATION

Chairman: Thomas L. Bailey, University of Florida
Gainesville, Florida

Friday, October 14 (Continued)

2:00 p.m. Session L: DISCHARGES

Chairman: W. W. Robertson, University of Texas Austin, Texas

L-1 VOLUME ION PRODUCTION COSTS IN TENUOUS PLASMAS

R. J. Sovie and J. V. Dugan, Jr. /44

L-2 TEMPERATURE MEASUREMENT OF AN ALKALI METALSEEDED PLASMA IN AN ELECTRIC FIELD

Tsu-Kai Chu and Chad F. Gottschlich /44

L-3 IONIZATION OF ATOM BY COLLISION WITH EXCITED ATOMS

T. Watanabe and K. Katsuura /44

L-4 PROBE CHARACTERISTICS IN OVERDAMPED MAGNETO IONIZED GAS

Nguyen T. Dzoanh /44

L-5* THE EFFECT OF THE PLASMA PROPERTIES ON THE EFFICIENCY AND POWER OUTPUT OF THE CO_2-N_2-He LASER

Peter O. Clark and Michael R. Smith /45

L-6* THEORY OF CO_2-N_2 LASER

Peter O. Clark and Michael R. Smith /45

L-7 AN EXPERIMENTAL STUDY OF THE RADIAL DISTRIBUTION OF EXCITED ATOMS AND IONS IN A CAPILLARY DISCHARGE IN ARGON

C. E. Webb /45

L-8 COLLISION EFFECT ON THE DENSITY DISTRIBUTION OF CHARGED PARTICLES IN A HIGH FREQUENCY ELECTROMAGNETIC FIELD

D. M. Kim /45

L-9 ENHANCEMENT OF THE 2062A IODINE LINE IN AN IODINE-INERT GAS FLASH DISCHARGE

A. G. Leiga and J. A. McInally /46

*Combined papers

/44

Session A

Wednesday, October 12

/44

9:00 a.m.

/44

/44

AFTERGLOWS

/45

/45

MS

/45

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

ES

/45

/46

A1 CHANGES IN THE ELECTRON VELOCITY DISTRIBUTION OF A NITROGEN PLASMA DUE TO A SMALL ADMIXTURE OF CO_2 AND O_2. J. H. NOON, P. R. BLASZUK, E. H. HOLT, Rensselaer Polytechnic Institute.*

We have previously reported[1] measurements, using a microwave technique, which established that early in the afterglow of a nitrogen plasma the form of the electron velocity distribution changes rapidly, although the mean energy decreases monotonically with time. A possible mechanism[2] to explain the observed secondary heating, attributed to generation of energetic electrons shortly after termination of the active discharge, is coupling between electrons and vibrationally excited states of the nitrogen molecule. Since there is an efficient energy interchange[3] between N_2^* (v=1) and CO_2 (00^01) energy levels, admixture of CO_2 to the N_2 should affect the radiation temperature of the afterglow plasma. We have demonstrated experimentally with mixtures of up to 10% of CO_2, that the amount of secondary heating of the electrons is significantly reduced, in agreement with the above hypothesis. However, an admixture of up to 5% of O_2 to the N_2 has a similar effect and leads to a faster decay of the electron temperature. The change in the form of the distribution function is quite different in the two cases, so it is likely that different mechanisms of energy interchange between the electrons and the neutral gas molecules are involved.

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

1. P. R. Blaszuk, E. H. Holt, Bull. Am. Phys. Soc. 11, 375 (1966).
2. I. R. Hurle, J. Chem. Phys. 41, 3592 (1964).
3. C. K. N. Patel, Phys. Rev. Letters 13, 617 (1964).

A2 A THEORY OF THE SHORT DURATION AFTERGLOW OF NITROGEN. O. OLDENBERG, Air Force Cambridge Research Laboratory and Harvard University.

The short duration afterglow of nitrogen (auroral afterglow), discovered 1932 by Kaplan, is explained in terms of well established properties of metastable molecules. In the gas pumped out of a discharge this afterglow appears as a short, bright flash. It is combined with ionization and separated from the discharge by a dark interval. An intense discharge contains a considerable concentration of atoms but very few metastable molecules since these are deactivated by the current. However, Kaplan identified metastables in the gas away from the discharge by their emission of the Vegard-Kaplan bands. It is assumed that in the gas pumped out, along the dark interval, recombining atoms form metastables which here, in the absence of a current, accumulate to a concentration high enough for two metastables to form N_2^+ or, by attachment, N_3^+ or N_4^+. The ions are excited by collisions with highly vibrating molecules or other metastables. Numerical estimates lead to plausible figures. A second flash is attributed to temperature effects.

A3 ELECTRON TEMPERATURE DEPENDENCE OF DISSOCIATIVE RECOMBINATION OF Ne_2^+ and N_2^+ IONS.* L. FROMMHOLD and MANFRED A. BIONDI, University of Pittsburgh.

Recombination loss of electrons from afterglows in pure neon and $\sim 10^4$:1 neon-nitrogen mixtures at ~ 30 Torr pressure has been studied by means of a 3-mode microwave system. Two high-Q cavity modes are used to ionize the gas and to determine the electron density from frequency shift measurements. The third mode is a non-resonant waveguide mode which permits application of various constant microwave heating fields to the electrons throughout the afterglow in order to control the electron temperature. Optical absorption apparatus is used to monitor neon metastable atom concentrations. Under recombination controlled conditions and $T_e=T_+=T_{gas}=300°K$ the recombination coefficients for Ne_2^+ and N_2^+ ions are in reasonable agreement with the results of other investigations[1,2]. The recombination coefficients decrease slowly with increasing electron temperature over the range $300 \leq T_e \leq 3000°K$ and $T_+=T_{gas}=300°K$. The closest simple power law fit to the data in both cases is an approximate $T_e^{-1/4}$ variation.

*This research was supported in part by the Defense Atomic Support Agency through the Army Research Office (Durham).

1. W. H. Kasner and M. A. Biondi, Phys. Rev. 137, A317 (1965).
2. M. A. Biondi and S. C. Brown, Phys. Rev. 76, 1697 (1949).

A4 ELECTRON REMOVAL IN NO AND NO-Ne MIXTURES* M. H. MENTZONI and J. DONOHOE, Sylvania Electronic Systems.

The electron density, N_e, and radiation temperature, T_e, have been measured in DC discharge afterglows in NO[1] and NO-Ne mixtures. Microwave techniques are used. The pressure of Ne was 20 Torr with the pressure of nitric oxide ranging from 0.005 to 0.10 Torr. For these mixtures, as well as in NO under certain conditions, $(1/N_e)$ varied linearly with time over extensive ranges of N_e with the slopes having values in reasonable agreement with the recently published recombination coefficients in photoionized NO.[2,3] The decay of T_e in the mixtures varied with the partial pressure of NO and discharge striking energy and was in general not exponential.

*Work partly supported by the Air Force Systems Command, U. S. Air Force.

1. M. H. Mentzoni and J. Donohoe, Can. J. Phys., 44, 693 (1966).
2. C. S. Weller and M. A. Biondi, Bull. Am. Phys. Soc. 11, 495 (1966).
3. R. C. Gunton and T. M. Shaw, Phys. Rev., 140, A756 (1965).

A5 THE RECOMBINATION COEFFICIENT OF NO^+ WITH e. ROBERT A. YOUNG and GILBERT ST. JOHN, Stanford Research Institute.

The dissociative recombination coefficient of NO^+ with e has been measured as $(4 \pm 1) \times 10^{-7}$ cm^3/sec. The ions were produced uniformly in space and time in a mixture of N, O, and N_2 by chemionization processes. Ion densities were measured by a pulsed total ion collection method. Analysis of the growth of ionization with time and analysis of the dependence of the square of ion density on ion production rate gives essentially identical values for the recombination coefficient.

A6 CHARGED PARTICLE PROCESSES IN AIRLIKE N_2:O_2 MIXTURES IRRADIATED BY 1.5 MEV ELECTRONS.* M.N. HIRSH, G. HALPERN, N.S. WOLF and J. SLEVIN, G.C. Dewey Corp.

We have studied charged particle reactions in 4:1 mixtures of N_2:O_2 irradiated by 1.5 Mev electrons, using a technique described previously (1). A beam electron traversing the gas at STP produces 68 ion pairs per cm, in agreement with calculated energy deposition rates (2). Above 1.5 Torr, thermal electrons are lost by 3-body attachment to O_2 molecules with the rate coefficient $(1.10\pm.05)\times10^{-31}cm^6/sec$. Electron diffusion at lower pressures is controlled by positive and negative ions. Ion loss by mutual neutralization has been inferred from the details of the electron diffusion, in a manner analogous to the treatment described elsewhere for oxygen(1). Electron-positive ion recombination has also been seen. An approximate analysis of the low-pressure data which treats the ions as a single "average" species each of positive and negative ions yields an effective electron-positive ion recombination coefficient of $(3\pm2)\times10^{-7}cm^3/sec$, and an effective mutual neutralization coefficient of $(2.5\pm1.5)\times10^{-7}cm^3/sec$, in agreement with values inferred from *in situ* measurements in the ionosphere. The positive ions observed during irradiation are NO^+ and O_2^+, along with a small, nearly pressure-independent N_2^+ concentration. Possible ion-molecule reactions leading to the observed ion spectra are also discussed.

*Work supported by Defense Atomic Support Agency through U.S. Army Signal Research Lab., Fort Monmouth.
1. M.N. Hirsh *et al*, Bull. Am. Phys. Soc, 11, 495 (1966)
2. A.T. Nelms, U.S. Bur. Stands. Circ. No. 577 (1957)

A7 ELECTRON-ION RECOMBINATION STUDIES IN OXYGEN*. W. H. KASNER and MANFRED A. BIONDI**, Westinghouse Research Laboratories.

Combined microwave and mass spectrometric techniques[1] have been used to study the afterglow decay of electrons and positive ions from "single pulse" microwave discharges in O_2-Ne and O_2-Ne-Ar gas mixtures under conditions where O_2^+ is the only significant afterglow ion species and where the recombination of electrons and O_2^+ ions is the dominant loss mechanism. Similar decay rates are observed for both O_2^+ ions and electrons over the major portion of the afterglow. At room temperature the measured recombination coefficient, $\alpha(O_2^+)$, has a value $(2.2 \pm 0.4) \times 10^{-7}$ cm^3/sec and shows no significant dependence on the neon or argon gas pressures. However, a systematic dependence on the oxygen pressure, within the quoted limits of error, is observed in both gas mixtures. A significant temperature dependence for $\alpha(O_2^+)$ has been observed, the values ranging from approximately 3.6×10^{-7} cm^3/sec at 200^oK to 1.8×10^{-7} cm^3/sec at 550^oK. These results are in reasonable agreement with recent data of Mentzoni[2] for unidentified ions in oxygen.

*This research has been supported in part by the Air Force Weapons Laboratory.
**Physics Department, University of Pittsburgh.
1. W. H. Kasner and M. A. Biondi, Phys. Rev. 137, A317 (1965).
2. M. H. Mentzoni, J. Appl. Phys. 36, 57 (1965).

A8 STUDY OF ELECTRONS, POSITIVE IONS AND NEGATIVE IONS IN OXYGEN AFTERGLOWS*. R. C. GUNTON, Lockheed Palo Alto Research Laboratories.

Oxygen at pressures near 1 torr was ionized in an X-band cavity by 10 to 1000 μsec pulses of microwave power. The time dependence of electron decay was monitored with a microwave signal and a probe at the wall; ion decay was monitored with the probe and a mass spectrometer. The observed time dependence of the major positive ion O_2^+ was analyzed with the aid of a computer program taking into account diffusion, recombination and attachment in a cylindrical cavity, and for a short pulse (10 μsec) the initial spatial distribution of positive ions was found to be highly peaked in the center. To explain the initial rapid loss of electrons observed by microwaves, assumption of electron-ion recombination with a rate coefficient of about 2×10^{-7} cm^3sec^{-1} was necessary in addition to 3-body attachment and higher mode diffusion. This value is in agreement with the measurement of Kasner and Biondi.[1] The rate of electron decay later in the afterglow was found to be dependent on ionizing pulse length, being slower for longer pulses, probably due to the production of larger numbers of detaching species during the longer pulse. The major negative ions observed were O^-, O_2^- and O_3^- as well as NO_2^- due to nitrogen impurity. The ions O^- and O_2^- peaked early in the afterglow, followed by O_3^- and NO_2^-, possibly formed by charge exchange.

* Supported by the Lockheed Independent Research Program.
1. W. H. Kasner in Air Force Weapons Laboratory Technical Report TR-64-178, July 1965.

A9 EFFECTS OF MICROWAVE HEATING ON A CRYOGENIC HELIUM AFTERGLOW.* J. P. KAPLAFKA, Gaseous Electronics Laboratory, University of Illinois.

Recombination light can be quenched by increasing the temperature of the electron gas, thus causing a reduction in the prevailing recombination coefficient. Electron heating with low level pulsed microwaves of nearly isothermal helium plasmas and neon plasmas at 77° K and helium plasmas at 4.2° K of high neutral number densities ($\sim 10^{18}$/cc) produces an additional feature. There is a large short term increase in the light intensity upon removal of the heating, several times the amplitude of the normal afterglow light at that time. Microwave measurements indicate a marked increase in electron number density (~50%) during heating at a level which increases the electron temperature from gas temperature to a point below 300° K. Electron production depends upon heating level. The "afterpulse" of light is ascribed to enhanced recombination caused by the rapid decay of electron temperature with removal of heating and the enhanced population of free electrons. Decay of the 5876 A He line in the tail of the afterpulse follows the relationship I (intensity) $\propto$ n (electron density) to the 2.5 power irrespective of heating level. Late normal afterglow decay gives the same relationship. This suggests collisional-radiative recombination with the He_2^+ ion which is expected to overwhelm He^+ population under these conditions and late times of the afterglow. Quenching in conjunction with microwave temperature measurements indicate a $T_e^{-3/2}$ dependence of the recombination coefficient from T_e = 77° K to T_e = 300° K.
*Sponsored by USAF Cambridge Res Lab.

A10 THE EFFECT OF THE GAS TEMPERATURE ON ELECTRON TEMPERATURE AND RECOMBINATION IN DENSE HELIUM AFTERGLOW PLASMAS. G. K. BORN AND R. G. BUSER, Institute for Exploratory Research, Fort Monmouth, N.J.

The generation of dense plasmas ($\sim 10^{13} e/cm^3$) is usually accompanied by a heating of the neutral gas.[1] The effect of the elevated gas temperature on electron temperature decay and recombination is investigated in helium afterglow plasmas (p~.1 torr) produced by a pulsed condenser discharge. The emitted afterglow is found characteristic[2] for collisional-radiative recombination. Electron temperature and relative density decay are deduced from measurements of the relative intensities of spectral lines. The absolute electron concentration is determined from the phase shift of a microwave signal, and the recombination coefficients found in the experiments are in approximate agreement with theoretical results.[3] In addition, the time varying gas temperature is determined[1] from the frequency of standing acoustic waves which are excited during the discharge pulse. No difference is detected between the temperatures of the electrons and the neutral gas (1000-3000°K). The slow electron temperature decay is controlled by the gas temperature decay, and afterglow electron heating mechanisms are unimportant in these experiments.

1. G. K. Born and R. G. Buser, to be published in J. Appl. Physics.
2. E. Hinnov and J. G. Hirschberg, Phys. Rev. 125, 795 (1962).
3. D. R. Bates, A. E. Kingston, R. W. P. McWhirter, Proc. Roy. Soc. (London) A267, 297 (1962).

Session B

Wednesday, October 12

9:00 a.m.

ARCS AND RADIATION TRAPPING

Chairman: Wulf B. Kunkel, Lawrence Radiation Laboratory, Berkeley, California

B1 ANALYSIS OF THE ELECTRODE PRODUCTS EMITTED BY DC VACUUM ARCS. W. D. DAVIS AND H. C. MILLER, General Electric Research and Development Center, Schenectady, New York

We have examined the particles emitted radially by d.c. arcs drawn in vacuum on Ag, Al, Mo, Ta, and Zr; as well as the axial (through-anode) products from a Cu cathode. The axial results for Cu agree grossly with our previous radial measurements.[1] If one expresses ion energy distributions (IED) in units of electron volts/unit charge, then the energy distributions for the various ions are similar. For a given element the IED tend to shift to lower energy with increasing arc current, and also with increasing degree of ionization. All IED observed peaked at voltages (with respect to the grounded cathode) above the arc voltage, tending to peak higher for elements with higher arc voltages. Significant quantities of singly-, doubly-, and triply-charged ions were seen for all elements examined, while quadruply ionized Mo, Ta, Zr and quintuply ionized Ta and Zr were readily seen. All arc volt-ampere characteristics were positive in the range of currents observed: 30 to 250 A. At 100 A, arc voltages were: Mo - 25-1/2 V, Ta - 24 V, Zr - 21-1/2 V, Al - 20 V, and Ag - 16-1/2 V.

1. W. D. Davis and H. C. Miller, Bull. Am. Phys. Soc. 11, 504 (1966).

B2 THE ROLE OF SELF-ABSORPTION IN Hg + Tl SENSITIZED FLUORESCENCE EXPERIMENTS. C. F. GALLO, Xerox Corporation.

At constant thallium gas density, Swanson and McFarland[1] have determined the intensity ratio (R) of the Tl 3776Å line to the Tl 5350Å line as the mercury density (D) is varied. The functional form of the dependence of R on mercury density (D) has been successfully interpreted in terms of the self-absorption theory of Holstein[2]. Specifically, the Tl 3776Å line is strongly self-absorbed at low Hg densities. As the Hg density increases, Hg-Tl collisions occur more frequently and the Tl 3776Å absorption line broadens, allowing more 3776Å radiation to escape. In this region, R varies as $D^{1/2}$. At still higher Hg densities, the 3776Å radiation readily escapes and R becomes a weak function of D and finally levels off to a constant value. These results constitute a semi-quantitative verification of Holstein's self-absorption theory for the case where the shape of the absorption line is determined by impact broadening.

(1) R. E. Swanson and R. H. McFarland, Phys. Rev. 98, 1063 (1955).
(2) T. Holstein, Phys. Rev. 72, 1212 (1947); 83, 1159 (1951).

B3 RADIATION TRAPPING AND ITS EFFECT ON ION LASER PERFORMANCE. MICHAEL A. LUTZ and MICHAEL R. SMITH, Hughes Research Laboratories.

A pulsed ion laser under certain discharge conditions and current pulse rise times has produced a laser output waveform which follows the initial rise in the current pulse up to a critical current value, but is observed to decrease as the current pulse continues to rise. Finally, at a later time the laser output is observed to recover. This dip in laser output is attributed to trapping of the ion resonance radiation, thereby effectively decreasing the radiative depopulation rate of the lower laser level. A simple phenomenological model is proposed to explain the functional dependence of the various discharge parameters on the observed laser output. Radiation trapping will affect laser performance when

$$\frac{I p_g}{R T_g^{3/2}} > \text{Const.}$$

where I is the discharge current, p_g is the gas pressure, R is the tube radius, and T_g is the gas temperature. At the beginning of the pulse, when the gas is near room temperature, this result predicts a critical current above which laser output is affected. Also, for a given steady current, the gas temperature is predicted, above which laser output will recover. The time required to heat the gas to this temperature by electron atom collisions has been calculated. This time, the critical current, and the inequality above are in good qualitative agreement with experimental observations.

B4 ANODE PHENOMENA IN METAL-VAPOR ARCS AT HIGH CURRENTS. J. A. RICH, L. E. PRESCOTT, AND J. D. COBINE, General Electric Research and Development Center, Schenectady, New York.

There is very little experimental information available concerning phenomena occurring at the anode of an arc. However, we have found that the anode plays an important role at high currents. The present investigation is concerned with the conditions associated with the development of an anode spot for metal-vapor (vacuum) arcs. Electrodes of Al, Cu, Sn and Mo were chosen for study in a plane parallel gap geometry. The onset of anode spot formation was determined with a high speed streak camera of novel design. An oscillographic record of the voltage and current of the arc was obtained simultaneously with the streak picture. From the data obtained particular interest attaches to: (1) the threshold current density for anode spot formation, (2) the arc voltage-current characteristic. In general, high current metal-vapor arcs have positive volt-ampere characteristics, exhibit a hysteresis effect, and show a rapid increase in the arc drop associated with the formation of an anode spot.

B5 THE EFFECT OF METAL IODIDE ADDITIVES TO MERCURY ARCS. D. H. POLLOCK and J. A. DUARDO, Electro-Optical Systems, Inc., A Subsidiary of Xerox Corporation.

It is the purpose of this paper to discuss the alterations in the electrical and radiation properties of the mercury arc created by metal iodide additives. Lead iodide, thallium iodide and aluminum iodide have been added to mercury arcs and the effects on arc performance experimentally observed. These observations included quantitative measurements of spectral line intensities of mercury and of the added metal under a variety of arc operating conditions. The arc devices were of quartz construction and included a metal iodide reservoir appendage which allowed independent control of metal iodide vapor pressure. Data will be presented showing that as the aluminum resonance line intensities increased to a maximum with increasing additive vapor pressure, the mercury ultraviolet lines decreased as much as a factor of six. This was correlated with a measured decrease in electron temperature. At the low additive vapor pressure the mercury electron temperature was measured to be approximately 10,000°K. When the aluminum radiation was maximized with the resultant quenching of the mercury radiation, the electron temperature had decreased to 7,400°K. Similar data will be presented for the other metal iodide additives.

In addition arc voltage and plasma appearance is correlated to additive vapor pressure.

B6 DISCHARGE CHARACTERISTICS OF VORTEX CONSTRICTED ARCS. D.G. VAN ORNUM AND F. WALTER, Giannini Scientific Corporation.

High pressure rare gas arcs can be operated continuously at current densities of 3-7,000 A cm^{-2}. Electron densities are 10^{17} to 10^{18} per cm^3, corresponding 10-15% ionization. Plasma temperatures in the neighborhood of 9-15,000° K prevail throughout most of the relatively uniform arc plasma column. Over 50% of the input power into the arc can be emitted as radiation. The spectral distribution of this radiation shows a strong continuum, in which broadened lines are all but submerged. Considerable lowering of the ionization potential due to strong microscopic field effects is observed*. Plasma diagnostic work on argon, krypton and xenon arcs will be discussed.

*D.G. Van Ornum, "Basic Studies on Vortex Stabilized Radiation Source for Improved Solar Simulation", NASA Contract Report, NASA CR-468, May 1966.

B7 THE INFLUENCE OF RADIATION ON HIGH PRESSURE ELECTRIC ARCS. J. J. LOWKE and E. R. CAPRIOTTI*, Westinghouse Research Laboratories.

The characteristics of high-pressure, high-power, wall stabilized electric arcs in air have been calculated numerically, using an iterative procedure. Account is taken of energy losses due to thermal conduction and radiation and also the effect of self absorption of radiation within the arc. We approximate the spatial variation of the radiation intensity at any radius r, to the form $A(r) + B(r)\cos\varphi$ where φ is the azimuthal angle measured from the radial direction. For any given electric current and field strength it is possible to derive temperature, thermal flux, radiative flux and average radiation intensity as functions of radius, provided that the thermal and electrical conductivities and the spectral absorption coefficients are known as functions of temperature. The spectral absorbtivity data is divided into 14 frequency bands extending to 400 A^0. Line radiation is omitted. For gas pressures of 30 atmospheres and above the arcs in air are found to be dominated by radiation, the temperature profiles being much flatter than for conduction dominated arcs. By assuming a constant temperature, the approximate properties of arcs for any given current and field strength can be predicted without deriving the exact solution.

*Now at Ohio State University.

B8 MEASUREMENT OF STARK WIDTHS OF S I AND S II LINES. J. M. BRIDGES and W. L. WIESE, National Bureau of Standards.

Stark widths of several lines of S I and S II have been measured from a wall-stabilized arc source operating in sulfur dioxide with a small admixture of hydrogen. The measured lines are all in the visible and near infrared spectral region. The arc column was observed both end-on and side-on. All measurements were performed photoelectrically. The profile of H_β was measured to obtain the electron density by comparing the observed profile with the theoretical profiles calculated by Griem, Kolb and Shen.[1] The measured sulfur line widths were then compared with those calculated by Griem[2] for the above determined electron density. For the S I lines the measured and calculated values agreed within the combined experimental and theoretical errors (~25%). The measured S II line widths were larger than the theoretically predicted widths by factors of 3-10. Recent improved calculations by Griem[3] of the S II widths give closer agreement with the measured values.

1. H. R. Griem, A. C. Kolb and K. Y. Shen, Astrophys. J. 135, 272 (1962).
2. H. R. Griem, Plasma Spectroscopy, McGraw Hill (1964).
3. H. R. Griem, Phys. Rev. Letters (to be published).

B9 MEASUREMENTS OF STARK PROFILES OF C II AND Ca II LINES.* JAMES R. ROBERTS and K. L. ECKERLE, National Bureau of Standards.

An electromagnetic T-tube was the source of a plasma to measure line profiles of singly ionized atoms. The profiles of CII lines emitted from a plasma composed of He and CO_2 in the ratio 95:5 were scanned with a monochromator. The profile scans were accomplished by repeated firings of the T-tube while advancing the monochromator in wavelength steps. Also measured was the profile of the 3934Å Ca II resonance line emitted from a plasma composed of He, CO_2 and H_2 in the ratio 45:45:10 with Ca as an impurity. The profile of the 3889Å He I line was also measured and its half-width was compared with calculations[1] to determine the plasma electron density in the case of the C II lines. Likewise H_α was used to determine the electron density in the case of the Ca II line. The experimental C II and Ca II Stark profile half-widths were compared with the calculated values[1] predicted by the above mentioned electron density measurements. The results are that the experimental half-widths are significantly broader (~ 30%) than the theoretically calculated values.[1] However, comparison between more recently improved calculations[2] appear to be in agreement.

*This research is a part of project DEFENDER, Sponsored by the Advanced Research Project Agency, Department of Defense, through the Office of Naval Research.

1. H. R. Griem, Plasma Spectroscopy, (McGraw-Hill, New York, 1964).
2. H. R. Griem, Phys. Rev. Letters (to be published).

B10 RETROGRADE MOTION OF ARC CATHODE SPOTS IN A MAGNETIC FIELD. J. G. WINANS and TSUNG-HSUN WU, State University of New York at Buffalo.

Additional observations have been made on the retrograde motion of the mercury arc cathode spot to help distinguish between various theories. With an arc tube like that used by Zei[1], and St. John, and Winans[2], the retrograde velocity was determined by projecting the spot image on a DuMont 6365 photomultiplier tube and using the output to give vertical deflections on a cathode ray oscillograph. The oscilloscope trace, showed the spot to have a sharp head and long tail. Sometimes the spot was double. Enlarged photographs showed the spot to be multiple, similar to spots photographed by Kesaev[3]. The effect of mercury vapor pressure on the spot velocity was measured for temperatures from 85°C to 103°C as determined by a thermistor. This corresponds to pressures 0.12 to 0.32 mm of Hg. The increase of vapor pressure by 0.2 mm produced a reduction in spot velocity of 50 m/sec. Comparison with results of St. John and Winans[2] showed mercury vapor to be over 200 times more effective in reducing spot velocity than argon. The mechanism proposed by St. John and Winans appears to provide a satisfactory description of all observations.

1. D. Zei and J. G. Winans, J. App. Phys. 30, 1813, (1959).
2. R. St. John and J. G. Winans, Phys. Rev. 98, 1664, (1955) and 44, 1097 (1954).
3. I. G. Kesaev, Cathode Processes in the Mercury Arc, p. 170, Consultants Bureau, New York, 1964.

B11 OBSERVATIONS OF THE LOW PRESSURE MERCURY ARC SPOT. C. G. SMITH, Ikor, Incorporated

Stable motion of relatively large arc spots has been obtained by an anchoring technique permitting measurements of arc spot size and integrated current density. Time resolved spectroscopic-spatial measurements have been obtained to distinguish between regions containing ionized mercury vapor. The arc spot size and retrograde speed in a strong magnetic field are seen to be related to the contour of the refractory metal anchor employed.

Considerable evidence exists for the development of a mercury film along the locus of the arc spot on the molybdenum anchor. The film would account for the absence of molybdenum in the arc spot spectrum and the absence of erosion of the anchor surface over hundreds of hours of arc running time. It is believed that the film properties may account for the observed electron emission currents as well as the retrograde motion.

Session C

Wednesday, October 12

2:00 p.m.

ELECTRON SCATTERING

Chairman: Arnold Russek, University of Connecticut
Storrs, Connecticut

C1 SWARM DETERMINATION OF THE CROSS SECTION FOR MOMENTUM TRANSFER IN ETHYLENE AND IN ETHYLENE MIXTURES.* L. G. CHRISTOPHOROU, G. S. HURST,† and W. G. HENDRICK,‡ Oak Ridge National Laboratory, Health Physics Division.

Data are reported on the temperature dependence of electron swarm drift velocities, w, in ethylene. The analysis of the data gave a velocity independent cross section for momentum transfer in ethylene, σ_E, at thermal electron energies which is equal to $(4.37 \pm 0.26) \times 10^{-16}$ cm^2. Using a constant σ_E, we investigated the dependence of w_E/w_M on gas concentration, where w_E is the drift velocity in ethylene, and w_M that in mixtures of ethylene with a polar impurity, P. Three regions of w_E/w_M dependence on gas concentration were distinguished: initial, intermediate, and final. The initial region can provide information about the velocity dependence of the cross section for momentum transfer, σ_P, for the polar impurity; the intermediate (better suited for experimentation) can easily provide σ_P if the velocity dependence of σ_P is known; and the final region provides a new way to measure the drift velocity for pure polar compounds, P, by simply measuring w_E/w_M in mixtures of P with ethylene. The latter is extremely important when P cannot be studied alone.

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

†Dept. of Phys., University of Kentucky, Lexington.
‡Space Radiation Effects Laboratory, Newport News, Va.

C2 ARGON TOTAL CROSS SECTION FOR ELECTRONS AT ENERGIES BELOW 1 VOLT. G. C. BALDWIN, General Electric Company.

The total cross section of Ar has been determined from the pressure dependence of the transmission of a 0.475-m drift path for electrons of various times of flight (1). Interdynode ion formation in the electron detector has limited measurements in Ar to energies above 200 millivolts. The cross section falls from 1.6 (-20) m^2 at 1.0 volt to a minimum of 0.4 (-20) m^2 at 300 millivolts. No structure is apparent. These results agree well with magnetic deflection measurements (2).

(1) G. C. Baldwin and S.I. Friedman, Bull. Amer. Phys. Soc. 9, 53 (1964).

(2) C. Ramsauer and R. Kollath, Ann. d. Physik 12, 837 (1932).

*Work supported by the Advanced Research Projects Agency thru the U.S. Office of Naval Research

C3 ABSOLUTE TOTAL e^- - N_2 SCATTERING CROSS SECTIONS FOR ENERGIES OF 0.3 TO 25 eV. D. E. GOLDEN, Lockheed Palo Alto Research Laboratory.

A modified Ramsauer technique[1,2] has been used to measure e^- - N_2 scattering cross sections from 0.3 to 25 eV. In the energy range from 0.4 to 3.3 eV 12 large resonances (~25% changes in cross section) of 0.2 eV width have been observed. These resonances are thought to be due to the temporary formations of the vibrational states of the virtual negative ion state of N_2^- ($^2\pi_g$). A large (~100% increase in cross section) broad peak (~1.5 eV width) in the cross section has been observed at about 2.25 eV. Much of this peak is probably due to direct vibrational excitation of $N_2(^1\Sigma_g^+)$.[3] Above about 5 eV the cross section is relatively independent of energy and equal to about 11a_0^2.

1. D. E. Golden and H. W. Bandel, Phys. Rev. 138, A14 (1965).
2. D. E. Golden, H. W. Bandel and J. A. Salerno, Phys. Rev. 146, A40 (1966).
3. G. J. Schulz, Phys. Rev. 135, A988 (1964).

C4 LOW-ENERGY SCATTERING OF ELECTRONS FROM MOLECULES --APPLICATION TO H_2. NEAL F. LANE*and S. GELTMAN, Joint Institute for Laboratory Astrophysics, Boulder, Colorado.

A close coupling calculation of low-energy scattering of electrons from diatomic molecules in the ground electronic and vibrational state has been carried out including up to four rotational states simultaneously. Elastic and rotational excitation cross sections associated with the rotational states $j = 0 - 5$ of H_2 have been calculated and will be presented. The adopted electron-molecule interaction potential consists of a short-range part, determined from the approximate charge distribution of H_2 and a long-range part which includes the quadrupole and effective polarization interactions, cut off sharply for $r \leq R$, where appropriate values of R are obtained by comparing calculated and observed total cross sections. An interesting result of these calculations is the fact that, while the elastic and inelastic cross sections are found to depend on the initial rotational angular momentum j of the molecule, their variation in j is such that the total cross section remains independent of j. The effects of "back-coupling" and coupling with higher rotational states are illustrated by comparing Born, distorted wave, and close coupling results for the same interaction potential; the distorted wave and close coupling inelastic cross sections are found to agree within 20% for all energies.

*Present address: Rice University, Houston, Texas.

C5 STRUCTURE OF RESONANCES IN ELASTIC e-H SCATTERING.* JOSEPH C. Y. CHEN, University of California at San Diego.

A study of the structure of resonances just below the n=2 excitation threshold in electron scattering by hydrogen atoms is carried out by utilizing an approximate method adopted from the projection-operator formalism. Analytic expressions for the level width near the threshold are obtained for both the singlet- and triplet-compound-state series with zero total angular momentum. It is found that the level widths behave like the level spacings in that they decrease exponentially as the levels approach the threshold. Nevertheless, the ratio between the level widths and spacings remains a less-than-one constant. It is then concluded that within the approximation adopted in this method neither the singlet nor the triplet series of the compound states become overlapping near the threshold. However, the Lamb shift may, by removing the degeneracy in the n=2 levels, cut off these infinite sequences of compound states, thereby restricting the number of allowed resonances. The interference between potential and resonance scatterings is also examined.

* Work supported in part by the Advanced Research Projects Agency (Project DEFENDER) and was monitored by the U.S. Army Research Office - Durham.

C6 QUALITATIVE ASPECTS OF RESONANCES IN ELECTRON-ATOM AND ELECTRON-MOLECULE SCATTERING, EXCITATION AND REACTIONS.* H. S. TAYLOR, G. V. NAZAROFF AND A. GOLEBIEWSKI, University of Southern California.

Resonances in electron scattering processes are attributed to the formation of quasi-bound states between the incoming electron and the target. A quasi-bound state occurs when there exists a bound-state eigenfunction of the full projectile-target Hamiltonian degenerate in energy with a scattering state of the same Hamiltonian. If the two states can interact the scattering cross section will exhibit resonant structure at an energy approximately equal to the eigenvalue of the bound-state solution. Quasi-bound states occurring in electron-atom and electron-molecule scattering processes are classified into three different kinds of states. Such a classification is useful in discussing experimental results and in selecting approximate wave functions. A general method is presented which can be used to calculate approximate resonance energies from intuitively guessed trial wave functions. The method is a generalization and improvement of the existing projection[1] and configuration-interaction[2] techniques and satisfies all of the requirements set down by Feshbach[3] necessary to describe resonant behavior.

*This research supported by NASA.

1. T. F. O'Malley and S. Geltman, Phys. Rev. 137, A1344 (1965)
2. L. Lipsky and A. Russek, Phys. Rev. 142, 59 (1966)
3. H. Feshbach, Ann. Phys. (N.Y.) 8, 287 (1962)

C7 A GENERAL ADIABATIC APPROXIMATION FOR ELECTRON SCATTERING. PHILIP M. STONE+ and P. de A. P. MARTINS, University College London.

The adiabatic approximation of slow electron - atom scattering has been formulated in a more general way than is usual. The variational principle for scattering in the no - exchange case is used to obtain two coupled equations for the scattering function and the atomic electron orbital. The equations are decoupled by the usual adiabatic approximation that the scattered electron is stationary while the atomic orbital is established. The atomic orbital obtained in this way can then be used in a wavefunction for the system that has the proper symmetry to allow for exchange. The complicated, non-linear equation for the atomic orbital is general in that it is not limited by perturbation theory and includes effects of virtual transitions to all states including the continuum. When only the first optically allowed transition is important the method reduces to an earlier treatment that chooses the orbital so as to minimize the energy of the distorted atom[1]. The formulation is presented and procedures to solve the atomic orbital equation are discussed. The relationship to other approximations is emphasized.

+Permanent address: Sperry Rand Research Center, Sudbury, Massachusetts 01776

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

C8 TREATMENT OF EXCHANGE IN ELECTRON-ATOM AND ELECTRON-DIATOMIC MOLECULE SCATTERING AT LOW ENERGIES. J. C. TULLY and R. STEPHEN BERRY, Department of Chemistry and Institute for the Study of Metals, University of Chicago, Chicago, Illinois.

As a step toward studying low-energy electron-molecule scattering processes, we have devised a reasonably tractable means of handling electron exchange for electron-atom and electron-molecule scattering. Instead of a conventional iterative solution of the Hartree-Fock integro-differential equations, we have used two different iterative procedures, based on a trial function taken from an optical model developed for bound state functions of atoms[1] and metals[2], and on orthogonalized plane waves. The calculated functions and phase shifts become self-consistent after one iteration for the helium atom, and phase shifts are to about 0.01 radian, in agreement with the pure exchange (no polarization) calculations.

1. B. T. Tong and L. J. Sham, Phys. Rev. 144, 1 (1966).
2. W. Kohn and L. J. Sham, Phys. Rev. 140, A1133 (1965).

C9 ELECTRON SCATTERING FROM $1s^2 2s^2 2p^q$ ATOMIC SYSTEMS.* W. R. GARRETT, Oak Ridge National Laboratory, Health Physics Division.

Elastic scattering cross sections have been calculated for low-energy electrons incident on the series of atomic systems having $1s^2 2s^2 2p^q$ configurations. In the case of oxygen detailed calculations were made of the adiabatic distortion of the target atom by the incident electron, utilizing the method of polarized orbitals.[1] The polarization potential due to distortion of other members of the series was obtained from the oxygen results through a Thomas-Fermi type scaling procedure utilizing the known asymptotic behavior of the dipole polarization potential. Results indicate that the determination of the polarization potential for one member provides an adequate representation of target distortion for other atoms of the same series. Since distortion effects are relatively difficult to determine, this could be particularly convenient for more complicated systems, as for example, heavy atoms or simple molecules. Results are compared with experimental values for oxygen, nitrogen, and neon.

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

1. W. R. Garrett and H. T. Jackson, Bull. Am. Phys. Soc. 11, 495 (1966).

C10 TRAJECTORIES OF MAGNETICALLY CONFINED ELECTRONS IN GASEOUS COLLISIONS. D. D. BRIGLIA, Ultek Corp., Palo Alto.

The trajectories of electrons in a magnetically confined beam are studied theoretically and experimentally with particular emphasis on the path lengths in electron collision experiments. The presence of non-axial velocity components leads to an increase in the electron path length and thus to a distortion of the ionization cross section vs. electron energy curve. For immersed cathode geometries in a uniform magnetic field, only electrostatic lens effects of the accelerating electrodes and scattering of the electrons by molecules and aperture edges can produce non-axial velocity components. It is shown that electrostatic lens effects can be eliminated by high enough magnetic fields such that the electron flow is confined. Path length errors due to molecular scattering can occur, but these can be detected by observation of the dependence of the cross section on the magnetic field and on the pressure. Elastic scattering can cause an electron-energy dependent path length increase which shifts the maximum of the ionization cross section to a lower energy. Conditions are determined which ensure that the electron path length is identical to the geometrical path length in ionization cross section measurements.

Session D

Wednesday, October 12

2:00 p.m.

METASTABLE AND EXCITED ATOMS

Chairman: A. L. Schmeltekopf, Environmental Science Services Administration, Boulder, Colorado

D1 ABSORPTION MEASUREMENTS IN A FLUCTUATING DISCHARGE. A. GARSCADDEN and D. R. POND, Aerospace Research Laboratories, USAF, Wright-Patterson AFB, Ohio.

The measurements of C. Kenty[1], on the role of metastable atoms in an Argon-Mercury discharge have been extended to the low current regime where self-excited moving striations occur. Time resolved absorption measurements have been made on the visible triplet lines. These lines, 5461, 4358, and 4047 have 7^3S_1 as a common initial level and end on $6^3P_{2,1,0}$ respectively. The experiments were performed in two ways; first by sampling and processing the data using a digital memory to improve the signal to noise ratio, and secondly by using a new grid-controlled photomultiplier tube which facilitates delayed gating operation and integration. The absorption on all three lines varied at the striation frequency. Although the absorption averaged over one cycle agreed well with Kenty's extrapolated data for low currents, the absorption showed variations as much as a factor of three during one cycle of a striation. The 5461 and 4047 absorptions are in phase with the emission of the striating discharge, but the 4358 line absorption is approximately 180 degrees out of phase. These results are interpreted in terms of the ionization and quenching of the 6^3P metastable levels.

1. C. Kenty, J. App. Phys. 21, 1309 (1950).

D2 DIFFUSE CONTINUA-EMITTING DISCHARGES IN THE RARE GASES AND THE ROLE OF MOLECULES. C. KENTY, General Electric Lamp Research Laboratory, Nela Park, Cleveland, Ohio.

A .4 ma DC discharge in 120 Torr Xe in a 10 cm diameter tube is diffuse, has a high gradient (150 V/cm, due mainly to elastic losses) and emits a whitish continuum extending from 1470Å to 3.5μ. Lines are absent save a few faint ones around 8500Å, probably due to dissociative recombination. If .15 Torr N_2 is added, the gradient drops to 8.5 V/cm and the ordinary XeI lines (and the continuum, now weaker) appear, both in the discharge and 5-sec. afterglow. The tremendous lowering of the gradient is attributed to multistage processes involving N_2 metastables, and the excitation of the Xe lines to triple collisions of $N_2{}^3\Delta u$, $N_2{}^3\Delta u$ and Xe. Evidently if Xe higher excited states are produced, they have time to radiate before molecule formation occurs; and the absence of the corresponding lines in pure Xe confirms the theory(1) that the continuum in argon is due to the excitation by electrons of Ar metastables, the rapid formation of Ar_2' (metastables) from these and the further excitation of Ar_2' by electrons to higher molecular states which radiate to repulsive states and thus emit continua.

(1) J. F. Prince and W. W. Robertson, Bull. Am. Phys. Soc., 11, 503, (1966).

D3 COLLISIONAL COUPLING OF HELIUM EXCITED STATES.* M. P. TETER and W. W. ROBERTSON, The University of Texas.

A helium plasma was irradiated with intense 5016 A(2^1S-3^1P) and 3889 A (2^3S-3^3P) light and it was found that the populations of the 3^1P and 3^3P states were increased significantly. Liquid filters were employed that transmitted either of these wavelengths and no other radiation coupled to the metastable states. By modulating the current of the pumping light, the populations of the 3^1P and 3^3P states were correspondingly varied. Radiation from the other n=3 states was observed to have oscillating components of the same frequency and phase as the pumping light which could be attributed to excitation transfer from the pumped state. By following the oscillating components as functions of current and pressure, information about the types of processes coupling the states was obtained and collisional rate coefficients determined.

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

D4 COLLISIONAL MIXING OF THE 2^3P STATES IN HELIUM†. NORMAN D. STOCKWELL AND G. KING WALTERS, Rice University.

Circularly polarized 2^3S_1-2^3P resonance radiation incident upon a weak ^4He discharge induces spin polarization in the 2^3S_1 state. The pumping cycle involves optical excitation of atoms from the 2^3S_1 state to one of the 2^3P levels with selection rule $\Delta m = +1$ (for right-hand circular polarization), followed by spontaneous decay back to the 2^3S_1 state. The resulting equilibrium distribution among the Zeeman sublevels of the 2^3S_1 state is determined by measuring the difference ΔI in absorption of pumping radiation in going from an unpumped to an optically pumped condition. ΔI depends critically upon whether mixing of the 2^3P state occurs during the pumping cycle. For an optically thin sample excited by a ^4He spectral lamp, the algebraic sign of ΔI is positive in the limit of complete P-state mixing and negative in the no-mixing limit. Our preliminary measurements for sample pressures down to 0.04 torr indicate that the P-states are always mixed, suggesting a very large cross-section ($3\times10^{-14}cm^2$) for mixing among the 2^3P_0, 2^3P_1, and 2^3P_1 states as a result of collisions with ground state (1^1S_0) helium atoms.

†Work supported in part by the U. S. Atomic Energy Commission.

D5 ATOM-ATOM INTERCHANGE IN He_2-He COLLISIONS†. RADFORD BYERLY, JR. AND G. KING WALTERS, Rice University.

Optical pumping techniques can be used to induce sizable nuclear polarization in gaseous ^3He excited by an electrical discharge. The achievable polarization is limited by collisional processes that randomize the nuclear spin states; the equilibrium polarization is the resultant of angular momentum "input" from the circularly polarized pumping radiation, balanced against the angular momentum "loss" in spin-randomizing collisions. Analysis of data on optical pumping dynamics in ^3He at pressures above 2 torr suggest that significant angular momentum loss occurs in collisions between polarized ground state $^3He(1^1S_0)$ atoms with $He_2(^3\Sigma_u^+)$ molecules and/or $He(^2\Sigma_u^+)$ molecular ions present in the discharge. Spin randomization occurs in such collisions because of rapid mixing of spin and rotational angular momentum in the molecule. To test for these collisional processes, ^3He samples were prepared with small admixtures of neon which is known to quench helium molecules. At a ^3He pressure of 8 torr it was found that a concentration of 10^{13} neon atoms per cm^3 led to a factor two increase in ^3He nuclear polarization. This result provides indirect evidence that atom-atom interchange in $He_2(^3\Sigma_u^+)$-$He(1^1S_0)$ collisions occurs with a cross section $\geq 10^{-17} cm^2$.

†Work supported in part by the U. S. Atomic Energy Commission.

D6 METASTABLE BEAMS, SECONDARY ELECTRON EMISSION, AND POSITIVE-ION EMISSION. R. N. VARNEY, Lockheed Palo Alto Research Laboratory.

A new method of producing beams of metastable atoms and molecules, by charge exchange, has been developed. To date, beams of hydrogen, nitrogen, neon and argon have been produced. The source is essentially a simple triode (resembling a Schulz-Phelps ionization gauge with a hole in the ion collector), operated at high enough pressure to assure charge changing collisions (10 to 80 μ). Emerging ions are deflected out of the beam leaving only the neutrals. The neutrals are allowed to strike a target of Mo, surrounded by a grid and a collector. Secondary electron liberation from the target was observed in every case at kinetic energies of the incident particles under 100 eV, establishing that the neutral particles must be excited. Not only secondary electron emission but resonance ionization (ejection of a positive ion from the target) was observed for argon and nitrogen. When resonance ionization does not occur, as for hydrogen, the metastable appears to be quenched radiatively at the target as tertiary electrons are strongly ejected from the surrounding collector. The alternative that the tertiaries were produced by metastables reflected from the target to the collector was reduced in likelihood by appropriate tests with an LiF window.

D7 PRODUCTION AND IDENTIFICATION OF METASTABLE $N_2(A^3)$ AND $CO(a^3)$ MOLECULES* K.BECKER**, K.BAYES, Dept. of Chemistry, University of California, L.A.

Compared with metastable atoms like $He(2^3S)$, the reactions of highly excited metastable molecules in gas discharges are less well known because these molecules are produced only to a small part by electron impact, but by reactions of the dissociated atoms. We found some new atom reactions which produce and identify $N_2(A)$ and CO(a). The reaction of O atoms with C_3O_2 and also with C_2H_2 produces metastable CO(a), in both cases via the same intermediate radical, very likely C_2O (1). The reaction $O + N_2H_4$ produces metastable $N_2(A)$. Both metastables have an excitation energy of about 6 eV. Recently it has been shown that in active nitrogen $N_2(A)$ excites Hg atoms to the state which emits the 2537 Å line (2). We could confirm this, and we found the same reaction with CO(a). We also found that $N_2(A)$ and CO(a) can transfer their energies to NO molecules which get excited, in the first case exclusively to the A state and in the second one to the A and B state of NO. For photochemical reactions which probably produce metastable N_2 molecules, recently the specific energy transfer from $N_2(A)$ to NO has been proposed (3).

*)Work supported by U.S.Air Force. **)present address: Institut f. Phys.Chemie, Universität Bonn.
(1) K.H.BECKER,K.D.BAYES,J.Chem.Phys.45,July(1966) (2) W.BRENNEN,G.B.KISTIAKOWSKY,J.Chem.Phys.44,2695 (1966). (3)K.H.WELGE,J.Chem.Phys.,to be publ.(1966)

D8 INTERACTION BETWEEN THE ELECTRON GAS AND EXCITED ATOMS IN A GASEOUS DISCHARGE.* R. J. FREIBERG, L. A. WEAVER, AND L. GOLDSTEIN, Gaseous Electronics Laboratory, University of Illinois.

A general property of all gaseous discharges is the dependence of the excited atomic state populations upon both the density and temperature of the electrons. The objective of this investigation is to determine the nature of this interaction. A gaseous laser is a suitable tool for this study since it is capable of imposing a highly selective perturbation upon the excited state populations. The work to be presented made use of a low pressure, dc excited, xenon discharge, which when placed in an appropriate optical cavity was capable of lasering upon the high gain 3.508 μ ($5d_{33}$-$6p_{22}$) xenon transition. As a result of the laser-induced perturbation of the $5d_{33}$ and $6p_{22}$ levels, the entire character of the gaseous discharge was altered. Spatially resolved microwave cavity and radiometric measurements, performed at various locations along the discharge and at several xenon pressures (12.5, 18.5 and 25.5 m Torr), revealed that, depending upon local discharge conditions, the electron density and temperature are either increased or decreased by the lasering process. These perturbations are attributed primarily to ionization by electron impact from the upper laser level and the xenon metastables. Confirming spectroscopic observations are reported and evidence of various radiative and collisional processes responsible for the propagation of the disturbance to other excited levels is presented.

*Work sponsored by U.S.A.F. Cambridge Research Lab.

D9 TIME DEPENDENT MEASUREMENTS OF METASTABLE OXYGEN ATOMS IN THE AFTERGLOW. E. C. ZIPF, University of Pittsburgh.

A highly automated data processing system has been developed for afterglow measurements. This versatile apparatus may be used to measure the intensity of afterglow emissions over a very wide dynamic range. When the system is used in a signal averaging mode, the time dependence of extremely weak afterglow radiation can be measured accurately. Decay times as short as a few nanoseconds can be accommodated. The data are obtained in a digital format and can be stored on paper tape for rapid analysis by an IBM 7090 computer. Standard statistical techniques are used to assess the reliability of the data and to optimize the actual data acquisition process itself. These techniques have been used to study the collisional deactivation of oxygen atoms in the metastable ^1S and ^1D states. The $O(^1S)$ and $O(^1D)$ atoms are produced by the dissociative recombination of O_2^+ ions; they are detected by a direct observation of the 5577A and 6300A lines emitted by these metastable atoms in the afterglow. In order to minimize the effects of extraneous background radiation, a monochromator is used to isolate the OI red and green lines for detailed study. The results of time dependent measurements of the density of $O(^1S)$ and $O(^1D)$ atoms in the afterglow will be reported.

Work supported by the National Aeronautics and Space Administration.

D10 A WAVELENGTH ANALYSIS OF THE VISIBLE FLUORESCENCE OF EXCITED CO PRODUCED BY VUV PHOTODISSOCIATION OF CO_2.† D. L. JUDGE, University of Southern California.

The total visible fluorescence resulting from VUV photon impact on CO_2 has been investigated most recently by Cook et al.,[1] employing a dispersed continuum background. In their case it has been possible to study the dependence of total fluorescence intensity on the excitation photon energy. Their results, in agreement with earlier work,[2] show a strong fluorescence for excitation energies greater than 715.7Å, the threshold for excitation of the $^2\Pi_u$ state of CO_2^+, and, in addition, a weak fluorescence for excitation photons between 750 and 850Å. The work reported in the present analysis concerns itself with this weak fluorescence. It is found that this radiation is characteristic of the triplet bands of CO, the $d^3A_1 \rightarrow a^3\Pi_r$ transitions.

†The support of the Office of Naval Research and Project Defender is hereby gratefully acknowledged.

1. G. R. Cook, P. H. Metzger and M. Ogawa, J. Chem. Phys. 44, 2935 (1966).
2. D. L. Judge, A. L. Morse and G. L. Weissler, Preceedings of the Sixth International Conference on Ionization Phenomena in Gases, VII, 27 (1963).

D11 NON-THERMAL IONIZATION CAUSED BY GASDYNAMIC VARIATIONS.* E. BARRETO and K. MARTINOT, Curtiss-Wright Corporation, Wood-Ridge, New Jersey.

It is shown that space charge accumulations caused by thermodynamic changes are produced whenever a corona discharge of the streamer type is maintained in a region of rapid and sustained mass density variation. When the streamers cross expansion waves, compression waves or shocks, the resulting charge accumulation is sufficiently large to modify the visual appearance of the discharge and to produce ionization in excess of the value due to the high field near the stressed corona electrode. A model is presented whereby the charge accumulation is ascribed to changes in electrical conductivity along the streamer propagation path. The experimental investigation uses a highly charged supersonic aerosol jet ($0.03\ coul/m^3$) at temperatures below 300^oK, and pressures below three atmospheres. The aerosol emerges from an underexpanded nozzle producing a characteristic series of expansion and compression regions. The charge density of the aerosol is sufficiently high so that electrical breakdown is induced at a grounded needle placed near or within the jet.

*Research supported by the Geophysics and Physics Branches of the Office of Naval Research.

Session E

Thursday, October 13

9:00 a.m.

BREAKDOWN

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

E1 VACUUM BREAKDOWN AS A FUNCTION OF GAP SEPARATION.*
A. WATSON and M. J. MULCAHY, Ion Physics Corporation.

Vacuum breakdown voltages up to 300 kv were measured at gap separations from 0.5 to 3.0 cm. Two experimental techniques were compared. First, the voltage was raised in steps for each gap separation, recording the first isolated breakdown and terminating the test. Second, the voltage was increased, neglecting isolated sparks, until repetitive sparking occurred. Both techniques yielded curves of the breakdown voltage as a function of gap separation at various stages of conditioning by sparking. Other curves were similarly obtained after leaving the vacuum system to decondition. The repetitive sparking voltage, but not the isolated sparking voltage, varied approximately linearly with the square root of the gap separation. The logarithm of the current immediately prior to breakdown was plotted as a function of the square root of gap separation for both techniques. A linear decrease was observed for repetitive sparking but no such trend appeared with isolated breakdown until after deconditioning. When the electrodes only were baked at 400°C, as opposed to the complete system, pressure surges of hydrogen were observed just below the breakdown voltage.
*Work sponsored by the Advanced Research Projects Agency, U. S. Department of Defense.

E2 FURTHER CALCULATIONS OF MIDGAP BREAKDOWN IN GASES. A. L. WARD, Harry Diamond Laboratories.

The author has reported calculations which have given good agreement[1] with Tholl's measurements of midgap breakdown in a N_2-CH_4 mixture. These calculations have been extended to study the variation of the breakdown parameters with gas pressure. Tholl measured three sequential current-growth constants: The space-charge-free time constant τ_o, a retarded-growth time constant τ_r, and an augmented-growth time constant τ_k. Since $\tau_o = (\alpha v_-)^{-1}$, where α is Townsend's first coefficient and v_- is the electron drift velocity, the input parameters determining α and v_- were slightly adjusted to obtain agreement between the experimental and calculated values of τ_o at each pressure. Then the calculated values of τ_r and τ_k were found to vary with pressure qualitatively very similar to the measured values. Calculated electron density contours plotted in time-distance space give good agreement with published[2] experimental rotating mirror photographs at different overvoltages and pressures. Exploratory calculations of breakdown in air at atmospheric pressure in long gaps - up to 1 km - will be presented.
1. A. L. Ward, J. Appl. Phys. 36, 2540 (1956); Physics 1, 215 (1965).
2. K. H. Wagner, Z. Physik 189, 465 (1966).

E3 THE MECHANISM OF THE ELECTRICAL BREAKDOWN OF GASES AT HIGH VOLTAGES
J. DUTTON* and W. T. MORRIS, Department of Physics, University College of Swansea, Wales, U.K.

An apparatus is described for the measurement of the spatial growth of pre-breakdown ionization in gases in uniform electric fields (E) at pressures (p) up to 10 atmospheres and for electrode separations up to 10 cm, using voltages up to 600 kV. Results are given of measurements made in dry air for E/p in the range 33 to 36 V/cm/torr for p up to 1650 torr. Over the whole range so far investigated (corresponding to sparking potentials up to 400 kV) the growth of ionization has been found to be in agreement with the well-known generalised Townsend equation. Moreover, at a pd_s = 12,200 torr cm (d_s is the sparking distance) the sparking potential of 408 ± 9 kV predicted using the Townsend breakdown criterion was in good agreement with the experimentally determined value of 403.4 ± 0.5 kV. The results showed that in this region the values of the secondary ionization coefficient (ω/α) and hence the sparking potential were dependent on the state of the cathode surface just as at lower values of pd_s. There was no experimental evidence for space-charge effects at the maximum measured values (~ 5 x 10^{-7} amp) of pre-breakdown ionization currents.

* Now at Joint Institute for Laboratory Astrophysics, Boulder, Colorado, U.S.A.

E4 THE COURSE OF NEGATIVE POINT-TO-PLANE BREAKDOWN IN FREE ELECTRON GASES. ABBASS HASSOUN, University of California, Berkeley.

As indicated by Loeb in 1948 and confirmed at the 18th GEC, a highly stressed cathode in an asymmetrical field is unstable leading directly to a spark transition with no intervening corona. A Townsend breakdown by γ processes rapidly builds up a highly localized glow discharge with a negative glow region of some 10^{12} ions/cm^3 adjacent to the cathode fall. Both fall and plasma remain constant but current increases by lateral spread of the discharge accompanied by ion plasma oscillations ~10^6 cycles per second. This discharge projects a plasma of ions and electrons with a sharp potential gradient towards the anode advancing as a negative ionizing space wave such as reported by Winn.[1] It is recorded as a highly luminous pulse of the order of a gap length which crosses the gap at 1 to 4x10^6 cm/sec. At current peak it may reach 10^{14} ions/cm^3. Space wave velocity exceeds the velocity of electrons in the channel so that current increases after the space wave has passed. Current increase ceases to be linear in time as potential starts to decline perceptibly with capacity drain.
*This research was supported by the Office of Naval Research and the Republic of Iraq.
1. William P. Winn, submitted for publication.

E5 POSITIVE STREAMER SPARK BREAKDOWN AT LOW PRESSURES IN AIR. T. OSHIGE, Kyushu Institute of Technology, Japan, and University of California, Berkeley.

Past studies appeared to indicate that streamer breakdown to a spark ceased around 50 Torr. Breakdown in room air using coplanar Lichtenberg figure and two-photomultiplier techniques have shown streamer breakdown to persist to below 4 Torr, at which point low luminosity makes study difficult. In all cases breakdown starts as a primary streamer from the anode. This broadens and decreases in branching so that at 15 Torr the channel is more than 1 cm wide, rarely shows a branch, and is quite faint. Photomultiplier signals persist to 4 Torr. Primary streamer speeds lie around 10^7 cm/sec. The scope shows no secondaries until the primary reaches the cathode, then a bright pulse appears at the cathode but progresses little. Nearly simultaneously a bright pulse that moves towards both the cathode and anode appears in midgap often at a branch point near the anode. It shows as a dark blotch on Lichtenberg figures. It appears to be triggered by a faint fast return pulse from the cathode. Photons from this secondary start a new negative pulse from the cathode which advances slowly at first ~10^6 cm/sec, the arc materializing when this meets the midgap streamer.

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

E6 CROSSED-FIELD BREAKDOWN IN HYDROGEN.* WULF B. KUNKEL and ARTHUR R. SHERWOOD, Lawrence Radiation Laboratory, Berkeley.

The formative time of electric breakdown in low-pressure hydrogen across a strong magnetic field ($20 < \omega\tau < 500$; maximum B of 18 kG) in a coaxial cylindrical geometry is measured. Attention is centered on that region of breakdown that occurs with a formative time shorter than the time required for an electron to cross the electrode gap in the applied fields. The crossing time is inferred by extrapolation of previous measurements.[1] If it is assumed that the breakdown goes to completion because of space-charge effects, then one expects the formative time to be inversely proportional to the gas pressure and otherwise primarily a function of E/B. The inverse pressure dependence is observed, but some deviation from the E/B dependence is found.

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

1. Melvin J. Bernstein, Phys. Rev. 127, 335 (1962).

E7 MECHANISMS FOR LASER-INDUCED BREAKDOWN OF SUPER-HIGH PRESSURE GASES.* ARWIN A. DOUGAL and DENNIS H. GILL, The University of Texas, Austin 78712.

Theoretical and experimental investigations are accomplished to delineate mechanisms responsible for laser-induced breakdown of super-high pressure gases. Comparison of experiment with microwave gas breakdown theory shows that breakdown occurs through electron-impact ionization following energy gain by free electrons accelerated in the incident field while undergoing collisions with neutrals. Multiquantum absorption predicts fields two orders of magnitude too high. Inverse bremsstrahlung absorption theory and subsequent electron-impact ionization gives fields agreeing with experiment for low pressures. In the classical limit as $\hbar\omega/\epsilon \to 0$ the inverse bremsstrahlung equations reduce to those of microwave breakdown. Breakdown occurs in He, Ar, H_2, and N_2 from 100 to 30,000 psi by focusing the radiation from a 30 MW giant-pulse laser within a pressure cell. Threshold fields are calculated from measured peak laser power and the focal diameter of 20 microns. Curves of threshold field versus pressure exhibit definite minima, indicative of electron-impact ionization. Microwave theory is extended to optical frequencies. Solutions are obtained for He from 100 to 30,000 psi for characteristic diffusion lengths from 10^{-4} to 10^{-1} cm. The magnitude and pressure dependence of the calculated threshold fields agree favorably with experiment.

*Supported by National Science Foundation, and in part by Joint Services Electronics Program.

Session F

Thursday, October 13

9:00 a.m.

MOBILITY AND DIFFUSION

Chairman: Ronald Geballe, University of Washington, Seattle, Washington

F1 ANALYSIS OF ION SWARM EXPERIMENTS BY MEANS OF MAXIMUM LIKELIHOOD ESTIMATORS, W. S. BARNES, Lawrence Radiation Laboratory.

Data gathered in ion swarm experiments by means of statistical counting techniques was analyzed by Barnes et al[1] by means of maximum likelihood estimators. A simple model was used which involved the drift velocity v of a primary ionic species, the diffusion coefficient D, and the rate constant α for an ion-molecule reaction converting the ions into another species. Here, an error in the above analysis is corrected. The design of statistical ion swarm experiments for the determination of v, D, and α, and methods for the calculation of the maximum likelihood estimators for $u = \sqrt{v^2 + 4 \alpha D}$ and D in several geometries are presented. The normal approximation to the bivariate distribution of the estimators of u and D produced by the statistical fluctuations of the ion populations (not experimental inadequacies) is investigated, and methods are given for calculating the variance of the estimators for u and D. The determination of the goodness of fit of the data to the model and the effects of several causes of a poor fit are discussed. A means for determining v and α from u, D, and the results of several experiments are presented.

1. W. S. Barnes, D. W. Martin, D. S. Harmer, and E. W. McDaniel, Mobility Measurements of Ions in Nitrogen and Hydrogen with Simultaneous Mass Identification of the Ionic Species, Tech. Rpt. #1, Proj. A-614, (Engr. Exp. Sta., Georgia Tech, Atlanta, Ga., June 1, 1963).

F2 IMPROVED ION CYCLOTRON RESONANCE CROSS SECTIONS*. D. WOBSCHALL, R. FLUEGGE, and J. R. GRAHAM, JR., Cornell Aeronautical Laboratory, Inc.

Various refinements of the existing ion cyclotron resonance (ICR) equipment[1] are now incorporated so as to reduce the error in measuring line width to the order of 5%. The total collision cross sections for Ar^+, He^+, N_2^+, N^+, O_2^+, O^-, H_3^+, H_2^+, and H^+ were calculated from line width measurements. For those ions whose mobilities are well established, the cross sections inferred from the mobilities at low E/P agree within 10-15% of those determined by the ICR method. To determine the cross sections at high E/P, the ions were heated by applying a dc electric field parallel to the magnetic field. It was found that the cross sections dropped fairly rapidly with increasing E/P to a certain point (e.g., 25 v/cm-torr for He^+) and then decreased slowly, with a slope proportional to Log (E/P). Such behavior is expected for the transition from the region where polarization forces dominate to that in which symmetrical charge exchange dominates. In most cases our cross sections agree with those obtained by high E/P dc mobility studies.

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

1. D. Wobschall, Rev. Sci. Instr. 36, 466 (1965).

F3 MEASUREMENT OF THE TEMPERATURE DEPENDENCE OF HELIUM ION MOBILITIES IN HELIUM.* P. L. PATTERSON, Joint Institute for Laboratory Astrophysics.

The mobilities of He^+ and He_2^+ were measured at temperatures ranging from 76°K to 300°K. At temperatures below 160°K, the He_2^+ was observed to react with the gas to form a third ion believed to be He_3^+. There are no previous reports of the existence of an He_3^+ ion. At 76°K, the rate of formation of He_3^+ from He_2^+ was at least as fast as the formation of He_2^+ from He^+. Also at 76°K, the He_3^+ could be broken up to reproduce He_2^+ by electrically heating the ions. The mobility of He_3^+ was found to be higher than that of He_2^+, in contrast with the usual dependence of mobility on ionic mass. The He^+ mobility was found to be in excellent agreement with existing theory which takes into account the process of resonant charge exchange.

*This research was supported by the Advanced Research Projects Agency (Project DEFENDER), and the National Bureau of Standards.

F4 MOBILITIES OF H_1^+ AND H_3^+ IONS IN HYDROGEN GAS.* D.L. ALBRITTON, T.M. MILLER, J.T. MOSELEY, D.W. MARTIN and E.W. McDANIEL, Georgia Institute of Technology.

Drift velocity measurements have been made as a function of E/p_0 for the ions H_1^+ and H_3^+ in hydrogen gas at room temperature using a pulsed ion-transit-time method. The recently constructed drift tube operates at low pressures (0.025 to 1000 Torr) and its movable electron bombardment ion source provides a variable drift distance (1 to 44 cm). Mass analysis is accomplished by a quadrupole mass filter and detection by an electron multiplier operated as a pulse counter. For the predominate ion H_3^+, the ratio of the drift velocity to the electric field has a maximum value near an E/p_0 of 53 V/cm-Torr but becomes constant for E/p_0 less than 10. Measurements extended down to an E/p_0 of 0.3 yield a zero-field reduced mobility, μ_0, of 11.1 cm^2/V-sec which is in general agreement with the recently published values of other investigators. For H_1^+ this ratio rises with declining E/p_0, as has been reported.[1] Our investigations show that below an E/p_0 of about 6, the ratio of drift velocity to electric field becomes constant. Measurements extended down to an E/p_0 of 2 give an apparent μ_0 of about 16 for H_1^+.

*Research supported in part by the Office of Naval Research in Project SQUID, University of Virginia.

1. M. Saporoschenko, Phys. Rev. 139, A349 (1965).

F5 MOBILITY OF CO^+, CO_2^+, AND $C_2O_2^+$ IONS IN CARBON MONOXIDE GAS. M. SAPOROSCHENKO AND G. W. BIELAK*, Southern Illinois University, Carbondale, Illinois.

The mobilities of CO^+, CO_2^+, and $C_2O_2^+$ ions in carbon monoxide gas have been measured over the range $15 \leq E/p_c \leq 180$ volts/cm-mm Hg using a Tyndall double shutter device with a glow discharge ion source. Gas pressure in the drift tube was in the 0.5 - 1.4 mm Hg range. The ions have been identified mass-spectrometrically simultaneously with measurement of the mobility. At p_c = 0.8 mm Hg and E/p_c below 85 the predominant ion is $C_2O_2^+$, and at E/p_c above 85 the predominant ions are CO_2^+ and CO^+. In addition, O_2^+, $C_3O_2^+$, $C_4O_2^+$, and $C_5O_2^+$ ions in considerably smaller abundance have been observed. The processes of formation of the secondary ions will be discussed. The mobility, extrapolated to zero field and atmospheric pressure, is 1.9 cm^2/volt-sec for both CO^+ and CO_2 ions. The mobility of $C_2O_2^+$ varies with E/p_0 going through a maximum value of 2.15 cm^2/volt-sec at E/p_c = 55. Similar behavior of the mobility has been observed in the cases of H_3^+ and N_3^+ ions. The zero-field mobility of the $C_2O_2^+$ ion has been found to be 1.61 cm^2/volt-sec in agreement with Varney's results.[1] The binding energy of the $C_2O_2^+$ ion against dissociation into CO^+ and CO is about 0.8 ev.

* Present address: The Boeing Co., Seattle, Wash.

1. R. N. Varney, Phys. Rev. 89, 708 (1953).

F6 DRIFT AND DIFFUSION OF OXYGEN IONS IN OXYGEN. J. DUTTON* and P. HOWELLS, Department of Physics, University College of Swansea, Wales, U.K.

An apparatus for the determination of the mobility and diffusion coefficient of selected ion species moving through a gas, under the influence of a uniform electric field, is described. Measurements of the mobility K and diffusion coefficient D for selected species of oxygen ions in oxygen were made over a range of values of E/p_0 from 2 to 100 V cm^{-1} $(mmHg)^{-1}$ and of p_0 from 0.4 to 7.1 mmHg (E is the electric field and p_0 the gas pressure reduced to 0° C). Two species of ion having approximately the same zero field mobility of 2.2 cm^2 sec^{-1} V^{-1} were observed. The identity of one species is thought to be O_2^+, while the identity of the other species is less certain. Measurements of the ratio D/K and the Townsend energy factor ε were made for both species. These measurements showed that the ions remained in thermal equilibrium with the gas molecules for values of E/p_0 up to about 20 V cm^{-1} $(mmHg)^{-1}$ in the case of the O_2^+ ions and up to about 14 V $cm^{-1}$$(mmHg)^{-1}$ in the case of the other species. Above these values of E/p_0 the mean energies increased.

* Now at the Joint Institute for Laboratory Astrophysics, Boulder, Colorado, U.S.A.

F7 DRIFT VELOCITIES OF NEGATIVE OXYGEN IONS IN OXYGEN. L. G. McKNIGHT, Bell Telephone Laboratories, Incorporated, Murray Hill, New Jersey and K. B. McAFEE, Bell Telephone Laboratories, Incorporated, Whippany, New Jersey.

Drift velocities have been measured for mass analyzed oxygen ions in oxygen between E/N = 0.28 and 42×10^{-16} volt cm^2 (E/P_0 between 1.0 and 150 volt cm^{-1} $torr^{-1}$) and at temperatures between 343 and 823°K. Oxygen pressures (P_0) were between 0.5 and 2 torr. The lowest field measurements indicate μN values of about 9.2, 5.6 and 7.8×10^{19} volt^{-1} cm^{-1} sec^{-1} (μ_0 = 3.4, 2.1 and 2.9 cm^2 volt^{-1} sec^{-1}) at 100°C for O^-, O_2^-, and O_3^- respectively.

To make the measurements, electrons were produced by a filament and allowed to drift in a low field region where attachment took place. A mixture of ions and electrons was admitted to the 3 cm drift space through a Tyndall double grid gate. After drifting through the cell, ions were withdrawn through an aperture and their mass and intensity determined as a function of time using a quadrupole mass analyzer and a gated particle multiplier.

O_2^- crossed the drift space as a single well-defined peak, and drift velocities are determined throughout the range of E/N. O^- and O_3^- interact at low E/N so that O^- is not observed after the long drift times (~1 millisec.) at $E/N < 0.6 \times 10^{-16}$ ($E/P_0 < 2$). O_3^- is not observed at $E/N > 5.5 \times 10^{-16}$ ($E/P_0 > 20$), and the ion disappeared at lower E/N for T > 280°C. O_2^- was not observed at temperatures > 500°C.

Session G

Thursday, October 13

2:00 p.m.

HIGH ENERGY ATOMIC COLLISIONS

Chairman: E. W. Thomas, Georgia Institute of Technology
Atlanta, Georgia

G1 DIFFERENTIAL CROSS SECTIONS FOR 2^3S AND HIGHER STATE EXCITATION IN $He^+ + He$ COLLISIONS. D. C. LORENTS, W. ABERTH and V. W. HESTERMAN, Stanford Research Institute.

Cross sections for excitation of the 2^3S as well as higher states of He by He^+ ions have been obtained as a function of scattering angle from measurements of the scattered ion energy loss spectra. Resolution was limited by an 0.8 to 1.0 eV energy spread but the 2^3S state was sufficiently resolved to allow direct measurement as a function of angle. Cross sections for the 2^1S and the $2^1P + 2^3P$ states were obtained from the energy loss profile of the N = 2 states by curve fitting with the beam energy distribution. Absolute cross sections were obtained by normalizing to the elastic cross sections[1] using the measured ratio of 2^3S to elastic signals at fixed angles. The noteworthy feature of the cross sections is that they all oscillate as a function of angle. The excitation is interpreted in terms of the crossing of the lowest $^2\Sigma_g^+$ state of He_2^+ with Σ_g states leading to excited atom states. The oscillations are related to the perturbations[2] observed in the elastic scattering and are explained by interferences between scattered waves generated by the two potentials in the region just above the crossing.

1. D. C. Lorents and W. Aberth, Phys. Rev. 139, A1017 (1965).
2. F. T. Smith, D. C. Lorents, W. Aberth and R. P. Marchi, Phys. Rev. Letters 15, 742 (1965).

G2 OPTICAL EXCITATION OF HELIUM ATOMS BY LOW ENERGY HELIUM IONS.* S.H. DWORETSKY, R. NOVICK, W.W. SMITH, and N. TOLK, Columbia Radiation Laboratory, Columbia University.

We have observed the optical excitation of helium in low energy (100-500 eV) He^+-He collisions. Three lines in the visible spectral region have been identified corresponding to the following atomic helium transitions: 2^3S-3^3P^0, 2^3P^0-4^3D, and 2^3P^0-3^3D. Although very low intensity radiation was detected from the 2^1P^0-3^1D transition, no other lines corresponding to singlet transitions (for example, 2^1S-3^1P^0 and 2^1P^0-4^1D) were observed. Also, no radiation was found arising from S state parent levels. Our results indicate that triplet states are favored over singlet states and that D and P states are strongly favored over S states. DeHeer et al.[1] found that the maxima in the capture cross sections into D levels occur at low energies while the corresponding P and S level maxima occur at successively higher energies. This is consistent with our observation.

*This work was supported in part by the Joint Services Electronics Program (U.S. Army, U.S. Navy, and U.S. Air Force) and in part by the National Aeronautics and Space Administration.

1. F.J. DeHeer, L. Wolterbeek Muller, and R. Geballe, Physica 31, 1745 (1965).

G3 RELATIVE PRODUCTION OF SINGLY AND DOUBLY CHARGED IONS IN HELIUM BY FAST PROTONS IN THE ENERGY RANGE 0.15 - 1.00 MEV.* L. J. PUCKETT, G. O. TAYLOR, and D. W. MARTIN, Georgia Institute of Technology.

The slow positive ions produced in helium gas by fast protons have been observed with a magnetic analyzer to obtain the relative total yields of singly and doubly charged ions in single collisions. The analyzer axis was oriented at right angles to the proton beam, and a repeller plate provided a transverse electric field to sweep the slow ions into the analyzer. Saturation of both of the ion count rates and constancy of their ratio with increasing repeller voltage was obtained, and the angle between the analyzer axis and the beam was varied over several degrees, to insure against appreciable error due to differences in initial energy and angular distributions. The dependence of the He^+ yield on the proton energy E can be represented as the power law $E^{-0.76}$ over this entire range, in excellent agreement with our previous measurements of the total positive ion current. The He^{++} yield can be represented by the power law $E^{-1.37}$. It amounts to 1.1% of the He^+ yield at 0.150 MeV, and 0.34% at 1.00 MeV. These results agree well with previous measurements below 0.180 MeV,[1] but they disagree with measurements above 0.800 MeV by Wexler,[2] who found the He^{++} fraction to be twice as great at 1.00 MeV, and to decrease less rapidly with proton energy, about as $E^{-1.16}$.

*Research supported by the U. S. Atomic Energy Commission.

[1]E. S. Solov'ev, et al., Zh. Eksperim. i Teor. Fiz. 42, 659 (1962). English transl.: Soviet Phys. - JETP 15, 459 (1962).
[2]S. Wexler, J. Chem. Phys. 41, 1714 (1964).

G4 DEDUCTION OF POTENTIALS AND INTERACTIONS FROM THE DIFFERENTIAL SCATTERING OF He^+ BY RARE GASES. FELIX T. SMITH and R. P. MARCHI, Stanford Research Institute.

Measurements by Lorents, Aberth and Hesterman show pronounced effects of curve crossings in the elastic[1] and inelastic[2] scattering of He^+ by He. The elastic scattering of He^+ by Ne and Ar[3] shows similar curve crossing effects, and also a pronounced loss process attributable to ground state charge transfer to $He + Ne^+$ or Ar^+. With the help of a new scaling law,[4] these low-energy data can be combined with the results of Everhart et al.[5] to give a unified picture of the scattering in these systems from 10 to 100,000 eV. From these curves we can deduce potential parameters, locations of curve crossings, and energies of interaction between several of the low-lying states of the diatomic system.

1. F. T. Smith, D. C. Lorents, W. Aberth and R. P. Marchi, Phys. Rev. Letters 15, 742 (1965).
2. D. C. Lorents, W. Aberth and V. W. Hesterman (paper to be presented at this meeting).
3. W. Aberth and D. C. Lorents, Phys. Rev. 144, 109 (1966).
4. F. T. Smith, R. P. Marchi and K. G. Dedrick, Phys. Rev., to be published.
5. E. N. Fuls, P. R. Jones, F. P. Ziemba and E. Everhart, Phys. Rev. 107, 704 (1957).

G5 EXCITATION OF HELIUM AND NITROGEN BY FAST PROTONS* E. W. THOMAS, G. D. BENT, and J. L. EDWARDS, Georgia Institute of Technology.

Protons in the energy range 150 to 1,000 keV were passed into the target gases helium and nitrogen, and the emitted radiation analyzed by a spectrometer-photomultiplier system. To maximize the signal-to-noise ratio, the light entering the spectrometer was chopped mechanically at 100 cps and the desired signal identified by its specific frequency and phase. The quantum detection efficiency of the system was determined using a tungsten filament lamp which in turn had been calibrated against a black body. Prominent emissions studied were 12 lines from the ^1S, ^1P, ^1D levels of helium and 8 bands of the N_2^+ first negative system ($B^2\Sigma \rightarrow X^2\Sigma$). Absolute emission cross sections of these spectral lines were measured as a function of the energy of the incident proton. The cross sections for excitation of various singlet levels in a helium target were calculated from the emission cross sections using known transition probabilities and experimentally determined corrections for resonant absorption, collisional transfer, and cascade. General agreement with the asymptotic high energy form of the Born approximation is found, both as regards the energy dependence of allowed and disallowed transitions, and the variation of the magnitude of the cross sections with the principal quantum number of the state. Cross sections for the excitation of the v = 0 and v = 1 vibrational levels of the $B^2\Sigma$ state of N_2^+ in a nitrogen target were also obtained.

*Research supported by the U. S. Atomic Energy Commission.

G6 THE MEASUREMENT OF CHARGE TRANSFER CROSS SECTIONS FOR 0.25 TO 2.5 MeV PROTONS AND HYDROGEN ATOMS INCIDENT UPON HYDROGEN AND HELIUM GASES. JAMES FRANCIS WILLIAMS*, Health Physics Research, Australian Atomic Energy Research Establishment, Australia.

Measurements of the single and double electron capture cross section for protons σ_{10} and σ_{1-1} respectively, and the single electron loss cross section for hydrogen atoms, σ_{01}, within the energy range 0.25 to 2.5 MeV for hydrogen and helium target gases have been made by the method of observing the rate of growth with target gas number density of the fast collision products from an originally pure primary beam. The present values of σ_{10} and σ_{01} agree well with the data of Barnett and Reynolds below 1 MeV and confirm that extrapolation of their data which passes through the single measurements of σ_{10} and σ_{01} for 12.9 and 21 MeV deuterons by Beckner. The experimental values of σ_{01} agree with calculated values derived from the Born and free-collision approximations within the experimental uncertainty of $\pm$ 10%. The values of σ_{1-1} in hydrogen decrease from 2.3×10^{-25} cm^2/mol at 0.4 MeV to 1.6×10^{-28} cm^2/mol at 1 MeV with an experimental uncertainty of up to 60% within which limit there is confirmation of the first Born approximation calculations by Mittleman.

*Now at the Université Laval - Québec, Canada.

G7 ELECTRON CAPTURE BY PROTONS IN HYDROGEN AND EFFECT OF AN ELECTRIC FIELD. K. OMIDVAR, Laboratory for Theoretical Studies, Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, Maryland

By treating an electric field in the direction of the incident proton as a perturbation, the electron capture cross section in the Brinkman Kramers approximation up to the first order in the field is obtained. The cross section for transition between principal quantum numbers, in particular for capture from the ground state into the ground state, is quadratic in the field. The experimental verification of this symmetry is desirable. The cross section in the zeroth order approximation for transition between two Stark levels is independent of the quantum numbers of these levels and depends only on their principal quantum numbers. The inclusion of the first order which is linear in the field split the cross section into different values. The simplicity of the zeroth order cross section formula between Stark levels allows through a transformation the evaluation of the cross section between the optical levels as a polynomials in the incident energy. A general expression for the capture from the state $n\lambda$ into the state $n'\lambda'$ is given.

G8 EXCITATION OF THE FIRST NEGATIVE SYSTEM OF N_2^+ BY HYDROGEN-ATOM IMPACT.* D. A. DAHLBERG, I. E. DAYTON, and D. K. ANDERSON, Montana State University.

Cross-sections for the excitation of the first negative system of N_2^+ by hydrogen-atom impact have been measured over an energy range from 20 to 130 kev. Proton cross-sections were measured over the same energy range, and an absolute calibration obtained by normalizing to the data of Philpot and Hughes.[1] The neutral particles were produced in a nitrogen-filled charge exchange chamber separated from the excitation chamber by differential pumping. Hydrogen-atom beam current was measured with a secondary-emission detector. For the (0,0) transition (3914 A) the cross-section decreases slowly with increasing energy and has a value of 3×10^{-17} cm^2 at an energy of 70 kev. This means that the hydrogen-atom cross-section is about half of the proton cross-section at 50 kev and about two-thirds of the proton cross-section at 100 kev. It is evident from this data that care must be taken in interpreting proton excitation measurements because of the possibility of charge exchange.

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

1. J. L. Philpot and R. H. Hughes, Phys. Rev. 133, A107 (1964).

G9 THE STUDY OF LONG-LIVED EXCITED STATES IN ION BEAMS. B. R. TURNER, J. A. RUTHERFORD, D. M. J. COMPTON, General Dynamics, General Atomic Division.

In a crossed beam experiment the reaction $O_2^+ + N_2 \rightarrow O_2 + N_2^+$ was found to have a very small cross section, of the order of 10^{-17} cm^2, when the O_2^+ ions were formed by electron bombardment with electron energies just above threshold and were therefore ground state; but when higher energy electrons were employed, introducing excited ions, the composite cross section for all of the O_2^+ states present was large, $\sim 10^{-15}$ cm^2. The increase in the cross section as excited ions were introduced into the beam depended on both the larger charge exchange cross section for the excited ions and the fractional concentration of the excited ions in the beam, but these two quantities could not be extracted separately. A separate experiment to determine the fractional concentration of the excited ions in an ion beam as a function of source electron energy has been developed. The determination is made approximately 20 μsec after formation of the ions so that only long-lived states remain in the beam. Basically, the method consists of attenuating the ion beam in a gas-filled chamber where, in general, the excited ion attenuation will be different from the ground state ion attenuation. The study has been completed for the case of an O_2^+ ion beam, and only one excited state appears to be important. These results and the method will be discussed, and the values of the ground state and excited state cross sections are given for the $O_2^+ + N_2 \rightarrow O_2 + N_2^+$ reaction.

G10 CHARGE TRANSFER CROSS SECTIONS FOR NEGATIVE IONS INCIDENT ON ATMOSPHERIC GASES.* R. D. RUNDEL,† W. R. SNOW,‡ and R. GEBALLE, University of Washington.

A measurement has been made of charge transfer cross sections for H^- and O^- incident on H_2, O_2 and NO_2 over the energy range from 300 to 3,000 eV. The measurements made use of a modulated crossed beam technique with a hot cathode arc source for the negative ions. Negative ions resulting from charge transfer were mass analyzed. The cross sections were normalized to the results of Bailey.[1] Cross sections for $H^- + O_2$, $H^- + NO_2$, and $O^- + NO_2$ all decrease monotonically with energy over the experimental range; $O^- + H_2$ was found to proceed by dissociative charge transfer with a cross section of the order of 3×10^{-17} cm^2. The $O^- + O_2$ cross section has a minimum of 1.5×10^{-16} cm^2 at 0.5 keV and appears to be approaching a maximum at 3 keV. The effect of polarization forces on negative ion charge transfer will be discussed.

*This work supported by the Army Research Office and the Office of Naval Research.
†Present address: Culham Laboratory, Culham, England.
‡Present address: Aerospace Corporation, Los Angeles.
[1]T. L. Bailey, "Second International Conference of Electronics and Atomic Collisions," Boulder, Colorado (1961).

G11 NEGATIVE ION CHARGE TRANSFER WITH ATOMIC TARGETS.* W. R. SNOW,† R. GEBALLE and J. S. RISLEY, University of Washington.

Relative cross sections for charge transfer of H^-, C^-, and O^- with H and O, have been measured over the range of 400 to 4,000 eV using a modulated crossed beam technique. The fraction of atoms in the neutral beam, which was produced by a microwave discharge, was determined from mass analysis of the ions made by electron bombardment of the beam. Relative cross sections were normalized to the $H^- + H$ charge transfer measurement of Hummer, et. al.[1] Maxima in cross sections are found at 600 eV for $H^- + O$, 900 eV for $C^- + O$, and 3,000 eV for $C^- + H$. The measured ratio of cross sections, $\sigma(H^- + O)/\sigma(O^- + H)$, is 1.4 which agrees with the value 1.33 predicted by detailed balancing. The slope $d(\sigma^2)/d(\ln v)$ for the resonant reaction $O^- + O$ agrees closely with Firsov's s-state formula,[2] but the cross section is only 50% of that calculated. It is shown that positive and negative ion resonant transfer have, respecting slope, nearly a common systematics.

*This work supported by the Army Research Office and the Office of Naval Research.
†Present address: Aerospace Corporation, Los Angeles.
[1]D. G. Hummer, et. al., Phys. Rev. 119, 668 (1960).
[2]O. B. Firsov, Soviet Physics, JETP 21, 1001 (1951).

Session H

Thursday, October 13

2:00 p.m.

ELECTRON TRANSPORT AND DISTRIBUTION FUNCTIONS

Chairman: W. P. Allis, Massachusetts Institute of Technology, Cambridge, Massachusetts

H1 MEASUREMENT OF THE ENERGY DISTRIBUTION OF SECONDARY ELECTRONS IN AN AURORA.* JOHN P. DOERING and WILLIAM G. FASTIE, The Johns Hopkins University, Baltimore, Maryland 21218.

The energy distribution of secondary electrons in an active aurora has been measured from 40 to 900 eV with a rocket-born electrostatic analyzer. An unusual design of the 180° hemispherical deflection system allowed the simultaneous measurement of a differential and integral electron spectrum. Suppression of secondary electrons generated inside the analyzer was achieved by the use of hemispherical deflection grids. The analyzer was mounted on a boom which extended from the side of the rocket in order to avoid blocking of low energy electron trajectories by the rocket body. Although part of the data were spoiled by an unexpectedly large visible light signal which interfered with the accelerator-scintillator electron detection system, we have obtained differential electron spectra near 160 km altitude which show a roughly exponential decrease in intensity from 40 to 900 eV with an e-folding energy of approximately 125 eV. Typical differential electron fluxes observed at 40 eV were near 3×10^5 electrons $(cm^2 \text{ sec. ster. eV})^{-1}$. The integral spectrum data are consistent with the results from the differential spectrometer. Our results are also in qualitative agreement with the previous auroral experiment of Heikkila and Matthews.[1]

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

1. W. J. Heikkila and D. L. Matthews, Nature, 202, 789 (1964).

H2 EXCHANGE OF ENERGY BETWEEN CHARGED PARTICLES. N. P. CARLETON, Smithsonian Astrophysical Observatory and Harvard University.

We wish to study exchange of energy in elastic collisions of charged particles in a homogeneous, isotropic plasma. Let us fix our attention upon the particles of one kind with energies between E_1 and $E_1 + \Delta E_1$, and also those between E_2 and $E_2 + \Delta E_2$. One may calculate that as a result of Coulomb collisions between particles in these two groups, particles are transferred through an energy change Y from E_1 (into a range ΔY) with a two body rate coefficient of $\sqrt{2}\pi e^4(4E_1 + 3Y)\Delta Y/3m^{1/2} E_2^{1/2} Y^3$ cm^3 sec^{-1}, where e and m are the charge and mass of the particles. This expression is valid if $(E_2 - E_1) > Y > 0$, and there are three other distinct but similar expressions for the rate for the other three permutations of these inequalities. This expression diverges as Y approaches zero, but the conventional cut-off of the Coulomb potential by Debye shielding can be transformed into an approximate cut-off on Y. These expressions can be used to calculate details of relaxation of a non-thermal particle distribution such as exists, for instance, in the day-time ionosphere. Similar expressions can be derived for particles of different mass, and these show that on the average, electrons are giving up energy to ions in a plasma even when their energy is much below the average energy of the ions. This statement does not contradict the second law of thermodynamics, or any other useful law.

H3 THEORY OF ELECTRON COLLISION EXPERIMENTS AT INTERMEDIATE AND HIGH GAS DENSITIES*. P. J. CHANTRY, A. V. PHELPS and G. J. SCHULZ, Westinghouse Research Laboratories.

Analytic solutions to the problem of predicting the transmitted current and the electron density within a collision chamber at any pressure have been obtained. The expression derived for the transmitted electron current is applicable to experiments of the Maier-Leibnitz type, and the expression for the electron density may be used to interpret the pressure dependence of ion currents when the electron energy is close to the threshold. The density of electrons effective in ion production is constant at low pressures, increases with increasing pressure due to elastic scattering, and finally decreases at the highest pressures due to inelastic collisions. This behavior is reflected in the measured ion current, whose exact form depends on the elastic and inelastic cross-sections, on the method of normalization to the electron beam, and on the spatial extent of the ion sample collected. Over a large range of parameters the pressure dependence of a sample taken from the center of the chamber does not differ by more than 10% from the case where the total ion current is collected. The theory is in good agreement with available experimental data.

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

H4 TIME-DEPENDENT TRANSPORT COEFFICIENTS FOR ELECTRONS IN DRY AIR. A. G. ENGELHARDT, Westinghouse Research Laboratories.

The relaxation in time of the electron energy distribution function and transport coefficients has been calculated by means of a numerical solution of the time-dependent Boltzmann transport equation for pulse and step function inputs of electrons in dry air at 300°K. Initially the electrons have a known distribution function[1] with a mean energy of 10 eV. Elastic and inelastic collisions have been taken into account. For a pressure of 20 Torr and times less than a microsecond, the effect of two and three body attachment of electrons to oxygen molecules was found to be small. Furthermore, since the electron density is assumed to be much less than the density of air molecules, electron loss due to recombination is negligible compared to that due to attachment. The variation in time of the electron distribution function, ionization and attachment frequencies, and normalized ac conductivity has been determined down to a value of the average energy within 25% of thermal.

1. R. E. Meyerott, R. K. M. Landshoff, and J. Magee, Lockheed Missile Systems Division Rept. No. IMSD48361 (1958).

H5 DRIFT VELOCITY AND THE ELASTIC COLLISION CROSS SECTION FOR ELECTRONS IN HELIUM.* J. C. BOWE and R. K. LANGS, Argonne National Laboratory.

Drift velocities v_d measured with a grid-free chamber by a single-pulse method were published by Bowe.[1] Later measurements by Pack and Phelps[2] (P-P) and by Crompton and Jory[3] (C-J), both using shuttered grids, led to values of the collision cross section $Q_m(u)$ that differ from each other by as much as 15% and from Bowe's by up to 30%. Therefore v_d was remeasured with improved instrumentation. In the interval $0.1 \leq E/p_o \leq 1.0$, the product $v_d(cm/\mu sec) \times (E/p_o)^{-1/2}$ is constant; the respective experimental values are: 0.852 ± 0.05 (P-P); 0.818 ± 0.005 (C-J); 0.800 ± 0.009 (present), where the uncertainty is the standard deviation of the data measured from the mean. The residual difference between (C-J) and the present value is sufficiently small to conclude that the two methods yield equivalent results. These results are consistent with the constant values (in A^2) $Q_m = 6.5 \pm 0.76$ (F-P)[4], 7.00 ± 0.09 (C-J), 7.3 ± 0.15 (present) which are obtained when thermal motion of the gas is neglected.

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

1. J. C. Bowe, Phys. Rev. 117, 1411 (1960).
2. J. L. Pack and A. V. Phelps, Phys. Rev. 121, 798 (1961).
3. R. W. Crompton and J. L. Jory, Conf. on Phys. of Electronic and Atomic Collisions, Quebec, 1965 (p. 118).
4. L. S. Frost and A. V. Phelps, Phys. Rev. 136, A1538 (1964).

H6 ANOMALOUS ELECTRON DIFFUSION PARALLEL AND PERPENDICULAR TO ELECTRIC FIELDS.* F. J. DAVIS and J. E. PARKS, Oak Ridge National Laboratory.

Measurements of electron diffusion in monatomic and diatomic gases by the time-of-flight method disagree with published values obtained by the Townsend-Huxley method. Since the two methods measure diffusion in different directions, i.e., parallel and perpendicular to the drift field, an experiment was designed to investigate this difference. In this experiment the electrons are brought to the center of a drift tube by a negative pulse. Here the electrons are subjected to a one megacycle square wave, either along the direction of the drift field or at right angles to it. After a controlled time interval the main axial drift field is reimposed and the electron time-of-arrival distribution at the anode is determined. Measurements made in H_2, N_2, and CO with the AC field in the two different directions showed a difference in diffusion by a factor of two which accounts for the discrepancies between the two methods. In C_2H_4 and CO_2 no difference was noted in the diffusion for the two directions, again in agreement with the two methods. It is felt that this experiment demonstrates that the diffusion coefficient exhibits a definite tensor character in presence of electric fields.

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

H7 ENERGY ANTICORRELATION OF ELECTRONS EMITTED IN ELECTRON IMPACT IONIZATION OF ATOMS. A. TEMKIN, NASA, Goddard Space Flight Center.

On the basis of the asymptotic form conjectured for S-wave electron-hydrogen ionization[1], it can be shown that there is a complete suppression of S-wave ionization events in which the energies of the two outgoing electrons are equal. The combination of such an S-wave cross section together with reasonable higher partial wave cross sections yields a total cross section in qualitative agreement with ionization loss measurement in helium by Heideman[2]. This anticorrelation in available energy also provides additional insight into the reasoning behind the expectation of a non-linear threshold yield curve.[1]

1. A. Temkin, Phys. Rev. Letters 16, 835 (1966).

2. H. G. M. Heideman, Bulletin of the American Phys. Soc. Series II 10, 455 (1965) and C. Kuyatt (private communications).

H8 SINGLET-TRIPLET EXCITATION OF THE HYDROGEN MOLECULE BY ELECTRON IMPACT. S. P. KHARE,* Goddard Space Flight Center, NASA.

One-center wave functions of Huzinaga[1] together with the Ochkur[2] approximation have been employed to investigate the exchange excitation of the hydrogen molecule by electron impact from the singlet electronic state $X(^1\Sigma^+_g)$ to the triplet electronic states namely a $(^3\Sigma^+_g)$, b $(^3\Sigma^+_u)$ and c $(^3\pi_u)$. The excitation of the molecules to the repulsive $^3\Sigma^+_u$ state produces dissociation of the molecule and that to the $^3\Sigma^+_g$ state gives rise to continuous radiation followed by dissociation. The efficiencies for the excitation of the continuous spectrum η_c and of the dissociation η_D for the incident electrons distributed according to Maxwellian law have been computed as a function of the ratio F/p of the electric field strength F in a column to the gas pressure p. The shape of the curves are in general agreement with the experimental results[3] although at higher values of F/p the theoretical value of η_D is about twice the experimental value.

*NAS-NRC Resident Research Associate.

1. S. Huzinaga, Prog. Theo. Phys. 17, 162 (1957).
2. V. I. Ochkur, Soviet Physics - JETP, 18, 503 (1964).
3. R. W. Lunt, C. A. Meek and E. C. Smith, Proc. Roy. Soc. A158, 729 (1937) and H. Poole, Proc. Roy. Soc. A163, 424 (1937).

H9 VIBRATIONAL AND ELECTRONIC EXCITATION OF CO_2 BY ELECTRON IMPACT.[/] R. D. Hake, Jr.[*] and A. V. Phelps, Westinghouse Research Laboratories.

Cross sections for excitation of vibrational states of CO_2 are obtained from experimental electron drift velocities and characteristic energies in CO_2 using techniques described previously[1]. The transport coefficient data are consistent with resonance type excitation cross sections with maxima near thresholds at 0.08, 0.3, 0.6 and 0.9 eV and with a Ramsauer minimum in the momentum transfer cross section near 1 eV. The shapes and relative magnitudes of the resonances near 0.3, 0.6, and 0.9 eV are based on electron beam studies.[2] The width at half maximum times magnitude of the resonant cross sections is about 3×10^{-17} cm^2 eV for the 0.08 eV process, 10^{-16} cm^2 eV for the 0.3 eV process, and 10^{-17} cm^2 eV for the 0.6 and 0.9 eV processes. It is not clear whether the resonance observed in total cross section measurements near 4 eV contributes to vibrational excitation. Analyses at higher electron energies yield electronic excitation cross sections which are consistent with ionization coefficient, drift velocity, and characteristic energy data.

/ Supported in part by Advanced Research Projects Agency.

* Now at the University of Pittsburgh.

1. A. G. Engelhardt, A. V. Phelps, and C. G. Risk, Phys. Rev. 135, A1566 (1964).
2. G. J. Schulz (private communication).

H10 DIRECT MEASUREMENTS OF THE ELECTRON ENERGY DISTRIBUTION FUNCTION IN A UNIFORM D. C. ELECTRIC FIELD IN HYDROGEN FOR LOW VALUES OF E/p. D. E. GOLDEN and H. NAKANO, Lockheed Palo Alto Research Laboratory.

Measurements of the electron energy distribution function have been made for a photo-electrically stimulated cathode for $20 < E/p_{300} < 200$ in a similar manner to that used by Roberts and Burch[1]. The distribution function has been obtained by making retarding potential measurements on a small sample of electrons leaving the anode through a small hole. The collector was designed so as to eliminate secondary electron emission from the collector. The resulting distribution function is shown to be stationary at constant E/p for sufficiently large values of gap voltage. Within the range of E/p used, the average energy found using the stationary distribution functions increased with E/p_{300} from about 4 to 25 eV.

1. T. D. Roberts and D. S. Burch, Phys. Rev. 142, A100 (1966).

Session I

Friday, October 14

9:00 a.m.

EXCITATION, IONIZATION, AND DISSOCIATION BY ELECTRONS

Chairman: Felix T. Smith, Stanford Research Institute
Menlo Park, California

I1 DISSOCIATIVE EXCITATION OF HYDROGEN BY ELECTRON IMPACT.* E. R. WILLIAMS+, J. V. MARTINEZ++, and C. H. DUNN, Joint Institute for Laboratory Astrophysics.+++

Cross sections for dissociative excitation of hydrogen by electron impact have been measured over the electron energy range of 0-400 eV. Measurements were made only for excitations yielding hydrogen atoms which give rise to H_α(6563A), H_β(4861A), and H_γ(4340A) radiation. The measurement technique was to observe the intensity of radiation as a function of electron energy. Peak cross section values are 0.014, 0.0055, and 0.0013 in units of πa_o^2 for H_α, H_β, and H_γ lines respectively. Occurrence of pronounced structure in the cross section curves allows interpretation involving transitions to several dissociative states.

*This research was supported in part by the U. S. Atomic Energy Commission.

+Present Address: Department of Physics, Wesleyan University, Middleton, Connecticut.

++Participant in the NSF Research Participation for College Teachers Program. Permanent Address: Department of Physics, St. John Fisher College, Rochester, N. Y.

+++Of the National Bureau of Standards and the University of Colorado, Boulder, Colorado.

I2 ELECTRON SCATTERING IN H_2; DERIVATION OF OSCILLATOR STRENGTH.* C. E. KUYATT and S. R. MIELCZAREK, National Bureau of Standards, Washington, D.C. and S. NATALI, University of Bari, Italy.

Energy loss measurements for forward scattering of electrons in H_2 have been converted to oscillator strengths for photon absorption in the range 11 to 40 eV. Agreement with photon absorption measurements is good in the range 14.5 to 40 eV, but from 11 to 14.5 eV the electron scattering results are two to three orders of magnitude larger than the results obtained from photon absorption. Since the electron scattering results agree well with theoretical calculations[2-4] we conclude that the photon absorption measurements in the range 11 to 14.5 eV seriously underestimate the absorption cross section of H_2. Reasons for this underestimation will be discussed. I

*This research was supported in part by the Advanced Research Projects Agency, U.S. Department of Defense.

1. G. R. Cook and P. H. Metzger, J. Opt. Soc. Am. 54, 968 (1964).
2. R. S. Mulliken and C. A. Rieke, Rept. Prog. Phys. 8, 231 (1941).
3. S. Ehrenson and P. E. Phillipson, J. Chem. Phys. 34, 1224 (1961).
4. J. C. Browne, J. Chem. Phys. 44, 835 (1966).

I3 THE IONIZATION OF H ATOMS NEAR THRESHOLD* J. WILLIAM McGOWAN**, General Dynamics, General Atomic Division, San Diego, California.

Considerable experimental evidence has been gathered which indicates that near threshold the cross section for the ionization of atomic hydrogen under electron impact is a nonlinear function of the electron energy in excess of the ionization potential, 13.595 eV. Much of the evidence for the nonlinear dependence is derived from other experiments(1,2) which were originally energy calibrated by using the ionization potential of H(1s) as reference and a linear extrapolation of our H^+ ionization data to this reference. It now is apparent that this linear extrapolation gave a calibration which was high by $\sim$ 0.03 eV.

* This research was supported by the National Aeronautics and Space Administration. The computer studies necessary for this report were supported by the Joint Institute for Laboratory Astrophysics, Boulder, Colo.

**1965-66 Visiting Fellow, Joint Institute for Laboratory Astrophysics, Boulder, Colorado.

1. J. Wm. McGowan and M. A. Fineman, Proceedings 4th International Conference on the Physics of Electronic and Atomic Collisions, August 2-6, 1965, Quebec, (Science Book Crafters, Inc., Hastings-on-Hudson, New York 1965), p. 429.
   J. Wm. McGowan, et al., submitted for publication.
2. J. Wm. McGowan, E. M. Clarke and E. K. Curley, Phys. Rev. Letters 15, 917 (1965) and Errata 17, (1966).

I4 DISSOCIATIVE IONIZATION OF H_2 AND D_2.* L. J. KIEFFER and G. H. DUNN, Joint Institute for Laboratory Astrophysics.

Previously[1] we have reported that although there was much better agreement between our measurements and theoretical predictions of the number of protons vs. proton energy from the dissociative ionization of H_2 by electron impact than previous measurements, there were still some discrepencies in detail. We have recently repeated these measurements in H_2 and also taken data for D_2. In addition we have made appearance potential measurements for these ions. We will report the following: 1) Very close agreement between the ion current vs. ion energy for H^+ from H_2 and D^+ from D_2; 2) Structure in the ion current vs. ion energy curve; 3) Appearance potential measurements and angular distribution measurements indicate that the final state of the dissociated system is a ground state atom and the ion; and 4) Since we now know the final state of the dissociating system the disagreement between the theoretical prediction using Franck-Condon overlaps and the measurements of ion current vs. ion energy is surprising.

*Work supported in part by Controlled Thermonuclear Branch of the U. S. Atomic Energy Commission.

1. G. H. Dunn and L. J. Kieffer, Phys. Rev. 132, 2109 (1963) and Bull. Am. Phys. Soc. Series II, 10, 180 (1965).

I5 CROSS SECTIONS FOR SINGLE AND MULTIPLE IONIZATION OF RARE GASES BY ELECTRON IMPACT.* J. T. DOWELL AND D. D. BRIGLIA**, Lockheed Palo Alto Research Laboratory, Palo Alto, Calif.

Single and multiple ionization of Ne, Ar and Kr by electron impact are studied experimentally from threshold to 900 eV. The apparatus is similar to that used in previous studies of total ionization cross sections,[1] but with provision for 180° magnetic mass analysis. The consistency checks required for accurate ionization cross section measurements are all satisfied in the present work. Attainment of flat-topped mass peaks and saturation of the mass analyzed ion current with magnetic field at all electron energies are interpreted as constant ion collection efficiency. The Ne^{+}, Ne^{++} and Ne^{+++} cross sections are reported in detail. Relative data on multiple ionization in the heavier rare gases will also be presented. The purpose of the measurements is to provide partial ionization cross section data for which all the consistency checks have been demonstrated.

* Work supported by the Lockheed Independent Research Program.

** Present address: ULTEK Corporation, Palo Alto, Calif.

1 D. D. Briglia and D. Rapp, J. Chem. Phys. 42, 3201 (1965).

I6 A CROSSED-BEAM MEASUREMENT OF THE ELECTRON IMPACT POLARIZATION OF HELIUM 4922Å OPTICAL RADIATION.* R. H. McFARLAND, Lawrence Radiation Laboratory.

Non-zero threshold polarization of helium 4922Å optical radiation as first reported[1,2] has since been observed by Heddle and Keesing.[3] A recent experiment designed to minimize elastic gas scattering of the electrons has involved helium pressures ranging from 10^{-7} to 10^{-5} torr, background pressures of 3×10^{-8} torr, less than 10 Å half-breadth width optical resolution, zero magnetic field focussing of electrons and gas scattering of the electron beam of less than 1%. Energy resolution of the electron beam was of the order of 0.2 volts half-breadth width. Customary photon counting rates varied from background to 100 counts/sec with background of less than 2 counts/sec. Thus, obtaining satisfactory counting statistics presented no appreciable problem, except at threshold. Results compare with those reported earlier,[1] suggesting that the energy dependence of the polarization which dips to a near threshold minimum of approximately 30% is a real effect. The observation has not been adequately explained at this time.

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

1. R. H. McFarland, Phys. Rev. Letters 10, 397 (1963).
2. R. H. McFarland, Phys. Rev. 133, A986 (1964).
3. D. W. O. Heddle and R. W. Keesing, "IV International Conference on the Physics of Electronic and Atomic Collisions," Quebec, Aug. 1965, Science Bookcrafters, Inc., p. 382.

I7 DISSOCIATION OF MOLECULAR IONS (N_2^+, O_2^+, AND H_2^+) BY ELECTRON IMPACT.* GORDON H. DUNN and BERT VAN ZYL, Joint Institute for Laboratory Astrophysics.

Absolute measurements[1] of the cross sections for dissociation by electron impact of N_2^+, O_2^+, and H_2^+ have been made over the energy ranges 10-500 eV, 10-500 eV, and 10-1500 eV respectively. Cross sections for N_2^+ and O_2^+ show the characteristic rise from threshold, peak between 70 eV and 100 eV and fall off with the expected $\frac{1}{E}$ log E dependence. High vibrational excitation of H_2^+ and a strong rise in cross section as a function of internuclear separation cause the H_2^+ cross section to show a continued rise even to the lowest energies measured. Comparison will be made with the theoretical calculation of Peek[2] for H_2^+.

1. Early measurements over a more limited energy range have been reported previously for H_2^+. G. H. Dunn, Bert Van Zyl, and Richard N. Zare, Phys. Rev. Letters 15, 610 (1965).
2. J. M. Peek, Phys. Rev. 140, All (1965); Phys. Rev. 134, A877 (1964); Private communication (to be published.)

*This research was supported in part by the Controlled Thermonuclear Branch of the U. S. Atomic Energy Commission.

I8 OPTICAL EXCITATION-IONIZATION CROSS SECTIONS OF HELIUM.* Richard J. Anderson,† Edward T. P. Lee, and Chun C. Lin‡, University of Oklahoma.

The cross sections for the production of the 3203 Å (n=5→3), 2733 Å (n=6→3), 2511 Å (n=7→3) lines of He^+ by excitation-ionization collisions between electrons and neutral helium atoms have been measured over the energy range of 0 to 350 eV. All the three excitation functions have their maximum values near 225 eV and show the same general shape as that of the 4686 Å (n=4→3) line. Typical values of the excitation cross sections for the 3203 Å, 2733 Å, 2511 Å lines are 3.9×10^{-22}, 2.3×10^{-22}, and 1.7×10^{-22} respectively at 200 eV. The theoretical cross sections for these transitions have been calculated by the Born approximation and the results are in reasonable agreement with the observed values.

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

†Present Address: Department of Physics, University of Arkansas, Fayetteville, Arkansas.

‡Alfred P. Sloan Foundation Fellow.

I9 INELASTIC COLLISIONS OF THE SECOND KIND IN MERCURY*. P. D. BURROW, University of California, Berkeley.

The relative cross section for inelastic collisions of the second kind between electrons and mercury atoms in the excited $^3P_1$ state was measured directly. Excited atoms were produced by absorption of the 2537 Å resonance radiation from a mercury arc. Electrons from a low energy beam collided with the excited atoms leaving them in the $^1S_0$ ground state. The electrons gaining kinetic energy were then detected by passing through a potential barrier which totally reflected unscattered electrons. The data are in good agreement with the cross section computed by applying the Klein-Rosseland equation[1] (detailed balance) to the known cross section for excitation to the $^3P_1$ state by electron impact. Some comments on an earlier investigation[2] will be made.

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

1. O. Klein and S. Rosseland, Z. Physik 4, 46 (1921).
2. G. D. Latyscheff and A. I. Leipunsky, Z. Physik 65, 111 (1930).

I10 ELECTRONIC EXCITATION OF THE SECOND POSITIVE SYSTEM OF N_2*. R. M. ST. JOHN and J. D. JOBE, University of Oklahoma.

Apparent cross sections of the second positive system of N_2 have been determined by the optical method. Ten excitation functions and peak absolute values for 23 transitions were obtained for upper levels with v'=0,1, and 2. At pressures of 0.04 torr or less secondary processes had negligible effect on the shape and magnitude of the excitation functions and the functions assumed the same shape. The functions show a sharp peak near 15 eV and tailed off to 0.07 times the peak value at 90 eV. The peak cross section of the (0,0) transition is $10,8 \times 10^{-18} cm^2$. Total excitation to the v' = 0,1, and 2 levels was obtained by extrapolation and summation of the members of each family. An automatic data processing system[1] was used in securing the excitation functions.

*This research supported in part by USAF, AFWL, Kirtland AFB.

1. R. M. St. John, C. C. Lin, R. L. Stanton, H. D. West, J. P. Sweeney, and E. A. Rinehart, Rev. Sci. Instr. 33, 1089 (1962).

Session J

Friday, October 14

9:00 a.m.

ION-MOLECULE REACTIONS

Chairman: C. F. Barnett, Oak Ridge National Laboratory
Oak Ridge, Tennessee

J1 USE OF CORONA DISCHARGES FOR STUDIES OF ION-MOLECULE REACTIONS. M. M. SHAHIN, Xerox Corporation.

Low pressure corona (or Townsend) discharges have been developed for studies of ion-molecule reactions at pressures which exceed those used in conventional high pressure mass spectrometry by orders of magnitude. The reactions occurring within the discharge are studied by means of a mass spectrometer, sampling the ionic species which arrive at the cathode of the discharge. The ease of pressure and gas composition determination, lack of problems of selective ion diffusion or ion-electron recombination reactions and wide range of available E/P, the pressure-reduced electric field, with the lower limit approaching close to thermal energies, makes the system very suitable for studies of ion-molecule reactions. Preliminary studies in the system have demonstrated the importance of the presence of trace quantities of water vapor in atmospheric gases through both ion-molecule reactions and charge-exchange processes. Reactions such as: (1) $N_2^+ + H_2O \longrightarrow N_2H^+ + OH$, and (2) $N_2^+ + H_2O \longrightarrow H_2O^+ + N_2$, which give rise to precursors of hydrated protons, $(H_2O)_nH^+$ where n = 1, 2, etc., recently reported present in the lower atmosphere, have been studied and their respective cross-sections measured.

J2 ON THE POSSIBLE EXISTENCE OF H_4^+. P. MARMET, Laboratoire de Physique Atomique et moléculaire, Université Laval, Québec, Canada.

It is possible to interpret many experiments results[1,2,3,4] performed in different laboratories in favor of the existence of the molecular ion H_4^+ in the following reaction:

$$H_2^+ + H_2 \rightarrow H_4^+ \rightarrow H_3^+ + H$$

We believe that those results show that H_4^+ although short lived, does exist.

a) The experiments performed by Carette et al.[1,2] measuring the relative cross section of H_3^+/H_2^+ proves that H_2^+ at v = o has a much larger probability to form H_3^+ than other vibrational levels. They also measured that the threshold of both ions was the same.

b) Kirchner[3] under special conditions in the ion source has been able to see directly the H_4^+ peak.

c) Stevenson et al.[4] also explain their results by the reaction $HD^+ + HD \rightarrow D_2^+ + H_2$. That reaction is easily explained in terms of an intermediate $H_2D_2^+$.

Those experiments and others giving different results will be discussed.

1. J. D. Carette, Thèse de Doctorat, Université Laval, (1966).
2. A Weingartshofer and E. M. Clarke, Phys. Rev. Letters 12, 59 (1964).
3. F. Kirchner, Z. fur Naturforschg 18A, 829 (1963).
4. D. P. Stevenson and D. O. Schissler, J. Chem. Physics 29, 282 (1958).

J3 A FIRST APPROACH TO THE STRUCTURE DETERMINATION OF H_4^+. J. LEFAIVRE et P. MARMET, Laboratoire de Physique atomique et moléculaire, Université Laval, Québec, Canada.

In order to gain information on the structure of the ion H_4^+, a program has been initiated to determine its energy in its lower state.

In the first part of this study, a plane and square configuration of side R is considered. Others will follow.

The wave function is built by means of a LCAO method using s-functions according to the Slater determinantal scheme[1].

Along with the side R, the effective charge Z is used as a parameter, following the idea of Wang[2].

Numerical results will be discussed.

1. J.C. Slater, Phys. Rev. 34, 1293 (1929).
2. S.C. Wang, Phys. Rev. 31, 579 (1928).

J4 CHARGE TRANSFER REACTIONS OF ARGON IONS AT NEAR THERMAL ENERGIES.* P. WARNECK, GCA Corporation.

A photoionization mass spectrometer[1] has been employed to study charge transfer processes involving $^2P_{3/2}$ argon ions at ion source pressures 15 to 60 microns and with a source acceleration potential of 0.5 eV. The average energy of the reacting ions is calculated and is found to be less than 0.17 eV. The following rate constants were obtained:

$A^+ + NO \rightarrow A + NO^+$ $k = 3.9 \times 10^{-10}$ cc/molecule sec

$A^+ + O_2 \rightarrow A + O_2^+$ $k = 1.1 \times 10^{-10}$ cc/molecule sec

$A^+ + CO_2 \rightarrow A + CO_2^+$ $k = 7.0 \times 10^{-10}$ cc/molecule sec

$A^+ + CO \rightarrow A + CO^+$ $k = 1.25 \times 10^{-10}$ cc/molecule sec

$A^+ + N_2 \rightarrow A + N_2^+$ $k = 0.66 \times 10^{-10}$ cc/molecule sec

The theoretical implications are discussed.

*Supported by the National Aeronautics and Space Administration.

1. P. Warneck and W. P Poschenrieder, Bull. Am. Phys. Soc. 11, 505 (1966).

J5 IONIC COLLISION PROCESSES AS STUDIED WITH A TANDEM ISOTOPE SEPARATOR-MASS SPECTROMETER COMBINATION
T. F. MORAN,[1] J. J. LEVENTHAL AND L. FRIEDMAN
Chemistry Dept., Brookhaven National Laboratory[2]

A new combination of isotope separator and mass spectrometer has been constructed for the study of ionic collision processes over an energy range of 0.25 eV to 60,000 eV. This combination consists of an isotope separator capable of delivering intense beams of mass analyzed ions into a collision chamber which serves as the source for the analyzing mass spectrometer. With the intensities available from the isotope separator, the collisions of the less prominent species in an ionic spectrum can be studied in detail. Absolute total cross sections for the reaction of ion beams of N_2D^+, D_3^+ and ArD^+ with diatomic molecules have been measured over a range of kinetic energies. It is shown that the Langevin[3] theory provides an upper limit to the ion-interchange reaction cross sections. Resonant charge exchange of isotopically labelled molecules has been studied at low reactant ion kinetic energies. These data are consistent with an impact parameter treatment[4] of the electron transfer mechanism. No evidence is found in resonant or near-resonant charge transfer processes for complex formation in which the reactant and target molecule atoms lose their identity.

[1]Presently: Chem. Dept., Georgia Inst. of Technology.
[2]Supported by the U.S. Atomic Energy Commission.
[3]G. Gioumousis and D. P. Stevenson, J. Chem. Phys. 29, 294 (1958).
[4]E. F. Gurnee and J. L. Magee, J. Chem. Phys. 26, 1237 (1957).

J6 THE FLOWING AFTERGLOW EXPERIMENT FOR THERMAL ENERGY ION-MOLECULE REACTION STUDIES*. A. L. SCHMELTEKOPF, F. C. FEHSENFELD, and E. E. FERGUSON, Institute for Telecommunication Sciences and Aeronomy, Environmental Science Services Administration, Boulder, Colorado

The ESSA flowing afterglow reaction system has undergone a number of modifications since its inception. These will be described in some detail. The gas flows in the tube are regulated by servo controlled valves with visual digital read out. The discharge proper is produced by a dc voltage which can be operated continuously or pulsed. Ion detection is by means of a multiplier which can be gated and whose output is pulse height analyzed and fed to a digital (as well as pen recorder) output. Detection can be reversed to measure both positive to negative ions.

Some characteristics of the ion signals obtained and the way in which they can be controlled will be described. Some recent results of positive ion reactions will be presented including the fast reactions $CO^+ + N_2O \rightarrow NO^+ + NCO$, $C^+ + N_2O \rightarrow NO^+ + CN$, $N_2^+ + N_2O \rightarrow N_2O^+ + N_2$ and the very slow (unobservable) reaction $NO^+ + O_3 \rightarrow$ products. The method of data analysis will also be described.

* This research was supported in part by the Defense Atomic Support Agency.

J7 THERMAL ENERGY NEGATIVE ION REACTIONS*. F. C. FEHSENFELD, A. L. SCHMELTEKOPF, and E. E. FERGUSON, Institute for Telecommunication Sciences and Aeronomy, Environmental Science Services Administration, Boulder, Colorado

The ESSA flowing afterglow system has been used to measure three kinds of negative ion-neutral reactions at 300°K.

(a) Exothermic associative detachment reactions as typified by

$$O^- + O \rightarrow O_2 + e \qquad (1)$$

for which the rate constant is $k_1 \approx 2 \times 10^{-10}$ cm^3/sec.

(b) Charge-transfer, as typified by

$$O^- + O_3 \rightarrow O_3^- + O, \quad k_2 = 7 \times 10^{-10} \text{ cm}^3/\text{sec} \qquad (2)$$

$$O_2^- + O_3 \rightarrow O_3^- + O_2, \quad k_3 = 3 \times 10^{-10} \text{ cm}^3/\text{sec} \qquad (3)$$

$$NO^- + O_2 \rightarrow O_2^- + NO, \quad k_4 = 9 \times 10^{-10} \text{ cm}^3/\text{sec} \qquad (4)$$

and (c) Ion-atom interchange or heavy particle transfer reactions, such as

$$O^- + N_2O \rightarrow NO^- + NO, \quad k_5 = 2 \times 10^{-10} \text{ cm}^3/\text{sec} \qquad (5)$$

Some negative ion energetics can be deduced from the reactions which have been studied. This includes the following results, Electron Affinity (EA) of NO < $EA(O_2)$, $EA(O) < EA(O_3) < 4.7$ eV, $EA(O_3) - 0.6$ eV < $D(CO_2 - O^-) < 4.1$ eV, and $EA(NO_3) > EA(O_3) + 0.9$ eV, where D = dissociation energy.

* This research was supported in part by the Defense Atomic Support Agency.

J8 THERMAL ENERGY NEGATIVE ION REACTION MECHANISMS AND APPLICATIONS*. E. E. FERGUSON, F. C. FEHSENFELD, and A. L. SCHMELTEKOPF, Institute for Telecommunication Sciences and Aeronomy, Environmental Science Services Administration, Boulder, Colorado

The ESSA thermal energy negative ion reactions studied so far lead to several interesting generalizations concerning reaction processes and also to some interesting applications. (a) Exothermic associative detachment reactions are often very fast, i.e. have rate constants greater than 10^{-10} cm^3/sec. Out of over a dozen reactions so far studied only one definite exception to this has been noted. (b) Charge-transfer reactions are found to be similarly fast in several cases where the neutral reactant is molecular. Similar observations in other laboratories suggest that this may prove to be a fairly general result. (c) The negative ion reactions so far observed suggest that CO_3^-, NO_2^-, and NO_3^- may be important ions in the D region of the earth's ionosphere, produced by the reactions

$$O_3^- + CO_2 \rightarrow CO_3^- + O_2, \quad k_1 = 4 \times 10^{-10} \text{ cm}^3/\text{sec}. \qquad (1)$$

$$CO_3^- + NO \rightarrow NO_2^- + CO_2, \quad k_2 = 9 \times 10^{-12} \text{ cm}^3/\text{sec}. \qquad (2)$$

and

$$O_3^- + NO \rightarrow NO_3^- + O, \quad k_3 = 1 \times 10^{-11} \text{ cm}^3/\text{sec}. \qquad (3)$$

Reaction (1) precludes O_3^- from being a dominant atmospheric ion.

* This research was supported in part by the Defense Atomic Support Agency.

J9 ENERGETIC STUDIES OF REACTIVE COLLISIONS FOR THE SYSTEMS $D_2^+ + D_2$ AND $D_2^+ + H_2$.* L.D. DOVERSPIKE and R. L. CHAMPION, University of Florida.

The reactions: (1) $D_2^+ + D_2 \rightarrow D_3^+ + D$ and

(2) $D_2^+ + H_2 \rightarrow (D_2H^+ , H_2D^+) + (H,D)$

have been studied with an angular ion scattering apparatus in which the kinetic energy distributions of the various product ions have been measured at ion laboratory energies in the range 2-15 eV. The K.E. distributions of D_3^+ show two distinct maxima, whereas only a single maximum is found in the K.E. profiles of D_2H^+ and H_2D^+. At c.m. collision energies below approximately 3 eV, the higher energy maximum of D_3^+ and the maxima in the D_2H^+ energy spectra very nearly correspond to the formation of the product ions by a simple "pickup process," i.e., very little momentum is transferred to the neutral product. The low energy group of D_3^+ along with the observed H_2D^+ arise from reactions in which approximately all of the available energy appears as excitation energy of the products. Since the energy profiles of D_2H^+ exhibit a single maximum (corresponding to the pickup process) this suggests that for the D_3^+ product, the high K.E. maximum is associated with a deuteron pickup by the incident ion and the low K.E. maximum in the distribution is associated with a D^+ ion pickup by the target molecule. Masses 1 and 2 are also observed, and are believed to come from the dissociation of excited products.

*Work supported by U. S. Air Force Office of Scientific Research and National Aeronautics and Space Agency.

J10 A MERGING BEAMS EXPERIMENT*. S. M. TRUJILLO, R. H. NEYNABER, AND ERHARD W. ROTHE, General Dynamics/Convair.

A different approach has been developed to measure two-body collision cross sections in the energy range from thermal to several hundred eV.[1] Two molecular beams are merged and move in the same direction along a common axis. Ion-neutral reactions will be discussed but the techniques could also be used for ion-ion and neutral-neutral collisions. Advantages of the merging beams technique over conventional beam-gas and crossed beam methods include accessibility (with good energy resolution) to the energy region from a few tenths of an eV to a few eV; the possibility of measuring cross sections for two general, labile species; and relative ease in collecting and detecting products for total reaction cross section measurements. The principles of the method and details of the instrument will be discussed. Cross sections for the resonant charge transfer of Ar have been measured including a value at a relative energy of (0.3 ±0.01) eV. Reasonable agreement with some previous measurements and theory, plus other tests, indicate that the basic principles of a merging beams technique are valid and that the apparatus performs satisfactorily.

*Supported by Advanced Research Projects Agency (Project Defender) through the Office of Naval Research.

1. S. M. Trujillo, R. H. Neynaber, Lawrence L. Marino, and Erhard W. Rothe, Paper L3, IVth Int. Conf. Phys. Electron. At. Collisions, Quebec, Canada, August 1965.

J11 CROSS SECTIONS FOR INWARDLY-SPIRALLING ION-MOLECULE COLLISIONS.* G. GIOUMOUSIS, Lockheed Palo Alto Research Laboratory.

For certain reactions (notably ion-molecule reactions[1]) for which long-range forces are significant, a cross section can be calculated from the equations

$$E - \varphi(r_0) - \frac{1}{2} r_0 \varphi'(r_0) = 0$$

$$\sigma = \pi b_0^2 = \pi r_0^3 \varphi'(r_0)/(2E).$$

Here φ is the long-range potential, b_0 the critical impact parameter b such that all trajectories with smaller b will spiral inwards, and r_0 the distance of closest approach with $b = b_0$. If the true potential is angle-dependent an effective φ may be found by assuming the orientation is always at minimum energy.[2] The effect on the Ar^+, H_2 cross section assuming a quadrupole moment and anisotropic polarizability is to decrease the cross section by about 25% (at one eV) compared to σ_{GS}.[1] A method of treating the problem that r_0 becomes smaller than the "radius r_2 of the molecule" for higher energies (say one eV) leads to the cross section

$$\sigma = \pi\sqrt{(2e^2\alpha/E)} \qquad \text{for } E \leq E_0 = e^2\alpha/(2r_2^4)$$

$$= \pi r_2^2(1 + e^2\alpha/(2r_2^4 E)) \qquad \text{for } E \geq E_0.$$

*This research was supported by the Defense Atomic Support Agency through the Office of Naval Research.

1. G. Gioumousis and D. P. Stevenson, J. Chem. Phys. 29, 294 (1958).
2. T. F. Moran and W. H. Hamill, J. Chem. Phys. 39, 7413 (1963).

Session K

Friday, October 14

2:00 p.m.

NEGATIVE IONS AND PHOTOIONIZATION

Chairman: T. L. Bailey, University of Florida,
Gainesville, Florida

K1 ABSOLUTE CROSS SECTIONS FOR PHOTODETACHMENT OF NEGATIVE IONS. BRUCE STEINER, National Bureau of Standards.

The absolute cross section for photodetachment from I^- has been redetermined in a new experiment. The new value $3.6_9 \pm 0.6_1 \times 10^{-17}$ cm^2 is significantly larger than the previous value: $2.0 \pm 1.0 \times 10^{-17}$ cm^2. The experiment will be described in detail sufficient to indicate the probable systematic sources of the discrepancy. The relevance of this work to past determinations of the absolute cross sections of other species will be reviewed and it will be shown that a revised uncertainty in other absolute photodetachment cross sections is still considerably less than the difference between the new and old cross sections for I^-.

1. B. W. Steiner, M. L. Seman, and L. M. Branscomb, J. Chem. Phys. 37, 6 (1962).

K2 PHOTODETACHMENT IN DRIFT TUBE*. S. B. WOO,+ E. C. BEATY, L. M. BRANSCOMB, Joint Institute for Laboratory Astrophysics, University of Colorado.

In view of the ambiguity of cross-beam photodetachment experiments with respect to the energy states of the molecular negative ions, this experiment undertakes to study the photodetachment of negative ions in a modified drift tube where the ions are in thermal equilibrium with the neutral gas at room temperature. Ions were produced in a cold-cathode discharge. They went through a thermalizing-region before entering the main drift space where the light beam crossed over. Negative ions of Oxygen, O^-, O_2^-, and O_3^-, have been studied. The atomic negative ion, O^-, having only one known energy state, and therefore having its electron affinity and cross section measurements well established by the cross-beam experiment of Burch, Smith and Branscomb, was used to calibrate the various efficiency factors of the system. Using the 1.42 sec^{-1} as the sun-light photodetachment rate of O^-, a 0.33 sec^{-1} ($\pm$ 30%) value was obtained for the sun-light photodetachment of O_2^-. In the case of O_3^-, a photodetachment rate that is 4.2 per cent that of O^- was detected.

*This research was supported in part by Defense Atomic Support Agency.

+Present Address: Physics Department, University of Delaware, Newark, Delaware.

K3 DETACHMENT OF ELECTRONS FROM NEGATIVE IONS BY ELECTRON IMPACT.* GARY C. TISONE, Joint Institute for Laboratory Astrophysics.

Recently the cross section for the detachment of electrons from H^- ions was measured in the energy range of 30 eV to 500 eV.[1] This measurement was in agreement with the calculation of McDowell and Williamson.[2] This cross section did not follow the usual scaling law for ions in the same isoelectronic sequence. Negative ions with electron affinities other than the 0.75 eV for H^- can be studied to see if a classical scaling law exists between negative ions.

The cross section for detachment of electrons from O^- (1.46 eV electron affinity) by electron impact has now been studied in the energy range of 15 eV to 400 eV. The cross section for O^- at 100 eV was found to be 6.0 πa_o^2. The cross section for H^- at 100 eV was previously found to be 24.5 πa_o^2. A comparison of the O^- and H^- electron detachment cross sections shows that the cross sections for these negative ions do not follow a classical scaling law.

1 G. C. Tisone and L. M. Branscomb, Phys. Rev. Letters 17, 236 (1966).

2 M. R. C. McDowell and J. H. Williamson, Phys. Letters 4, 159 (1963).

* This Research was supported by the Advanced Research Projects Agency (Project DEFENDER), and the National Bureau of Standards.

K4 OBSERVATION OF ELECTRONS PRODUCED IN ASSOCIATIVE DETACHMENT REACTIONS. J. W. EKIN, J. L. MORUZZI, J. L. PACK and A. V. PHELPS, Westinghouse Research Laboratories.

Free electrons produced in the associative detachment reaction, $H_2 + O^- \rightarrow H_2O + e$ have been observed in mixtures of hydrogen and oxygen. The experimental technique is the same as that used in previous studies[1] of electron detachment in O_2. This technique allows the initial and detached component of the electron current to be measured and from the ratio of these quantities the product of the electron attachment and detachment coefficients is determined. Using the known drift velocities and attachment coefficients for pure O_2, the rate coefficient for the above detachment reaction is found to be 1.1×10^{-9} cm^3 sec^{-1} which is in good agreement with mass spectrometric results[2,3]. The E/p dependence of this reaction in the range 3 - 20 $V.cm.^{-1}$ $Torr^{-1}$ shows that the reaction rate coefficient is independent, within $\pm$ 30%, of ion energy.

1. J. L. Pack and A. V. Phelps, J. Chem. Phys. 44, 1870 (1966).
2. J. L. Moruzzi and A. V. Phelps, submitted to J. Chem. Phys. (1966).
3. F. C. Fehsenfeld, A. L. Schmeltekopf, G. I. Gilman, L. G. Plus, and E. E. Ferguson, Bull. Amer. Phys. Soc. 11, 505 (1966) and private communication.

K5 CALCULATION OF DISSOCIATIVE ATTACHMENT IN HOT O_2* T. F. O'MALLEY, Defense Research Corporation.

The very large shift and broadening found by Fite et al[1] in the DA cross section in hot O_2 has been reproduced closely by a semi-empirical calculation. A Maxwell distribution of vibrational (v) and rotational (J) states is assumed and the theoretical expression[2] for $\sigma_{v,J}$ is averaged over this distribution. The fitting consisted in parametrizing the potential curve V(R) of the final O_2^- resonance state as well as its width $\Gamma_a(R)$, and attempting to choose the parameters to fit the observed cross sections at different temperatures. The result was successful with reasonable values found for V(R) and $\Gamma(R)$. To analyze the temperature effect, it seems that with increased T first the presence of excited vibrational states broadens the cross section. Then multiplication by the survival probability factor, a decreasing function of electron energy (and very rapidly so for O_2), shifts the cross section curves to the left, shifting the broadened 2000° curve more than the narrower 300° one. Finally including rotational states adds an additional small shift in the same direction of the order of kT. The minor role of rotational states is at variance with some of the conclusions of Fite et al[1]. The present results are also approximated very closely for small E and large T by the formula $\sigma(T,E) = C(E)\exp(-D(E)/kT)$.

*Supported by the Advanced Research Projects Agency.

1. W.L. Fite and R.T. Brackmann, 4th Int. Conf. on Ionization Phenomena in Gases, 1963, Vol. 1, p.21. W.L. Fite, R.T. Brackmann and W. R. Henderson, 4th Conf. on Elect. and Atomic Collisions (1965) p.100.
2. T.F. O'Malley, Phys. Rev. 149, Sept. 1966.

K6 ISOTOPE EFFECT IN THE DISSOCIATIVE ATTACHMENT IN H_2 AT LOW ENERGY*. G. J. SCHULZ** and R. K. ASUNDI, Westinghouse Research Laboratories.

The dissociative attachment cross section for formation of H^- and D^- from H_2, HD, and D_2 has been measured in the threshold range from 3.75 to 5 eV using a mass spectrometer for ion identification. A pronounced isotope effect is observed. The cross section of H^- from H_2 has a peak value of 1.6×10^{-21} cm^2, D^- or H^- from HD, 1×10^{-22} cm^2; and D^- from D_2, 8×10^{-24} cm^2, all peaks occurring at 3.75 eV. Negative ion formation in this energy range proceeds[1] via the compound state, $^2\Sigma_u^+$, whose lifetime against autodetachment is calculated from the above cross sections to be about 1×10^{-15} sec. Because of this short lifetime and the relatively long time needed for the atoms to separate, the probability of survival of the negative ion (and therefore the dissociative attachment in H_2 at 3.75 eV) is small. For the heavier isotopes the separation time is even longer and therefore the cross section is minute. The same compound state is also responsible for vibrational excitation of the hydrogen molecule.

1. H. S. Taylor and J. Gerhauser, J. Chem. Phys. 40, 244 (1964).

*This research was supported in part by ARPA through ONR.

**Present address: Yale University

K7 TEMPORARY NEGATIVE ION FORMATION IN COMPLEX MOLECULES.* R. N. COMPTON, L. G. CHRISTOPHOROU, G.S. HURST,† and P. W. REINHARDT, Oak Ridge National Laboratory, Health Physics Division.

The formation and decay of parent negative ions have been studied with electron swarm and electron beam techniques. The rate of electron attachment at thermal energies under electron swarm conditions for SF_6 and $C_6H_5NO_2$ was found to be 1.24×10^9 and 2.1×10^7 sec^{-1} torr^{-1}, respectively. The lifetime against autoionization for SF_6^{-*}, $C_6H_5NO_2^{-*}$, $(CHO)_2^{-*}$, and $(CH_3CO)_2^{-*}$ was determined with a time-of-flight mass spectrometer to be 25, 40, 2.5, and 12 microseconds, respectively. The absolute rate of electron attachment in SF_6 was independent of the temperature ($298° \leq T \leq 410°K$), which is consistent with an electron capture cross section that varies inversely with the speed of the electron. The attachment rates and lifetimes were combined through the principle of detailed balance to calculate the ratio of the density of states of the negative ion to that of the neutral molecule plus the electron. A simple theoretical treatment which regards the negative ion as a system of weakly coupled harmonic oscillators is presented, and the possibility of estimating electron affinities from measurements of negative ion lifetimes and attachment cross sections is discussed.

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

†Dept. of Phys., University of Kentucky, Lexington.

K8 THE PHOTOIONIZATION OF OXYGEN, NITROGEN AND NITRIC OXIDE AT 584 A. D.C. FROST, C.A. McDOWELL and D.A. VROOM, Chemistry Dept., University of B.C., Vancouver.

A spherically symmetrical retarding field has been used to measure the kinetic energy spectra of positive ions and photoelectrons produced by monochromatic (584A, or 21.21 ev) irradiation of oxygen, nitrogen and nitric oxide.

In the case of oxygen 7.6% of the positive ions are formed with kinetic energy, maximum value 1.25 ± 0.03 ev. The energetic ions are clearly O^+ associated with the O_2^+ dissociation limit at 18.73 ev.

For each species, groups of photoelectrons resulting from transitions to all the spectroscopically known states (including the O_2^+ $^2\Sigma_g^-$ at 20.31 ev) are observed. Where ions may be formed in several vibrational states the relative transition probabilities are given, and where possible compared with the calculated Franck-Condon factors. The six ionization potentials found for nitric oxide and their probable assignments are as follows:

9.32 ev	$X^1\Sigma^+$	14.84 ev	$^3\Sigma^+$	15.72 ev	?
16.62 ev	$^3\Delta$	17.18 ev	$^3\pi$	18.24 ev	$A^1\pi$

This research was supported by the National Research Council of Canada.

K9 THE PHOTOIONIZATION OF LITHIUM. Kenneth G. Sewell, LTV Research Center, Dallas, Texas.

The photoionization cross section of the lithium atom has been computed over a wavelength range from threshold to 650 A. The effects of correlation were included by utilizing the wavefunction of James and Coolidge[1] for the lithium atom. The wavefunction of the free electron in the presence of the lithium ion was computed by the Hartree-Fock method[2] employing the analytical wavefunctions of Clementi[3] for the ion. The cross section was also computed using Clementi's[3] atomic wavefunctions so that the effects of correlation are illustrated. The theoretical results are compared with recent experimental data[4].

1. H. M. James and A. S. Coolidge, Phys. Rev., 49, 688 (1936).
2. K. G. Sewell, Phys. Rev., 138, A418 (1965).
3. E. Clementi, IBM J. Res. Develop. 9, 2 (1965).
4. R. D. Hutson and V. L. Carter, Phys. Rev. 137, A1648 (1965).

Session L

Friday, October 14

2:00 p.m.

DISCHARGES

Chairman: W. W. Robertson, University of Texas, Austin, Texas

L1 VOLUME ION PRODUCTION COSTS IN TENUOUS PLASMAS. R. J. SOVIE and J. V. DUGAN, JR., NASA - Lewis Research Center.

The energy cost for ion production has been calculated for optically thin plasmas with a Maxwellian distribution of free electron energies by comparing the relative probabilities for the competing inelastic processes of excitation and ionization. Detailed results have been obtained for helium[1], argon[2], cesium and hydrogen[3] gases. Experimental excitation cross sections from the ground state have been used for the helium case. The semi-classical Gryzinski[4] method has been used to determine theoretically the cross-section needed for the argon and cesium calculations. This method has also been used to calculate excitation and ionization cross-section for interaction between electrons and the metastable 2^1S and 2^3S states of helium. These cross-sections have been used to calculate the effects of electron-metastable atom interactions on the volume ion production processes in helium[5]. An approximate theory is also presented which gives the volume ion production cost for a general atom as a function of electron kinetic temperature. The results of this theory are compared with the results of the more detailed calculations for hydrogen, helium, argon and cesium.

1. Sovie, R.J., Klein, B.M.:NASA TN D-2324, 1964.
2. Sovie, R.J., Dugan, J.V.,Jr.:NASA TM X-52064, 1964.
3. Monnin, C.F., Prok, G.M.: To be published.
4. Gryzinski, M.: Rept. N., PAN-448/XVIII, Inst. Nuclear Res., Polish Acad.Sci.(Warsaw), June 1963.
5. Sovie, R.J., Dugan, J.V.,Jr.:NASA TN D-3121,1965.

L2 TEMPERATURE MEASUREMENT OF AN ALKALI METAL-SEEDED PLASMA IN AN ELECTRIC FIELD.* TSU-KAI CHU and CHAD F. GOTTSCHLICH, University of Pennsylvania.

Potassium-sodium (9 to 1 by weight) is seeded in atmospheric argon (1350° - 1750°K) in an 1.27 cm - diameter cylinder at NaK - argon ratio (by weight) α = 0.132, 0.198, 0.396, and 0.93%. The gas temperature T, measured by thermocouples, increases in the presence of an applied longitudinal electric field. Radially, it deviates from uniformity at about r/r_o = 0.8. Longitudinally, in the direction of flow it decreases at low but increases at high input current. The electron temperatures T_e determined from three nonresonance transitions of atomic potassium are in agreement and T_e is higher than T. At current density of about 12 amps/cm^2, T_e is larger by a factor of 2. Its radial distribution is also nearly uniform. When compared with the values calculated from an energy balance equation, it is lower. The largest discrepancy is 2% at α = 0.93%. The conductivity obtained from probes agrees with that reported by Kerrobrock and Hoffman[1], but is in general higher than that calculated from the measured T_e. At α = 0.93% and $T_e \simeq 2700$°K, the measured electrical conductivity is larger by a factor of 2.

*Work supported by the National Aeronautics and Space Administration.

1. Kerrobrock, J. L. and Hoffman, M. A., J. AIAA 2, 1080 (1964).

L3 IONIZATION OF ATOM BY COLLISION WITH EXCITED ATOMS. T. WATANABE and K. KATSUURA*, University of Notre Dame, Radiation Laboratory+.

A formula for the cross section of the ionization of an atom colliding with an excited atom $A^* + B \rightarrow A + B^+ + e$, is obtained for the cases where the transitions $A^* \rightarrow A$ and $B \rightarrow B^+ + e$ are both of S-P type. The methods employed here are the straight line trajectory and the impact parameter methods. All degenerate states of A^* and B + e at an infinite distance are taken into account. The cross section for the process is $13.88\ (\mu^2 \mu_{E_o}^2/\hbar v)^{2/5}$ where μ, μ_{E_o} are the transition dipole moments for the transitions $A^* \rightarrow A$ and $B \rightarrow B^+ + e$ and v is the relative incident velocity. Cross sections for some typical examples are listed. Comparisons with the calculations by other workers are made. The velocity dependence of the cross section for the above process other than the S-P type process are also obtained as $\propto v^{-2/(2n-1)}$ where n is the inverse exponent of the interaction potentials.

*Present address: Kurashiki Rayon Company, Kurashiki-shi, Japan.

+The radiation Laboratory of the University of Notre Dame is operated under contract with the U.S. Atomic Energy Commission. This is AEC document number COO-38-490.

L4 PROBE CHARACTERISTICS IN OVERDAMPED MAGNETO IONIZED GAS. NGUYEN T. DZOANH, Illinois Institute of Technology, Chicago, Illinois.

It is well known that the behavior of electrostatic probes is significantly modified when a magnetic field is applied to the plasma at low pressures.[1,2] In the present work the probe characteristics in a crossed magneto-electrostatic field were theoretically investigated for the case of high pressure ionized gas in which the mean free path of charged particles is small compared to the dimensions of the probe and the collision with neutral gas is dominant. The cylindrical probe of small circular or elliptic section is parallel to the magnetic lines of force and normal to the radial electric field. The mechanism of the collection of charged particles by the probe is described in term of the charging process by ion flux along the electric lines of force. The effect of the longitudinal magnetic field on the probe becomes important if the magnetic field strength is such that the cyclotron frequency of charged particles exceeds or is comparable to the collision frequency with neutral gas. The theoretical relation Voltage-Current of the probe in a crossed magneto-electrostatic field is obtained. Discussions on the shape effect of the probe section are also given.

1. B. Bertotti, Phys. Fluid 4, 1047 (1961).
2. K. Nobata, Japan J. Appl. Phys. 2, 719 (1963).

L5 THE EFFECT OF THE PLASMA PROPERTIES ON THE EFFICIENCY AND POWER OUTPUT OF THE CO_2-N_2-He LASER. PETER O. CLARK and MICHAEL R. SMITH, Hughes Research Laboratories

A thorough experimental investigation of the plasma properties, electron temperature and electron density, of the CO_2-N_2-He laser system has been made as a function of gas mixture, discharge current and tube diameter. The electron temperature measurement was made using a double probe and the electron density was determined by a microwave cavity technique. The measured power output and efficiency of the CO_2-N_2-He laser as a function of gas mixture, discharge current and tube diameter are correlated with the variation of the plasma properties of the laser discharge.

L6 THEORY OF CO_2-N_2 LASER. PETER O. CLARK and MICHAEL R. SMITH, Hughes Research Laboratories.

It is well known that the addition of N_2 to the CO_2 laser increases the power output due to the increased excitation of the upper laser level through collisions with excited N_2. However, it had not been possible previously to predict the variation of power output as a function of N_2 additive or discharge current. A theory is derived for the excitation rate of the upper laser level as a function of gas pressures and plasma electron temperature. An experimental determination of the plasma electron temperature as a function of N_2 additive and discharge current in a CO_2-N_2 laser discharge was made using a double probe technique. Incorporating this data, the resulting semi-empirical theory is compared with experimental CO_2-N_2 laser power output as a function of N_2 additive and discharge current. The results indicate that the variation of power output as a function of N_2 additive and discharge current is due mainly to the variation of the plasma electron temperature.

L7 AN EXPERIMENTAL STUDY OF THE RADIAL DISTRIBUTION OF EXCITED ATOMS AND IONS IN A CAPILLARY DISCHARGE IN ARGON. C. E. WEBB, Bell Telephone Laboratories

The radial distribution of neutral gas atoms, electrons and excited ions are essential items of data in formulating a theory of the plasma processes important in the rare gas ion lasers. An experimental method is described which permits the radial profile of spontaneous emission in transitions of the excited atom and ion to be displayed directly as an X-Y recorder trace. Light is collected from the discharge tube ($\sim$2 mm. diam.) by a system of collimating optics "end-on" to the tube, which selectively accepts light generated within a cylindrical volume element parallel to the tube axis. The tube is translated from side to side in order to perform the radial scan. Since the individual profiles are recorded at a fixed value of discharge current, they measure the radial variation of excited state population at a fixed electron mean energy*, and in particular the profiles for ion transitions provide a sensitive indicator of the dominant ion loss mechanism. For filling pressures above 2 torr (i.e. pd > 0.4 torr cm) the ion profiles fit those predicted by ambipolar diffusion theory, while for filling pressures below 0.5 torr (pd < 0.1 torr cm) the profiles predicted by the Tonks-Langmuir theory provide a better fit to the data. The results further indicate that the excited states of the atom are predominantly depopulated by electron collisions, and that the neutral gas density is constant across the tube diameter.

*Radial invariance of electron mean energy is evidenced by the neutral atom emission profiles.

L8 COLLISION EFFECT ON THE DENSITY DISTRIBUTION OF CHARGED PARTICLES IN A HIGH FREQUENCY ELECTROMAGNETIC FIELD.* D. M. KIM, Yale University, New Haven, Conn.

The possibility of trapping ions in a suitable electric field offers an interesting application for r.f. spectroscopy of free atomic systems.[1] It will be shown by kinetic theory[2] how this possibility is affected by collisions between atoms and charged particles with arbitrary mass. For ion-atom collisions, where the ratio of masses m/m' is of order unity, the approximation procedure based on expanding the Boltzmann collision integral in powers of m/m' fails. Instead, one can exploit the fact that the deflections are small and thus use the Fokker-Planck collision integral.[3] The result is simply the collision expression for electrons multiplied by $\eta = [\frac{m'}{m+m'}]^2$. In a given field $\underset{\sim}{E}(\underset{\sim}{r})\cos\omega t$, electrons are more readily localized than ions. For example, if $\underset{\sim}{E}(\underset{\sim}{r})$ varies linearly with $\underset{\sim}{r}$, one obtains Gaussian density distribution with half-width $\propto\sqrt{m}$ for particles of mass m. But, these half-widths can be reduced by varying $\underset{\sim}{E}(\underset{\sim}{r})$, and our approximation allows greater possible variation of $\underset{\sim}{E}(\underset{\sim}{r})$ for ions.

*. Work supported by the U.S. Office of Naval Research.

1. H. G. Dehmelt and F. G. Major, Phys. Rev. Letters 8, 213 (1962).
2. H. Margenau, Phys. Rev. 73, 297 (1948).
3. I. B. Bernstein, Lecture, Princeton Summer Institute (1962).

L9 ENHANCEMENT OF THE 2062A IODINE LINE IN AN IODINE-INERT GAS FLASH DISCHARGE. A. G. LEIGA and J. A. MCINALLY, Xerox Corporation.

The spectral output of flash discharge lamps containing iodine, and mixtures of iodine and the inert gases were studied at selected wavelengths. It was found that addition of xenon or krypton to iodine produced a marked enhancement of the 2062A iodine line compared to the output from a pure iodine discharge. The enhancement of this line was found to be a maximum at approximately 130 Torr with either of the inert gases with an enhancement of about 100 times with xenon and over 200 times with added krypton. It was postulated that energy transfer collisions between metastable xenon and ground state iodine atoms produced an enhanced population of iodine atoms in the $6p^4P_{3/2}$ state. Since the $6p^4P_{3/2}$ state can decay to the 2062A emitting state, $6s^2P_{3/2}$, emitting 9114A radiation an enhancement in this line was expected and was experimentally verified in the xenon-iodine mixtures. No enhancement was found at 5119A since the transition occurs from an iodine atom level significantly above the energy available from the metastable xenon atom. With the krypton-iodine mixtures the metastable krypton level is in close energy resonance with a multitude of upper levels of the iodine atom and collisions of the second kind can produce these atoms in a variety of excited states. Many of these iodine energy levels cascade down to the $6s^2P_{3/2}$ level. In addition, a reaction of the metastable krypton atom with iodine molecules is possible, producing one ground state iodine atom and one in the $6p^4P_{3/2}$ state.

INDEX TO AUTHORS

INDEX TO AUTHORS (Continued)

INDEX TO AUTHORS (Continued)