

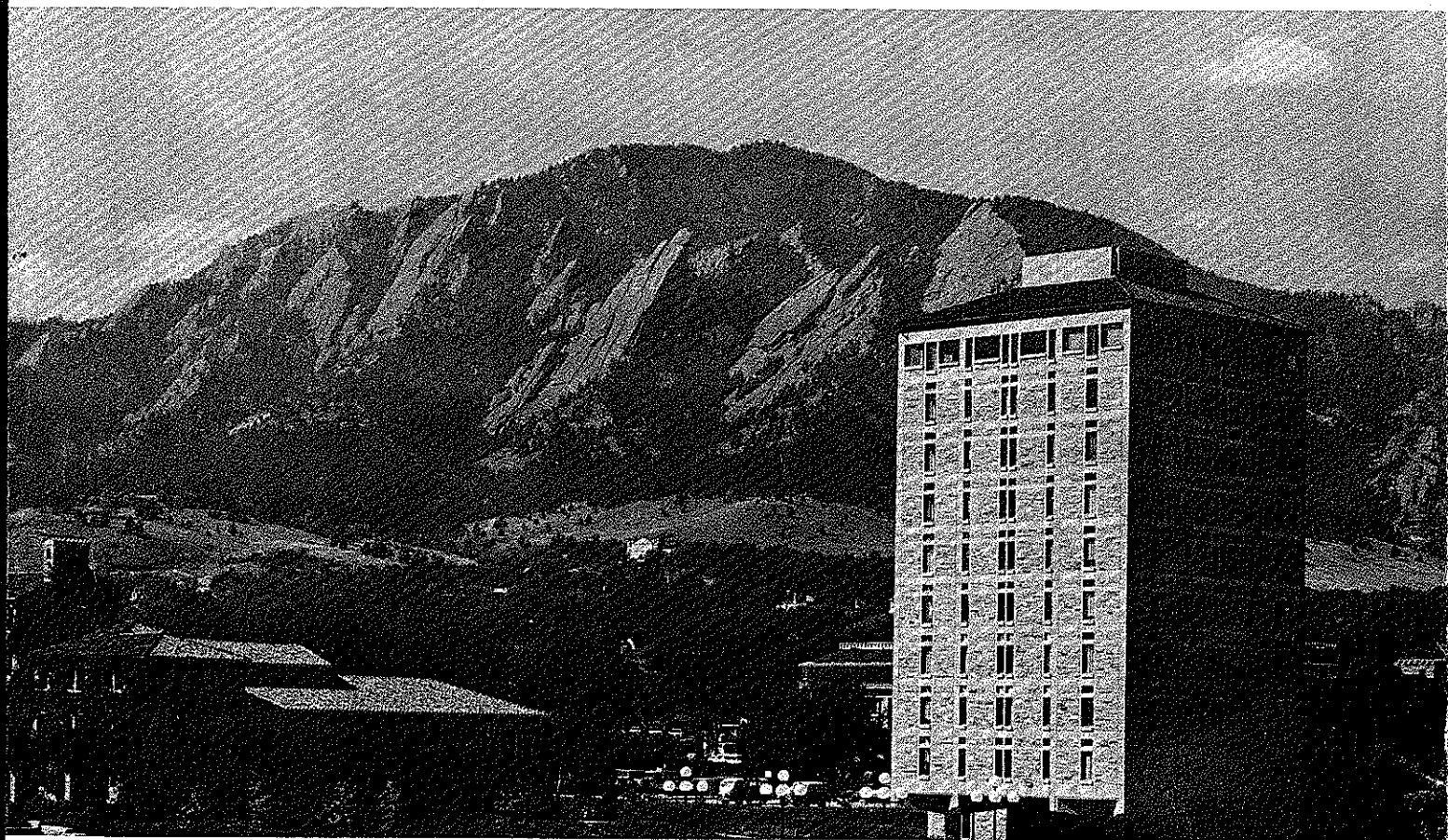
21st
annual

GASEOUS ELECTRONICS CONFERENCE

Topical Conference of the American Physical Society

October 16-18, 1968

BOULDER, COLORADO



JOINT INSTITUTE for LABORATORY ASTROPHYSICS
of
THE NATIONAL BUREAU of STANDARDS
and
THE UNIVERSITY of COLORADO

PROGRAM AND ABSTRACTS

TWENTY-FIRST ANNUAL
GASEOUS ELECTRONICS CONFERENCE

16, 17, 18 OCTOBER

1968

JOINT INSTITUTE FOR LABORATORY ASTROPHYSICS

UNIVERSITY OF COLORADO

BOULDER, COLORADO

PROGRAM
TWENTY-FIRST ANNUAL
GASEOUS ELECTRONICS CONFERENCE

Tuesday Evening, 15 October

7:30 - 10:00 p.m.

Own-Host Reception and Registration
Century Room, Harvest House Hotel

Wednesday Morning, 16 October

8:00 a.m.

Registration Alumni Hall, University
Memorial Center (UMC), University of Colorado

9:00 a.m. - 12:30 p.m.

Session A ELECTRON COLLISIONS I

Forum Room, UMC

Chairman: Stephen J. Smith, JILA

- A-1 IONIZATION OF AIR BY SLOW ELECTRONS
Robert N. Varney
- A-2 DETERMINATION OF THE ELECTRON-HELIUM TOTAL SCATTERING CROSS SECTION BY
BEAM TECHNIQUES OVER THE ENERGY RANGE FROM 0.05 TO 3.0 eV
R. H. Bullis, T. L. Churchill and W. J. Wiegand
- A-3 TOTAL CROSS SECTIONS FOR ELECTRON-POTASSIUM SCATTERING
R. E. Collins, B. Bederson, M. Goldstein and K. Rubin
- A-4 COMPOUND STATE FORMATION IN CO₂
M. J. W. Boness and G. J. Schulz
- A-5 ANGULAR DEPENDENCE OF THE VIBRATIONAL EXCITATION OF N₂ BY 20 eV ELECTRONS
S. Trajmar, J. K. Rice, D. G. Truhlar and R. T. Brinkmann

10:30 - 10:50 Coffee Break - Fountain Patio, UMC

- A-6 THE PRODUCTION OF METASTABLE MERCURY ATOMS BY ELECTRON IMPACT
Walter L. Borst
- A-7 LYMAN-ALPHA PRODUCTION IN ELECTRON H₂(D₂) COLLISIONS
J. William McGowan, J. F. Williams and W. Meckbach
- A-8 EXCITATION OF NEON BY ELECTRON COLLISION
Francis A. Sharpton, Robert M. St. John, Chun C. Lin, Fredric E. Fajen
- A-9 THRESHOLD BEHAVIOUR OF THE CROSS SECTION FOR IONIZATION OF He AND Ar
BY MONO-ENERGETIC ELECTRONS
P. Marchand, C. Paquet, P. Marmet
- A-10 EXCITATION OF NITROGEN BY ELECTRONS: THE MEINEL SYSTEM OF N₂⁺
B. N. Srivastava and I. M. Mirza
- A-11 ELECTRON CROSS SECTIONS OF THE FIRST NEGATIVE AND MEINEL BANDS OF N₂⁺
Paul N. Stanton and Robert M. St. John

12:30 p.m. Conference Luncheon, East and Center Ballrooms, UMC

Wednesday Morning, 16 October

9:00 a.m. - 12:30 p.m.

West Ballroom, UMC

Session B BREAKDOWN AND CORONA

Chairman: Earl W. McDaniel, Georgia
Institute of Technology

- B-1 PULSED RF BREAKDOWN IN NON UNIFORM FIELDS
M. H. Mentzoni and J. Donohoe
- B-2 EFFECT OF PREIONIZATION ON MICROWAVE BREAKDOWN
A. D. MacDonald and H. W. Bandel
- B-3 A UNIFIED CRITERION FOR MICROWAVE BREAKDOWN IN A MOVING GAS
Paul E. Bisbing
- B-4 IONIC FIELD ENHANCEMENT INSTABILITY AS THE CAUSE OF VACUUM BREAKDOWN
Alan Watson
- B-5* VOLTAGE AND FIELD THRESHOLD FOR POSITIVE STREAMER ONSET
M. Heiszler and E. Nasser
- B-6* THE PASCHEN CURVES FOR DIVERGENT FIELDS IN AIR AND N₂
D. C. Schroder and E. Nasser
- B-7* THE FORMATION OF SECONDARY LEADER CHANNELS IN AIR AND N₂ BREAKDOWN
E. Nasser and D. C. Schroder
- B-8 BACK CORONA DISCHARGE IN A TRANSVERSE MAGNETIC FIELD
N. T. Dzoanh

10:30 - 10:50 Coffee Break - Fountain Patio, UMC

- B-9 THE ADJECTION DISCHARGE PHENOMENON
John C. Bryner and William J. Coleman
- B-10 MECHANISM OF THE RADIO FREQUENCY OZONIZER DISCHARGE
M. P. Freeman and T. Aiba
- B-11 MASS TRANSPORT BY A PULSED VACUUM ARC
D. A. Butter
- B-12 ANODE SPOT FORMATION IN A VACUUM DISCHARGE
G. Ecker
- B-13 PROPERTIES OF RADIATION DOMINATED ARCS
J. J. Lowke
- B-14 HOLLOW CATHODE DISCHARGE WITH THERMIONIC CATHODES
Harald L. Witting
- B-15 SPECTROSCOPIC INVESTIGATIONS ON A Hg-SnI₂ HIGH PRESSURE ARC
W. H. Bloss

12:30 p.m. Conference Luncheon, East and Center Ballrooms, UMC

* Combined Papers

Wednesday Afternoon, 16 October

2:00 - 5:30 p.m.

Forum Room, UMC

Session C ELECTRON COLLISIONS II

Chairman: Edward Gerjuoy, University of
Pittsburgh

- C-1 NON-ADIABATIC ATOMIC DISTORTION IN LOW ENERGY ELECTRON AND POSITRON SCATTERING
W. R. Garrett
- C-2 CALCULATION OF CROSS SECTIONS FOR ELECTRON-HELIUM COLLISIONS
H. H. Michels
- C-3 ELECTRON SCATTERING FROM ALKALI ATOMS WITHOUT EXCHANGE
Philip M. Stone and Norman P. Dorn
- C-4 INVESTIGATION OF POSSIBLE e^+ - H RESONANCE BELOW THE POSITRONIUM THRESHOLD
A. K. Bhatia and A. Temkin
- C-5 CALCULATION OF ELECTRON EXCITATION CROSS SECTIONS OF HYDROGEN MOLECULES BY THE METHOD OF CLOSE COUPLING
Fredric E. Fajen and Chun C. Lin

3:30 - 3:50 Coffee Break - Fountain Patio, UMC

- C-6 DIFFERENTIAL CROSS SECTIONS FOR ELECTRON- H_2 SCATTERING
N. F. Lane and S. Geltman
- C-7 EXCHANGE EFFECTS IN LOW ENERGY ELECTRON- H_2 SCATTERING
Ronald J. W. Henry and Neal F. Lane
- C-8 MEASUREMENT OF THE ENERGY DEPENDENCE OF ELECTRON-ION RECOMBINATION IN NITROGEN BY AN ION BEAM TECHNIQUE
Gunter Hagen
- C-9 STUDIES OF DISSOCIATIVE ELECTRON-ION RECOMBINATION USING A SUPERIMPOSED-BEAM TECHNIQUE
Lowell P. Theard
- C-10 ELECTRON DETACHMENT FROM THE NEGATIVE HYDROGEN ION BY ELECTRON IMPACT
Sanford B. Schwartz
- C-11 ELECTRON IMPACT IONIZATION OF POSITIVE IONS AND NEUTRAL ATOMS BY SUPERIMPOSED BEAM TECHNIQUE
P. Mahadevan
- C-12 ABSOLUTE FLUORESCENCE YIELDS IN N_2 AND AIR EXCITED BY RELATIVISTIC ELECTRONS
M. N. Hirsh and E. Poss

6:00 p.m. Horseback Ride

7:00 p.m. Steak Fry, Hidden Valley Ranch (Green Meadows Riding Stables)

Wednesday Afternoon, 16 October

2:00 - 5:30 p.m.

Session D GLOWS AND AFTERGLOWS

West Ballroom, UMC

Chairman: Karl Persson, National Bureau of Standards, Boulder

- D-1 CONTINUUM ELECTROSTATIC PROBE THEORY FOR LARGE SHEATHS ON SPHERES AND CYLINDERS
R. E. Kiel
- D-2 THE EFFECT ON THE TONKS-DATTNER RESONANCES OF VARYING ELECTRON RADIAL DISTRIBUTION IN THE MODULATED PLASMA COLUMN
C. J. Burkley and M. C. Sexton
- D-3 EXPERIMENTAL OBSERVATION OF THE SPONTANEOUS APPEARANCE OF LONGITUDINAL WAVES IN VARIOUS GAS DISCHARGES
R. E. McIntosh and N. P. Hansen
- D-4 IONIZATION BY SECONDARY PROCESSES IN THE NEGATIVE GLOW OF RARE GAS DISCHARGES
R. F. Pottie, M. J. Vasile and P. Lightman
- D-5 NONLINEAR EFFECTS IN THE POSITIVE COLUMN OF A MODULATED GAS DISCHARGE
J. Polman
- D-6 IONIC ANALYSIS OF CATAPHORESIS IN He-Ne MIXTURES
J. P. Gaur and L. M. Chanin

3:30 - 3:50 Coffee Break - Fountain Patio, UMC

- D-7 CONSTRICTION OF CURRENTS PERPENDICULAR TO A MAGNETIC FIELD IN AN INHOMOGENEOUS PLASMA
Melvin J. Kofoid
- D-8 THE EFFECT OF OPTICAL THICKNESS ON SPECTROSCOPIC DIAGNOSTICS AND VOLUME ION PRODUCTION IN TENUOUS HELIUM PLASMAS
R. J. Sovie
- D-9 THE ELECTRON TEMPERATURE HISTORY IN A HELIUM AFTERGLOW PLASMA WITH PULSED MULTIPLE ELECTROSTATIC PROBES
Edwin Blue
- D-10* LATE-TIME SOURCE OF ATOMIC LIGHT IN THE HELIUM AFTERGLOW
W. B. Hurt and C. B. Collins
- D-11* COLLISIONAL-RADIATIVE RECOMBINATION OF IONS AND ELECTRONS IN HIGH PRESSURE PLASMAS IN WHICH THE ELECTRON TEMPERATURE EXCEEDS THE GAS TEMPERATURE
C. B. Collins
- D-12† LIGHT EMISSION AND ION DENSITY STUDIES OF DECAYING RARE GAS PLASMAS
G. E. Veatch and H. J. Oskam
- D-13† INFLUENCE OF THE PLASMA SHEATH DIMENSIONS ON AMBIPOLAR DIFFUSION STUDIES
G. E. Veatch and H. J. Oskam
- D-14† STUDIES OF THE AFTERGLOW OF PLASMAS PRODUCED IN HELIUM-NITROGEN MIXTURES
A. R. DeMonchy and H. J. Oskam

6:00 p.m. Horseback Ride

7:00 p.m. Steak Fry, Hidden Valley Ranch (Green Meadows Riding Stables)

*Combined Papers

†Combined Papers

Thursday Morning, 17 October

8:30 - 10:30 a.m.

Session E ELECTRON ATTACHMENT

Forum Room, UMC

Chairman: A. V. Phelps, Westinghouse
Research Laboratories

- E-1 TEMPERATURE DEPENDENCE OF ELECTRON ATTACHMENT IN I_2 VAPOR
F. K. Truby
- E-2 DEDUCTION OF CROSSING POINT OF THE REPULSIVE I_2^- AND GROUND STATE
 I_2 POTENTIAL ENERGY CURVES FROM MEASUREMENTS OF THE ELECTRON
DISSOCIATIVE ATTACHMENT COEFFICIENT
Edward J. Shipsey
- E-3 TEMPERATURE DEPENDENCE OF DISSOCIATIVE ATTACHMENT IN N_2O
P. J. Chantry
- E-4 ELECTRON IMPACT EXCITATION AND NEGATIVE ION FORMATION IN NH_3 AND ND_3
R. N. Compton, J. A. Stockdale, and P. W. Reinhardt
- E-5 NONDISSOCIATIVE ELECTRON ATTACHMENT TO AROMATIC HYDROCARBONS
R. P. Blaunstein and L. G. Christophorou
- E-6 MEASUREMENT OF THERMAL ELECTRON ATTACHMENT RATES IN SF_6 , C_6F_6 ,
 C_6F_{11} , CF_3 , AND Tef_6 BY A TIME-OF-FLIGHT SWARM METHOD
D. R. Nelson and F. J. Davis
- E-7 TRANSIENT NEGATIVE ION STATES IN SELECTED ALICYCLIC AND AROMATIC
FLUOROCARBONS
C. Dewey Cooper, W. T. Naff and R. N. Compton

10:30 - 10:50 Coffee Break - Fountain Patio, UMC

10:50 a.m.

Session G PLENARY SESSION

Forum Room*

Chairman: Leon H. Fisher, Lockheed Missiles
and Space Company

INVITED PAPER[†]

R. W. Crompton

THE CONTRIBUTION OF SWARM TECHNIQUES TO THE SOLUTION
OF SOME PROBLEMS IN LOW ENERGY ELECTRON PHYSICS

11:35 a.m. BUSINESS MEETING

12:00 p.m. Conference Luncheon, East & Center Ballrooms, UMC

*There will be a seating shortage at this Session

[†]This paper will include a report of "The Cross Section for the $J = 0 - 2$
Rotational Transition in H_2 Derived from an Analysis of Transport Data in
Parahydrogen," by R. W. Crompton, D. K. Gibson and A. I. McIntosh; and "The
Pressure Dependence of the Drift Velocities of Low Energy Electrons in H_2 ,
 D_2 and He at 77°K," by R. W. Crompton and A. G. Robertson

Thursday Morning, 17 October

8:30 - 10:30 a.m.

West Ballroom, UMC

Session F CHARGE TRANSFER

Chairman: Robert C. Amme, University of Denver

- F-1 NEAR RESONANT CHARGE TRANSFER TO EXCITED STATES
Julius Perel and Howard L. Daley
- F-2 INVESTIGATION OF THE EFFECT OF INTERNAL AND KINETIC ENERGY ON THE CHARGE-EXCHANGE CROSS SECTION OF $\text{NO}^+ + \text{Cs}$
Thomas L. Churchill
- F-3 METALLIC ION FORMATION BY CHARGE TRANSFER
J. A. Rutherford and B. R. Turner
- F-4 MODIFIED IMPACT PARAMETER METHOD (MIPM)
H. W. Hilsinger
- F-5 CHARGE EXCHANGE IN $\text{H}^+ - \text{H}^-$ COLLISIONS
R. D. Rundel, K. L. Aitken and M. F. A. Harrison
- F-6 DAMPING IN THE ELECTRON-TRANSFER PROBABILITY FOR THE (H^-, H) SYSTEM
Joseph C. Y. Chen and Junya Mizuno

10:30 - 10:50 Coffee Break - Fountain Patio, UMC

10:50 a.m.
Forum Room *

Session G PLENARY SESSION

Chairman: Leon H. Fisher, Lockheed Missiles and Space Company

INVITED PAPER[†]

R. W. Crompton

THE CONTRIBUTION OF SWARM TECHNIQUES TO THE SOLUTION OF SOME PROBLEMS IN LOW ENERGY ELECTRON PHYSICS

11:35 a.m. BUSINESS MEETING

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Thursday Afternoon, 17 October

1:45 - 5:30 p.m.

Forum Room, UMC

Session H ION NEUTRAL REACTIONS
(Plenary Session)

Chairman: Eldon E. Ferguson, Environmental
Science Services Administration

- H-1 ISOTOPIC EFFECTS IN REACTIONS BETWEEN NITROGEN MOLECULAR IONS
AND NITROGEN MOLECULES
William B. Maier II
- H-2 THE PRODUCTION OF NaO^+ AND NaN^+ FROM Na AND NO^+ IN MERGED BEAMS
E. A. Entemann and P. K. Rol
- H-3 FLOWING AFTERGLOW STUDIES OF ION-MOLECULE ASSOCIATION REACTIONS
D. K. Bohme, D. B. Dunkin, F. C. Fehsenfeld and E. E. Ferguson
- H-4 SOME ION-MOLECULE REACTIONS INVOLVING SILICON
F. C. Fehsenfeld
- H-5 THE REACTION OF A^+ WITH ARGON TO MAKE A_2^+
William Peterson and Earl C. Beaty
- H-6 DRIFT TUBE MEASUREMENTS OF $\text{N}_2^+ + \text{O}_2$ AND $\text{O}_2^+ + \text{NO}$ REACTION RATES
FROM THERMAL ENERGY TO $\sim 1 \text{ eV}$
R. Johnsen, H. L. Brown and Manfred A. Biondi
- H-7 IONIC REACTION RATES IN AFTERGLOWS OF Ar AND Ar - O_2 MIXTURES
D. Smith, C. V. Goodall and N. G. Adams

3:30 - 3:50 Coffee Break - Fountain Patio, UMC

(Session H Continued on Next Page)

Thursday Afternoon, 17 October (Continued)

3:50 - 5:30 p.m.

Forum Room, UMC

Session H ION NEUTRAL REACTIONS
(Plenary Session)

Chairman: Eldon E. Ferguson, Environmental
Science Services Administration

- H-8 MEASUREMENTS OF SOME NEGATIVE ION-MOLECULE REACTION CROSS SECTIONS
IN THE REGION FROM 0 TO 2 ELECTRON VOLTS
J. A. Stockdale, R. N. Compton and P. W. Reinhardt
- H-9 MEASUREMENTS OF THE RATE OF ION-MOLECULE REACTION IN METHANE AND
AMMONIA AT NEAR-THERMAL ENERGY
Robert A. Fluegge
- H-10* NUMERICAL EVIDENCE FOR THE EXISTENCE OF LONG-LIVED MOLECULAR ION
COMPLEXES IN ION-MOLECULE COLLISIONS
John V. Dugan, Jr., James H. Rice and John L. Magee
- H-11* CALCULATION OF CAPTURE CROSS SECTIONS AND A STUDY OF SPIRALING IN
COLLISIONS BETWEEN IONS AND SYMMETRIC TOP POLAR MOLECULES
John V. Dugan, Jr., John L. Magee
- H-12† FORMATION OF CLUSTERED POSITIVE IONS IN NITRIC OXIDE
W. C. Lineberger and L. J. Puckett
- H-13† NEGATIVE IONS IN NITRIC OXIDE
L. J. Puckett and W. C. Lineberger
- H-14 TRANSITION FROM POSITIVE ION-ELECTRON AMBIPOLAR DIFFUSION TO POSITIVE
ION-NEGATIVE ION AMBIPOLAR DIFFUSION IN AFTERGLOWS
Mark D. Kregel
- H-15 IMPORTANCE OF MINOR CONSTITUENTS IN AIR-LIKE DISCHARGES
F. E. Niles

6:30 p.m. Social Hour Ballroom, Harvest House Hotel (Cash Bar)

7:30 p.m. Banquet Ballroom, Harvest House Hotel

Speaker: James P. Lodge, National Center for Atmospheric Research
"An Atmospheric Scientist's View of Pollution"

* Combined Papers

† Combined Papers

Friday Morning, 18 October

8:30 a.m. - 12:30 p.m.

Forum Room, UMC

Session I ATOM - ATOM COLLISIONS

Chairman: F. C. Fehsenfeld, Environmental
Science Services Administration

- I-1 INTENSE POLARIZED ELECTRON BEAMS FROM OPTICALLY-PUMPED HELIUM DISCHARGES
M. V. McCusker, L. L. Hatfield, J. Kessler and G. K. Walters
- I-2* OBSERVATION OF SPIN-EXCHANGE ACCOMPANYING ENERGY TRANSFER COLLISIONS
BETWEEN METASTABLE HELIUM AND NEON ATOMS
L. D. Schearer
- I-3* MEASUREMENT OF THE COLLISIONAL-DEPOLARIZATION CROSS SECTION OF 3P_2
NEON ATOMS BY OPTICAL PUMPING
L. D. Schearer
- I-4 DIFFERENCES BETWEEN $He(2^1S)$ AND $He(2^3S)$ PENNING IONIZATION REACTIONS
H. Hotop, A. Niehaus and A. L. Schmeltekopf
- I-5 ISOTOPE EFFECTS IN THE IONIZATION OF H_2 , HD, and D_2 ON IMPACT OF
 2^3S AND 2^1S HELIUM ATOMS
K. D. Foster and E. E. Muschlitz, Jr.
- I-6 PENNING IONIZATION ELECTRON SPECTROSCOPY OF MERCURY
Z. Herman and V. Cermák
- I-7 CROSS SECTIONS FOR ASSOCIATIVE IONIZATION OF THE $n = 3$ STATES OF
HELIUM
C. H. Turner and W. W. Robertson

10:30 - 10:50 Coffee Break - Fountain Patio, UMC

- I-8 EXCITATION TRANSFER OF METASTABLE HELIUM IN NORMAL HELIUM
H. J. Kolker and H. H. Michels
- I-9 EXCITATION TRANSFER AND TOTAL SCATTERING IN COLLISIONS BETWEEN
 $He(2^3S)$ AND $He(1^1S)$ ATOMS
S. A. Evans and Neal F. Lane
- I-10 DEACTIVATION CROSS SECTIONS FOR $He^* + He$ COLLISIONS
Manfred Hollstein, D. C. Lorents and J. R. Peterson
- I-11 TRANSITIONS WITHIN THE ALKALI 2P STATE IN COLLISIONS WITH RARE
GAS ATOMS
M. B. Hidalgo and S. Geltman
- I-12 COLLISIONAL MIXING IN ALKALI 2P STATES
Hirsch I. Mandelberg
- I-13 ADSORBATE EFFECTS IN ELECTRON EJECTION BY RARE GAS METASTABLE ATOMS
T. A. Delchar, D. A. MacLennan and A. M. Landers

12:30 p.m. Conference Luncheon, East and Center Ballrooms, UMC

* Combined Papers

Friday Morning, 18 October

8:30 a.m. - 12:30 p.m.

West Ballroom, UMC

Session J TRANSPORT PROPERTIES AND DISTRIBUTIONS

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

- J-1 DIFFUSE BACKSCATTERING AND QUENCHING OF RESONANCE RADIATION IN
Cs-N₂ MIXTURES
C. L. Chen and A. V. Phelps
- J-2 THE EFFECT OF COULOMB COLLISIONS ON THE ELECTRON ENERGY DISTRIBUTION
IN PARTIALLY IONIZED GASES
William L. Nighan
- J-3 TRANSPORT OF THERMAL ELECTRONS THROUGH POLAR GASES
L. G. Christophorou, D. Pittman and A. A. Christodoulides
- J-4 EXPERIMENTAL LONGITUDINAL ELECTRON DIFFUSION COEFFICIENTS IN He, Ar,
Xe, D₂, N₂, AND H₂O
J. L. Pack, R. E. Voshall and A. V. Phelps
- J-5 EVIDENCE FOR MOLECULAR LOW-ENERGY RESONANCE SCATTERING STATES
Lothar Frommhold and D. J. Kouri
- J-6* MOBILITIES AND LONGITUDINAL DIFFUSION COEFFICIENTS OF MASS-IDENTIFIED
NITROGEN AND POTASSIUM IONS IN NITROGEN
J. T. Moseley, R. M. Snuggs, D. W. Martin, E. W. McDaniel, T. M. Miller
- J-7* TRANSVERSE DIFFUSION COEFFICIENTS AND ION-MOLECULE REACTION RATES OF
MASS-IDENTIFIED NITROGEN AND POTASSIUM IONS IN NITROGEN
E. W. McDaniel, D. W. Martin, R. M. Snuggs, J. T. Moseley
- 10:30 - 10:50 Coffee Break - Fountain Patio, UMC
- J-8 NEGATIVE ION MOBILITIES IN OXYGEN
Carl Shafer and Earl Beaty
- J-9 TRANSPORT PROPERTIES OF METASTABLE O(¹S) ATOMS
E. C. Zipf
- J-10 NON-MAXWELLIAN EQUILIBRIUM VELOCITY DISTRIBUTION OF THE FREE
ELECTRONS IN A PLASMA
O. Theimer and T. Wright
- J-11 THE DETERMINATION OF THE SECONDARY ELECTRON DISTRIBUTION FUNCTION
PRODUCED BY ENERGETIC PARTICLE BOMBARDMENT OF NITROGEN
J. A. Llewellyn and R. E. Glick

12:30 p.m. Conference Luncheon, East and Center Ballrooms, UMC

* Combined Papers

Friday Afternoon, 18 October

2:00 - 5:00 p.m.

Session K HEAVY PARTICLE COLLISIONS

Forum Room, UMC

Chairman: Benjamin Bederson, New York University

- K-1 ELASTIC DIFFERENTIAL SCATTERING OF H^+ , He^+ , AND He^{++} BY Ar
R. S. Snyder, J. W. Boring and G. D. Magnuson
- K-2 DIFFERENTIAL ELASTIC SCATTERING OF LOW ENERGY PROTONS BY He
AND Ar ATOMS
F. A. Herrero, E. M. Nemeth and T. L. Bailey
- K-3 He^+ (2S) -He INELASTIC COLLISIONS
C. J. Artura, R. Novick and N. Tolc
- K-4 EXCITATION OF METASTABLE ATOMS IN LOW-ENERGY ARGON ION-ATOM COLLISIONS
R. C. Amme, P. O. Haugsjaa and N. G. Utterback
- K-5 IONIZING COLLISIONS BETWEEN NEUTRAL ATOMS: Ne-Ne, Ar-Ar, and Kr-Kr
P. O. Haugsjaa and R. C. Amme

3:30 - 3:50 Coffee Break - Fountain Patio, UMC

- K-6 EMISSION CROSS SECTIONS FOR SODIUM D LINES IN COLLISIONS WITH ATOMS
AND MOLECULES
Charles A. Boitnott and Howard F. Savage
- K-7 VIBRATIONAL EXCITATION IN ION-MOLECULE COLLISIONS
John H. Moore, Jr. and John P. Doering
- K-8 DE-EXCITATION OF EXCITED NO^+ IONS
R. F. Mathis, B. R. Turner and J. A. Rutherford
- K-9 POST-COLLISION CHARGE STATES IN $O^+ + Ar$ SCATTERING AT 50-100 keV
Felton W. Bingham
- K-10 COINCIDENCE MEASUREMENTS OF INELASTIC ENERGY LOSSES IN 1 MeV, $Ne^+ - Ne$
AND $Ne^+ - Ar$ COLLISIONS
Quentin C. Kessel

Friday Afternoon, 18 October

2:00 - 5:00 p.m.

West Ballroom, UMC

Session L ATOMIC AND MOLECULAR STRUCTURE
AND PHOTON-ATOM INTERACTION

Chairman: Chun C. Lin, University of
Wisconsin

- L-1 THE N_2O^- POTENTIAL CURVES ARISING FROM $O^-(^2P) + N_2(X^1\Sigma_g^+)$
E. E. Ferguson
- L-2 RKR FRANCK-CONDON FACTORS FOR THE DIATOMIC MOLECULES COMPOSED OF C,
N, O, AND H ATOMS
D. L. Albritton and A. L. Schmeltekopf and R. N. Zare
- L-3 RADIATIVE LIFETIMES OF Ne I RESONANCE LINES
G. M. Lawrence and Harvey S. Liszt
- L-4 THE CONFIGURATION MIXING OF CONTINUUM STATES
Antonio J. Mendez
- L-5 OSCILLATOR STRENGTHS OF SPECTRAL LINES OF NEUTRAL AND SINGLY
IONIZED SILICON
Erhard Schulz-Gulde

3:30 - 3:50 Coffee Break - Fountain Patio, UMC

- L-6 CHARGE TRANSFER CONTRIBUTION TO THE INTERACTION ENERGY OF ION/ATOM
SYSTEMS
M. J. Redmon and M. G. Menendez
- L-7 ULTRAVIOLET ABSORPTION IN CESIUM-SEEDED HYDROGEN
Paul J. Freyheit, David W. Norcross and Philip M. Stone
- L-8 THE PHOTOIONIZATION CROSS SECTION OF CADMIUM
R. Bryan Cairns, Halstead Harrison and Richard I. Schoen
- L-9 HIGHER IONIZATION POTENTIALS OF MOLECULES DETERMINED BY PHOTOELECTRON
SPECTROSCOPY
James A. R. Samson
- L-10 PROTON EXCITATION OF THE ARGON ATOM
G. S. Hurst and T. E. Bortner and T. D. Strickler

GASEOUS ELECTRONICS CONFERENCE COMMITTEE

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

W. P. Allis, Honorary Chairman
Massachusetts Institute of Technology

C. F. Barnett
Oak Ridge National Laboratory

W. Roth
Heliodyne Corporation

E. C. Beaty
Joint Institute for Laboratory
Astrophysics

G. J. Schulz
Yale University

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Mrs. E. E. Ferguson

SESSION A

Wednesday Morning, 16 October

9:00 a.m.

ELECTRON COLLISIONS I

Chairman: *Stephen J. Smith*, Joint Institute for
Laboratory Astrophysics, Boulder, Colorado

A-1. IONIZATION OF AIR BY SLOW ELECTRONS.* Robert N. Varney, Lockheed Palo Alto Research Laboratory.

Ionization of air, taken directly from the laboratory, has been studied over the range of pressure from 10^{-3} to 2 Torr. The ionization was produced by electrons with kinetic energies between 0 and 30 eV. The results are:

Ions Observed in Air

| Mass | Probable Identity | Comment |
|------|----------------------|--|
| 14 | N^+ | Only below 10^{-2} Torr |
| 16 | O^+ | Only below 10^{-2} Torr |
| 19 | $H^+ \cdot (H_2O)$ | |
| 28 | N_2^+ | Only below 3×10^{-2} Torr |
| 29 | N_2H^+ | Decreases with increasing p |
| 30 | NO^+ | |
| 32 | O_2^+ | |
| 37 | $H^+ \cdot (H_2O)_2$ | Only above ~ 0.8 Torr |
| 46 | NO_2^+ | Comparable current with O_2^+ above about 1 Torr |
| 55 | $H^+ \cdot (H_2O)_3$ | Only above ~ 1.3 Torr |

*Work supported by Lockheed Independent Research funds.

A-2. DETERMINATION OF THE ELECTRON-HELIUM TOTAL SCATTERING CROSS SECTION BY BEAM TECHNIQUES OVER THE ENERGY RANGE FROM 0.05 to 3.0 eV, R. H. Bullis, T. L. Churchill and W. J. Wiegand, United Aircraft Research Laboratories.

The electron-helium total collision cross section has been measured over the energy range of 0.05 to 3.0 eV with beam techniques. The energy of the electron beam was precisely determined through the use of a field free collision chamber in conjunction with magnetic energy selection techniques. At 0.5 eV the most probable value of the total cross section is 5.0\AA^2 which may be compared with 6.6\AA^2 for the momentum transfer cross section.^{2,3} Below this energy the total and momentum transfer cross sections converge with values at 0.05 eV of 4.8\AA^2 and 5.6\AA^2 , respectively. This result serves to illustrate the decreasing contribution to the scattering amplitude of p-wave interactions with decreasing energy. Determination of the scattering length based on these measurements is consistent with the value established in references 2 and 3. No resonance in the structure of the cross section was observed.

¹R. H. Bullis et al., V International Conference on the Physics of Electronic and Atomic Collisions: Abstracts of Papers, I. P. Flaks, Ed., (Publishing House Nauka, Leningrad, 1967) p. 263.

²L. S. Frost and A. V. Phelps, Phys. Rev. 136, A1538 (1964).

³R. W. Crompton et al., Aust. J. Phys. 20, 369 (1967).

A-3. TOTAL CROSS SECTIONS FOR ELECTRON-POTASSIUM SCATTERING.* R. E. Collins, B. Bederson, M. Goldstein and K. Rubin,† New York University.

The total cross sections for the scattering of electrons by potassium, for energies from below 0.4 to 9 eV, have been remeasured. The atomic beam recoil technique¹ was used, with an improved electron gun which employs photo-etched grid assemblies to provide good electron optics. The energy spread is measured to be ~ 200 meV (FWHM). The electron energy was determined using retarding potentials, and independently checked at certain energies by measuring the recoil-scattered angles of the velocity-selected atomic beam. Care was taken to avoid possible systematic errors due to electron reflection and secondaries and to background gas scattering. The results fall considerably below (\sim factor of two) earlier data.² Only a very small inflection, rather than a large peak, is seen at about 1.5 eV. Otherwise the cross section increases monotonically with decreasing energy. Estimated statistical plus random errors is $\pm 15\%$. The curve is in excellent agreement with a recent close-coupling calculation of Karule. Possible reasons for disagreement with earlier work will be discussed.

*Work supported by the Advanced Research Projects Agency and the National Science Foundation.

†Permanent address: CCNY, New York.

¹G. Sunshine, B. B. Aubrey and B. Bederson, Phys. Rev. 154, 1 (1967).

²R. B. Brode, Phys. Rev. 34, 673 (1929); J. Perel, P. Englander and B. Bederson, Phys. Rev. 128, 1148 (1962).

A-4. COMPOUND STATE FORMATION IN CO₂*. M. J. W. Boness and G. J. Schulz, Mason Laboratory, Yale University.

We report recent progress in extending the current concepts of compound state formation in diatomic molecules to the case of a tri-atomic molecule, CO₂. A rotatable double electrostatic analyzer has been employed to observe differential energy loss spectra at various fixed impact energies over the range 0-5 eV. In the energy range 0.3-3 eV vibrational excitation of the asymmetric stretch modes (001), (002) are the dominant processes exhibiting peak cross sections at 0.9 eV of the order 10^{-16} cm² and 10^{-17} cm² respectively. Around 3.8 eV, excitation of several members of the symmetric stretch mode (100,200 etc.) occurs. Scattering from the asymmetric stretch modes is observed to be p-wave and from the symmetric stretch series, s-wave. Our data are consistent with the formation of two short-lived compound states, CO₂⁻. The existence of the upper state at 3.8 eV is confirmed by the structure observed in the elastic cross section and by the existence of dissociative attachment, around 4 eV. A third compound state leading to dissociative attachment lies in the region of 8 eV. This model is supported by an inspection of the molecular orbitals which reveals the possibility of three low-lying shape resonances whose configurations are consistent with the observed angular distributions.

*Work supported by the National Science Foundation and by the Defense Atomic Support Agency.

A-5. ANGULAR DEPENDENCE OF THE VIBRATIONAL EXCITATION OF N₂ BY 20 eV ELECTRONS* *S. Trajmar, J. K. Rice, D. G. Truhlar and R. T. Brinkmann, California Institute of Technology.*

Direct vibrational excitation of N₂ was observed at 20 eV electron impact energy. The angular dependence of the excitations to the v' = 1, 2, 3, and 4 vibrational levels within the ground electronic state was studied in the 10° to 90° angular region. The relative intensities of these vibrational features normalized to the elastic peak are practically independent of angle at low angles. At around 40° this ratio starts increasing and at 80° the ratio is larger by about a factor of five than at low angles. The angular dependence of the elastic cross section (in arbitrary units) was determined. With the help of this information the relative differential cross sections for the vibrational excitations (in arbitrary units) were obtained. Theoretical calculations of these differential cross sections are being carried out using a model which includes a first order central potential, a polarization potential, and a quadrupole interaction.

*Work supported by the National Aeronautics and Space Administration and by the U. S. Atomic Energy Commission.

A-6. THE PRODUCTION OF METASTABLE MERCURY ATOMS BY ELECTRON IMPACT. *
Walter L. Borst,† University of California, Berkeley.

The excitation function for the 6³P₂ metastable state (5.46 eV) was measured from threshold up to 8.5 eV using an electron beam of 0.1 eV halfwidth as produced by the RPD-method. Excited atoms were detected by electron ejection from a tungsten surface. A comparison of the few existing excitation functions shows serious discrepancies, partly because low resolution or indirect methods were used. The absolute cross section was measured by monitoring slow inelastically scattered electrons near threshold. A maximum value of $3.2 \times 10^{-16} \text{ cm}^2 \pm 40\%$ occurred at 5.8 eV. This agrees well with a recently reported theoretical maximum cross section of $3.0 \times 10^{-16} \text{ cm}^2$.¹ The measured cross section dropped to half its maximum value at about 8 eV. The high work function of the detector prevented electron ejection due to the 6³P₀ metastable state (4.67 eV) and the two resonant states. The secondary electron yield for the 6³P₂ state was of the order of 2×10^{-4} . Pronounced structure in the detector current above 8.5 eV will be discussed briefly.

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

†Present address: Department of Physics, University of Pittsburgh.

¹B. L. Moiseiwitsch and S. J. Smith, Rev. Mod. Phys. 40, 238 (1968).

A-7. LYMAN-ALPHA PRODUCTION IN ELECTRON H₂ (D₂) COLLISIONS.*

J. William McGowan and J. F. Williams, Gulf General Atomic Incorporated, and W. Meekbach, Centro Atomico Bariloche.

The dissociative excitation of H₂ and D₂ giving atoms which subsequently radiate Lyman α has been studied. Electrons with a resolution less than 0.06 eV were used to bombard the target gas while an EMR multiplier phototube with a potassium bromide photocathode and lithium fluoride optics was used to detect the radiation. When dry molecular oxygen was used as the gaseous filter in front of the phototube, nearly 20% of all the radiation observed was due to molecular radiation. The most prominent feature in the dissociative excitation cross sections is the onset for the formation of a ground state atom plus an excited state atom. Competing with the direct dissociative process is excitation to a bound state of the molecule which subsequently predissociates. Dissociative excitation leading to a proton-excited atom pair and to an excited atom pair is recognizable in our data. The position at which this structure agrees is consistent with what was observed by Burrows and Dunn for the excitation of the Balmer series. Although a marked isotope effect was found for the production of excited atoms from molecular hydrogen and deuterium, this effect is less than that recently reported by Vroom and deHeer.

*Work supported by the National Aeronautics and Space Administration and by the U. S. Atomic Energy Commission.

A-8. EXCITATION OF NEON BY ELECTRON COLLISION.* *Francis A. Sharpton,***


Robert M. St. John, Chun C. Lin,† University of Oklahoma and Fredric E. Fajen, Los Alamos Scientific Laboratory.

Measurements of the electron excitation functions have been made for the s, p, and d states with n values ranging from 2 to as high as 6 (Paschen notations) by the optical method. Of the four members of an ns configuration, the purely triplet states s₃(J = 0) and s₅(J = 2) show relatively narrow peaks in their excitation functions as compared to s₂ and s₄(J = 1) which have mixed singlet and triplet characteristics. Similar narrow-peak excitation functions were also found for the purely triplet states (2p_g, 3p_g and 4d_g) in the np and nd groups. As with helium, the optically allowed states (s₂ and s₄) have the broadest excitation functions and their cross sections are much higher than those of the triplet states of the same configuration. The populations of the 2p states due to cascade from the upper levels have been estimated and the direct excitation cross sections of these states have been obtained.

*Work supported by the U. S. Air Force Office of Scientific Research and by the U. S. Atomic Energy Commission.

**Present address: Department of Physics, Olivet Nazarene College, Kankakee, Ill.

†Present address: Department of Physics, University of Wisconsin, Madison.



A-9. THRESHOLD BEHAVIOUR OF THE CROSS SECTION FOR IONIZATION OF He AND Ar BY MONO-ENERGETIC ELECTRONS. P. Marchand, C. Paquet, P. Marmet, Centre de Recherches sur les Atomes et les Molécules, Université Laval, Québec.

We are currently conducting experiments on ionization probability by electron impact as a function of electron energy near the ionization threshold, with a new apparatus consisting of a molecular beam, a cylindrical electrostatic electron energy selector, a quadrupole mass filter and an electron multiplier used in pulse-counting mode.¹ Great care is taken to avoid surface effects² in the ion source. The entire ion counting system is digital, permitting numerical analysis of results. New computer techniques determine structure and threshold laws. For He⁺ and Ar⁺ a simple power law yields a good representation of the experimental results for each ion state, with a different power in each case. Curve fitting of the He⁺ curves in the first eV above threshold gives a simple power law with power $1.16 \pm 1\%$. The Ar⁺ curves consist of two sections, closely following simple power laws, and joining, within the limits of experimental errors, at the expected energy for the onset of the $^2P_{1/2}$ level. No other structure is observed in the first eV.

¹P. Marchand, C. Paquet, P. Marmet, Rev. Sci. Instr. 37, 1702 (1966).

²Y. Petit-Clerc, J. D. Carette, Vacuum 18, 7 (1967).

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A-10. EXCITATION OF NITROGEN BY ELECTRONS: THE MEINEL SYSTEM OF N₂⁺ *
B. N. Srivastava and I. M. Mirza,[†] Geophysical Institute, University of Alaska.

As part of a study of the emission from nitrogen excited by an electron beam, cross sections for the $\lambda 7850\text{A}$ (2,0), $\lambda 8080\text{A}$ (3,1) and $\lambda 7065\text{A}$ (4,1) bands of the N₂⁺ Meinel system were measured using single photon counting techniques for the electron energies of 80 eV to 4 keV. The measurements were made at low enough pressure ($\approx 5 \times 10^{-4}$ mm of Hg) that band intensities were proportional to the gas pressure. The maximum cross sections for the (2,0), (3,1) and (4,1) bands are 6.02×10^{-18} , 2.35×10^{-18} and 6.76×10^{-19} cm², respectively near 100 eV electron energy. The average intensity ratios of the (2,0), (3,1) and (4,1) bands are 1:0.4:0.12. These intensity ratios correspond to a vibrational temperature of nearly 2250°K. The intensity ratio of the (2,0) and (3,1) bands is in reasonable agreement with the results of proton impact data.

* Work supported by the National Science Foundation.

[†]On leave from Pakistan Space & Upper Atmosphere Research Committee, Karachi, Pakistan.

A-11. ELECTRON CROSS SECTIONS OF THE FIRST NEGATIVE AND MEINEL BANDS OF N_2^+ .* Paul N. Stanton[†] and Robert M. St. John, University of Oklahoma.

Cross section measurements for electron impact have been made for the simultaneous production of excitation and ionization of N_2 . The first negative bands ($B^2\Sigma_u^+ - X^2\Sigma_g^+$) and the Meinel bands ($A^2\Pi_u - X^2\Sigma_g^+$) were observed at 90° to the electron beam. Relative excitation functions from 0 to 450 eV for the (0,0) and (1,0) first negative bands were obtained, each with a broad maximum at 120 eV. Absolute cross sections of 12 N_2^+ first negative bands were obtained for an electron energy of 120 eV ($15.6 \pm 0.6 \times 10^{-18}$ cm² for the [0,0] band). Absolute apparent cross sections at 120 eV for the lowest four vibrational levels of the $B^2\Sigma_u^+$ state of N_2^+ were calculated using Franck-Condon factors. Relative excitation functions from 0 to 450 eV for the (3,0) and (4,1) Meinel bands were obtained, each with a broad maximum at 100 eV. Absolute cross sections of 10 Meinel bands were obtained for an electron energy of 100 eV ($11 \pm 1 \times 10^{-18}$ cm² for the [1,0] band). Absolute apparent cross sections at 100 eV for the lowest six vibrational levels of the $A^2\Pi_u$ state of N_2 were calculated using Franck-Condon factors.

*Work supported by the U. S. Air Force Office of Scientific Research.
[†]Present address: Esso Production Research Company, Houston.

SESSION B

Wednesday Morning, 16 October

9:00 a.m.

BREAKDOWN AND CORONA

Chairman: *Earl W. McDaniel*, Georgia Institute of
Technology, Atlanta, Georgia

B-1. PULSED RF BREAKDOWN IN NONUNIFORM FIELDS.* M. H. Mentzoni and J. Donohoe, Sylvania Electronic Systems.

Pulsed rf breakdown in dry air and helium has been investigated at microwave frequencies (X-band). The aperture of a rectangular waveguide radiator which has a highly nonuniform electric field distribution was the site of breakdown. The phenomenological development of the luminous plasma was followed by time and spatially resolved detection. Also measured were the reflection/transmission characteristics of the breakdown plasma. The results indicate a finite growth rate of the luminous plasma from regions of high to lower E-fields. There is also evidence which seems to indicate that a transitory plasma configuration located at the maximum of the fundamental TE₁₀-mode leads to a mode conversion, the latter governing the further spatial growth of the breakdown process. Some of these features may also characterize breakdown inside waveguides and cavities.

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

B-2. EFFECT OF PREIONIZATION ON MICROWAVE BREAKDOWN.* A. D. MacDonald and H. W. Bandel, Lockheed Palo Alto Research Laboratory.

Breakdown electric fields have been measured for neon in microwave cavities of varying characteristic diffusion lengths as a function of initial electron density. Electron concentrations at the time the field was applied varied from about 10^6 to 10^9 electrons/cm³ and were the result of a prior high power microwave pulse. The cavities were resonant at 3000 Mc/sec and the characteristic diffusion length varied from 0.2 to 0.8 cm. The threshold field for breakdown decreased by as much as 90% with increasing preionization concentrations. This large reduction occurs because ambipolar diffusion becomes the dominant loss mechanism. The transition from free to ambipolar diffusion is thus measured. Calculated values of diffusion coefficients, and of the transition from free to ambipolar diffusion are compared with the data and theories of other workers.

*Work supported by the Lockheed Independent Research Fund.

B-3. A UNIFIED CRITERION FOR MICROWAVE BREAKDOWN IN A MOVING GAS.
Paul E. Bisbing, Missile and Space Division, General Electric Co.

A number of authors have generalized the classical diffusion theory of microwave breakdown to include the effects of gas motion. All authors give results in terms of an additive term in the breakdown criterion for the ionization frequency; but the results have been given in various contradictory forms. These differences arise from alternative assumptions regarding the effect of convective flux as an electron loss process and the form of the electron convective flux. A unified theory of the effect of gas motion has been derived by solving an idealized problem in one dimension, using the theory of Allis and Rose.¹ The disparate results of previous authors appear as special cases of regimes of pressure and electron density. The general result is obtained that the contribution of gas convection to the breakdown criterion is approximately equal to the smaller of two simple factors.

¹W. P. Allis and D. J. Rose, *Phys. Rev.* 93, 84 (1954).

B-4. IONIC FIELD ENHANCEMENT INSTABILITY AS THE CAUSE OF VACUUM BREAKDOWN.* *Alan Watson*, Ion Physics Corporation.

Experimental studies¹ of sparking in vacuum have stimulated the development of a theoretical model of the breakdown process as follows. Geometrical field enhancement by a cathode protrusion decreases due to surface migration if the applied voltage is raised. Positive ionic space charge from the accumulated impact ionization all along the resultant electron beam will supplement the enhancement and amplify the Fowler-Nordheim current. A voltage exists for which the overall field enhancement is unstable and depends upon the gas density which is derived from both anode vaporization and cathode sputtering. Either of these may dominate the condition determining the breakdown voltage which consequently depends upon the square root or linear power of the gap separation for uniform fields. The theory accounts for the ability of a weak transverse magnetic field to influence the breakdown voltage positively or negatively.¹

* Work sponsored by the Advanced Research Projects Agency.

¹Alan Watson, W. R. Bell, and M. J. Mulcahy, *Proceedings of Third International Symposium on Discharges and Electrical Insulation in Vacuum*, Paris, September (1968).

B-5. VOLTAGE AND FIELD THRESHOLD FOR POSITIVE STREAMER ONSET. *
M. Heiszler and E. Nasser, Iowa State University.

The onset of corona breakdown in air has never been accurately measured under the effect of impulse voltage due to the difficulty in detecting the extremely transient ionization process whose lifetime is in the order of a few nanoseconds. The Lichtenberg figure technique provided a means of revealing what may be assumed to be the very first ionization manifestation at point electrodes. Since this first study was conducted with the point being positive, the first detectable ionization process was in the form of the positive primary streamer. The onset voltage of these streamers ranged from 7.2 to 27.2 kV for the points having 0.5 mm to 5.0 mm radii, respectively. The distance between anode and cathode is of little importance, especially at small point radii. Evaluation of the field intensity at the tip of the anode, using a digital computer program, revealed that the critical field intensity remains constant for a particular anode curvature and lies between 86.0 and 37.0 kV for the 0.5 and the 5.0 mm radius points, respectively. These field values and the field gradient are used to correlate the formation of an avalanche in the highly divergent field and to establish a tentative criterion for streamer onset.

*Work supported by the National Science Foundation.

B-6. THE PASCHEN CURVES FOR DIVERGENT FIELDS IN AIR AND N₂ * . *D. C. Schroder and E. Nasser, Iowa State University.*

In an investigation of the breakdown mechanism of air and N₂, it was found necessary to obtain the breakdown voltages V_b of the point-to-plane gap in pressures between 760 and 100 Torr. Curves of V_b as a function of electrode spacing d showed a high irregularity for the positive polarity of the point, both at impulse and static potentials. In air these irregularities are more pronounced under static voltages, whereas in N₂ they are greater under impulse voltages. In general, the negative point polarity has shown much smoother curves. Redrawing the curves for V_b as a function of pd shows a tremendous departure from the Paschen Law in the region between 10 and 300 cm-Torr for the positive impulse breakdown in air and N₂. This suggests the simultaneous occurrence of more than one breakdown mechanism causing the statistical scatter observed in the breakdown values. The two possible competing mechanisms could be the formation of secondary channels and the formation of highly ionized channels due to field emission and backstroke.

*Work supported by the National Science Foundation.

B-7. THE FORMATION OF SECONDARY LEADER CHANNELS IN AIR AND N₂ BREAKDOWN.* *E. Nasser and D. C. Schroder, Iowa State University.*

In gaseous breakdown under pulse conditions, particularly in air and N₂, it has never been quite established how the transition from the low ion density of the primary streamers to the high carrier density of the pre-spark channel occurs. To investigate this phase of development, the Lichtenberg figure technique was used under pressures varying between 50 and 760 Torr. It was surprising to detect a completely different ionization process which may be termed a "secondary leader." This process leads to the formation of relatively highly ionized channels that were previously observed under static voltages and in very long gaps. Their paths are narrow and follow a radial pattern. They terminate in "threads" of low intensity that have an irregular circular pattern. Quantitative data were obtained on their onset voltage and their rate of growth in air and in N₂ as a function of the voltage and pressure. Their onset voltage in air lies between 4 and 12 kV for 100-400 Torr and in N₂ it is about 15% lower. Their length is linearly dependent upon the voltage, though the rate of growth differs according to pressure.

*Work supported by the National Science Foundation.

B-8. BACK CORONA DISCHARGE IN A TRANSVERSE MAGNETIC FIELD. *N. T. Dzocanh, University of Notre Dame.*

In this paper the experimental results concerning the effects of a transverse magnetic field on the threshold and sparking potentials of the back corona discharge in oxygen at the pressure range from 0.1 to 30 mm Hg are reported. The discharge is created between a high voltage wire and a grounded coaxial cylinder. In order to enhance the secondary emission on the passive electrode the inner surface of the cylinder is coated with a layer of porous material of high resistivity. It has been found that the sparking potential and the threshold potential increase significantly with the magnetic field. Both follow the general pattern of the Paschen curves for increasing pressures. However the effects of the magnetic field are much larger and damp out much less quickly with pressures when the voltage on the wire is positive. The characteristic current-voltage curves of the back corona discharge show that the ionization current may be increased by many orders of magnitude before a spark takes place if a transverse magnetic field of about 1,500 G is present. The characteristics of the corona discharge obtained in the same experimental conditions will be presented for comparison and the physical mechanism underlying the observed phenomenon will be discussed.

B-9. THE ADJECTION DISCHARGE PHENOMENON. John C. Bryner and William J. Coleman, North American Rockwell Corporation.

When high velocity gas is directed over a charged, pointed conductor, the space charge limitation of the corona discharge is reduced and the resulting more powerful phenomenon is called the Adjection Discharge. This paper presents the results of a preliminary experimental and analytical study of the phenomenon using 2 cm point-to-plane geometry in the atmosphere. With the point raised to +30 kV the discharge current could be varied from about 35 μA with no air flow (corona discharge) to a maximum of 600 μA with an air chamber pressure of 60 psig. The discharge current was found to vary almost linearly with streamer avalanche frequency, which increased from about 10^3 sec^{-1} to $4 \times 10^4 \text{ sec}^{-1}$ under the same conditions. The current was decidedly non-linear with air chamber pressure, however, being independent of it below the threshold of 27 psig and then rising rapidly for pressures above threshold. Details of this relationship and other quantitative data will be presented. Theoretical considerations of space charge removal by the adjection air process are also treated.

B-10. MECHANISM OF THE RADIO FREQUENCY OZONIZER DISCHARGE. M. P. Freeman* and T. Aiba, Massachusetts Institute of Technology.

The radio frequency (1-20 MHz) ozonizer discharge or "chemical corona" has been compared in its operation in oxygen to the same device operated at 60 Hz. Comparable chemical, energetic and electrical data were taken. In the high frequency regime where the behavior of the discharge is dominated by a steady state accumulation of excess positive ions in the gap, the best energy efficiency is several orders of magnitude worse than at low frequencies. A simple model, assuming minimization of the rate of production of entropy, relating the electrical parameters and the observed contraction of the discharge is seen to account for this difference in chemical efficiency. Regions of E/p sufficiently high to support the underlying ionization avalanche mechanism and to create ozone molecules are seen to be confined to layers comparable in thickness to the Debye length adjacent to the electrode (barrier) and thin compared to the aerodynamic boundary layer which probably accounts for the remarkable insensitivity of this discharge to flow rate.

*Permanent address: American Cyanamid Company, Stamford, Conn.

B-11. MASS TRANSPORT BY A PULSED VACUUM ARC. D. A. Butter,[†]
University of Western Ontario.

An experimental and theoretical investigation has been performed to measure the mass of a pulsed vacuum arc. The arc is formed by a 1 μ sec discharge across the tips of two parallel electrodes and the ionized material of the arc is projected away from the electrodes by the asymmetric magnetic forces of the discharge. Experimental measurements of the speed V at which this ionized material is moving verifies the theoretical prediction: $V = \langle I \rangle \sqrt{\alpha / \pi \rho}$ where $\langle I \rangle$ is the average current, ρ is the line density of the arc, and α is a theoretically calculated constant of the geometry of the experiment. The mass m of the arc is deduced theoretically to be: $m = \langle I \rangle \tau \sqrt{\alpha \pi \rho}$ where τ is the duration of the current pulse. This formula predicts the mass of the vacuum arc to increase from 0.03 μ g to 0.2 μ g for the current range of interest, and these predicted masses are verified to within 20% by a new experimental technique.

[†]Present address: General Electric Company, Nela Park, Cleveland.

B-12. ANODE SPOT FORMATION IN A VACUUM DISCHARGE.^{*} G. Ecker,
Inst. f. Theor. Phys. der Universität Bochum, W. Germany.

We consider two plane-parallel electrodes at a given distance. They are homogeneous and of identical material. In the volume between these electrodes we assume absolute vacuum. There are no impurities, either in the electrodes or in the volume. It is an experimental fact that during the passage of the current through this vacuum device an "anode spot" at the anode may or may not develop, depending on parameters like electrode material, geometry and shape of the current pulse. We study this constriction process starting at the time when a laterally uniform distribution is reached after ignition. The analysis of the expansion of neutrals and charged particles produces the cause for anode spot formation and explains the existence of a threshold current. It predicts numerical values for the critical peak currents in agreement with the experimental observation.

^{*}Work supported by the General Electric Research Laboratory, Schenectady.

B-13. PROPERTIES OF RADIATION DOMINATED ARCS. J. J. Lowke,
Westinghouse Research Laboratories.

Methods of calculating temperature profiles of electric arcs that have been reported previously¹ showed that if radiation is the principal energy loss process, the arc consists of an arc core of almost uniform temperature surrounded by a sheath where conduction is significant. By assuming an isothermal arc core it is possible to calculate approximate values of electric field strength and central temperature as a function of arc current, for any given radius. Exact calculations show that the central temperature and radius of the arc core are markedly insensitive to the value of the wall temperature and thermal conductivity. By solving the energy balance equation for the temperature profile between the wall temperature and temperature of the arc core it is possible to show that the approximate thickness of the outer sheath of the arc and fraction of the input energy emitted by conduction are given by $(\pi/2E)(S/\sigma)^{1/2}$ and $2(\pi S/IE)^{1/2}$ where σ and S are the electrical conductivity and heat conductivity potential at the core temperature, I is the electric current and E the electric field strength.

¹J. J. Lowke and E. R. Capriotti, Bull. Am. Phys. Soc. 12, 220 (1967).

B-14. HOLLOW CATHODE DISCHARGE WITH THERMIONIC CATHODES. Harald
L. Witting, General Electric Research and Development Center.

The properties of a hollow cathode discharge with thermionic emitting cathodes have been investigated. The hollow cathode is formed by two facing, planar cathodes of variable separation. The discharge is operated between the cathodes and a movable, planar anode, in argon at a few Torr. Current-voltage characteristics of the discharge were obtained as functions of the cathode-cathode separation, cathode-anode separation, cathode emission current and gas pressure. Three stable regions of operation were identified: the Anode Glow Mode, the Ball of Fire Mode, and the Langmuir Mode. A hollow cathode effect was found in the Ball of Fire Mode, i.e. for a fixed discharge current and gas pressure there is an optimum cathode separation where the discharge voltage has a minimum. This hollow cathode effect is less pronounced than in the case of hollow cathode discharges with cold cathodes.¹

¹D. J. Sturges and H. J. Oskam, J. Appl. Phys. 37, 2405 (1966).

B-15. SPECTROSCOPIC INVESTIGATIONS ON A Hg-SnI₂ HIGH PRESSURE ARC.
W. H. Bloss, University of Florida.

Radiation from an arc plasma in Hg-SnI₂ (about 10 atm) in a quartz tube (18mm diameter, electrode spacing 10mm) has been measured in the spectral range from 3,600 to 14,500 Å. From measurements of radial emission distribution of characteristic lines of Hg and Sn and molecular bands of I₂ and iodine compounds, the radial temperature distribution and the different processes of radiation (recombination and inverse photodissociation) have been derived. By variation of electrical power input (250 to 500 W) the partial pressure of SnI₂ is changed in a defined way. The corresponding variation of spectral emission distribution shows the contribution of molecular radiation. The absorption coefficient of the plasma has been found from an arrangement with two identical discharge tubes. The computed local intensities of radiation from Abel inversion and unfolding show that line emission is mainly from the hot central plasma core whereas continuous molecular radiation originates from the outer plasma regions.

SESSION C

Wednesday Afternoon, 16 October

2:00 p.m.

ELECTRON COLLISIONS II

Chairman: *Edward Gerjuoy*, University of Pittsburgh
Pittsburgh, Pennsylvania

C-1. NON-ADIABATIC ATOMIC DISTORTION IN LOW ENERGY ELECTRON AND POSITRON SCATTERING.* W. R. Garrett, Health Physics Division, Oak Ridge National Laboratory.

A perturbation method is used to obtain equations for the dynamic distortion of the target atom in low energy electron and positron scattering. In an approximation which is adequately simple for application to heavier systems, the equations for hydrogen are reduced to a form analogous to the perturbation equations of the method of polarized orbitals. Expressing the interaction of the incident particle with an atomic electron in terms of a multipole expansion, the equations are solved for the multipole components of the polarization potential where the equations governing the distortion are dependent on the energy of the incident particle. Phase shift results for electron and positron scattering on hydrogen are compared with adiabatic results and with results obtained by other non-adiabatic and variational methods.

*Work sponsored by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

C-2. CALCULATION OF CROSS SECTIONS FOR ELECTRON-HELIUM COLLISIONS.* H. H. Michels, United Aircraft Research Laboratories.

The elastic scattering of slow electrons from a helium target atom has been studied using analytic procedures for representing the scattered electron wave. The stationary-state wave function is written as $\Psi = a_1\psi_1 + a_2\psi_2 + \Phi$ where ψ_1 and ψ_2 are known asymptotic forms and Φ is a compound-state wave function represented by a configuration-interaction (CI) expansion built from Slater-type orbitals. For the s-wave component, Φ was constructed from spin-projected functions which included Sturmian sets of the type $(1s^2 n's)$ and correlation functions such as $(ns n's n''s)$, $(np n'p n''s)$, $(np n'p nd)$, etc. Similar terms were employed for the higher partial waves. The target atom was studied in the Hartree-Fock approximation ($E = -2.8617$) and with a CI expansion ($E = -2.8977$). Our computed cross sections are in close agreement with those reported by Callaway, et al.¹ below 5 eV but show systematic deviation at higher energies. We find a scattering resonance in the s-wave channel at 18.82 eV with a HF target and at 19.04 eV with a CI target atom. Our calculated scattering length is $1.145 a_0$. A comparison of the calculated cross sections with experiments has been made.

*Work sponsored in part by the Air Force Office of Scientific Research.
¹J. Callaway, R. W. LaBahn, R. T. Pu and W. M. Duxler, Phys. Rev. 168, 12 (1968).

C-3. ELECTRON SCATTERING FROM ALKALI ATOMS WITHOUT EXCHANGE.*
 Philip M. Stone and Norman P. Dorn, University of Pittsburgh.

Equations for elastic scattering in the adiabatic approximation are derived as an approximation to a variational statement. Calculations without exchange for electron scattering by sodium and lithium are presented and compared with close coupling (nonadiabatic) results of Karule. The adiabatic phase shifts are corrected by a second use of the variational statement and are then in good agreement with Karule below about 0.50 eV; above 0.50 eV the $\ell = 1$ partial wave becomes increasingly poor. The sensitivity of the calculation to different atomic wave functions is explored and found to be small. This technique of correcting adiabatic results by a variational statement appears promising. The work is part of a program to determine quantitative limitations to adiabatic theory.

* Work supported by the Advanced Research Projects Agency.

C-4. INVESTIGATION OF POSSIBLE $e^+ - H$ RESONANCE BELOW THE POSITRONIUM THRESHOLD. A. K. Bhatia and A. Temkin, Laboratory for Theoretical Studies, Goddard Space Flight Center.

The possibility of a resonance below the threshold of positronium formation was investigated by using Feshbach's Q-operator formalism. The resonance energy is given by $E = \epsilon_Q + \Delta_Q$. The variational calculation minimizes the $[\epsilon_Q] = \langle \Psi Q H Q \Psi \rangle (\langle \Psi Q \Psi \rangle)^{-1}$ where φ_0 is the ground state of the hydrogen atom, and $Q = 1 - \varphi_0(r_2) \langle \varphi_0(r_2) |$. Ψ was taken to be an S-state of the form

$$\Psi(r_1, r_2) = e^{-(\gamma r_1 + \delta r_2 + \alpha r_{12})} \sum_{\ell, m, n} C_{\ell, m, n} r_1^\ell r_2^m r_{12}^n.$$

The variational calculation for this type of wave function can be carried through by the same technique as described previously.¹ A search routine was programmed to find values of α, γ, δ which minimized ϵ_Q for a given number of optimized linear terms. With up to 20 terms we found that independent of the starting values, results always tended to $\epsilon_Q = -0.5 \text{ Ry}$ from above, with $\gamma, \delta \rightarrow 0$ and $\alpha \rightarrow 1/2$. This corresponds to a positronium at infinity with respect to a stationary proton, i.e., no resonance. In order to investigate the possibility of a negative shift Δ_Q and/or a possible resonance slightly above the positronium threshold, we are looking for local minimum in γ, δ, α - space even if its energy is above the pickup threshold. Although such local minima could be misleading, the generality of our variational Ψ leads us to believe that such a local minimum would be meaningful should it occur.

¹A. K. Bhatia, A. Temkin, and J. F. Perkins, Phys. Rev. 153, 177 (1967).

2 p Gailites
Ohm & McWeeny } Li, 2p } Ohm, & McWeeny
Vesselov } } Clementi, Ohm, McWeeny
Na 35, 3p

C-5. CALCULATION OF ELECTRON EXCITATION CROSS SECTIONS OF HYDROGEN MOLECULES BY THE METHOD OF CLOSE COUPLING. Fredric E. Fajen, Los Alamos Scientific Laboratory and Chun C. Lin,* University of Oklahoma.

The electron excitation cross sections of the hydrogen molecule from the ground electronic and vibrational state into the vibrational levels of the electronic state $B^1\Sigma_u^+$, $C^1\Pi_u$, and $E^1\Sigma_g^+$ have been calculated by the method of close coupling using the coupled representation which includes all these excited states. The molecular wave functions at various internuclear distances are expressed by the natural orbital expansion and the vibrational wave functions are obtained by a numerical solution of the potential curves. For the B state the results of the close-coupling calculations agree well with those of the method of distorted waves. The C and E states show considerable coupling and the partial cross sections of the latter are strongly influenced by the presence of the former. The coupling between the various vibrational levels within an electronic state was found to have little effect on the electronic excitation cross sections, whereas the cross sections for vibrational excitation within the ground electronic state are greatly affected by the coupling between these vibrational levels and the higher electronic states.

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C-6. DIFFERENTIAL CROSS SECTIONS FOR ELECTRON-H₂ SCATTERING.*
N. F. Lane, Rice University and S. Geltman, Joint Institute for Laboratory Astrophysics.

Differential elastic and rotational-excitation cross sections for electron-H₂ scattering have been calculated and compared with recent beam measurements¹ in the energy range 1 to 10 eV. The S-matrix elements used in evaluating the differential cross sections were obtained in a close-coupling calculation² which included the effects of long-range polarization but not exchange. The calculated total $J=1\rightarrow 3$ rotational-excitation cross section appears to be in good agreement with the measurements below about 10 eV. The calculated angular distribution for elastic scattering is also found to agree well with the measurements over the energy range considered. The calculation for the $J=1\rightarrow 3$ rotational transition agrees with experiment to a somewhat lesser degree. This may partly be due to a larger uncertainty in the experimental points, as the signal is down by a factor of 30 from the elastically scattered signal.

* Work supported in part by the U. S. Atomic Energy Commission and the Advanced Research Projects Agency.

¹H. Ehrhardt and F. Linder, Phys. Rev. Letters 21, 419 (1968), and private communication.

²N. F. Lane and S. Geltman, Phys. Rev. 160, 53 (1967).

C-7. EXCHANGE EFFECTS IN LOW ENERGY ELECTRON-H₂ SCATTERING.*
Ronald J. W. Henry, Kitt Peak National Observatory,† and Neal F. Lane,
Rice University.

The scattering formalism of Arthurs and Dalgarno¹ is generalized to take account of exchange in the scattering of slow electrons by molecular hydrogen. Adiabatic polarization terms² are included in the direct potential. Elastic and rotational excitation cross sections are calculated by a close coupling method; elastic cross sections are in good agreement with experimental results;³ inclusion of exchange increases the $j = 0 \rightarrow 2$ rotational cross sections over those calculated without exchange.

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

†Operated by the Association of Universities for Research in Astronomy under contract with the National Science Foundation.

¹A. M. Arthurs and A. Dalgarno, Proc. Roy. Soc. A256, 540 (1960).

²N. F. Lane and R. J. W. Henry, Phys. Rev. 173, (1968).

³D. E. Golden, H. W. Bandel, and J. A. Salerno, Phys. Rev. 146, 40 (1966).

C-8. MEASUREMENT OF THE ENERGY DEPENDENCE OF ELECTRON-ION RECOMBINATION IN NITROGEN BY AN ION BEAM TECHNIQUE.* Gunter Hagen,†
University of California at Los Angeles.

A collinear beam technique has been developed for measuring absolute cross sections of electron-ion reactions at low interaction energies. As an example of this technique, absolute recombination cross sections have been measured for diatomic molecular nitrogen ions and electrons over an energy range of 0.1 to 5 eV. The size of the cross section is consistent with the assumption of dissociative recombination. It is found that the recombination coefficient is essentially independent of the interaction energy from 0.1 to 0.6 eV and has a value of $\alpha(N_2^+) = (2.67 \pm 0.5) \times 10^{-7}$ cm³/sec. For interaction energies greater than 0.6 eV, the recombination coefficient decreases essentially exponentially with energy. A ground state N₂⁺ ion beam was produced by an oscillating electron bombardment ion source, mass analyzed by a Paul type rf quadrupole mass filter, energy analyzed by a 45° electrostatic energy analyzer, and collimated by means of a set of thin circular apertures. The ion beam was merged with a collinear electron beam. The recombination cross section was determined by measuring the neutral particles resulting from the recombination reaction. The main competing process and source of noise is the energetic neutrals from the charge exchange reaction. In order to discriminate against the noise, the electron beam is modulated. The signal-to-noise ratio is then improved by synchronous digital data averaging.

*Work supported in part by the Air Force Cambridge Research Laboratories, Office of Aerospace Research.

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C-9. STUDIES OF DISSOCIATIVE ELECTRON-ION RECOMBINATION USING A SUPERIMPOSED-BEAM TECHNIQUE. *Lowell P. Theard*, Douglas Advanced Research Laboratories.

An instrument in which a beam of electrons can be superimposed upon a beam of ions has been constructed. The beam particles travel in the same direction along the axis of a solenoid. Neutral particles generated by electron-ion recombination continue along the paths of the precursor ions. At the end of the interaction region electrons leave the beam axis following the curvature of the solenoidal field. Unneutralized ions are then deflected away electrostatically, leaving only energetic neutrals which can be detected with a particle multiplier. Virtually any ion can be studied without interference from others since the ion beam is provided by a mass selector. The instrument has been used to measure the overall neutralization cross section for CH_5^+ ions with electrons for a nominal interaction energy of 1 eV, relative to that for N_2^+ with electrons under identical conditions. Results indicate that the cross section for CH_5^+ is about half that for N_2^+ . This implies a value of 10^{-14} cm² for thermal (300°K) encounters. The corresponding neutralization rate constant is of the order of 10^{-7} cm³/sec. Such information is of great interest in the radiation chemistry of methane, since CH_5^+ is the predominant ion in the irradiated gas.

C-10. ELECTRON DETACHMENT FROM THE NEGATIVE HYDROGEN ION BY ELECTRON IMPACT. *Sanford B. Schwartz*, Douglas Advanced Research Laboratories.

New calculations are reported for the cross section for electron detachment from the H^- ion by electron impact. The Born (ii) approximation described by Rudge and Schwartz,¹ but modified for complex atoms as discussed by the above authors,² was used to perform these calculations. In the present calculation, a Hartree-Fock wave function was used for the initial state of the ion, while the final state was represented by a continuum function corresponding to the same Hartree-Fock potential. The incident electron was represented by a Coulomb continuum function corresponding to a unit repulsive potential, and the scattered electron was represented by a plane wave. The results are in good agreement with experiment³ above 30 eV, and fall below experiment by as much as 40% at the lowest measured energy, about 9 eV. For incident energies of 2.83, 5.03, 7.54, 15.1, 30.2, and 60.4 eV, the calculated cross sections are 0.048, 5.01, 18.2, 35.5, 33.0, and 24.1 square Angstroms, respectively.

¹M. R. H. Rudge and S. B. Schwartz, Proc. Phys. Soc. 88, 563 (1966).

²M. R. H. Rudge and S. B. Schwartz, Proc. Phys. Soc. 88, 579 (1966).

³D. F. Dance, M. F. A. Harrison, and R. D. Rundel, Proc. Roy. Soc. A. 299, 525 (1967).

C-11. ELECTRON IMPACT IONIZATION OF POSITIVE IONS AND NEUTRAL ATOMS BY SUPERIMPOSED BEAM TECHNIQUE. P. Mahadevan, Douglas Advanced Research Laboratories.

Beams of He^+ , Ar^+ , N_2^+ , and O_2^+ collide with a superimposed beam of electrons over a long interaction path (15cm). The impact results in ionization of the singly charged ions. The product ions are analyzed electrostatically. The electron energy is varied from below threshold to about 300 eV. The relative ionization efficiency is plotted as a function of the kinetic energy of the electrons. The plots typically show a broad maximum followed by gradual fall off. For purposes of comparison, the ionization of certain neutral species is also studied. The maximum of the ionization curve for Ar^+ occurs at a cm energy of 130 eV for the electrons while that for Ar, occurs at 100 eV electron energy. For N_2^+ and O_2^+ , the doubly charged molecular ion and the singly charged atomic ion formed by collisional dissociation respectively, are indistinguishable at present except by the onset electron energy. The electrons are produced from two indirectly heated cathodes, mounted 30° off axis, (operating temperature 1100°C), accelerated to the desired energy and merged along the primary beam axis using a solenoidal field. The electron beam itself is modulated at 15 cps electronically. The product signal is amplified using an electron multiplier and detected with a phase sensitive lock-in-amplifier.

C-12. ABSOLUTE FLUORESCENCE YIELDS IN N_2 AND AIR EXCITED BY RELATIVISTIC ELECTRONS.* M. N. Hirsh and E. Poss, The G.C. Dewey Corporation.

Absolute photon yields have been measured for several visible features of the nitrogen fluorescence excited by the impact of 0.7 to 1.7 Mev electrons on N_2 and airlike $\text{N}_2:\text{O}_2$ mixtures. In the experiment, all secondary electrons produced by ionization of the gas are utilized in further excitation and ionization. The observed fluorescence appears to result from direct excitation of ground state N_2 molecules. The effective cross section for the production of 3914 Å photons in the First Negative (0,0) band of N_2^+ , including the contribution of the secondary electrons, is $\sigma_e = (1.24 \pm .15) \times 10^{-19} \text{ cm}^2$ over the energy range investigated; the constancy of σ_e over this energy range is predicted by the Relativistic Born Approximation (RBA). If the measured cross section is scaled to 1 keV by RBA, we find $\sigma_e(1 \text{ keV}) = (1.65 \pm 0.25) \times 10^{-17} \text{ cm}^2$, a factor 3.2 larger than that recently observed¹ for primary excitation alone. This agrees with Bethe's original prediction² of the ratio of primary to secondary ionization in air and N_2 . The fluorescence efficiency for the 3914 Å band in air at 1.5 Mev is $(3.7 \pm 0.5) \times 10^{-3}$, to be compared with Hartman's recent value 3.4×10^{-3} determined for 750 eV electrons. Results for other bands will also be presented.

* Work supported by the Defense Atomic Support Agency.

¹B. N. Srivastava and I. M. Mirza, Bull. Am. Phys. Soc. II 13, 896 (1968); R. F. Holland *ibid.*, 897.

²H. Bethe, Ann. Physik 5, 325 (1930).

³P. A. Hartman, Bull. Am. Phys. Soc. II 13, 897 (1968).

SESSION D

Wednesday Afternoon, 16 October

2:00 p.m.

GLOWS AND AFTERGLOWS

Chairman: *Karl Persson*, National Bureau of
Standards, Boulder, Colorado

D-1. CONTINUUM ELECTROSTATIC PROBE THEORY FOR LARGE SHEATHS ON SPHERES AND CYLINDERS. *R. E. Kiel*, Bell Telephone Laboratories.

An approximate analysis is presented for spherical and cylindrical electrostatic probe operation under conditions such that large collision dominated sheaths are obtained. Analytical expressions are given for the sheath growth as a function of experimentally determined parameters. Use of these results makes possible the direct interpretation of electron number density from a single probe measurement. To obtain probe currents, the usual assumption was made for the existence of only two electrostatic regions, i.e., sheath and quasineutral. Existing solutions for the quasineutral region were used to determine the flux into the sheath. The sheath size was obtained by solving the mobility dominated, space-charge-limited equations for spherical and circular symmetry. A normalized sheath radius, R_s , was thus obtained to replace the probe radius in the quasineutral solutions. R_s can be expressed in terms of the ambient number density, or, if number density is the unknown quantity, R_s can be described as a function of the probe current. For spherical symmetry and equal ion and electron temperature, the present results agree very well with the available numerical solutions. Use of these results for interpretation of probe currents in a recent discharge tube experiment give agreement with microwave measurements to better than 50% in all cases.

D-2. THE EFFECT ON THE TONKS-DATTNER RESONANCES OF VARYING ELECTRON RADIAL DISTRIBUTION IN THE MODULATED PLASMA COLUMN.* *C. J. Burkley and M. C. Sexton*, University College, Cork, Ireland.

The locations of the Tonks-Dattner resonances in current-modulated cylindrical plasmas using microwave absorption have previously been shown to depend on whether the increasing or decreasing current half-cycle was under observation.¹ Further experiments, using a microwave cavity, in which the resonant spectra were located as a function of the more fundamental parameter, average electron density, have exhibited a similar effect. Since the crucial dependence of the radial electron distribution on the locations of the resonances has been shown theoretically,² an experimental measurement of the radial distribution itself has been undertaken using the two-cavity technique, recently introduced.³ Variations in the distribution have now been shown to account for the difference in the resonant locations under increasing and decreasing conditions, an effect which has not been previously reported. Moreover, these variations are in agreement with theoretical predictions relating to the resonant locations.

*Work supported by the English Electric Valve Co., Essex, U.K. and by the European Office of Aerospace Research, U. S. Air Force.

¹A. A. Cremin and M. C. Sexton, *Electronics Letters* 1, 297 (1965).

²J. V. Parker, J. C. Nickel and R. W. Gould, *Phys. Fluids* 7, 1489 (1964).

³C. J. Burkley and M. C. Sexton, *J. Appl. Phys.* (to be published).

D-3. EXPERIMENTAL OBSERVATION OF THE SPONTANEOUS APPEARANCE OF LONGITUDINAL WAVES IN VARIOUS GAS DISCHARGES.* *R. E. McIntosh and N. P. Hansen, University of Massachusetts.*

The spontaneous appearance of longitudinal waves in various gas discharges (air, argon, helium and neon) has been observed experimentally to agree with the dispersion relation obtained from theory.¹ Both electron and ion oscillations have been observed using a wide dispersion microwave spectrum analyzer coupled to a specially designed plasma filled slab structure. The frequency of the oscillations under consideration are below 1 GHz and are related to the plasma frequency in the prescribed manner. The power spectral density of these oscillations has been measured as a function of the neutral background pressure for each of the gases (5 - 50 μ of Hg) and the spacing between the two conducting slabs. It is seen that the amplitudes of the oscillations are strongly dependent on the electron-neutral collision frequency.

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

¹G. Bekefi, Radiation Processes in Plasmas (John Wiley & Sons, Inc., New York, 1966).

D-4. IONIZATION BY SECONDARY PROCESSES IN THE NEGATIVE GLOW OF RARE GAS DISCHARGES. *R. F. Pottie, M. J. Vasile and P. Lightman, National Research Council of Canada.*

The predominant process for ion-production in the negative glow of gas discharges is usually that which results from impacts of high energy electrons that have been accelerated by the field in the cathode dark space. Additional sources of ionization are considered to be unimportant because of the absence of a field in the glow itself. However, earlier studies^{1,2} in this laboratory showed the presence of much higher concentrations of impurity ions (Ar^+ , Kr^+ , Xe^+) in mixtures of these gases with helium and neon, than could be accounted for by direct ionization. We have carried out extensive studies of low current (0.3 mA) discharges in similar systems by utilizing screened probes, optical line absorption and mass spectrometry, and we conclude that the major source of this excess ionization is Penning reactions of metastable helium and neon atoms. These metastables are produced mainly at the cathode edge of the glow, most probably by secondary electrons.

¹p. F. Knewstubb and A. W. Tickner, J. Chem. Phys. 36, 674 (1962).

²p. F. Knewstubb and A. W. Tickner, J. Chem. Phys. 36, 684 (1962).

D-5. NONLINEAR EFFECTS IN THE POSITIVE COLUMN OF A MODULATED GAS DISCHARGE. *J. Polman*, Philips Research Laboratories, Eindhoven, The Netherlands.

A calculation is presented of the properties of the positive column of a gas discharge sustained by a sinusoidally modulated current. The modulation depth β is so large, that the equations of motion, continuity and energy conservation of the electron gas cannot be linearized with respect to β . It appears that even for small values of β (≤ 0.05) the linearized model may give results deviating clearly from the exact calculation. Modulation of electron temperature, density, and electric field is highly anharmonic for larger β . At frequencies comparable with the ionization frequency, the mean electron temperature may be as low as 0.5 times the value given by theory for the steady state. For higher frequencies, electron temperature and density become approximately constant in time, the latter being higher than that of the dc case. Gases considered are helium and neon, modulation frequencies are $10^3 - 10^6$ Hz. The pressure range is 0.1 - 25 Torr. Experiments, in which i.a. densities, of the order of 10^{12} cm⁻³, are measured by means of a 4 mm microwave interferometer, are in agreement with the above theoretical results.

¹P. Davy, Rev. Phys. Appl. 2, 65 (1967).

D-6. IONIC ANALYSIS OF CATAPHORESIS IN He-Ne MIXTURES.* *J. P. Gaur and L. M. Chanin*, University of Minnesota.

For studies of cataphoresis in He-Ne mixtures an analytic expression is derived for the axial dependence of the neon atoms in a dc discharge. The production and loss mechanisms of the Ne⁺ ions are included in the analysis. The present theory can be used to predict the degree of ionization of neon at a given pressure and current, when the appropriate rate coefficients are known. In addition, techniques for ion sampling and mass analysis have been used in the experimental investigation. Measurements have been made in commercial helium gas samples having a quoted neon concentration < .001%, and in samples containing .05% neon. Studies were conducted over a pressure and current range 7-30 Torr and 8-80 mA, respectively. Depending on the experimental conditions the ions observed were He₂⁺, Ne⁺, HeNe⁺ and Ne₂⁺. The present results enable an estimate to be made of the rate coefficient for the reaction Ne⁺ + 2He → HeNe⁺ + He. Experimentally obtained values of the degree of ionization are in good agreement with the theoretical values.

*Work supported by the National Science Foundation and the Air Force Cambridge Research Laboratories.

D-7. CONSTRICTION OF CURRENTS PERPENDICULAR TO A MAGNETIC FIELD IN AN INHOMOGENEOUS PLASMA. *Melvin J. Kofoid*, Boeing Scientific Research Laboratories.

With homogeneous plasmas the conductivity perpendicular to a magnetic field is greatly reduced when $\omega_e \tau_e \gg 1$. However, Alfvén has shown¹ with a theoretical model that in inhomogeneous plasmas with a uniform electric cross field the main effect of the magnetic field is to cause most of the current to concentrate into the region of highest ordinary conductivity σ_0 . We have observed in the laboratory very considerable constriction of current flow perpendicular to a steady magnetic field B_0 in inhomogeneous plasma. A 5 cm diam plasma 40 cm long was produced in 1.0 Torr argon by a 0.5 MHz axially-directed magnetic field B_z . A larger B_0 was applied parallel to B_z . The induced annular electric fields E_θ and currents j_θ were then perpendicular to B_0 . B_z and σ_0 vs radius r were found from probe measurements, j_θ vs r from $\partial B_z / \partial r$. Analysis indicates the constriction of current will be identical whether either σ_0 , or E_θ , or the $\sigma_0 E_\theta$ product is locally increased by some factor β . The experimental current peaked at the r where $\sigma_0 E_\theta$ was maximum. With outward as well as inward constriction of j_θ (compared to the $B_0 = 0$ distribution of j_θ vs r), only Alfvén's explanation appears applicable.

¹Alfvén and Fälthammer, Cosmical Electrodynamics, (Oxford Press, 1963), 2nd ed., p. 185.

D-8. THE EFFECT OF OPTICAL THICKNESS ON SPECTROSCOPIC DIAGNOSTICS AND VOLUME ION PRODUCTION IN TENUOUS HELIUM PLASMAS. *R. J. Sovie*, NASA-Lewis Research Center.

The effect of the absorption of resonance radiation on the excited state population rates in low density helium plasmas has been studied. Resonance trapping for radiation from the n'P series members up to $n = 8$ has been included. The effects of this process on the determination of electron temperature from the relative intensities of helium singlet and triplet series spectral lines¹⁻³ is discussed. In general, this effect lowers the electron density limit for valid use of this technique. Optical trapping of the resonance radiation is found to have a small effect on the volume ion production cost when metastable states are considered. Finally, limits on spectroscopic diagnostics used for levels above the thermal limit are discussed.

¹S. P. Cunningham, USAEC Rep WASH-289 (1955).

²R. J. Sovie, *Phys. Fluids* 7, 13 (1964).

³R. J. Sovie, *J. Quant. Spectrosc. Radiat. Transfer* 8, 833 (1968).

D-9. THE ELECTRON TEMPERATURE HISTORY IN A HELIUM AFTERGLOW PLASMA WITH PULSED MULTIPLE ELECTROSTATIC PROBES.* *Edwin Blue*, Lockheed Palo Alto Research Laboratory.

The electron temperature history in a helium afterglow plasma has been measured with three different types of pulsed electrostatic probes. The plasma was produced by rf breakdown with 21 MHz repetitively pulsed voltage. Current-voltage characteristics were measured with a cylindrical double probe, a cylindrical Langmuir probe and a triple probe. In all measurements the voltage was applied to the probe in the form of a fast pulse. At high pressures and at early times in the afterglow there is evidence of a non-Maxwellian electron energy distribution with one group of electrons having "temperatures" of the order of several volts and another with temperatures of the order of tenths of volts. At later times the high energy group disappears and the electrons thermalize to room temperature. At low pressures the electron "temperature" is observed to fall below room temperature in accord with the Biondi diffusion cooling mechanism. The sources of error will be discussed and particular attention will be focused on the accuracy of the measurements as determined by the measured temperature in the late afterglow of the higher pressure plasmas.

*Work supported by Lockheed Independent Research funds.

D-10. LATE-TIME SOURCE OF ATOMIC LIGHT IN THE HELIUM AFTERGLOW.
W. B. Hurt and C. B. Collins, Southwest Center for Advanced Studies.

The time-dependent behavior of the light emitted from a pulsed helium afterglow at 3 Torr has been investigated with an improved spectrometric system of sufficient sensitivity-bandwidth ratio to resolve the behavior of the atomic light over a 50 msec time interval. The relationship between the atomic light and the time-resolved electron density, as measured with a 36 GHz free-space microwave interferometer, was found to indicate the importance of a persistent source of ionization at late times. Absorption measurements of time dependent behavior of both the atomic 2^3S and molecular $2^3\Sigma$ metastable species were found to strongly favor mutual ionization of two metastable molecules as being the most important source of late time ionization at 3 Torr.

D-11. COLLISIONAL-RADIATIVE RECOMBINATION OF IONS AND ELECTRONS IN HIGH PRESSURE PLASMAS IN WHICH THE ELECTRON TEMPERATURE EXCEEDS THE GAS TEMPERATURE. C. B. Collins, Southwest Center for Advanced Studies.

The recombination rate of electrons in a hypothetical helium-like plasma at high pressure is calculated for cases in which the gas temperature is fixed at 300°K and the electron temperature is varied from 300°K to 2000°K. Neutral collision-induced recombination, as well as electron collision-induced recombination, is considered for ranges of electron density from 10^8 to 10^{13} cm⁻³ and gas densities from 10^{16} to 10^{19} cm⁻³. Recombination rate coefficients for purely neutral-assisted and purely electron-assisted processes are found to be simply additive for electron temperatures in the range 300-500°K and non-additive for higher electron temperatures. An inverse three-halves dependence of recombination coefficient on electron temperature is found for certain densities.

D-12. LIGHT EMISSION AND ION DENSITY STUDIES OF DECAYING RARE GAS PLASMAS.* G. E. Veatch and H. J. Oskam, University of Minnesota.

Detailed studies of the time dependence of the spectral emission and of that of the number density of ions have been made during the decay period of plasmas produced in helium containing various concentrations of neon atoms. The studies confirmed the occurrence of recombination processes previously reported for He⁺, Ne⁺, He₂⁺ and Ne₂⁺. Evidence has been found for the population of the 4d levels of neon by He (2¹s) metastable atoms. The production of He⁺ by mutual collisions between He (2³s) metastable atoms has been established to be the important ionization process during the plasma decay period, both in pure helium and in helium-neon mixtures. New values for the conversion frequency of the following processes were obtained: Ne⁺ + 2 He → (HeNe)⁺ + He ($\nu_{\text{conv}} = 26 p_0^2$ (He)); Ne⁺ + He + Ne → Ne₂⁺ + He ($\nu_{\text{conv}} = 370 p_0$ (He) p₀(Ne)), while (HeNe)⁺ + Ne + He → Ne₂⁺ + 2 He was found to be an extremely efficient process. Results of analogous studies in helium-argon mixtures will also be given.

*Work supported by the Air Force Cambridge Research Laboratories and the National Science Foundation.

D-13. INFLUENCE OF THE PLASMA SHEATH DIMENSIONS ON AMBIPOLAR DIFFUSION STUDIES.* G. E. Veatch and H. J. Oskam, University of Minnesota.

During mass spectrometer studies of the properties of decaying rare gas plasmas it was found that during the latter part of the decay period the apparent ambipolar diffusion coefficient increased with decreasing ion density. This phenomenon cannot be explained by the ambipolar to free diffusion transition theory.^{1,2} The measurements can be explained as follows: The assumption of quasineutrality of the plasma is valid except in the region adjacent to the plasma boundary. The thickness of this region is related to the Debye length. Thus the loss of all charged particles is governed by ambipolar diffusion in a plasma region the dimensions of which decrease with decreasing charged particle densities. An analogous discussion of the influence of the plasma sheath on the rate of electron loss has been given by Holstein.^{3,4}

* Work supported by the Air Force Cambridge Research Laboratories and the National Science Foundation.

¹W. P. Allis and D. J. Rose, Phys. Rev. 93, 84 (1954).

²C. D. Maldonado, J. Plasma Phys. 2, 167 (1968).

³T. Holstein, Phys. Rev. 75, 1323 (1949).

⁴A. V. Phelps, Physics of Quantum Electronics (McGraw-Hill, New York, 1966) p. 538.

D-14. STUDIES OF THE AFTERGLOW OF PLASMAS PRODUCED IN HELIUM-NITROGEN MIXTURES.* A. R. DeMonchy and H. J. Oskam, University of Minnesota.

The time dependence of the density of N^+ , N_2^+ , N_3^+ , and N_4^+ was studied during the afterglow of a rf excited plasma in helium-nitrogen mixtures (N_2 concentrations: 0.05 to 0.5%), simultaneously with that of the intensity of the first positive, second positive and first negative band systems of nitrogen. The important production mechanism for N_2^+ during the decay period is $N_2^m + N_2^m \rightarrow N_2^+ + N_2 + e$ as was also found in pure nitrogen.¹ The radiative lifetime of N_2^m is larger than 20 msec, so that N_2^m can be $A^3\Sigma_u^+$ and/or $a^1\Sigma_u^-$. The ambipolar diffusion coefficient of N_2^+ in helium is in agreement with that reported by Kasner, *et al.*² The time dependence of the first negative band intensity is consistent with the explanation advanced by Brömer and Döbler,³ while that of the first positive band is controlled by the recombination of atomic nitrogen.

* Work supported by the Air Force Cambridge Research Laboratories and the National Science Foundation.

¹R. E. Lund and H. J. Oskam, Bull. Am. Phys. Soc. 13, 219 (1968).

²W. H. Kasner, W. A. Rogers and M. A. Biondi, Phys. Rev. Letters 7, 321 (1961).

³H. H. Brömer and F. Döbler, Z. Physik 185, 278 (1965).

SESSION E

Thursday Morning, 17 October

8:30 a.m.

ELECTRON ATTACHMENT

Chairman: *A. V. Phelps*, Westinghouse Research
Laboratories, Pittsburgh, Pennsylvania

E-1. TEMPERATURE DEPENDENCE OF ELECTRON ATTACHMENT IN I₂ VAPOR.*
F. K. Truby, Sandia Laboratory.

Two body dissociative electron attachment coefficients have been obtained for iodine in the presence of helium as a function of gas temperature over a temperature range of from 253°K to 467°K. The data were obtained using microwave cavity frequency shift techniques where the initial electron concentration was produced by a hydrogen flash lamp adjacent to the microwave cavity containing the helium iodine mixture and the time dependence of the electron number density was determined after a single photoionization light pulse.¹ The attachment coefficients varied by more than a factor of four over the above stated temperature range, being $.91 \times 10^{-10}$ cm³/sec (per molecule) at 253°K and 4.2×10^{-10} cm³/sec at 467°K. The data obtained were used by E. J. Shipsey² in determining the I + I, I + I⁻ curve crossing.

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

¹F. K. Truby, Phys. Rev. 172, 24 (1968).

²E. J. Shipsey, Paper to be presented at this conference.

E-2. DEDUCTION OF CROSSING POINT OF THE REPULSIVE I₂⁻ AND GROUND STATE I₂ POTENTIAL ENERGY CURVES FROM MEASUREMENTS OF THE ELECTRON DISSOCIATIVE ATTACHMENT COEFFICIENT.* Edward J. Shipsey, Sandia Laboratory.

The expression derived by O'Malley¹ for the dissociative attachment cross section has been used to calculate the temperature dependence of the attachment coefficient. Comparison with the measurements of Truby² shows that the crossing occurs at $.066 \pm .007$ eV above the minimum of the ground state curve. This crossing is above the second vibrational level. Besides the intersection point, the attachment coefficient is a function of two other parameters which together effectively control only the absolute magnitude of the attachment coefficient in the region of temperature investigated. The height of the point of intersection above the ground state minimum affects both the mean slope and the curvature of the electron attachment coefficient versus temperature curve, so that the quality of fit obtained is a good verification of the applicability of this procedure.

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

¹T. F. O'Malley, Phys. Rev. 150, 14 (1966).

²F. Truby, Paper to be presented at this conference.

E-3. TEMPERATURE DEPENDENCE OF DISSOCIATIVE ATTACHMENT IN N₂O.
P. J. Chantry, Westinghouse Research Laboratories.

The attachment of low energy electrons (<4 eV) by the reaction $e + N_2O \rightarrow O^- + N_2$ has been studied as a function of gas temperature from approximately 150°K to 1000°K. The ions produced by a mono-energetic electron beam are detected by total ion collection or mass-analysis. The shape and magnitude of the cross-section below 2 eV is found to be sensitive to gas temperature throughout the above range of T. The differences in shape and threshold observed by previous workers¹ occur in this electron energy range, and may be reconciled by postulating a reasonable gas temperature for each experiment. As with the similar but weaker temperature dependence observed previously in O₂² the present results imply a strongly enhanced cross section for attachment to vibrationally excited N₂O.

- ¹R. K. Curran and R. E. Fox, J. Chem. Phys. 34, 1590 (1961). G. J. Schulz, J. Chem. Phys. 34, 1778 (1961). D. Rapp and D. D. Briglia, J. Chem. Phys. 43, 1480 (1965).
W. L. Fite, R. T. Brackmann and W. R. Henderson, in Proceedings of the IV International Conference on the Physics of Electronic and Atomic Collisions (Science Bookcrafters, Inc., New York, 1965), p. 100;
T. F. O'Malley, Phys. Rev. 155, 59 (1967).

E-4. ELECTRON IMPACT EXCITATION AND NEGATIVE ION FORMATION IN NH₃ AND ND₃.* R. N. Compton, J. A. Stockdale, and P. W. Reinhardt,
Health Physics Division, Oak Ridge National Laboratory.

Threshold electron impact excitation of ammonia has been studied using both "trapped electron" and "SF₆ electron scavenger" techniques. Dissociative electron capture cross sections for NH₃ and ND₃ have been measured with a total ionization chamber, and the various ions also were recorded as functions of the electron energy with a TOF mass spectrometer using electron beams with resolution of 0.1 eV. Results from the two excitation studies are in excellent agreement and in both cases four well-defined peaks were observed in the energy range from 6 to 12 eV. The "scavenger" spectrum also exhibits a small peak below the first singlet state similar to that previously found for H₂O. The total negative ion cross section for NH₃ is ~1.1 times larger than the ND₃ cross section in agreement with the results of reference 1. The electron energy scale determined from Cl⁻/HCl in the mass spectrometer study of the various ion current peaks corresponds exactly to that obtained for the cross sections using the 19.31 eV He⁻ resonance in the total ionization measurements. Accurate H⁻(D⁻) ion kinetic energy measurements have also been made as a function of the incident electron energy and yield a dissociation energy of 4.35 ± 0.1 eV for NH₂-H(or ND₂-D).

* Work supported by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

¹T. E. Sharp and J. T. Dowell, J. Chem. Phys. (to be published).

E-5. NONDISSOCIATIVE ELECTRON ATTACHMENT TO AROMATIC HYDROCARBONS.*
R. P. Blauenstein and L. G. Christophorou, Oak Ridge National Laboratory.

Electron attachment rates and mean electron attachment cross sections as a function of mean electron energy for nondissociative electron attachment to nine aromatic hydrocarbons have been measured employing electron swarm techniques in the temperature range 25°C to 210°C. All the hydrocarbons studied exhibit sharp attachment cross sections peaking at thermal energies. The thermal values of the attachment cross sections are (in cm^2) $< 1.27 \times 10^{-20}$, $\leq 1.27 \times 10^{-19}$, 5.6×10^{-16} , 2.6×10^{-18} , 1.01×10^{-16} , 1.2×10^{-16} , 2.46×10^{-15} , 5.13×10^{-17} , and 1.27×10^{-15} for benzene, naphthalene, anthracene, phenanthrene, triphenylene, chrysene, 1,2-benzanthracene, pyrene, and perylene, respectively. The electron attachment rate for triphenylene, anthracene, and 1,2-benzanthracene is independent of temperature over the range 100°C to 210°C. This is consistent with a v^{-1} velocity dependence for the attachment cross section (assumed to be expressed in powers of velocity) at and near thermal energies. Independent measurements of the equilibrium constants for some of the molecules studied¹ combined with the present data on the attachment rates show a strong temperature dependence for the autoionization lifetime of the temporary negative ion. The electron attachment cross section was found to increase with increasing electron affinity of the parent molecule and decreasing energy of the first excited π -singlet state.

*Work supported by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

¹W. E. Wentworth, E. Chen, and J. E. Lovelock, J. Phys. Chem. 70, 445 (1966).

E-6. MEASUREMENT OF THERMAL ELECTRON ATTACHMENT RATES IN SF₆, C₆F₆, C₆F₁₁CF₃, AND TeF₆ BY A TIME-OF-FLIGHT SWARM METHOD.* D. R. Nelson and F. J. Davis, Health Physics Division, Oak Ridge National Laboratory.

A dwell-drift technique for measurement of attachment rates, ωw , has been devised. The electron swarm from the photocathode is pulsed to the center of the reaction chamber where it is left in a zero electric field for accurately measured periods of dwell time, T, before being pulsed to the electron multiplier detector at the anode. The number of electrons per light flash is obtained as a function of T. The slope of this function plotted on semi-log coordinates gives the value of $\omega w p$ where p is the pressure. The thermal values of ωw for SF₆, C₆F₆, C₆F₁₁CF₃, and TeF₆ were found to be 5.9×10^9 , 2.6×10^9 , 1.2×10^9 , and 1.4×10^6 sec^{-1} , respectively. Low-energy measurements ($E/P < 0.6$ volts cm^{-1} Torr⁻¹) of ωw for SF₆ and C₆F₆ show a decrease with increasing energy of the electron swarm while the ωw for C₆F₁₁CF₃ shows an increase with increasing energy.

*Work supported by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

E-7. TRANSIENT NEGATIVE ION STATES IN SELECTED ALICYCLIC AND AROMATIC FLUOROCARBONS.* C. Dewey Cooper, W. T. Naff, University of Georgia, and R. N. Compton, Oak Ridge National Laboratory.

The formation of short-lived (lifetime $\sim 10^{-15} - 10^{-13}$ sec) and long-lived (lifetime $10^{-6} - 10^{-3}$ sec) temporary negative ion states in twelve cyclic fluorocarbon molecules has been studied in the gas phase with monoenergetic electron beams. Autoionization lifetimes of the long-lived negative ion states in $C_4F_6^-$, $C_4F_8^-$, $C_6F_6^-$, $C_5F_8^-$, $C_7F_8^-$, $C_6F_{10}^-$, $C_6F_{12}^-$, and $C_7F_{14}^-$ exhibited a systematic increase (from 7 to 800 μ sec) with increasing number of vibrational degrees of freedom thereby supporting a previous theoretical model¹ which describes nondissociative attachment in polyatomic molecules. The long-lived ions showed a maximum attachment cross section at electron energy < 0.05 eV, and widths of resonances observed were instrumental with the exception of that for C_7F_{14} , which showed a width at one-half maximum of 0.2 eV. Short-lived negative ion resonances were studied in the fluorinated benzenes using the SF_6 scavenger technique. Evidence was found that the addition of each fluorine to the benzene ring increases the electron affinity by 0.4 eV.

* Work supported by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

¹R. N. Compton, L. G. Christophorou, G. S. Hurst, and P. W. Reinhardt, J. Chem. Phys. 45, 4634 (1966).

SESSION F

Thursday Morning, 17 October

8:30 a.m.

CHARGE TRANSFER

Chairman: *Robert C. Amme*, University of Denver
Denver, Colorado

F-1. NEAR RESONANT CHARGE TRANSFER TO EXCITED STATES.* *Julius Perel*
and Howard L. Daley, Electro-Optical Systems.

The charge transfer cross sections for $\text{Li}^+ + \text{Cs}$, $\text{Cs}^+ + \text{Li}$, and $\text{Hg}^+ + \text{Cs}$ were measured to determine whether the magnitude and shape of the cross section-velocity curves could be correlated with the presence (or absence) of a near resonance for transfer to an excited state. The $\text{Li}^+ + \text{Cs}$ cross section has a maximum greater than 10^{-14} cm^2 at a velocity of $2.9 \times 10^7 \text{ cm/sec}$ and is much larger than the $\text{Cs}^+ + \text{Li}$ cross section over the velocity range common to the two curves. The data show that for $\text{Li}^+ + \text{Cs}$, near resonance transfer to the Li 2P state ($\Delta E = -0.35 \text{ eV}$) dominates over transfer to the ground state ($\Delta E = 1.5 \text{ eV}$) and that the conjugate reaction $\text{Cs}^+ + \text{Li}$ which does not have a near resonance results in the transfer to the Cs ground state ($\Delta E = -1.5 \text{ eV}$). The $\text{Hg}^+ + \text{Cs}$ data also indicate that transfer to an excited state (i.e., the Hg 6^1P_1 state with $\Delta E = 0.17 \text{ eV}$) dominates the measured cross section because the energy defect for such a reaction is much smaller than the energy defect for transfer to the ground state.

* Work supported by U. S. Army Research Office.

F-2. INVESTIGATION OF THE EFFECT OF INTERNAL AND KINETIC ENERGY
ON THE CHARGE-EXCHANGE CROSS SECTION OF $\text{NO}^+ + \text{Cs}$. *Thomas L. Churchill,*
United Aircraft Research Laboratories.

The small angle, resonant component of the charge-exchange cross section has been measured for the aeronomic reaction $\text{NO}^+(\text{X}^1\Sigma^+) + \text{Cs}(^2\text{S})$ over a relative energy range of 0.33 to 3.05 eV. In this system resonant exchange is possible provided that the product NO is excited to a level equal to the difference in ionization potentials. Measurements were obtained in a 90° crossed-beam apparatus which employed a controlled-energy, electron bombardment NO^+ source whose purpose was to restrict the formation of metastable, excited ions which can modify the probability of exchange. The measured charge-exchange cross section was found to rise from approximately 10\AA^2 at 3 eV to a peak of 65\AA^2 at 0.6 eV. More importantly, however, the results revealed an extremely sensitive dependence of charge exchange on the energy of the bombarding electrons and hence on the internal energy of the reactant ions. In addition, the most significant variation in the dependence occurred with an electron energy of less than the appearance potential of the first excited state suggesting that vibrational excitation may be at least as important as electronic excitation in influencing the probability of charge exchange.

* Work supported in part under AFCRL.

F-3. METALLIC ION FORMATION BY CHARGE TRANSFER.* J. A. Rutherford
and B. R. Turner, Gulf General Atomic Incorporated.

The metallic ions, Na^+ , Ca^+ , and Mg^+ were formed by charge transfer from N^+ , O^+ , NO^+ , N_2^+ , O_2^+ , and H_2O^+ to the neutral metal atoms. The reactions were studied using the crossed beam technique. The neutral beam of the metallic atoms was modulated and the incident ion energy was varied over the range 2 to 400 eV. The metal ions resulting from charge transfer at the intersection of the two beams were extracted, analyzed in a magnetic mass spectrometer, and the cross section for their production was determined. A major consideration in this experiment was the determination of the neutral beam intensity; the neutral beam effused from a resistively heated furnace 10 cm from the interaction region and its intensity was a sensitive function of the furnace temperature. Neutron activation analysis was used to determine the neutral beam intensity. The results of these experiments will be compared with those derived at thermal energies using flowing afterglows.¹

* Work supported by the Defense Atomic Support Agency.

¹A. L. Farragher, J. A. Peden and W. L. Fite, (to be published).

F-4. MODIFIED IMPACT PARAMETER METHOD (MIPM). H. W. Hilsinger,
Worcester Polytechnic Institute.

The impact parameter method (IPM) has been applied successfully to atomic collisions involving incident nuclei whose de Broglie wavelength is much smaller than atomic dimensions. However, a large class of collision phenomena involving excitation and rearrangement are excluded from the usual approach because, while $\lambda < a_0$, the electronic excitation energies are comparable to the impact energies. We have modified the IPM to describe the case where electronic energy is significantly different after collision than before. The resulting time rate of change of the expansion coefficients is different due to inclusion of a factor of $\Delta v/v$, where Δv is the difference of relative velocities before and after excitation and v is the average velocity before and after. However, our results will be shown to reduce to the usual IPM equations for high relative velocities. The MIPM is as easy to use as the IPM and results of its application will be shown for the collision $\text{He}^{++} + \text{H}(1s) \rightarrow \text{He}^+(2p) + \text{H}^+$, in the incident energy range 25 eV to 100 eV. In this collision the initial and final states are degenerate, but at finite internuclear separations the states differ by as much as 7 eV. The MIPM predicts an exchange probability 22% larger than the IPM at the lower impact energy.

F-5. CHARGE EXCHANGE IN $H^+ - H^-$ COLLISIONS. R. D. Rundel, K. L. Aitken, and M. F. A. Harrison, Culham Laboratory, U.K.

The cross section for the reaction $H^+ + H^- \rightarrow H + H$ has been measured over an energy range of 0.25 to 10 keV using the inclined beams technique. A proton beam collides with an H^- beam at an intersection angle of 20° , and hydrogen atoms formed in the above reaction are detected. This technique provides a relative collision energy much lower than the energy of either ion beam, but preserves the advantages of a well-defined collision geometry and separation of reaction products from the two beams after the collision. Compared with the theoretical calculations of Bates and Lewis,¹ the measured cross section is a factor of $2 \frac{1}{2}$ larger at 1 keV relative collision energy, and falls off more rapidly with increasing energy.

¹D. R. Bates, J. T. Lewis, Proc. Phys. Soc. A68, 173 (1955).

F-6. * DAMPING IN THE ELECTRON-TRANSFER PROBABILITY FOR THE (H^-, H) SYSTEM. * Joseph C. Y. Chen and Junya Mizuno, University of California, San Diego.

Recent measurement on resonant electron-transfer probability carried out by Keever *et al.*¹ has shown that the amplitude of the oscillation in the resonant reaction $H^- + H \rightarrow H + H^-$ is too small to be noticeable within their experimental resolution. This behavior is in contrast to resonant electron-transfer probability involving positive ions such as $H^+ + H \rightarrow H + H^+$ and $He^+ + He \rightarrow He + He^+$, for example. The large damping in the oscillatory behavior of electron-transfer probability for the (H^-, H) system may be explained within the context of multichannel collision theory involving negative ions² as due to the coupling with electron detachment channels. A semiclassical method is developed and applied to the calculation of the electron-transfer probability for the (H^-, H) system.

* Work supported by the Advanced Research Projects Agency.

¹W. C. Keever, G. J. Lockwood, H. F. Helbig and E. Everhardt, Phys. Rev. 166, 68 (1968).

²J. C. Y. Chen, Phys. Rev. 156, 12 (1967), 152, 1454 (1966).

SESSION H

Thursday Afternoon, 17 October

1:45 p.m.

ION NEUTRAL REACTIONS

Chairman: *Eldon E. Ferguson*, Environmental Science
Services Administration, Boulder, Colorado

H-1. ISOTOPIC EFFECTS IN REACTIONS BETWEEN NITROGEN MOLECULAR IONS AND NITROGEN MOLECULES.* *William B. Maier II*, Los Alamos Scientific Laboratory.

Reactions of $^{15}\text{N}_2^+$ with $^{14}\text{N}_2$ and of $^{14}\text{N}_2^+$ with $^{15}\text{N}_2$ are studied. Nitrogen molecular ions are produced by bombarding nitrogen with 18-19 eV electrons and are mass-analyzed prior to reaction. Cross sections are measured for the production of $^{14}\text{N}^+$, $^{15}\text{N}^+$, $^{14}\text{N}_2^{15}\text{N}^+$, and $^{14}\text{N}^{15}\text{N}_2^+$ with projectile ion kinetic energies below 45 eV. These cross sections depend on the mass of the projectile ion, so there is at least one reaction path producing N^+ and N_3^+ which does not involve transition states in which the projectile identity is lost. The ratio of the cross section for the formation of $^{14}\text{N}_2^{15}\text{N}^+$ to the cross section for the formation of $^{14}\text{N}^{15}\text{N}_2^+$ takes on values from 0.5 to 4 for the range of projectile ion energies studied. The ratio of cross sections for the formation of $^{14}\text{N}^+$ and $^{15}\text{N}^+$ is between 0.7 and 1.5. All of the reactions studied exhibit thresholds; the apparent threshold energies for $^{14}\text{N}_2^{15}\text{N}^+$ and $^{14}\text{N}^{15}\text{N}_2^+$ differ by about 1 eV and depend on the identity of the projectile.

* Work supported by the U. S. Atomic Energy Commission and the Advanced Research Projects Agency.

H-2. THE PRODUCTION OF NaO^+ AND NaN^+ FROM Na AND NO^+ IN MERGED BEAMS.* *E. A. Entemann and P. K. Rol*, Space Science Laboratory, General Dynamics/Convair.

The reactions $\text{Na} + \text{NO}^+ \rightarrow \text{NaO}^+ + \text{N}$ and $\text{Na} + \text{NO}^+ \rightarrow \text{NaN}^+ + \text{O}$ have been studied at low interaction energies (0.1 to 5 eV) in merged beams.¹ The charged product of each reaction is scattered primarily in the direction of the incident Na in the c.m. coordinate system. The reaction cross section for production of NaO^+ decreases monotonically with increasing interaction energy, whereas the cross section for NaN^+ production reaches a maximum at a low interaction energy. Energy analysis has revealed that the translational energy of the products is considerably higher than predicted by the spectator stripping model. A better fit to the data has been achieved using the modified stripping model of Herman, *et al.*² that considers the acceleration due to the charge-induced dipole force.

* Work supported by the Defense Atomic Support Agency through the Air Force Cambridge Research Laboratories.

¹The technique is described by S. M. Trujillo, R. H. Neynaber and E. W. Rothe, *Rev. Sci. Instr.* **37**, 1655 (1966).

²Z. Herman, J. Kerstetter, T. Rose and R. Wolfgang, *Discussion Faraday Soc.* **44**, 123 (1967).

H-3. FLOWING AFTERGLOW STUDIES OF ION-MOLECULE ASSOCIATION REACTIONS. *D. K. Bohme, D. B. Dunkin, F. C. Fehsenfeld, and E. E. Ferguson,* ESSA Research Laboratories.

Positive and negative ion-molecule association reactions have been measured in the ESSA flowing afterglow system at 82°K and 280°K with helium as a third body over a pressure range 0.1 to 3.0 Torr. At low pressures the kinetics of association is termolecular as expected for the ground state ions studied. Specific rates have been measured for the association reactions of $\text{Ar}^+ + \text{Ar}$, $\text{O}^+ + \text{N}_2$, $\text{N}^+ + \text{N}_2$, $\text{O}_2^+ + \text{O}_2$, $\text{N}_2^+ + \text{N}_2$, and $\text{O}^- + \text{CO}_2$. At 82°K the kinetics of association for both $\text{O}_2^+ + \text{O}_2$ and $\text{N}_2^+ + \text{N}_2$ becomes bimolecular above helium pressures of about 1.3 Torr and 0.2 Torr respectively. This observation is qualitatively, but not quantitatively, consistent with the simple mechanism usually invoked for association reactions. The termolecular rate coefficients were found to decrease significantly with increasing temperature. The results also indicate that termolecular association is less strongly dependent upon temperature when the number of atoms in the collision intermediate is increased. A consideration of available laboratory data on ion-neutral termolecular association in which a stable complex is formed indicates a surprisingly systematic variation of the termolecular rate coefficient with the number of atoms in the product ion cluster. The cluster ions N_6^+ , N_7^+ , N_8^+ , N_9^+ , and Ar_3^+ were identified mass spectrometrically at 82°K, apparently for the first time.

H-4. SOME ION-MOLECULE REACTIONS INVOLVING SILICON. *F. C. Fehsenfeld,* ESSA Research Laboratories.

Observations of Si^+ and SiO^+ ions in the earth's ionosphere have prompted a series of investigations on silicon ion reactions in the ESSA flowing afterglow system. It is found that Si^+ does not react with O_2 , on the contrary the reaction



has a rate constant $k_1 \sim 10^{-10} \text{ cm}^3 \text{ sec}^{-1}$ at 300°K. This establishes that $D(\text{SiO}^+) < D(\text{O}_2)$, in disagreement with published values of the SiO^+ dissociation energy. Also the reactions $\text{SiO}^+ + \text{N} \rightarrow \text{Si}^+ + \text{NO}$, $\text{SiO}^+ + \text{CO} \rightarrow \text{Si}^+ + \text{CO}_2$, $\text{SiO}^+ + \text{NO} \rightarrow \text{NO}^+ + \text{SiO}$, and $\text{SiO}^+ + \text{SO}_2 \rightarrow \text{SO}^+ + \text{SiO}_2$ have been measured and their reaction rate constants will be reported.

H-5. THE REACTION OF A^+ WITH ARGON TO MAKE A_2^+ . *William Peterson and Earl C. Beatty*, Joint Institute for Laboratory Astrophysics.

A determination has been made of the rate of reaction of A^+ with argon gas to form A_2^+ . The equipment used was a double shutter drift tube which has been previously described in connection with other measurements.¹ The reaction rate information was obtained from an analysis of the distribution of arrival times of the primary and secondary ions at a collector near the second shutter. Identification of the reactants was by their mobility. The relationship between mobility and mass for these ions has been established by McAfee *et al.*² The resultant rate constant is 3×10^{-31} cm⁶/sec.

¹P. L. Patterson, thesis, University of Colorado (1966).

²Kenneth B. McAfee, Jr., D. Sipler, and D. Edelson, *Phys. Rev.* **160**, 130 (1967).

H-6. DRIFT TUBE MEASUREMENTS OF $N_2^+ + O_2$ AND $O_2^+ + NO$ REACTION RATES FROM THERMAL ENERGY TO ~ 1 eV.* *R. Johnsen, H. L. Brown, and Manfred A. Biondi*, University of Pittsburgh.

Ions generated in a pulsed discharge ion source enter a drift mobility tube (containing a reactant gas at low density in a buffer gas) where they may undergo reaction during passage to the collector end of the tube. The drift field determines the ion energy. Both parent and product ions are sampled by a differentially pumped quadrupole mass spectrometer. By reversing or interrupting the drift field, the ion residence time can be varied. Reaction rates are determined by comparison of ion signals for different residence times. At thermal energies, the measured $N_2^+ + O_2$ and $O_2^+ + NO$ reaction rates are in good agreement with results of flowing afterglow experiments.¹ In addition, the $O_2^+ + NO$ reaction rate is found to be independent of energy from thermal energy (0.04 eV) to ~ 1 eV, while the $N_2^+ + O_2$ reaction rate decreases by almost a factor of 10 in the same range.

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

¹See, for example, E. E. Ferguson, *Rev. Geophys.* **5**, 305 (1967).

H-7. IONIC REACTION RATES IN AFTERGLOWS OF ARGON AND ARGON-OXYGEN MIXTURES. *D. Smith, C. V. Goodall and N. G. Adams,*[†] University of Birmingham, England.

Following the observations made in this laboratory of the diffusion and conversion of Ar^+ ions in pure argon afterglow plasmas,¹ measurements have been made of the electron dissociative recombination coefficient $\alpha(\text{Ar}_2^+)$ of Ar_2^+ ions in these plasmas. Further, the charge transfer rate coefficient, K_{Ar^+} , of Ar^+ ions with oxygen molecules and the electron dissociative recombination coefficient, $\alpha(\text{O}_2^+)$, of the O_2^+ ions formed in this charge transfer reaction in afterglows of argon-oxygen mixtures have also been measured. The measurements have involved the simultaneous use of a mass spectrometer to sample positive-ion wall currents and Langmuir probes operated in the orbital-limited-current regime to monitor electron density decay.² The value of $\alpha(\text{Ar}_2^+)$ at a vessel wall temperature of 295°K was measured as $(4.7 - 12.6) \times 10^{-7} \text{ cm}^3 \text{ sec}^{-1}$, the variation being closely correlated inversely with the discharge pulse power and tentatively explained in terms of an inverse dependence of $\alpha(\text{Ar}_2^+)$ with electron temperature. A value of $(5.5 \pm 0.5) \times 10^{-11} \text{ cm}^3 \text{ sec}^{-1}$ was obtained for K_{Ar^+} at a vessel wall temperature of 295°K and preliminary measurements at several temperatures of up to 578°K indicated a reducing K_{Ar^+} with increasing temperature. $\alpha(\text{O}_2^+)$ was measured to be $(2.1 \pm 0.3) \times 10^{-7} \text{ cm}^3 \text{ sec}^{-1}$ at a vessel wall temperature of 295°K.

[†]Visiting Research Fellow, University of Colorado.

¹D. Smith and P. R. Cromey, *J. Phys. B. (Proc. Phys. Soc.)*, II, 1, 638 (1968).

²C. V. Goodall and D. Smith, *Plasma Phys.* 10, 249 (1968).

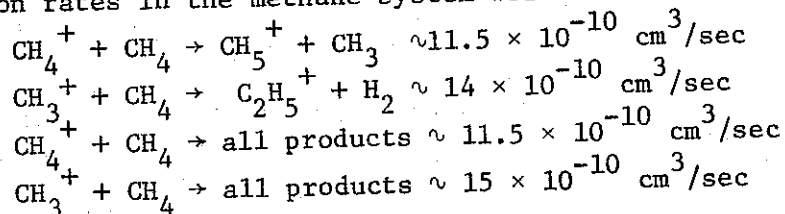
H-8. MEASUREMENTS OF SOME NEGATIVE ION-MOLECULE REACTION CROSS SECTIONS IN THE REGION FROM 0 TO 2 ELECTRON VOLTS.^{*} *J. A. Stockdale, R. N. Compton, and P. W. Reinhardt,* Health Physics Division, Oak Ridge National Laboratory.

Rates and cross sections of the reactions $\text{O}^- + \text{NO}_2 \rightarrow \text{NO}_2^- + \text{O}(1)$, $\text{O}^- + \text{N}_2\text{O} \rightarrow \text{NO}^- + \text{NO}(2)$, $\text{H}^- + \text{H}_2\text{O} \rightarrow \text{OH}^- + \text{H}_2(3)$, and $\text{D}^- + \text{D}_2\text{O} \rightarrow \text{OD}^- + \text{D}_2(4)$ have been measured at a number of points in the ion energy range from 0 to 2 eV. Primary ions were produced by dissociative electron attachment in the field free source region of a time-of-flight mass spectrometer. Rates were calculated from primary and secondary ion currents recorded as functions of a continuously variable field-free reaction time. Application of a small modulating voltage to the retarded electron beam and phase sensitive ion detection allowed ion energy resolution of better than 0.2 eV. The cross section for reaction (1) increased from $7.1 \pm 0.7 \times 10^{-15} \text{ cm}^2$ at 0.65 eV to $4.2 \pm 0.8 \times 10^{-14} \text{ cm}^2$ at 0.25 eV; for reaction (2) the cross section was $1.5 \pm 0.3 \times 10^{-16} \text{ cm}^2$ at 0.65 eV, and the cross sections for reactions (3) and (4) increased from $1.6 \pm 0.3 \times 10^{-14} \text{ cm}^2$ and $5.8 \pm 1.2 \times 10^{-14} \text{ cm}^2$ at ion energies of 1.9 and 1.8 eV, respectively, to values corresponding to a reaction rate of the order of $5 \times 10^{-7} \text{ molecule}^{-1} \text{ cm}^3 \text{ sec}^{-1}$ for near zero energy H^- and D^- ions.

^{*}Work supported by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

H-9. MEASUREMENTS OF THE RATE OF ION-MOLECULE REACTION IN METHANE AND AMMONIA AT NEAR-THERMAL ENERGY.* Robert A. Fluegge, Cornell Aeronautical Laboratory.

Primary ions formed using 1 to 3.5 MeV alpha particles in methane and ammonia have been used to study subsequent ion molecule reactions. Single alphas are detected, counted, and their number compared to the number of ions formed in the reaction chamber. A pulsed time-of-flight type of mass spectrometer is used to vary ion-molecule reaction times and to separate ions according to their mass to charge ratios. The reaction rates in the methane system were found to be:



The very well defined "zero" time of interaction in this pulse counting experiment allows one to estimate a "lifetime" for short-lived intermediates; the results indicate a lifetime near 0.15 μsec for the excited C_2H_7^+ ion formed as a collision complex of CH_3^+ and CH_4 .

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

H-10. NUMERICAL EVIDENCE FOR THE EXISTENCE OF LONG-LIVED MOLECULAR ION COMPLEXES IN ION-MOLECULE COLLISIONS. John V. Dugan, Jr., James H. Rice, NASA-Lewis Research Center, and John L. Magee, University of Notre Dame.

It has been suggested that spiraling leads to long collision times τ_c and large cross sections (CS) in ion-molecule (IM) collisions.¹ Thus the degree to which spiraling occurs in IM collisions with polarizable and/or polar targets is investigated numerically. The collision orbits and IM interaction behavior are studied for a range of collision parameters² using the IBM 360/67 computer with the CDC DD80 plotter. The interaction potential consists of a hard-sphere term V_0 plus the attractive potential (s). Spiraling is observed only in collisions with permanent dipoles where multiple reflections occur off the hard-core barrier. No spiraling is observed in pure polarization (Langevin) collisions where simple specular reflection occurs. Some τ_c values are 10^3 times corresponding values for specular reflections. Certain collisions exhibit 50-1500 "spirals" (reflections) off V_0 at IM separations of 1-3 Å. Large τ_c values, however, do not mean large cross sections; the capture CS^2 are much less than predicted by the adiabatic theory.¹

¹D. K. Bohme, J. B. Hasted, and P. P. Ong, Chem. Phys. Letters, 1, 259 (1967).

²J. V. Dugan, Jr., J. H. Rice, and J. L. Magee, Chem. Phys. Letters (To be published).

H-11. CALCULATION OF CAPTURE CROSS SECTIONS AND A STUDY OF SPIRALING IN COLLISIONS BETWEEN IONS AND SYMMETRIC TOP POLAR MOLECULES. *John V. Dugan, Jr., NASA-Lewis Research Center, and John L. Magee, University of Notre Dame.*

The manner in which molecular geometry affects capture collisions of polarizable polar molecules with ions is investigated. Capture cross sections (CS) σ_c are calculated numerically and compared with results for linear polar targets.¹ These CS are calculated for varying relative velocity over a range of collision parameters including dipole moment μ , electronic polarizability α and moments of inertia I . Results are compared with the maximum σ_M and Langevin CS for CH_3CN ¹ and the pseudo symmetric tops "HCl" and "CO". The σ_c values depend strongly on μ but are generally $< .5 \sigma_M$ except for CO where the α term dominates the interaction. The large σ_c values (100-700 Å²) for symmetric tops are within 30% of linear molecule² results. The probability of orienting the dipole during collision increases markedly going from "HCl" to CH_3CN . The IM collision orbits are studied for spiraling behavior as a function of I values. Both orbital shape and collision time are functions of molecular geometry. These results have implications for energy randomization in polyatomic IM collision complexes.

¹J. V. Dugan, Jr., J. H. Rice and J. L. Magee, NASA TM X-1586, May 1968.

²J. V. Dugan, Jr., and J. L. Magee, J. Chem. Phys. 47, 3103 (1967).

H-12. FORMATION OF CLUSTERED POSITIVE IONS IN NITRIC OXIDE. *W. C. Lineberger and L. J. Puckett, Ballistic Research Laboratories.*

Mass spectrometric measurements of the disappearance of charged particles following the photoionization of nitric oxide contained in an 18 inch diameter cylindrical cavity by the 123.6 nm krypton resonance line have been utilized to determine ambipolar diffusion coefficients and rate constants for the formation of clustered positive ions. For pure NO in the pressure range 10-200 mTorr, the NO^+ decay during the early afterglow is describable by positive ion-electron ambipolar diffusion with $D_{ap} = 85_{-10}^{+15} \text{ cm}^2 \text{ Torr sec}^{-1}$ and three-body conversion of NO^+ to the dimer $\text{NO}^+\cdot\text{NO}$ with a rate constant of $5 \pm 1 \times 10^{-30} \text{ cm}^6 \text{ sec}^{-1}$ at 294 K. The positive ion-electron ambipolar diffusion coefficient for $\text{NO}^+\cdot\text{NO}$ is approximately the same as that for NO^+ . No evidence was seen for the trimer $\text{NO}^+\cdot(\text{NO})_2$. In $\text{NO}-\text{H}_2\text{O}$ mixtures, the NO^+ decay is describable by ambipolar diffusion, three-body conversion to $\text{NO}^+\cdot\text{NO}$, and three-body conversion of NO^+ to the water-clustered ion $\text{NO}^+\cdot\text{H}_2\text{O}$ with a rate constant of $1.5 \pm 0.5 \times 10^{-28} \text{ cm}^6 \text{ sec}^{-1}$ at 294 K. Several other clustered ions have been identified.

H-13. NEGATIVE IONS IN NITRIC OXIDE. *L. J. Puckett and W. C. Lineberger*, Ballistic Research Laboratories.

The static afterglow apparatus at BRL has been employed for the production and observation of negative ions in NO, NO-H₂O, and air-NO afterglows. In the pressure range from 30 to 600 mTorr the dominant negative ion in NO is NO₂⁻. At the lower pressure NO₂⁻ is ~ 20 times more abundant than the next largest ion HN₂O₄⁻, however, at the higher pressures the two ions are present in about equal quantities. In laboratory air with small admixtures of NO, HN₂O₄⁻ (mass 93) is found to be the dominant ion by a factor of more than 20, with masses 64:NO₂⁻·H₂O, 82:NO₂⁻·2H₂O, 46:NO₂⁻, and 100:NO₂⁻·3H₂O following in order of intensity. Also observed were masses 32:O₂⁻; 35, 37:Cl⁻; and 53, 55:Cl⁻·H₂O. Preliminary investigation has established that the principal loss mechanism for NO₂⁻ is the fast three-body reaction NO₂⁻ + H₂O + NO → NO₂⁻·H₂O + NO. It appears, since NO₂⁻·H₂O is lost extremely quickly compared to NO₂⁻, that NO₂⁻·H₂O + NO → HN₂O₄⁻ + H may be the formation mechanism of mass 93, which was identified with the aid of isotopic substitution. Also, the principal loss of Cl⁻ is through the reaction Cl⁻ + H₂O + NO → Cl⁻·H₂O + NO. Reaction rates and further reactions among the negative ions will be discussed. In the decay of the positive ion afterglow in this apparatus the transition from positive ion-electron diffusion to positive ion-negative ion diffusion was observed. Similar observations of the negative ion afterglow indicates that indeed the negative ions are effectively contained within the plasma until such times as this transition occurs.

H-14. TRANSITION FROM POSITIVE ION-ELECTRON AMBIPOLAR DIFFUSION TO POSITIVE ION-NEGATIVE ION AMBIPOLAR DIFFUSION IN AFTERGLOWS. *Mark D. Kregel*, Ballistic Research Laboratories.

Iterative techniques based on the Crank-Nicholson scheme have been used to study the transition from positive ion-electron ambipolar diffusion to positive ion-negative ion ambipolar diffusion during the afterglow of discharges in the pressure range 10 to 200 mTorr. The electric field is calculated by applying Gauss's law with the electron, positive ion, and negative ion particle currents calculated from particle density gradients and from the electric field strength. The assumption of quasi-neutrality is not made. The particle densities are calculated using the continuity equation and particle currents. Wall current and volume density for the ions and electrons are calculated as a function of time. Numerical results are compared with experimental results for a chamber 42 cm in diameter. Characteristic structures in the measured positive and negative ion wall currents agree with the numerical calculations and with simple theory. The transition from positive ion-electron ambipolar diffusion to free diffusion is also considered.

H-15. IMPORTANCE OF MINOR CONSTITUENTS IN AIR-LIKE DISCHARGES.

F. E. Niles, Ballistic Research Laboratories.

Discharges in air produce several species which were originally present in no more than minute amounts. Research grade air contains a few ppm impurities, where an impurity is anything other than N_2 or O_2 . Other impurities in air discharges are contributed by the experimental apparatus although the employment of ultrahigh vacuum techniques minimizes these impurities. The principal impurities which enter into the reaction sequence are H_2O , CO_2 , NO , NO_2 , and N_2O . In addition to the forenamed species, electrons, NO_2^- , NO_3^- , O^- , O_2^- , O_3^- , CO_3^- , N^+ , N_2^+ , NO^+ , $NO^+ \cdot H_2O$, $NO^+ \cdot NO$, O^+ , N , NO_3 , O , and O_3 are created in the discharge by ionization and reactions. Of the excited states produced, $O_2(^1\Delta)$ is the most important to the reaction sequence. Assuming a constant reservoir of N_2 , O_2 , and H_2O , simultaneous time-rate-of-change equations were solved for the number densities of the 23 remaining forenamed species for continuous ionization at a rate of 3.4×10^{10} ion pairs $cm^{-3} sec^{-1}$, total pressure of 10.7 Torr, and different initial number densities for the minor constituents. The solutions reveal that the detectable species are greatly affected by the initial number densities of the minor constituents with the magnitude of the effect depending on the duration of the discharge.

SESSION I

Friday Morning, 18 October

8:30 a.m.

ATOM - ATOM COLLISIONS

Chairman: *F. C. Fehsenfeld*, Environmental Science
Services Administration, Boulder, Colorado

I-1. INTENSE POLARIZED ELECTRON BEAMS FROM OPTICALLY-PUMPED HELIUM DISCHARGES.* *M. V. McCusker, L. L. Hatfield, J. Kessler† and G. K. Walters,* Rice University.

Polarization analysis of electrons extracted from an optically-pumped helium discharge can provide information on electron-exchange collisions and cumulative ionization processes. In these experiments, atoms in the metastable 2^3S_1 state of He^4 are spin-polarized by circularly polarized 1.08μ resonance radiation.¹ Spin-polarization studies of extracted electrons indicate that cumulative ionization processes involving 2^3S_1 atoms play a major role in low-pressure discharge dynamics. Extraction from a continuous rf discharge yields an electron beam current of approximately 1 μA , energy spread approximately 20 eV, and polarization approximately 10% (as determined by Mott Scattering at 120 keV from a gold foil). Extraction from the optically-pumped discharge afterglow (where ionization occurs principally as a result of metastable-metastable collisions) yields beam polarizations as high as 14%. The degree of beam contamination by secondary (unpolarized) electrons is presently unknown, so that the primary beam polarization may in fact be substantially greater than the figures quoted above.

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

† On leave from Physikalisches Institute der Universitat, Karlsruhe, West Germany.

¹L. D. Schearer, Advances in Quantum Electronics (Columbia University Press, New York, 1961), pp. 239-251.

I-2. OBSERVATION OF SPIN-EXCHANGE ACCOMPANYING ENERGY TRANSFER COLLISIONS BETWEEN METASTABLE HELIUM AND NEON ATOMS. *L. D. Schearer,* Texas Instruments Incorporated.

Spin exchange which accompanies energy transfer collisions between optically oriented metastable (2^3S_1) helium atoms and neon atoms has been observed. The magnetic resonance of the helium metastable atoms is observed by monitoring changes in the polarization of the radiation emitted by neon atoms which have been excited by collisions with the helium metastables. The polarization changes are also seen in cascade transitions in a wide variety of neon transitions.

$$\sigma(\text{Ne}^m - \text{He}) = 4.10 \times 10^{-17}$$

$$\sigma(\text{Ne}^m - \text{Ne}) = 166 \times 10^{-17}$$

485 diffusion
(42)

I-3. MEASUREMENT OF THE COLLISIONAL-DEPOLARIZATION CROSS SECTION OF $^3\text{P}_2$ NEON ATOMS BY OPTICAL PUMPING. L. D. Scheerer, Texas Instruments Incorporated.

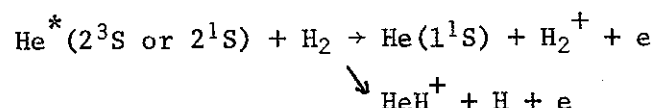
This experiment describes the first successful attempt to optically pump neon metastable atoms. Since metastable neon has a P configuration, it was expected to have a large spin disorientation cross section as a result of collisions with the buffer gas. The results of this experiment, however, indicate that the $^3\text{P}_2$ neon can undergo a large number of collisions before its spin state is changed. The depolarization cross section for collision with $^1\text{S}_0$ helium atoms, determined from the neon magnetic resonance linewidth, is $\sigma \leq 5.4 \times 10^{-17} \text{ cm}^2$, approximately 100 times smaller than the gas kinetic cross section obtained from diffusion experiments. The measured g value for the $^3\text{P}_2$ neon level is $g_j = 1.50152 \pm .00064$.

I-4. DIFFERENCES BETWEEN He(2^1S) AND He(2^3S) PENNING IONIZATION REACTIONS. H. Hotop, A. Niehaus, Physikalisches Institut der Universität Freiburg, and A. L. Schmeltekopf, ESSA Research Laboratories.

Reaction products from reactions of He metastable atoms with various gases have been observed in an atomic beam apparatus. The electron energy is measured by means of a retarding potential field and the ions detected by a mass spectrometer. In order to separate the role played by the He(2^1S) from that of the He(2^3S), the He(2^1S) density is modulated by resonance radiation. The electron energy distributions show marked differences for the singlet and triplet atoms. For reaction with Hg the electron distribution from He(2^3S) is narrow while the singlet distribution is wide and shows distinct structure. It is apparent that the electron energy distribution curves provide a sensitive measure of the details of the interaction forces between the colliding particles. Complex ions are formed preferentially by one or the other of the He metastables. Additionally, for the complex ion HeAr^+ , the lifetime of the complex is strongly dependent on both the background gas pressure and on the initial energy (temperature) of the colliding atoms.

I-5. ISOTOPE EFFECTS IN THE IONIZATION OF H₂, HD, AND D₂ ON IMPACT OF 2³S AND 2¹S HELIUM ATOMS.* K. D. Foster and E. E. Muschlitz, Jr., University of Florida.

Measurements of relative cross sections for the competing processes:



have been made using a beam of helium atoms excited by electron impact. The ions formed are extracted from the collision region at right angles to the beam and identified by mass analysis. The ion ratios given below

| | HeH ⁺ /H ₂ ⁺ | HeH ⁺ /HD ⁺ | HeD ⁺ /HD ⁺ | HeD ⁺ /D ₂ ⁺ |
|-----------|---|-----------------------------------|-----------------------------------|---|
| Ion Ratio | .105 | .037 | .060 | .089 |
| Gas | H ₂ | HD | HD | D ₂ |

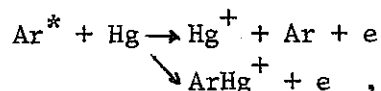
are independent of the energy of the exciting electrons and hence are the same for both 2¹S and 2³S helium atoms. Ions of the type HeX₂⁺ could not be detected. The agreement with prior unresolved measurements¹ on H₂ and HD is excellent for H₂ but poor for HD. Possible mechanisms will be discussed in the light of these results.

*Work supported by the National Science Foundation.

¹H. Hotop and A. Niehaus, Abstracts of the Conference on Heavy Particle Collisions, Belfast (1968).

I-6. PENNING IONIZATION ELECTRON SPECTROSCOPY OF MERCURY. Z. Herman[†] and V. Čermák, Institute of Physical Chemistry, Czechoslovak Academy of Sciences, Prague.

The energy distribution of electrons released in ionization of mercury by excited metastable helium, neon, and argon was measured, and the first three ionization potentials of mercury were determined. In ionization by He*(2¹S) a part of the potential energy of the reactants is transformed into kinetic energy of the products. The population of Hg⁺ ions in various states differs from that one determined by photo-electron spectroscopy.² A group of electrons presumably resulting from the formation of HeHg⁺ was observed. In ionization of mercury by metastable argon, where two processes can occur with approximately equal cross sections,³



it was determined that the onset of the electron energy is about 0.1 - 0.15 eV below the ionization limit. Therefore, ArHg⁺ formed in the associative ionization reaction must be strongly rotationally and vibrationally excited.

[†]On leave of absence at Department of Chemistry, University of Colorado.

¹V. Čermák, Z. Herman, Chem. Phys. Letters (to be published).

²D. C. Forst, C. A. McDowell, J. S. Sanahu, D. A. Vroom, Advances in Mass Spectrometry, (Institute of Petroleum, London 1968). Vol. 4, p. 781.

³Z. Herman, V. Čermák, Collection Czech. Chem. Comm. 31, 649 (1966).

I-7. CROSS SECTIONS FOR ASSOCIATIVE IONIZATION OF THE $n = 3$ STATES OF HELIUM.* C. H. Turner and W. W. Robertson, University of Texas, Austin.

Cross sections for the reaction $\text{He}^* + \text{He} \rightarrow \text{He}_2^+ + e$ have been measured for the 3^1P , 3^3P , 3^1D , and 3^3D states in the positive column of a glow discharge in helium. By means of optical filters and a helium pumping light, the populations of the $n = 3$ states were selectively and periodically modulated and monitored spectroscopically, while the corresponding changes in $[\text{He}_2^+]$ were observed with a quadrupole mass filter. Five different optical filters were used at discharge currents of 10 and 20 mA, each at pressures of 1.0, 1.5, 2.0, and 3.0 Torr. The resulting 40 independent relations between the 4 unknown cross sections were solved with a least-squares program for over-determined sets of equations, yielding $\sigma(3^1\text{P}) = 2.2$, $\sigma(3^1\text{D}) = 1.6$, $\sigma(3^3\text{P}) = 1.2$, and $\sigma(3^3\text{D}) = 0.8$, each times 10^{-15} cm^2 . For the 40 sets of data, these cross sections reproduce the observed $\Delta[\text{He}_2^+]$ with a standard error of 6%. The systematic errors are difficult to evaluate, involving the measurement of change in excited state populations and in molecular ion concentrations, as well as knowledge of electron temperatures and densities in the discharge.

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

I-8. EXCITATION TRANSFER OF METASTABLE HELIUM IN NORMAL HELIUM.*
H. J. Kolker and H. H. Michels, United Aircraft Research Laboratories.

The dynamics of the resonance collision of metastable and normal helium atoms has been examined in the theoretical framework formulated by Buckingham and Dalgarno¹ for elastic scattering, diffusion and excitation transfer. In order to evaluate the cross sections for these reactions, the interaction potentials associated with the $^3\Sigma_{g,u}$ states of the He_2 molecule must be known with high accuracy. To facilitate this analysis, we have carried out accurate *ab initio* calculations of the pertinent interaction potentials. An interesting aspect of both these and previous calculations is the prediction of a maximum in the $^3\Sigma_u$ potential curve. One of the implications of this maximum is the existence of an energy of activation for the excitation transfer reaction. We find a barrier height of 0.1 eV for this state, a value lower than any previously reported. The use of these more accurate potential curves still leads to serious discrepancies between calculations and experiment for the elastic scattering cross section and the coefficient of diffusion. The rate constant for the excitation transfer reaction, however, is in reasonable agreement with experiment over a wide range of temperatures.

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

¹F. A. Buckingham and A. Dalgarno, Proc. Roy. Soc. (London) A213, 506 (1952).

I-9. EXCITATION TRANSFER AND TOTAL SCATTERING IN COLLISIONS BETWEEN He(2^3S) AND He(1^1S) ATOMS.* *S. A. Evans and Neal F. Lane, Rice University.*

Excitation-transfer and total cross sections have been calculated for collisions between 2^3S and 1^1S helium atoms at energies (CM) of 0.01 to 500 eV. Using latest available adiabatic $^3\Sigma_u^+$ and $^3\Sigma_g^+$ potential curves, we find the calculated excitation-transfer cross section to increase monotonically with energy up to about 0.3 eV, attaining a value of about 1.4×10^{-15} cm². At higher energies the cross section is found to oscillate and, on the average, decrease with energy. The structure is seen to be closely related to the short-range nature of the difference between the $^3\Sigma_u^+$ and $^3\Sigma_g^+$ potential curves. In an attempt to simulate a possible "diabatic" collision, the adiabatic $^3\Sigma_g^+$ curve was replaced by a fully repulsive curve with the same asymptotic behavior but which, in the united atom limit, corresponds to the $1s^2 2p3p$ configuration of Be. The resulting excitation-transfer cross sections show somewhat higher-frequency oscillations, otherwise they are much the same. Structure in the total and differential cross sections will also be discussed.

*Work supported in part by U. S. Atomic Energy Commission.

I-10. DEACTIVATION CROSS SECTIONS FOR He* + He COLLISIONS.* *Manfred Hollstein, D. C. Lorents, and J. R. Peterson, Stanford Research Institute.*

The deactivation of fast metastable He atoms has been measured by optical techniques, over a range of kinetic energies from 100 to 1000 eV. The deactivation is believed to be dominated by energy transfer reactions. Whereas in our earlier studies¹ collisional ionization was used to indicate the presence of metastables in the beams, we have now measured the 5876Å ($3^3D \rightarrow 2^3P$) and 6678Å ($3^1D \rightarrow 2^1P$) emissions, which are excited whenever the fast metastable beams pass through a gas. The singlet radiation indicates a deactivation cross section which is about twice as large as that shown by the triplet line. The two cross sections bracket the earlier results, which were not state-selective. It appears that the radiations are consistent with spin conservation in the exciting collisions, and thus may be used as labels for the 1^1S and 3^1S metastable atoms in the beam.

*Work supported by the Advanced Research Projects Agency.

¹Manfred Hollstein, D. C. Lorents, and J. R. Peterson, *Bull. Am. Phys. Soc.* **13**, 197 (1968).

I-11. TRANSITIONS WITHIN THE ALKALI 2P STATE IN COLLISIONS WITH RARE GAS ATOMS.* *M. B. Hidalgo and S. Geltman*, Joint Institute for Laboratory Astrophysics.

Fine-structure collisional transitions in the 2P states of alkali atoms give rise to sensitized fluorescence and depolarization of resonance radiation. The cross sections for these transitions are being investigated in an impact parameter model^{1,2} in which the dominant interaction is Van der Waals, $V_{ij} = -1/2\alpha e^2 \langle r^2 \rangle R^{-6} \Lambda_{ij}(\theta)$. Straight-line paths are assumed for all collisions with impact parameter greater than the gas kinetic radius, and for smaller impact parameters a specularly reflected path is taken. The six coupled equations connecting all the j_m states in the doublet have been solved numerically and compared with the unitarized approximation. This latter approximation is found to be quite good for the strongest transitions ($|\Delta m| = 0, 2$) and poorer for the weaker ones ($|\Delta m| = 1, 3$). A unitarized "distortion" approximation is also being tried.

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

¹J. Callaway and E. Bauer, Phys. Rev. 140, A1072 (1965).

²H. I. Mandelberg, Proceedings of Conference on Heavy Particle Collisions, Belfast, 1968, p. 177.

I-12. COLLISIONAL MIXING IN ALKALI 2P STATES. *Hirsch I. Mandelberg*, Laboratory for Physical Sciences, University of Maryland.

Calculations have been made of the cross sections for transitions between the (J, M_J) components of the resonance 2P multiplets of the alkali metals Na, K, Rb, and Cs in collision with rare gas atoms. The method used is the semi-classical impact parameter treatment with a Van der Waals interaction potential. The resultant coupled equations are symmetrized as suggested by Seaton¹ and are solved by the approximate method of Callaway and Bauer.² Computer calculations were made so that the non-zero energy difference between the states, ignored in previous calculations, could be accounted for. Cross sections were calculated as a function of velocity and averaged over a Maxwellian distribution at temperatures from 350 K to 1000 K. The calculated values show the great range exhibited by the experimental measurements of these cross sections, as well as their tendency to decrease with increasing energy difference and reduced mass, although the agreement is only fair in detail.

¹M. J. Seaton, Proc. Phys. Soc. 79, 1105 (1962).

²J. Callaway and E. Bauer, Phys. Rev. 140A, 1072 (1965).

Na
K
Use Van der Waals $\frac{1}{R^6} \Lambda^2 P_a$
40-65-710
10-75

I-13. ADSORBATE EFFECTS IN ELECTRON EJECTION BY RARE GAS METASTABLE ATOMS. *T. A. DeLehar, D. A. MacLennan[†] and A. M. Landers^{††}*, General Electric Research and Development Center.

The effect of adsorbed layers of CO, N₂ and H₂ on the ejection of electrons by rare gas metastable atoms has been investigated for the following surfaces: the (111) and (110) planes of a tungsten single crystal and a principally (100) oriented polycrystalline tungsten ribbon. No correlation was found between changes in the ejected electron yield and the known work function changes accompanying adsorption. In those cases where the ejected electron yield was sharply reduced following adsorption (CO on all surfaces studied and N₂ on the (100) surface) the ejected-electron energy spectrum revealed a marked diminution of the number of high energy electrons. In the case of carbon monoxide on the (111) and (110) planes, there was essentially a "cut off" in the energy spectrum. The results are interpreted with a model in which bonding electrons from the adsorbed atom participate in the ejection process. The theory, applied to the data for CO, predicts that the CO bonding electrons lie 12.6 eV below the vacuum level. It is inferred also, that nitrogen atoms adsorbed on the (111) plane lie in the surface, while on the (100) plane they protrude from the surface.

[†]Present address: General Electric, Nela Park, Cleveland.

^{††}Present address: Massachusetts Institute of Technology, Cambridge, Mass.

SESSION J

Friday Morning, 18 October

8:30 a.m.

TRANSPORT PROPERTIES AND DISTRIBUTIONS

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

J-1. DIFFUSE BACKSCATTERING AND QUENCHING OF RESONANCE RADIATION IN Cs-N₂ MIXTURES.* C. L. Chen and A. V. Phelps, Westinghouse Research Laboratories.

The diffuse backscattering of resonance radiation at high Cs densities ($10^{15} - 10^{16}$ atom/cm³) is used to study the transport of resonance radiation and the quenching of atoms in the resonance states by foreign gases ($10^{16} - 10^{18}$ molecule/cm³). The Cs vapor is contained in a parallel plane geometry cell and is irradiated with white light. It appears that there are two major components of the backscattered radiation: a) the radiation reemitted by excited atoms before collisions redistribute the radiation in wavelength and b) the radiation which is collisionally redistributed throughout the resonance line and which eventually is radiated at a wavelength such that the radiation can escape from the cell.¹ Theoretical and experimental spectral distributions and integrated line intensities (equivalent widths) will be presented. The derived quenching rate coefficients for N₂ are in approximate agreement with the results obtained by McGillis and Krauss² at low Cs densities.

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

¹T. Holstein, Phys. Rev. 72, 1212 (1947); 83, 1159 (1951) and L. M.

Biberman, J. Exptl. Theoret. Phys. U.S.S.R. 17, 416 (1947).

²D. A. McGillis and L. Krauss, Can. J. Phys. 46, 1051 (1968).

J-2. THE EFFECT OF COULOMB COLLISIONS ON THE ELECTRON ENERGY DISTRIBUTION IN PARTIALLY IONIZED GASES. William L. Nighan, United Aircraft Research Laboratories.

Because of the efficiency of energy exchange in electron-electron collisions and the very large coulomb cross section at low energy, electron-electron collisions can significantly influence the electron energy distribution $f(u)$ in partially ionized gases for very low values of fractional ionization. This effect has been investigated in the present work by numerically solving the combined Boltzmann-Fokker-Planck equation for partially ionized gases for which reliable electron-neutral cross section data are available. The transition of $f(u)$ from the generalized Druyvesteyn distribution characteristic of electron-neutral collision dominance to the Maxwellian distribution typical of electron-electron collision dominance has been determined with degree of ionization α as the variable. In several experimentally interesting cases, electron-electron collisions have been found to influence $f(u)$ for values of α much lower than the values in the 10^{-4} to 10^{-2} range often suggested in the literature as a reasonable lower limit to the influence of coulomb collisions. The important effect of coulomb collisions is vividly illustrated in argon for average electron energies near the Ramsauer minimum. For this case, it has been found that electron-electron effects become important for values of α as low as 10^{-10} and result in a nearly Maxwellian distribution for α of about 10^{-7} .

J-3. TRANSPORT OF THERMAL ELECTRONS THROUGH POLAR GASES.* L. G. Christophorou, D. Pittman, and A. A. Christodoulides,† Health Physics Division, Oak Ridge National Laboratory.

Drift velocities (w) for thermal electrons in a large number of polar molecules (38) in the pure form, with dipole moments (μ) ranging from 0 to ~ 4.1 Debye units (D.u.), have been measured. These measurements allowed determination of mean scattering cross sections at thermal energies. For a number of polar molecules, w has been measured as a function of the temperature T . This allowed determination of the velocity (v) dependence of the momentum transfer cross section $\sigma_m(v)$ assumed to have the form

$$A/v^\alpha \text{ and } \frac{B}{v} + \frac{C}{v^2}$$

where A , B , and C are positive constants. This extensive study confirmed our earlier finding that the scattering of slow electrons by polar molecules is predominantly controlled by the long-range electric dipole field of the molecule. The point-dipole Born approximation calculation of Altshuler has been found to be in better agreement with experiment than the exact calculation of Mittleman and von Holdt. Further, the experimental cross sections have been found to be higher than those predicted by Altshuler for all $\mu \leq 2.4$ D.u. and smaller when $\mu \geq 2.4$ D.u., while their behavior at and around the minimum dipole moment, μ_{\min} , required to bind an electron to a dipole has been found to be complicated. The overall dependence of the experimental cross sections on μ has indicated the possible effect of the binding of an electron to a polar molecule (when $\mu > \mu_{\min}$) and the possible effect of a potential resonance as predicted by Takayanagi and Itikawa.

* Work supported by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

† Graduate student, University of Tennessee.

J-4. EXPERIMENTAL LONGITUDINAL ELECTRON DIFFUSION COEFFICIENTS IN He, Ar, Xe, D₂, N₂, and H₂O. J. L. Pack, R. E. Voshall and A. V. Phelps, Westinghouse Research Laboratories.

Values of the ratio of the longitudinal diffusion coefficient¹ D_L to the mobility μ for electrons in He, Ar, Xe, D₂, N₂ and H₂O have been obtained by analysis of the widths of electron current pulses observed during previous measurements² of electron mobility. As predicted,¹ using previously derived momentum transfer cross sections,³ the experimental D_L/μ values for Ar, Kr and Xe show a pronounced peak at values of electric field to gas density E/N where the values of the ratio of the transverse diffusion coefficient D_T to the mobility are increasing rapidly with E/N . Theory¹ shows that the occurrence of values of $(D_L/\mu)/(D_T/\mu)$ greater than unity near and below the peak of the D_L/μ vs E/N curve is caused by the rapid decrease in momentum transfer collision cross section with increasing electron energy at energies just below the Ramsauer minimum. Values of $(D_L/\mu)/(D_T/\mu) > 1$ are obtained in H₂O at E/N near $6 \times 10^{-16} \text{V-cm}^2$.

¹J. H. Parker, Jr. and J. J. Lowke, Bull. Am. Phys. Soc. 13, 201 (1968).

²J. L. Pack and A. V. Phelps, Phys. Rev. 121, 798 (1961) and J. L. Pack, R. E. Voshall and A. V. Phelps, Phys. Rev. 127, 2084 (1962).

³L. S. Frost and A. V. Phelps, Phys. Rev. 136, A1538 (1964).

J-5. EVIDENCE FOR MOLECULAR LOW-ENERGY RESONANCE SCATTERING STATES.*
Lothar Frommhold, University of Texas at Austin, and D. J. Kouri,
University of Houston.

A somewhat unexpected pressure dependence of the electron drift velocities in gases (H₂, D₂, N₂) has been observed by various authors (see reference 1). It is believed to be due to electron trapping molecular states, because alternative interpretations are inconsistent with the existing data. The assumed existence of rotational resonances in electron-molecule scattering does lead to a consistent, semi-quantitative description of the observations, if the lifetimes are taken to be $\sim 10^{-13}$ sec. The two resonance energy levels are somewhat below the $(J + 2)$ th. and $(J + 4)$ th rotational levels, if the rotator (molecule) is in the J th rotational state.² Hence, at electron energies near .01 eV, deuterium should and hydrogen should not exhibit a pressure effect, because D₂ does have and H₂ does not have a resonance level near .01 eV. Furthermore, both D₂ and H₂ should exhibit a strong effect at somewhat higher electron energies, near .04 eV. At much higher energies no noticeable effect due to these resonances is expected. Atomic gases (He) should not show a pressure effect. All these predictions are in agreement with experiments.^{1,3}

* Work supported by J.S.E.P.

¹L. Frommhold, Phys. Rev. 172, 118 (1968).

²D. J. Kouri, in preparation and J. Chem. Phys. 45, 154 (1966).

³R. W. Crompton, A. Robertson, in preparation.

J-6. MOBILITIES AND LONGITUDINAL DIFFUSION COEFFICIENTS OF MASS-IDENTIFIED NITROGEN AND POTASSIUM IONS IN NITROGEN.* J. T. Moseley, University of West Florida, R. M. Snuggs, D. W. Martin, and E. W. McDaniel, Georgia Institute of Technology, and T. M. Miller, New York University.

The mobilities and longitudinal diffusion coefficients, D_L , of N^+ , N_2^+ and K^+ ions have been measured at room temperature on the E/N range from 7 to $700 \times 10^{-17} \text{Vcm}^2$ at pressures from 0.02 to 1.00 Torr using a pulsed time of flight method. In addition, the mobilities of N_3^+ and N_4^+ have been measured on the E/N range from 2 to $40 \times 10^{-17} \text{Vcm}^2$. The drift tube mass spectrometer on which these measurements were made is (in most respects) the same as described by Albritton et al.,¹ except that more precise control of the ion swarm entering the drift tube is provided by an electric shutter. The mobilities are determined from the mean arrival time of the ion profiles¹ obtained from the apparatus. The longitudinal diffusion coefficients are determined from the shape of the profiles. The zero-field reduced mobilities of N^+ , N_2^+ , N_3^+ , N_4^+ , and K^+ were determined to be 2.97, 1.87, 2.26, 2.33, and 2.55 $\text{cm}^2/\text{V sec}$, respectively, and each of these values is believed to be free of the effects of ion-molecule reactions. The longitudinal diffusion coefficients were observed to have the value predicted from the mobility by the Einstein relation at low E/N and to increase as E/N was increased.

* Work supported by the U. S. Air Force Office of Scientific Research.
¹D. L. Albritton, T. M. Miller, D. W. Martin, and E. W. McDaniel, Phys. Rev. 171, 94 (1968).

J-7. TRANSVERSE DIFFUSION COEFFICIENTS AND ION-MOLECULE REACTION RATES OF MASS-IDENTIFIED NITROGEN AND POTASSIUM IONS IN NITROGEN.*

E. W. McDaniel, D. W. Martin and R. M. Snuggs, Georgia Institute of Technology, and J. T. Moseley, The University of West Florida.

The transverse diffusion coefficients, \mathcal{D}_T , of N^+ , N_2^+ and K^+ have been determined at room temperature on the E/N range from 12 to 500×10^{-17} Vcm². The reaction rate coefficients for the reactions $N^+ + 2N_2 \rightarrow N_3^+ + N_2$ and $N_2^+ + N_2 \rightarrow N_4^+ + N_2$ have been determined on the E/N range from 12 to 100×10^{-17} Vcm². Pressures from 0.02 to 0.4 Torr were used. These measurements were made on the same apparatus used to determine the mobilities and longitudinal diffusion coefficients discussed in the above paper, but a different type of data and analysis techniques were used. The variable drift distance of the apparatus was used to vary the residence time of the ions in the gas and the reaction rates and diffusion coefficients were determined from the resulting attenuation of the detected ion intensity as the residence time was increased. The reaction rate at low E/N for the N^+ reaction was determined to be 1.8×10^{-29} cm⁶/sec; for N_2^+ to be 5.0×10^{-29} cm⁶/sec. Both rates decreased slowly as E/N was increased. In each case, the data clearly supported a three-body process for the reaction. The transverse diffusion coefficients were in agreement with the Einstein relation predictions at low E/N, and increased as E/N was increased. In each case, for a given ion, $\mathcal{D}_T \leq \mathcal{D}_L$.

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

J-8. NEGATIVE ION MOBILITIES IN OXYGEN.* Carl Shafer and Earl Beaty,
Joint Institute for Laboratory Astrophysics.

A double shutter drift tube with a differentially pumped quadrupole mass spectrometer has been used to measure mobilities of negative ions in oxygen at room temperature. In addition to O^- , O_2^- , O_3^- and O_4^- , impurity ions of mass 46 and 60 (presumably NO_2^- and CO_3^-) have been found in sufficient quantities to permit measurement of their drift velocities. These measurements show that the previous ion identifications in pure oxygen are correct.^{1,2} For E/p_0 between 4 and 20 V/cm-Torr the ions of mass 46 and mass 60 have mobilities which are slightly higher and lower respectively than the mobility of O_3^- . The measured mobility of O_4^- ions is about the same or slightly higher than that of O_2^- . These results indicate that on the basis of mobility, O_2^- can be easily distinguished from O_3^- and the impurity ions of mass 46 and 60, but that it cannot be easily distinguished from O_4^- .

*Work supported in part by the Defense Atomic Support Agency and in part by the Advanced Research Projects Agency.

¹D. S. Burch and R. Geballe, Phys. Rev. 106, 183 (1957).

²H. Eiber, Z. Angew. Phys. 15, 103, 461 (1963).

J-9. TRANSPORT PROPERTIES OF METASTABLE $O(^1S)$ ATOMS. E. C. Zipf,
University of Pittsburgh.

The Lennard-Jones potential parameters for oxygen atoms in the metastable 1S state have been evaluated from measurements of the $O(^1S)$ diffusion coefficients in neon, argon and molecular oxygen. $O(^1S)$ atoms were produced in a periodically pulsed microwave discharge by the dissociative recombination of O_2^+ ions. Their temporal behavior was studied in the afterglow by observing the decay of the OI green line [$^1S \rightarrow ^1D$; $\lambda 5577 \text{ \AA}$] using digital time-sampling techniques and the effective lifetime of the metastable atoms was measured as a function of the gas pressure and the fundamental diffusion length of the discharge cell. Ultra-high vacuum gas-handling techniques were used to minimize the effects of impurities. From these data the following diffusion coefficients were deduced for $O(^1S)$ atoms in argon [$D = 260 \pm 6 \text{ cm}^2/\text{sec}$], in neon [$D = 410 \pm 10 \text{ cm}^2/\text{sec}$], and in oxygen [$D = 260 \pm 10 \text{ cm}^2/\text{sec}$] at 1 Torr and 298 °K. These results are consistent with a Lennard-Jones collision diameter $\sigma = 2.79 \text{ \AA}$ and a force constant $\epsilon/k = 35.7 \text{ }^\circ\text{K}$.

J-10. NON-MAXWELLIAN EQUILIBRIUM VELOCITY DISTRIBUTION OF THE FREE ELECTRONS IN A PLASMA. *O. Theimer and T. Wright*, New Mexico State University.

It is shown that the thermal equilibrium velocity distribution of the free electrons in a plasma has the non-Maxwellian form

$$F(v) = \text{Const} \exp(-mv^2/2kT) \int_{x_0}^{x_0+x_1} y^{-1} \exp(y) dy .$$

$$x_0 = e^2/r_0 kT , \quad x_1 = \left(\frac{1}{2} mv^2 + e^2/D\right)/kT ,$$

where r_0 is the average particle separation, D the Debye length, and e the electron charge. For a cesium plasma at 3000°K and 10^{16} cm^{-3} electron density the maximum of the distribution is displaced about 5% relative to the Maxwell distribution. Other consequences of the new distribution are discussed.

J-11. THE DETERMINATION OF THE SECONDARY ELECTRON DISTRIBUTION FUNCTION PRODUCED BY ENERGETIC PARTICLE BOMBARDMENT OF NITROGEN.*

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

Emission spectra induced by 5 MeV proton and 3 MeV electron bombardment of gaseous nitrogen and nitrogen-oxygen mixtures, pressure 1 to 800 Torr, have been found to be identical to each other and equivalent to spectra obtained by Davidson and O'Neil¹ as effected by 50 keV electron bombardment under comparable conditions. The principal bands in emission are N_2 second positive and N_2^+ first negative. If we assume that observed excitation processes are initiated by energetic electrons, then a knowledge of electron excitation emission cross sections, quenching cross sections and the quantitative emission data should provide the necessary information to obtain the secondary electron energy flux distribution, generally the only unknown function associated with such studies. We have performed the indicated emission and cross section measurements and have determined that the secondary electron distribution per $\text{cm}^2\text{-sec}$ is approximately proportional to $(1/E) dE$. The implication of these results for energetic particle irradiation of gases at high pressures will be discussed.

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

¹G. Davidson and R. O'Neil, J. Chem. Phys. 41, 3946 (1964).

SESSION K

Friday Afternoon, 18 October

2:00 p.m.

HEAVY PARTICLE COLLISIONS

Chairman: *Benjamin Bederson*, New York University,
New York, New York

K-1. ELASTIC DIFFERENTIAL SCATTERING OF H^+ , He^+ , AND He^{++} BY Ar.
R. S. Snyder, J. W. Boring and G. D. Magnuson, University of Virginia.

Elastic differential scattering measurements of H^+ , He^+ , and He^{++} on Ar have been obtained at relative energies from 100 eV to 2 keV and scattering angles of 0.25° to 20° . The experimental system includes a low pressure ion source,¹ a magnet section for mass analysis of the ion beam and a cylindrical 127° electrostatic analyzer for energy analysis of the scattered particles. The energy spread of the beam due to the ion source is $0.6 \text{ eV} \pm 0.3 \text{ eV}$ FWHM, the energy resolution of the electrostatic analyzer is 0.3% and the angular resolution of the system is 0.02° . Elastic differential scattering cross sections for He^+ on Ar will be compared for various energies with those of Aberth and Lorents.² Elastic differential scattering cross sections for H^+ and He^{++} on Ar and a potential to describe the interactions will be presented.

¹C. E. Carlston and G. D. Magnuson, *Rev. Sci. Instr.* **33**, 905 (1962).

²W. Aberth and D. C. Lorents, *Phys. Rev.* **144**, 109 (1966).

K-2. DIFFERENTIAL ELASTIC SCATTERING OF LOW ENERGY PROTONS BY He AND Ar ATOMS.* *F. A. Herrero, E. M. Nemeth, and T. L. Bailey, University of Florida.*

Relative differential cross sections for elastic scattering in the systems $H^+ - He$ and $H^+ - Ar$ have been measured at a number of collision energies in the range 5-50 eV. The experiments are of the ion-beam gas-scattering type, and employ a mass spectrometer ion gun for production of primary H^+ ions. Elastically scattered H^+ ions emerging from the scattering region are distinguished from inelastically scattered H^+ (and other ions) by electrostatic retardation, and are detected with an electron multiplier. The effective angular resolution is approximately $\pm 1^\circ$. For both the $H^+ - He$ and $H^+ - Ar$ systems, plots of relative differential cross sections versus scattering angle show pronounced oscillatory structure. We believe that this structure arises from rainbow scattering, since its behavior is in qualitative agreement with the semiclassical description of this phenomenon. Interpretation of the experimental results, using semiclassical scattering theory and an assumed three parameter, 12-6-4, effective potential gives well-depths for the $H^+ - He$ and $H^+ - Ar$ which agree fairly well with currently accepted values. However, the equilibrium internuclear separations obtained in this manner differ markedly from the expected results. Further interpretation, using more realistic assumed potentials, will be discussed.

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

K-3. He⁺(2S)-He INELASTIC COLLISIONS.* C. J. Artura, R. Novick,
and N. Tolk,[†] Columbia University.

In the course of studying the two-photon spectrum using single-photon counting techniques, radiation due to the impact of low-energy metastable singly ionized helium on helium and on the other rare gases has been detected. This is the first experimental study of very low-energy ion-atom excitation where one of the collision partners is initially in an excited state. For the He⁺(2S) on He case, above 50 eV of ion beam energy, preliminary results indicate that at least one third of the entire signal arising in the visible part of the spectrum is caused by the 4713-Å (4³S-2³P) line of He I. We have made initial attempts to understand these measurements in terms of the molecular potential-curve-crossing model. In this model, the ground-state and excited-state potential-energy curves of the He⁺-He molecular system viewed as a function of internuclear separation R have points of pseudocrossings among the various levels. During the collision as R decreases and passes the points of pseudocrossings, the system can evolve into any of the participating states. The interference of the various possible paths leading to the same final excited state is believed to result in the observed energy peaks and other oscillatory structure.

* Work supported in part by the Joint Services Electronics Program and in part by the National Aeronautics and Space Administration.

[†] Present address: Bell Telephone Laboratories, Inc., Whippany, N. J.

K-4. EXCITATION OF METASTABLE ATOMS IN LOW-ENERGY ARGON ION-ATOM COLLISIONS.* R. C. Anne and P. O. Haugsjaa, University of Denver, and N. G. Utterback, AC Electronics, General Motors Corporation.

Metastable argon atoms in a beam formed by a symmetric charge transfer have been detected by the process of Penning ionization of acetylene. Beam energies ranged from threshold for the (2P_{3/2})4s configuration (23 eV) up to 100 eV. A relative maximum in the excitation cross section is observed at a beam energy of 30 eV, or about 3.5 eV above threshold in the Ar-Ar c.m. system. The energy dependence of the Penning cross sections, upon which these measurements depend, is assumed to be given by the deactivation cross sections for Ar* in C₂H₂ reported by Hollstein *et al.*¹ With this assumption, the excitation cross section is estimated to be $2 \times 10^{-3} \text{ \AA}^2$ at 30 eV. The relative concentration of the metastable neutral beam component is thus about 0.004% at this energy.

* Work supported by the National Aeronautics and Space Administration.

¹M. Hollstein, D. C. Lorents, J. R. Peterson, and R. A. Young,

"Research on Metastable Species in Atomic and Molecular Beams Produced by Charge Transfer," SRI Semi-Annual Report, 27 Dec. (1967), Menlo Park, Calif.

K-5. IONIZING COLLISIONS BETWEEN NEUTRAL ATOMS: Ne-Ne, Ar-Ar, AND Kr-Kr.* *P. O. Haugsjaa and R. C. Amme, University of Denver.*

Neutral beams of the noble gases neon, argon, and krypton have been used to study the total cross section for ionization in symmetric collisions as a function of incident energy. Of special concern was the behavior near threshold. For the case of argon atoms colliding with argon atoms, hydrogen gas was used to neutralize the argon ion beam in order to assure a ground-state atomic beam. Although the neon-neon ionization cross section is found to be a smoothly varying quantity from about 60 eV to 2000 eV, there is considerable structure in the cross section curves for Ar-Ar and Kr-Kr collisions. Results are shown as a function of the center-of-mass energy in excess of the respective ionization potentials, and compared with results at higher energies by other investigators.^{1,2}

* Work supported by the National Aeronautics and Space Administration.

¹V. V. Afrosimov, R. N. Il'in, V. A. Oparin, E. S. Solov'ev, and N. V. Federenko, *J. Expt'l. Theoret. Phys. (USSR)* 41, 1048 (1961).

²I. P. Flaks, *Zhur. Tekh. Fiz.* 31, 367 (1961).

K-6. EMISSION CROSS SECTIONS FOR SODIUM D LINES IN COLLISIONS WITH ATOMS AND MOLECULES. *Charles A. Boitnott and Howard F. Savage, NASA - Ames Research Center.*

Emission cross sections have been measured for the D lines of sodium resulting from collisions with various molecules, atoms, and ions. Energetic beams of argon, helium, oxygen, and nitrogen with energies between 300 and 2000 eV are crossed with a thermal sodium beam and the resulting radiation detected by a photomultiplier-optical filter combination. The measured cross sections were found to be of the order of 10^{-15} cm², and to decrease with decreasing energy. Cross sections for interactions involving ions were greater, by a factor of about 10 at the lower energies, than those involving neutrals.

K-7. VIBRATIONAL EXCITATION IN ION-MOLECULE COLLISIONS.* *John H. Moore, Jr. and John P. Doering, Johns Hopkins University.*

Relative band intensities have been measured for four bands of the $\Delta v = -1$ sequence (λ 4278 Å) of the N_2^+ first negative system produced in ion-molecule collisions in order to study the vibrational population of the $B^2\Sigma^+$ state of N_2^+ as a function of excitation conditions. H^+ , H_2^+ , He^+ , N^+ , and Ne^+ ions with energies of 100 eV to 10 keV as well as 150 eV electrons have been used in these experiments. The apparatus was a "multi-stage" device in which ions were withdrawn at a high voltage from a duoplasmatron ion source, magnetically mass analyzed, and focused and decelerated to the desired final energy. The ion beam then entered a collision chamber which was closely coupled to a 1.0 meter Fastie-Ebert monochromator. Ion currents of 2 to 50 μA were used. The results indicate that vibrational excitation is solely a function of the projectile laboratory velocity without regard for its chemical nature. At velocities greater than 2×10^8 cm sec⁻¹ the vibrational energy distribution of the $B^2\Sigma^+$ state agrees with that predicted by the Franck-Condon principle. Below this velocity the populations of states with $v' > 0$ increase monotonically with increasing duration of the ion-molecule encounter. At the lowest projectile velocity the population of the $v' = 1$ state is nearly equal to that of the $v' = 0$ state and the populations of the $v' = 2$ and $v' = 3$ states are several orders of magnitude greater than predicted by the Franck-Condon principle.

*Work supported by the National Science Foundation.

K-8. DE-EXCITATION OF EXCITED NO^+ IONS.* *R. F. Mathis, B. R. Turner and J. A. Rutherford, Gulf General Atomic Incorporated.*

The cross section for the de-excitation of excited NO^+ ions (which are long-lived excited electronic states) during collisions with neutral NO molecules has been measured. In this experiment, all of the metastable states are treated in the aggregate; however, it is probable that most of the excitation was to the $^3\Sigma^+$ state and much of the remainder of the $^3\Delta$ state. The de-excitation reaction occurred at near thermal energy in a mass spectrometer ion source. The composition of the NO^+ ion beam from the source was analyzed in terms of ground and excited states using an attenuation technique which has been described previously.¹ From the dependence of the composition upon the pressure in the ion source, the cross section for de-excitation was calculated and found to be $3.3 \pm 2.0 \times 10^{-15}$ cm².

*Work supported by the Defense Atomic Support Agency.

¹B. R. Turner, J. A. Rutherford, and D. M. J. Compton, *J. Chem. Phys.* 48, 1602 (1968).

K-9. POST-COLLISION CHARGE STATES IN O^+ + Ar SCATTERING AT 50-100 keV. *
Felton W. Bingham, Sandia Laboratory.

A recent study¹ of O^+ + Ar collisions has used coincidence techniques to measure distributions of Q , the energy transferred to inelastic processes, at a number of values of r_0 , the distance of closest approach of the colliding particles. A continuation of this study at bombarding energies of 50 and 100 keV has provided values of \bar{m} , the average charge in the scattered oxygen-ion beam, as a function of r_0 ; the \bar{m} values increase slowly as r_0 decreases from 0.24 to 0.09 Å. For r_0 between 0.11 and 0.2 Å the Q distributions consist of two partially overlapping Gaussian curves¹ with average values Q^I and Q^{II} . In this region \bar{m} values have been determined separately for collisions characterized by the two energy transfers Q^I and Q^{II} . Surprisingly, \bar{m} is the same for either of these values, although the extra energy transferred in the Q^{II} collisions is 100-200 eV. This extra energy apparently goes into promotion of an argon L-shell electron and subsequent electron ejection; it does not, on the average, go into further ionization of the oxygen ion.

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

¹F. W. Bingham, Bull. Am. Phys. Soc. 13, 613 (1968).

K-10. COINCIDENCE MEASUREMENTS OF INELASTIC ENERGY LOSSES IN 1 MeV, Ne^+ - Ne AND Ne^+ - Ar COLLISIONS. *Quentin C. Kessel, High Voltage Engineering Corporation.*

Coincidence techniques have been used to measure the average inelastic energy losses occurring for large angle collisions of 1 MeV neon ions with neon atoms and argon atoms. The angular range investigated includes scattering from 4° to 20° in the laboratory system. The inelastic energy losses for these collisions are found to increase gradually as the scattering angle is increased. Inelastic energy losses between 1 and 2 keV were measured for the Ne^+ - Ne collisions, and losses between 1.5 and 2 keV were measured for the Ne^+ - Ar collisions.

SESSION L

Friday Afternoon, 18 October

2:00 p.m.

ATOMIC AND MOLECULAR STRUCTURE AND
PHOTON-ATOM INTERACTION

Chairman: *Chun C. Lin*, University of Wisconsin,
Madison, Wisconsin

L-1. THE N_2O^- POTENTIAL CURVES ARISING FROM $O^-(^2P) + N_2(X^1\Sigma_g^+)$.
E. E. Ferguson, ESSA Research Laboratories.

Information is presently available to allow qualitative descriptions of the three N_2O^- electronic states which correlate with ground state O^- and N_2 . The observations of Phelps and Voshall on thermal electron attachment to N_2O implies a ground state N_2O^- curve below $N_2O X^1\Sigma^+$ in the linear configuration. By the Walsh rules for molecular geometry, this X state of N_2O^- will lower its energy for a non-linear shape. The N_2O adiabatic electron affinity must therefore be appreciable, probably $> 1/2$ eV. The X state of N_2O^- is probably a $^2\Pi$ state in the linear configuration. The removal of degeneracy upon bending suggests the existence of a stable excited state (A) of N_2O^- , roughly $1/2$ eV above the ground state, with a less bent geometry. The very low appearance potential for O^- in the dissociative-attachment of N_2O , implies that the second excited state (B) of N_2O^- is repulsive for linear N_2O^- . The very slow associative-detachment of O^- and N_2 , $k < 10^{-14}$ cm³/sec, requires that this B state not decrease energy rapidly with angle bending and also supports the arguments on the X and A states. These potential curves are compatible with the generalized orbital level diagrams given by Herzberg.

L-2. RKR FRANCK-CONDON FACTORS FOR THE DIATOMIC MOLECULES COMPOSED OF C, N, O, AND H ATOMS.* D. L. Albritton and A. L. Schmeltekopf, ESSA Research Laboratories, and R. N. Zare, Joint Institute for Laboratory Astrophysics.

Franck-Condon factors have been computed for a number of transitions between the electronic states of the molecules C_2 , CN, CO, CH, N_2 , NO, NH, O_2 , OH, H_2 , and corresponding ions. The body of spectroscopic data for these molecules was collected and assessed, and the calculations were confined to those electronic states for which accurate and independent sets of measured vibrational level spacings and rotational constants are available. Rydberg-Klein-Rees potential energy curves were constructed for these states from a weighted least-squares fit to the spectroscopic data. Direct numerical solution of the radial Schrödinger equation gave vibrational wave functions which, in turn, led to the Franck-Condon factors. A comparison of the calculated and measured vibrational energy spacings shows that these RKR potentials reproduce the spectroscopic data within the experimental errors. The flexibility exists to perform these calculations for isotopic molecules or different rotational states. For each molecular species, Franck-Condon factors are reported for the possible combinations of (a) the ground and excited electronic states of the neutral and ion separately (absorption and emission), (b) the ground state of the neutral and the various states of the ion (ionization), and (c) the ground state of the ion and the various states of the neutral (recombination).

* Work supported in part by the Defense Atomic Support Agency.

L-3. RADIATIVE LIFETIMES OF Ne I RESONANCE LINES. G. M. Lawrence
and Harvey S. Liszt, Douglas Advanced Research Laboratories.

Pulsed electron measurements of radiative lifetimes yield 1.87 ± 0.18 nsec for the 735.895\AA line of Ne I and 31.7 ± 1.6 nsec for the 743.718\AA (triplet) line. An extrapolation to zero pressure was made. These values confirm the Hartree-Fock calculations of Gold and Knox. The f -values implied by these lifetimes are in good agreement with the generalized f -value results of Geiger, which gives support to the use of the Born approximation for normalization of cross sections at high energy. A rigorous cascade analysis of the decay curves yields cascading fractions for the $3p$ - $3s$ cascade which are an order of magnitude less than the corresponding $4p$ - $4s$ cascades in Ar I. Similar results for the higher series levels, $4s$, $5s$, and $3d$ have been obtained.

L-4. THE CONFIGURATION MIXING OF CONTINUUM STATES. Antonio J.
Mendez, Northrop Corporate Laboratories.

There are conceptual advantages to the description of spectroscopic data in terms of configurations, even for spectra strongly influenced by autoionization. For this reason Fano's treatment¹ of autoionization as a case of configuration mixing of discrete and continuum states has proven popular among experimentalists. In this paper the formalism which Fano uses for discrete-continuum state mixing is applied to the configuration mixing of continuum states. The continuum eigenfunctions χ are written as linear combinations: $\chi_E = a(E)\psi_E + P \int a(E, E')\psi_{E'} dE'$, where $H_0|\psi_E\rangle = E|\psi_E\rangle$ and $(H_0 + H')|\chi_E\rangle = E|\chi_E\rangle$. This procedure leads to an integral equation for the expansion coefficients. The iterations of this equation generate the same correction terms as the reaction matrix approach;² the expansion involves the "continuum level shift," $f(E, E') = P \int V_{E''} V_{E'E} V_{E''E'} (E - E')^{-1} dE''$. This parameter is discussed in light of Altick's calculations;³ the extension to several continua is given.

¹U. Fano, Phys. Rev. 124, 1866 (1961).

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³P. L. Altick, and A. E. Glassgold, Phys. Rev. 133, A632 (1964).

L-5. OSCILLATOR STRENGTHS OF SPECTRAL LINES OF NEUTRAL AND SINGLY IONIZED SILICON. *Erhard Schulz-Gulde*,[†] Universität Kiel.

The emission spectra of a cascade arc operated at atmospheric pressure in argon containing small admixtures of SiCl_4 or SiCl_3 and hydrogen have been analyzed under the assumption that local thermodynamic equilibrium is established in the arc. The radial temperature distribution has been calculated from the experimentally determined radial emission coefficients of ArI lines and from the known values of the transition probabilities. The radial electron pressure distribution has also been obtained from the measured radial profiles or halfwidths of the Stark broadened H_β and ArI 6032 Å lines. Relative oscillator strengths for 48 SiI and SiII lines were obtained from the corresponding emission coefficients. In addition, an absolute calibration of the relative f -values was attempted using the remaining experimental data. The absolute f -values are partly in agreement with those given by other experimentalists. However, major discrepancies occur between the f -values for SiI lines determined in the present study and the f -values calculated using the Coulomb approximation method and the assumption of L,S-coupling.

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L-6. CHARGE TRANSFER CONTRIBUTION TO THE INTERACTION ENERGY OF ION/ATOM SYSTEMS. *M. J. Redmon*,[†] Valdosta State College, and *M. G. Menendez*, Martin Marietta and Rollins College.

A model for the interaction potential between two singlet-S atoms has been developed¹ which attempts to account for charge exchange forces. The attractive exchange contribution is calculated using Mulliken's second order perturbation theory treatment of charge transfer in molecules.² The model is applied to alkali ion/inert gas systems and it is shown that the charge exchange contribution to the interaction potential is sufficiently large to account for the observed stability of these molecular ions.³ The electron cloud repulsive term is calculated using Firsov's theory of interacting Fermi-Thomas-Dirac atoms.⁴ The parameters of previous models are eliminated except one which is adjusted by insisting that the interaction potential be essentially equal to the calculated repulsive term at small internuclear distances. The criterion for determining the validity of the parameter adjustment will be examined and interaction potentials for the alkali ion/inert gas systems will be presented.

[†]Present address: University of Florida, Gainesville.

¹M. J. Redmon, thesis, Rollins College.

²R. S. Mulliken, *J. Am. Chem. Soc.* 74, 811 (1952).

³Z. Herman and V. Čermák, *Nature* 199, 588 (1963).

⁴Adolf A. Abrahamson, *Phys. Rev.* 133, A990 (1964).

L-7. ULTRAVIOLET ABSORPTION IN CESIUM-SEEDED HYDROGEN.* *Paul J. Freyheit, Sperry Rand Research Center, David W. Norcross, University College, London, and Philip M. Stone, The State University of New York at Buffalo.*

The influence of cesium-seed fraction on the ultraviolet photoabsorption coefficient of a cesium-hydrogen plasma is determined over the pressure range from 0.1 to 100 atmospheres. Plasma temperatures from 5,000°K to 20,000°K, and cesium-hydrogen ratios of 10^{-1} , 10^{-2} , 10^{-3} and zero are investigated, maintaining a constant electron density. The plasma photoabsorption coefficient is calculated in the ultraviolet region (4.0 - 25.0 eV). The most pronounced effect is due to the bound-free absorption of cesium at energies below the hydrogen ionization energy. This effect is important at low plasma temperatures.

*Work supported by NASA Electronics Research Center, Cambridge, Mass.

L-8. THE PHOTOIONIZATION CROSS SECTION OF CADMIUM. *R. Bryan Cairns, Halstead Harrison, and Richard I. Schoen, Boeing Scientific Research Laboratories.*

Relative values of the photoionization cross section of cadmium have been measured in the wavelength range from threshold 1379 Å to 247 Å. Details of the experimental method and the results will be presented. The experiment involves the mass analysis and subsequent detection of ions found by the interaction of dispersed vacuum ultraviolet radiation with a modulated cadmium atomic beam. Strong absorption in the neighborhood of several of the autoionizing transitions ($4d \rightarrow np$, $4d \rightarrow nf$) was observed. The cross section increases monotonically toward shorter wavelength in the spectral region below the threshold for removal of a 4d electron.

L-9. HIGHER IONIZATION POTENTIALS OF MOLECULES DETERMINED BY PHOTO-ELECTRON SPECTROSCOPY. *James A. R. Samson, GCA Corporation.*

The photoelectron spectrum of NO, CO, CO₂ has been obtained at wavelengths of 469.8 Å (26.39 eV) and 416.2 Å (29.79 eV). In the case of NO a higher ionization potential was observed at 21.57 eV. No level was found corresponding to the Tanaka α -series at 14.23 eV. However, an ionization potential was found at 15.52 eV. For CO and CO₂ no new ionization potentials were found up to the limiting photon energy of 29.79 eV. Mulliken has predicted a higher ionization potential for the ejection of the 1 σ electrons at an energy less than 32 eV.

L-10. PROTON EXCITATION OF THE ARGON ATOM. *G. S. Hurst and T. E. Bortner*, University of Kentucky, and *T. D. Strickler*, Berea College.

Studies of the excitation of argon with 4 MeV protons have been carried out by making use of a vacuum ultraviolet scanning monochromator and a 6 MeV Van de Graaff accelerator. Four continua near 2100 Å, 1900 Å, and 1300 Å, and 1100 Å, respectively, were observed. These four continua, as well as escape radiation originating from the 1048 Å resonance line, were studied as a function of pressure. Studies of the intensity of the four main continua (per unit of proton power dissipation) as a function of pressure led us to the conclusion that each continuum has a separate atomic precursor. We suggest that the 1300 Å continuum and the 1100 Å continuum are dissociative diatomic continua, and originate from the 1P_1 (11.83 eV) and the 3P_1 (11.62 eV) resonance atomic states, respectively. We tentatively suggest that the continua near 2100 Å and near 1900 Å are recombination spectra involving the formation of argon excimers with binding energies of about 4 eV. The 1300 Å and the 1100 Å continua have been observed in gas discharges but these were interpreted as a single continuum originating from the 3P_1 state. We believe that the present experimental method, which makes possible gas kinetic observations at spectroscopically defined photon energies is indeed a powerful tool for the study of atomic and molecular structure and processes.

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