23rd Annual Gaseous Electronics Conference

Second Arc Symposium

Published with the support of
The Connecticut Research Commission

A TOPICAL CONFERENCE OF THE AMERICAN PHYSICAL SOCIETY
ASSISTED BY UNITED AIRCRAFT RESEARCH LABORATORIES
OCTOBER 20-23,1970 IN HARTFORD, CONNECTICUT

P. Burch
Ne paper
George Lawrence

Diss. $e + N_2 \rightarrow X^* + X$

(a) $\sigma(E)$ Threshold–100 eV
Aurora " – 1 keV

PROGRAM

(b) $f(v)$
1. Thermal economy (atm. not hot)
2. ~~Hot~~ atom chem.

$O(^1S), O(^1D), N(^2P), N(^2D)$

c. X(resonance), O, N
trapped rad.

TWENTY-THIRD ANNUAL

GASEOUS ELECTRONICS CONFERENCE

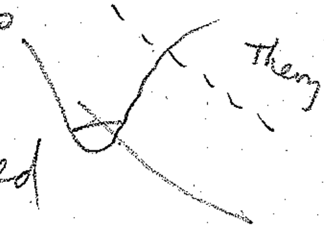
AND

SECOND ARC SYMPOSIUM

$e + N$
$e + O$
Dissociative Recom.
$e + O_2^+ \rightarrow O^* + O$
$^1S, ^1D$

Theory said unlikely $^1S + ^3P$, but expt. said yes

NO^+ ionosphere
O^+ Many bands NO
$\sigma(E)$
Processes leading to vibrationally excited species by e impact



OCTOBER 20-23, 1970

PROGRAM

SECOND ARC SYMPOSIUM

REGISTRATION

On the Mezzanine Level of the Hartford Hilton:

Monday, October 19:	4:00 p.m. - 10:00 p.m.
Tuesday, October 20:	8:00 a.m. - 10:00 p.m.
Wednesday, October 21:	8:00 a.m. - 6:00 p.m.

(See GEC Program for remainder of schedule.)

Tuesday, October 20

9:00 a.m. - 11:00 a.m.: Terrace Room

SESSION A. THERMODYNAMIC AND TRANSPORT PROPERTIES

Chairman: J. J. Lowke
Westinghouse Research

A1. CONSIDERATION OF SIMPLE MODEL ATOMS FOR ARGON DISCHARGE CALCULATIONS
J. R. Rose and J. V. Dugan, Jr.

A2. PRESSURE DEPENDENCE OF THE POPULATION DENSITY OF ENERGY LEVELS IN He-ARCS
J. Uhlenbusch and L. Detloff

A3. THE DETERMINATION OF PLASMA ELECTRON DENSITY FROM REFRACTION MEASUREMENTS
P. W. Schreiber, A. M. Hunter, and D. R. Smith

A4. DETERMINATION OF ELECTRON DENSITY AND TEMPERATURE IN A NON-LTE HELIUM ARC
W. G. Braun, J. W. Birkeland, and R. D. Franklin

10:10 a.m. - 10:30 a.m.: Coffee Break

A5. HIGH PRESSURE ARGON ARCS
U. H. Bauder

A6. TRANSPORT PROPERTIES OF PARTIALLY IONIZED ARGON - REVISION AND EXTENSION
R. S. Devoto

11:00 a.m. - 11:50 a.m.: Terrace Room

SESSION B. RADIATIVE PROPERTIES

Chairman: J. Yos, AVCO, Wilmington

B1. THE VACUUM ULTRAVIOLET CONTINUUM OF DOUBLY IONIZED ARGON
J. C. Morris

B2. MEASUREMENTS OF ELECTRON BROADENED WIDTHS OF ATOMIC NITROGEN LINES
R. U. Morris and J. C. Morris

B3. TRANSITION PROBABILITIES FOR SULFUR LINES FROM WALL-STABILIZED ARC MEASUREMENTS
E. Schulz-Gulde

B4. SPECTRAL CHARACTERISTICS OF THE HIGH CURRENT, LOW PRESSURE MERCURY DISCHARGE
P. D. Johnson

11:50 a.m. - 12:10 p.m.: Terrace Room

ARC BUSINESS MEETING

Chairman: A. V. Phelps
JILA
University of Colorado

2:00 p.m. - 4:20 p.m.: Terrace Room

SESSION C. VACUUM ARCS

Chairman: G. Frind
General Electric
Philadelphia

INVITED SPEAKER G. H. Ecker
Ruhr-Universität Bochum

RECENT DEVELOPMENTS IN THE THEORY OF THE VACUUM ARC

C1. ENERGY DISTRIBUTIONS OF IONS FROM PULSED VACUUM ARCS
J. T. Grissom and G. W. McClure

3:10 p.m. - 3:30 p.m.: Coffee Break

C2. PLASMA EXPANSION INTO A FIELD-FREE VACUUM ENVIRONMENT
D. L. Mangan

C3. THE TEMPERATURE MEASUREMENT OF CATHODE SPOTS IN VACUUM ARCS
T. Utsumi

C4. A MODEL FOR THE VACUUM ARC
M. F. Hoyaux

4:20 p.m. - 5:20 p.m.: Terrace Room

SESSION D. TRANSIENT ARCS Chairman: W. C. Roman
United Aircraft
Research Laboratories

D1. TIME RESOLVED SPECTROSCOPIC INVESTIGATION OF SHORT GAP DISCHARGES
J. A. Augis and E. W. Gray

D2. LINE INTENSITY BEHAVIOR IN A DECAYING ARC PLASMA
J. B. Shumaker, Jr. and W. H. Venable, Jr.

D3. THE TRANSIENT BEHAVIOR OF A DC ARC RELEVANT TO A DC "SWITCHING OFF" PROBLEM
V. Fuchs

D4. RATES OF EXCITATION AND IONIZATION IN ARCS
A. R. Fairbairn

7:00 p.m. - 10:00 p.m.: Terrace Room

GEC AND ARC MIXER (cash bar)

Wednesday, October 21

8:30 a.m. - 11:30 a.m.: Boston/Buffalo/New York Rooms

SESSION E. STEADY STATE AND RF ARCS Chairman: D. R. Keefer
University of Florida

E1. THERMODYNAMICS AND KINETICS OF CHLORIDE ARCS
D. M. Speros and R. M. Caldwell

E2. TIN CHLORIDE ARC TEMPERATURE MEASUREMENTS
R. H. Springer and R. P. Taylor

E3. MODE SHIFT IN MOLECULAR VAPOR ARCS
R. J. Zollweg

E4. THE MASON DARK SPACE AND HIGH PRESSURE ARC RE-IGNITION
J. E. White

E5. LOCAL HEAT TRANSFER TO WIRES IMMERSED IN AN ARC PLASMA
T. W. Petrie and E. Pfender

E6. EFFECTS OF ELECTRON TEMPERATURE VARIATIONS ON SPECTRAL LINE INTENSITY RATIOS
R. F. Weber and A. Garscadden

10:00 a.m. - 10:20 a.m.: Coffee Break

E7. COMPUTER MODEL OF A WALL-STABILIZED METAL VAPOR ARC
A. J. Froelich, D. S. Becker, and F. C. Francl

E8. EXPERIMENTAL STUDY OF AN ARGON PLASMA VORTEX SEEDED WITH XENON
A. E. Mensing

E9. INVESTIGATION OF A HIGH-INTENSITY RF RADIANT ENERGY SOURCE
W. C. Roman

E10. MEASUREMENT OF THE RF MAGNETIC FIELD DISTRIBUTION IN A THERMAL INDUCTION PLASMA
H. U. Eckert

11:45 a.m. - 12:30 p.m.: Capitol Ballroom

PLENARY SESSION — Chairman: W. P. Allis, Massachusetts Institute of Technology

HOLLOW CATHODE DISCHARGES AND APPLICATION TO ION LASERS
J. L. Delcroix

2:00 p.m. - 3:25 p.m.: Boston/Buffalo/New York Rooms

SESSION F. FLOW EFFECTS — Chairman: D. M. Benenson, State University of New York, Buffalo

F1. EXPERIMENTAL INVESTIGATION OF FLOW IN AN INDUCTION PLASMA
J. D. Chase

F2. NON-VORTEX STABILIZED ELECTRODELESS ARCS
D. R. Keefer, P. J. Gross, R. E. Martin, and J. C. Swingle

F3. TURBULENT CHARACTERISTICS OF A PLASMA JET PRODUCED BY A VORTEX-STABILIZED ARC
A. K. Ghosh, C. Richard, and T. W. Johnston

F4. A RELAXATION METHOD OF CALCULATING PROPERTIES OF CONVECTION STABILIZED ELECTRIC ARCS
J. J. Lowke

F5. A VOLTAGE CORRELATION FOR FREE-BURNING ARCS WITH TRANSPIRATION COOLED ANODES
J. R. Mahan and C. J. Cremers

3:25 p.m. - 3:45 p.m.: Coffee Break

3:45 p.m. - 4:55 p.m.: Boston/Buffalo/New York Rooms

SESSION G. MAGNETIC FIELD EFFECTS Chairman: H. O. Schrade
Aerospace Research
Laboratories, WPAFB

G1. HEAT TRANSFER FROM A MAGNETICALLY-BALANCED ELECTRIC ARC TO A CROSS-FLOW STREAM
L. S. Han, W. C. Roman, and D. H. Kihara

G2. EXPERIMENTS ON MAGNETICALLY BALANCED CROSS-FLOW ARCS
A. J. Baker and D. M. Benenson

G3. ANALYSIS OF MAGNETICALLY BALANCED CROSS-FLOW ARCS
V. R. Malghan and D. M. Benenson

G4. MAGNETIC PUMPING EFFECTS IN GAS-BLOWN SF_6 ARCS
J. F. Perkins and L. S. Frost

G5. "HOT" ELECTRODE STUDIES IN A SUPERSONIC PLASMA STREAM WITH A MAGNETIC FIELD
M. A. Mantenieks

5:00 p.m. - 9:00 p.m.: United Aircraft Research Laboratories

UARL TOUR AND BUFFET SUPPER

Buses will leave from the front entrance of the Hartford Hilton starting at 5:00 p.m. A ticket for each person (no charge) should be obtained from the Meeting Cashier by noon, and presented at the bus. Please do not bring photographic or sound recording equipment.

Thursday, October 22

(See GEC program for technical sessions.)

5:00 p.m.: Glastonbury Hills Country Club

BANQUET AND RECEPTION

Chairman: Dr. George J. Schulz
Professor of Applied Science
Yale University

Welcoming Remarks: Mr. Charles M. Kearns, Jr.
Vice President for Research
United Aircraft Corporation

Principal Speaker: Dr. Rolf M. Sinclair
Program Director for Atomic, Molecular, and Plasma Physics
National Science Foundation

Topic: "Federal Support of Atomic Physics, and the National Science Foundation"

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Friday, October 23

(See GEC program for technical sessions.)

PROGRAM

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GASEOUS ELECTRONICS CONFERENCE

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Thursday, October 22:	8:00 a.m. - 6:00 p.m.
Friday, October 23:	8:00 a.m. - 6:00 p.m.

Tuesday, October 20

(See ARC Program for technical sessions.)

7:00 p.m. - 10:00 p.m.: Terrace Room

GEC AND ARC MIXER (cash bar)

Wednesday, October 21

8:30 a.m. - 10:00 a.m.: Capitol Ballroom

SESSION H. GLOW DISCHARGES

Chairman: W. J. Wiegand
United Aircraft
Research Laboratories

H1. RADIAL DENSITY DISTRIBUTION MEASUREMENTS OF NEUTRAL Cs IN THE POSITIVE COLUMN OF A Cs-Ar DC DISCHARGE
H. V. Tongeren and C. V. Trigt

H2. THE RADIAL DISTRIBUTION OF Ga ATOMS IN A GaJ_3-Ar DISCHARGE
J. H. Waszink

H3. MICROWAVE AND LANGMUIR PROBE MEASUREMENTS OF CO_2 PLASMAS
L. A. Schlie, P. Bletzinger, and A. Garscadden

H4. V-I CHARACTERISTICS AND DEPLETION EFFECTS IN A MULTICOMPONENT GAS DISCHARGE
G. L. Rogoff

H5. SOLUTIONS TO THE CONTINUITY EQUATION WITH VARIABLE TRANSPORT COEFFICIENTS IN A ONE-DIMENSIONAL NEGATIVE GLOW AND FARADAY DARK SPACE
W. B. Hurt

H6. PLASMA DIAGNOSTIC TECHNIQUE USING A BEAM OF SLOW POSITRONS
G. H. Lohnert, M. W. Schikorr, and R. T. Schneider

8:30 a.m. - 10:00 a.m.: Terrace Room

SESSION I. IONIZATION (PANEL)

Chairman: C. E. Kuyatt
National Bureau of Standards

I1. THRESHOLD IONIZATION OF KRYPTON BY ELECTRON IMPACT
N. Swanson, J. W. Cooper, and C. E. Kuyatt

I2. ENERGY AND ANGULAR DISTRIBUTIONS OF ELECTRONS EJECTED FROM N_2 BY ELECTRON IMPACT
G. C. Tisone

I3. SECONDARY ELECTRON DISTRIBUTION FROM He and N_2
W. K. Peterson, C. B. Opal, and E. C. Beaty

I4. DISTRIBUTIONS IN ENERGY AND ANGLE OF ELECTRONS EJECTED FROM HYDROGEN BY FAST PROTONS
L. H. Toburen and W. E. Wilson

I5. ELECTRON DISTRIBUTIONS FROM HYDROGEN FOR 0.6, 1.0, and 1.5 MeV HYDROGEN IONS
W. E. Wilson and L. H. Toburen

I6. MULTIPLE IONIZATION OF Ne, Ar, and Kr, BY SOFT X-RAYS
G. S. Lightner, R. J. Van Brunt, and W. D. Whitehead

10:00 a.m. - 10:15 a.m.: Coffee Break

10:15 a.m. - 11:30 a.m.: Capitol Ballroom

SESSION J. ELECTRON SCATTERING (PANEL) Chairman: B. Bederson
New York University

J1. MEASUREMENTS OF THE TOTAL CROSS SECTIONS FOR THE SCATTERING OF LOW ENERGY ELECTRONS FOR K, Cs, AND Rb
K. Rubin, P. J. Visconti, and J. A. Slevin

J2. DEPENDENCE OF GENERALIZED OSCILLATOR STRENGTHS ON MOMENTUM TRANSFER AND EFFECTIVE NUCLEAR CHARGE FOR s, p, AND d ATOMIC TRANSITIONS
K. J. Miller

J3. ELASTIC SCATTERING OF ELECTRONS BY A FREELY ROTATING ELECTRIC DIPOLE: EFFECT OF CLOSED CHANNELS
W. R. Garrett

10:15 a.m. - 11:30 a.m.: Terrace Room

SESSION K. HEAVY PARTICLE EXCITATION Chairman: E. E. Muschlitz, Jr.
University of Florida

K1. ROTATIONAL EXCITATION OF N_2^+ PRODUCED IN Na^+-N_2 COLLISIONS
R. E. Mickle and R. P. Lowe

K2. EXCITATION OF N_2^+ IN ION-MOLECULE COLLISIONS AT LOW-ENERGY
S. H. Neff, N. H. Tolk, and C. W. White

K3. EXCITATION OF THE 2^3S METASTABLE STATE HELIUM BY 50 keV HELIUM IONS
D. R. Schoonover and J. T. Park

K4. SPECTRAL EXCITATION BY COLLISIONS OF THE $He^+ + H_2$ AND $H_2^+ + He$ SYSTEMS
R. D. Nathan and R. C. Isler

K5. CROSS SECTIONS FOR EMISSION OF LYMAN-α RADIATION IN COLLISIONS OF 1-30 keV HYDROGEN ATOMS WITH INERT GASES
J. H. Birely and R. J. McNeal

11:45 a.m. - 12:30 p.m.: Capitol Ballroom

PLENARY SESSION Chairman: W. P. Allis
Massachusetts Institute of Technology

HOLLOW CATHODE DISCHARGES AND APPLICATION TO ION LASERS
J. L. Delcroix

2:00 p.m. - 4:45 p.m.: Capitol Ballroom

SESSION L. ATOMIC AND MOLECULAR PROPERTIES (PANEL)

Chairman: H. H. Michels
United Aircraft
Research Laboratories

L1. TRANSITION PROBABILITIES FOR THE CO 4th POS SYSTEM
G. M. Lawrence

L2. MEASUREMENT OF TRANSITION PROBABILITIES FOR O I IN THE VACUUM ULTRAVIOLET
W. R. Ott

L3. LIFETIME MEASUREMENTS IN METALLIC VAPORS
A. R. Schaefer and R. G. Fowler

L4. HYDROGEN BALMER LIFETIMES
R. A. Mickish and R. G. Fowler

3:15 p.m. - 3:30 p.m.: Coffee Break

L5. LIFETIMES OF METASTABLE CO AND N_2 MOLECULES
W. L. Borst and E. C. Zipf

L6. ENERGIES OF METASTABLES PRODUCED IN ELECTRON IMPACT DISSOCIATION OF ATMOSPHERIC GASES
W. L. Borst and E. C. Zipf

L7. AUTOIONIZATION IN THE UV PHOTO-ABSORPTION OF ATOMIC CALCIUM
V. L. Carter, R. D. Hudson, and E. L. Breig

L8. AUTOIONIZATION LEVELS IN CESIUM
Y. Hahn, K. J. Nygaard, D. R. Kastelein, and L. A. Roe

2:00 p.m. - 4:45 p.m.: Terrace Room

SESSION M. AFTERGLOWS

Chairman: C. Lineberger
JILA
University of Colorado

M1. BEHAVIOR OF He(2^3S) METASTABLES IN HELIUM PLASMAS
P. A. Miller, J. T. Verdeyen, and B. E. Cherrington

M2. INVESTIGATION OF THE Ne($1s_5$) METASTABLE ATOM CONCENTRATION IN THE EARLY AFTERGLOW OF PULSED NEON PLASMAS
E. E. Wisniewski, J. T. Verdeyen, and B. E. Cherrington

M3. STABILIZATION OF THE RECOMBINATION OF He^+ AND He_2^+ IN A HIGH PRESSURE HELIUM AFTERFLOW
H. S. Hicks, W. E. Wells, and C. B. Collins

M4. THE ROTATIONAL DISTRIBUTION OF He_2^* RESULTING FROM RECOMBINATION OF He_2^+ AND He_3^+ IN A HELIUM AFTERGLOW
A. W. Johnson

M5. ROLE OF He_3^+ IN THE RECOMBINATION OF 300°K HELIUM PLASMA
M. A. Gusinow, R. A. Gerber, and J. B. Gerardo

3:15 p.m. - 3:30 p.m.: Coffee Break

M6. AFTERGLOW BEHAVIOR OF THE 4s,p,d,f → 3s,p,d LINES OF He^+ BY HIGH-RESOLUTION INTERFEROMETRY
W. W. Kuhlow, F. L. Roesler, and C. C. Lin

M7. MASS SPECTROMETRIC STUDY OF LOW PRESSURE RARE GAS AFTERGLOW PLASMAS
A. K. Bhattacharya

M8. DIFFUSION COOLING
J. H. Ingold

M9. DECAY OF LOW PRESSURE NEON AFTERGLOWS
K. V. Narasinga Rao

M10. A NEW AFTERGLOW TECHNIQUE FOR THE MEASUREMENT OF ELECTRON ATTACHMENT IN GASES
L. J. Puckett, M. D. Kregel, and M. W. Teague

5:00 p.m. - 9:00 p.m.: United Aircraft Research Laboratories

UARL TOUR AND BUFFET SUPPER

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Thursday, October 22

8:30 a.m. - Noon: Capitol Ballroom

SESSION N. HEAVY PARTICLE COLLISIONS: EXPERIMENTAL — Chairman: W. W. Smith, University of Connecticut

N1. EXCITATION IN Li^+ + He COLLISIONS
D. C. Lorents and G. Conklin

N2. CHARGE TRANSFER BETWEEN Li^+ AND ALKALI METAL ATOMS
J. Perel and H. L. Daley

N3. ION-ION MUTUAL NEUTRALIZATION CROSS SECTIONS FOR $O_2^+ + NO_3^-$ AND $NO^+ + NO_3^-$
J. Moseley, W. Aberth, and J. R. Peterson

N4. ELECTRON TRANSFER FROM O^- to Na^+ AT LOW COLLISION ENERGIES
J. Weiner, W. B. Peatman, and R. S. Berry

N5. REACTIONS BETWEEN H^+ AND D_2
W. B. Maier, II

N6. LOW ENERGY ELASTIC DIFFERENTIAL SCATTERING FOR PROTON-RARE GAS ATOM SYSTEMS
S. M. Bobbio, W. G. Rich, R. Champion, and L. Doverspike

10:00 a.m. - 10:15 a.m.: Coffee Break

N7. ELASTIC PERTURBATIONS IN THE LOW ENERGY DIFFERENTIAL SCATTERING OF He^+ BY RARE GAS ATOMS
W. G. Rich, S. M. Bobbio, L. Doverspike, and R. Champion

N8. TOTAL CROSS SECTION MEASUREMENTS FOR THE SCATTERING OF He BY He FROM 300 TO 3000 eV
W. J. Savola, Jr., F. J. Eriksen, and E. Pollack

N9. ENERGIES OF FORMATION OF H^- BY H^+ IMPACT AT 4 keV ON VARIOUS GASES
F. C. Witteborn and D. E. Ali

N10. COMPARISON OF INELASTIC SCATTERING OF HYDROGEN AND DEUTERIUM ATOMS IN NITROGEN
C. F. Barnett, J. A. Ray, and H. H. Fleischmann

N11. COINCIDENCE STUDY OF Ar^+ - Kr AT 15 TO 230 keV
R. Del Boca and H. Hayden

N12. FAST ELECTRON-SLOW ELECTRON COINCIDENCE STUDIES OF THE VIOLENT ARGON ION-ATOM COLLISION
G. M. Thomson, P. C. Laudieri, and W. W. Smith

N13. DELAYED-COINCIDENCE STUDY OF O^+ + Ne COLLISION
F. W. Bingham

8:30 a.m. - 10:00 a.m.: Terrace Room

SESSION O. TRANSPORT PROPERTIES

Chairman: J. H. Ingold
General Electric Company

O1. MOTION OF GASEOUS IONS IN A UNIFORM ELECTRIC FIELD
J. H. Whealton

O2. INTERPRETATION OF DRIFT TUBE RATE CONSTANTS IN TERMS OF CROSS SECTIONS
S. B. Woo and S. F. Wong

O3. MICROWAVE CONDUCTIVITY OF AN ELECTRON GAS EXCITING COMPOUND STATES IN ATOMS AND MOLECULES
J. L. Hirshfield, A. S. Ratner, and J. M. Wachtel

O4. EXCITATION AND IONIZATION OF NEUTRAL SPECIES IN A DENSE DISCHARGE
C. Deutsch and L. Herman

O5. BISTABLE ELECTRON TEMPERATURE IN VIBRATIONALLY EXCITED GASES
A. Cohn

10:00 a.m. - 10:15 a.m.: Coffee Break

10:15 a.m. - Noon: Terrace Room

SESSION P. ELECTRON DISTRIBUTIONS (PANEL) — Chairman: W. P. Allis, Massachusetts Institute of Technology

P1. ELECTRON VELOCITY DISTRIBUTIONS IN A PULSED LOW-PRESSURE ARC DISCHARGE
J. Polman

P2. ENERGY DISTRIBUTIONS OF ELECTRONS IN ARGON TOWNSEND DISCHARGES
D. S. Burch and J. Losee

P3. EFFECTS OF NON-MAXWELLIAN ELECTRON ENERGY DISTRIBUTION IN LOW-VOLTAGE NEON DISCHARGES
D. T. Shaw

P4. ON THE SPATIAL ELECTRON RELAXATION TO EQUILIBRIUM NEAR PLASMA BOUNDARIES
F. T. Wu and D. T. Shaw

P5. EFFECT OF SUPERELASTIC COLLISIONS ON THE ELECTRON VELOCITY DISTRIBUTION IN NITROGEN
J. H. Noon, M. Foster, and W. C. Jennings

P6. ELECTRON ENERGY DISTRIBUTIONS AND COLLISION RATES IN ELECTRICALLY EXCITED N_2, CO, AND CO_2
W. L. Nighan

Noon - 12:30 p.m.: Capitol Ballroom

GEC BUSINESS MEETING — Chairman: G. J. Schulz

2:15 p.m. - 5:00 p.m.: Capitol Ballroom

SESSION Q. BREAKDOWN

Chairman: T. L. Churchill
United Aircraft
Research Laboratories

Q1. REDUCTION OF BREAKDOWN VOLTAGES AT CONDITIONS BELOW PASCHEN'S MINIMUM DUE TO A MAGNETIC FIELD PARALLEL TO THE AXIS OF ROD ELECTRODES
M. J. Kofoid

Q2. A MAGNETIC MEMORY EFFECT IN VACUUM BREAKDOWN
A. Watson

Q3. ANALYSIS OF PREBREAKDOWN CURRENT GROWTH DUE TO TWO EMISSION MECHANISMS
E. P. Oppenheimer, A. N. Michel, and E. Nasser

Q4. AC ELECTRICAL BREAKDOWN OF NEON WITH EXTERNAL ELECTRODES
H. Veron and C. C. Wang

3:25 p.m. - 3:40 p.m.: Coffee Break

Q5. TRANSIENT MICROWAVE BREAKDOWN OF LOW PRESSURE GASES
S. E. El-Khamy, S. F. Marlier, and R. E. McIntosh

Q6. OPTICAL BREAKDOWN IN COLORED GASES
W. Holzer, P. Ranson, and P, Peretti

Q7. GLASS FIBER OPTICS IN THE INVESTIGATION OF CORONA DISCHARGES
A. J. Schwab

Q8. OBSERVATIONS OF THE COMPETITION OF TRICHEL PULSES FROM NEGATIVE CORONA NEEDLES
W. L. Lama and C. F. Gallo

Q9. THE TRANSITION FROM PRIMARY STREAMER THROUGH THERMALIZATION TO THE ARC IN POSITIVE POINT-TO-PLANE CORONA
T. Suzuki

2:15 p.m. - 5:00 p.m.: Terrace Room

SESSION R. ELECTRON AFFINITIES: O_2, ETC. (PANEL)

Chairman: P. J. Chantry
Westinghouse Research
Laboratories

R1. VIBRATIONAL EXCITATION OF O_2 AND NO BY ELECTRON IMPACT
D. Spence and G. J. Schulz

R2. VIBRATIONAL EXCITATION AND ATTACHMENT BY SLOW ELECTRONS BOMBARDING O_2
C. J. Chapman and A. Herzenberg

R3. ELECTRON AFFINITY OF O_2 BY LASER PHOTODETACHMENT
R. Celotta, R. Bennett, J. Hall, J. Levine, and M. W. Siegel

R4. DOPPLER BROADENING IN BEAM EXPERIMENTS
P. J. Chantry

3:30 p.m. - 3:45 p.m.: Coffee Break

R5. DRIFT TUBE MEASUREMENTS OF THE $O^- + O_2$ REACTION FROM THERMAL ENERGY TO ~ 3 eV
R. Johnsen, H. L. Brown, and M. A. Biondi

R6. MOLECULAR ELECTRON AFFINITIES DERIVED FROM COLLISIONAL IONIZATION OF ALKALI ATOMS
K. Lacmann and D. R. Herschbach

R7. CHARGE EXCHANGING COLLISIONS BETWEEN Cs and NO_2
S. J. Nalley, R. N. Compton, and P. W. Reinhardt

R8. PHOTODETACHMENT OF O_3^-
S. F. Wong, T. V. Vorburger, and S. B. Woo

5:00 p.m.: Glastonbury Hills Country Club

BANQUET AND RECEPTION

Chairman: Dr. George J. Schulz
Professor of Applied Science
Yale University

Welcoming Remarks: Mr. Charles M. Kearns, Jr.
Vice President for Research
United Aircraft Corporation

Principal Speaker: Dr. Rolf M. Sinclair
Program Director for Atomic, Molecular, and Plasma Physics
National Science Foundation

Topic: "Federal Support of Atomic Physics, and the National Science Foundation"

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Friday, October 23

8:30 a.m. - 10:15 a.m.: Capitol Ballroom

SESSION S. ION CLUSTERS (PANEL) Chairman: E. E. Ferguson
ESSA Research Laboratories

S1. THE REACTION OF NO^+ AND $NO^+ \cdot (H_2O)_n$ WITH H_2O AND NH_3.
F. C. Fehsenfeld and E. E. Ferguson

S2. THREE-BODY CLUSTERING OF NO^+ WITH O_2, N_2, AND CO_2
E. E. Ferguson, D. B. Dunkin, and F. C. Fehsenfeld

S3. RATES OF FORMATION OF WATER CLUSTERS FOR $O_2{}^+$ AND NO^+
C. J. Howard, H. W. Rundle, and F. Kaufman

S4. DRIFT TUBE STUDIES OF CARBON DIOXIDE CLUSTERING TO POTASSIUM AND SODIUM IONS
G. E. Keller and R. A. Beyer

S5. CLUSTERING OF Cs^+ IONS IN ATMOSPHERIC GASES
L. G. McKnight and J. M. Sawina

S6. HYDRATION OF OXYGEN NEGATIVE IONS
J. L. Pack and A. V. Phelps

S7. REACTIONS OF NO^+ IN $NO-H_2O$ AND $NO-NH_3$ GAS MIXTURES
L. J. Puckett and M. W. Teague

8:30 a.m. - 10:15 a.m.: Terrace Room

SESSION T. COLLISION PROCESSES IN GASEOUS LASERS Chairman: W. L. Nighan
United Aircraft Research Laboratories

T1. DISCHARGE AND GAIN PROPERTIES OF THE CO_2 LASER
W. J. Wiegand, M. C. Fowler, and J. A. Benda

T2. A QUANTITATIVE ANALYSIS OF THE DEPENDENCE OF CO_2 LASER PERFORMANCE ON ELECTRIC DISCHARGE PROPERTIES
M. C. Fowler

T3. PLASMA PROPERTIES OF AN ELECTRIC DISCHARGE CONVECTION LASER
C. O. Brown

T4. THE CO LASER PLASMA
P. Bletzinger and A. Garscadden

T5. EXCITATION PROCESSES IN THE CATHODE REGION OF A GLOW DISCHARGE THROUGH METAL-VAPOR-NOBLE-GAS MIXTURES
A. J. Palmer and J. W. McGowan

T6. MICROWAVE DENSITY MEASUREMENTS IN ION LASER PLASMAS
L. D. Pleasance and E. V. George

T7. VACUUM ULTRAVIOLET PERTURBATION SPECTROSCOPY ON THE He-Ne LASER
H. Merkelo and R. C. Quinn

10:15 a.m. - 10:30 a.m.: Coffee Break

10:30 a.m. - 12:30 p.m.: Capitol Ballroom

SESSION U. THEORY OF HEAVY PARTICLE COLLISIONS (PANEL) Chairman: N. Lane, Rice University

U1. LOW ENERGY ELASTIC AND FINE-STRUCTURE EXCITATION SCATTERING OF $C^+(^2P)$ BY $H(^2S)$
J. C. Weisheit and N. F. Lane

U2. CLOSE COUPLING STUDY OF EXCITATION IN LOW-ENERGY ATOM-ATOM SCATTERING
S. A. Evans, J. S. Cohen, and N. F. Lane

U3. ELECTRONIC TRANSITIONS BETWEEN s AND p STATES IN SLOW ATOMIC COLLISIONS
P. G. Cable

U4. LONG RANGE FORCES IN NEAR-RESONANT CHARGE TRANSFER
F. T. Smith and R. E. Olson

U5. OBTAINING INTERATOMIC POTENTIALS FROM ELASTIC SCATTERING DATA
R. Klingbeil

U6. COMPARISON OF NUMERICAL CAPTURE CROSS SECTIONS WITH REACTION CROSS SECTIONS FOR NH_3 AND H_2O TARGETS
J. V. Dugan, Jr. and J. L. Magee

U7. VIBRATIONAL EFFECTS ON ION-DIPOLE CAPTURE CROSS SECTION; COMPUTER MOVIES OF CLASSICAL TUNNELING
J. V. Dugan, Jr. and R. B. Canright, Jr.

10:30 a.m. - 12:30 p.m.: Terrace Room

SESSION V. NEGATIVE IONS

Chairman: J. F. Paulson
Air Force Cambridge
Research Laboratories

V1. THE DETACHMENT OF ELECTRONS FROM F^- IONS IN A SHOCK-HEATED CESIUM FLUORIDE-ARGON MIXTURE
A. Mandl, B. Kivel, and E. W. Evans

V2. NEGATIVE ION PRODUCTION FROM SF_6 AND N_2O AT HIGH TEMPERATURES
J. H. Mullen and J. M. Madson

V3. DETERMINATION OF THERMAL ELECTRON DIFFUSION (D) AND ATTACHMENT RATE (α_W) COEFFICIENTS FOR OXYGEN
D. R. Nelson and F. J. Davis

V4. MOBILITIES OF LARGE SIZE IONS
P. L. Patterson

V5. NEGATIVE ION DECAY IN PHOTOIONIZED BROMINE
F. K. Truby

V6. ELECTRON IMPACT STUDIES OF ACETONE AND HALOGENATED ACETONE
W. T. Naff and R. N. Compton

V7. DISSOCIATIVE ELECTRON ATTACHMENT TO BROMINATED ALIPHATIC HYDROCARBONS
A. A. Christodoulides, L. G. Christophorou, P. M. Collins, and J. G. Carter

2:00 p.m. - 5:00 p.m.: Capitol Ballroom

SESSION W. ELECTRON EXCITATION (PANEL)

Chairman: E. C. Zipf
University of Pittsburgh

W1. ABSOLUTE EXPERIMENTAL CROSS SECTIONS FOR THE EXCITATION OF Ba^+ IONS BY ELECTRON IMPACT
M. O. Pace and J. W. Hooper

W2. EXCITATION OF RESONANCE STATES IN ELECTRON IMPACT ON ATOMIC OXYGEN AND NITROGEN
E. J. Stone and E. C. Zipf

W3. ELECTRON EXCITATION FUNCTIONS OF ARGON
J. K. Ballou, C. C. Lin, and F. E. Fajen

W4. CLOSE-COUPLING CALCULATION OF ELECTRON EXCITATION CROSS SECTIONS OF THE 3^2D STATE OF SODIUM
D. F. Korff, S. Chung, and C. C. Lin

W5. EXCITATION OF OI 1304A AND NI 1493A LINES BY ELECTRON IMPACT ON OXYGEN AND NITROGEN MOLECULES
W. A. Brown and J. N. Bradbury

3:30 p.m. - 3:45 p.m.: Coffee Break

W6. EXCITATION OF THE $a^1\Pi_g$ STATE OF THE NITROGEN MOLECULE BY ELECTRON IMPACT
S. Chung and C. C. Lin

W7. EXCITATION OF THE CO FOURTH POSITIVE BAND SYSTEM BY ELECTRON IMPACT ON CO AND CO_2
M. J. Mumma, E. J. Stone, and E. C. Zipf

W8. DISSOCIATIVE EXCITATION OF O_2 BY ELECTRON IMPACT WITH THE FORMATION OF METASTABLE ^5S AND HIGH-RYDBERG ATOMS
R. S. Freund

W9. ROTATIONAL-VIBRATIONAL EXCITATION OF H_2 BY LOW-ENERGY ELECTRONS
R. J. W. Henry and E. S. Chang

2:00 p.m. - 5:00 p.m.: Terrace Room

SESSION X. PENNING EXCITATION AND IONIZATION (PANEL) Chairman: L. D. Schearer, Texas Instruments, Inc.

X1. STUDIES OF PENNING AND CHARGE-TRANSFER COLLISIONS BETWEEN NOBLE GASES AND GROUP II ATOMS
L. A. Riseberg and L. D. Schearer

X2. POLARIZATION OF MOLECULAR IONS VIA PENNING COLLISIONS WITH OPTICALLY ORIENTED METASTABLE HELIUM ATOMS
L. D. Schearer and L. A. Riseberg

X3. DIRECT OBSERVATION OF THE SPIN DEPENDENCE OF IONIZING COLLISIONS BETWEEN $He(2^3S_1)$ METASTABLE ATOMS
L. D. Schearer and L. A. Riseberg

X4. ANGULAR DISTRIBUTION OF PENNING ELECTRONS
H. Hotop and A. Niehaus

3:30 p.m. - 3:45 p.m.: Coffee Break

Inc.

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ABSTRACTS

SECOND ARC SYMPOSIUM

20-21 OCTOBER

1970

HARTFORD HILTON HOTEL

HARTFORD, CONNECTICUT

SESSION A

Tuesday Morning, 20 October

9:00 a.m.

THERMODYNAMIC AND TRANSPORT PROPERTIES

Chairman: J. J. Lowke, Westinghouse Research

A1. Consideration of Simple Model Atoms for Argon Discharge Calculations. JAMES R. ROSE and JOHN V. DUGAN, JR., NASA-LeRC - Simple model atoms are required for satisfactory calculation of plasma properties in low electron temperature T_e gas discharges.[1] Model atoms of 2-, 3-, and 5-levels give ionization fractions f in agreement with 26-level results for cesium plasmas that are optically thick (OT) to resonance radiation.[2] The calculation of non-equilibrium f values is extended to argon discharges for T_e values of 8000° K and 1 eV (11,605° K). Curves of f versus argon nuclei number density N^0_{Ar} resemble the OT results for cesium. However, these f values are sensitive to the radiative transition frequency A_{32}. For low N^0_{Ar}, f values are sensitive to the choice of radiative capture coefficients. The f values check satisfactorily with Saha predictions in the completely thick radiation limit.

[1] J. V. Dugan, Jr., F. A. Lyman, and L. U. Albers, NASA TM X-52190, July 1966.

[2] J. V. Dugan, Jr., Repts. 27th Phys. Elect. Conf., p. 323, March 1967.

A2. Pressure Dependence of the Population Density of Energy Levels in He-arcs. J. Uhlenbusch, L. Detloff, I. Phys. Inst. Techn. Hochschule Aachen In an earlier paper[1] it was shown that the behaviour of He-arcs under normal pressure is mainly influenced by diffusion processes and Saha-equilibrium is not valid. For simplification partial LTE was assumed for all excited levels. The density of ground state atoms was derived from the rate equation including diffusion. Here the assumption of partial LTE for the population of excited levels is dropped. The appropriate rate equations in connection with the energy balance of the total gas and the electron gas alone are solved simultaneously for various pressures and the results are compared with those derived assuming partial LTE for all excited levels. Collision and radiation rate coefficients were taken from[2].

[1] Uhlenbusch, J., E. Fischer, J. Hackmann, Z. Phys. in print - [2] Drawin, H. W. and F. Emard, Report EUR-CEA-FC-534, Fontenay aux Roses, France (1970)

A3. The Determination of Plasma Electron Density From Refraction Measurements. P. W. Schreiber, A.M.Hunter, Aerospace Research Laboratories, and D. R. Smith, Air Force Institute of Technology. The internal state of an axisymmetric plasma can be determined from externally measured lateral profiles of various optical properties. This technique requires inverting an integral equation of the Abel form, and it is subject to many subtle errors because the derivative of measured data is required. A new mathematical analysis is developed which allows the axial electron density of an axisymmetric plasma to be determined without inverting an integral equation. The required input data includes the deviation of a laser beam as a function of lateral distance. Data at several wavelengths are required to eliminate contributions to the refractivity due to atoms and ions. Experimental data have been collected at several wavelengths for a stable argon discharge at atmospheric pressure. The analysis of these data yield electron densities which are in good agreement with thermodynamic calculations.

A4. Determination of Electron Density and Temperature in a non-LTE Helium Arc. W.G. BRAUN, J.W. BIRKELAND and R. D. FRANKLIN, Aerospece Research Labs, WPAFB, Ohio.--Line profiles have been measured in a vortex stabilized pure helium arc at a pressure of 1.4 atm and a current of 140A. Correlation with theory requires reliable determination of electron density and temperature profiles. Side-on spectroscopic measurements indicate that electrons bound in n>2 states are in equilibrium at a common electron temperature. Macroscopic equilibrium criteria predict that the equilibrium does not extend to the neutral ground state but does include the free electrons. With this assumption the electron temperature profile of the arc has been computed from local neutral line intensities and local electron densities obtained from Stark broadening. Absolute line intensities are not in agreement with LTE but can be reconciled by a reasonable degree of ground state overpopulation rather than a heavy particle temperature lower than the electron temperature.

A5. High Pressure Argon Arcs. U.H. Bauder, Aerospace Research Laboratories, WPAFB, Ohio. - Results of experiments with wall stabilized arcs in the pressure range up to 130 atm are reported. The arc is operated steady state in a "Maecker-type" cascade. From measurements of the electrical arc characteristics and temperature distributions the electrical conductivity σ of argon was determined at p= 50atm and p = 100atm. The maximum centerline temperatures reached at these pressures were 12,500°K and 10,800°K respectively. The spectroscopic temperature measurements are performed side-on using the absolute continuum intensity at several wavelength near 4,000Å. The values determined agree with calculations by DEVOTO. Measurements of the total radiation emitted from the column are used to determine the unabsorbed part of the total radiation source strength of argon at 50atm. A comparison of the experimental results with computations based on the energy equation for wall stabilized arcs indicates that the absorbed energy is a small fraction of the total energy emitted in the temperature range.

A6. Transport Properties of Partially Ionized Argon - Revision and Extension. R. S. DEVOTO*, Stanford Univ., - Recent, more accurate measurements of the transport properties of partially ionized argon as well as revisions in atomic cross sections have made it desirable to repeat computations of these properties. This has recently been carried out and some of the results are presented and compared with experiments. Very good agreement between theory and experiment is noted for the electrical conductivity from 9000-15000°K. The measured thermal conductivity is still somewhat greater than theory, probably due to incomplete inclusion of energy transport via radiation within the hot gas. The effect of an imposed DC magnetic field as well as non-equilibrium of electron and atom-ion temperatures on the transport properties, particularly the thermal conductivity, with applications to the electric arc are discussed.

*Research sponsored by Aerospace Research Laboratories, USAF.

SESSION B

Tuesday Morning, 20 October

11:00 a.m.

RADIATIVE PROPERTIES

Chairman: J. Yos, AVCO, Wilmington

B1. The Vacuum Ultraviolet Continuum of Doubly Ionized Argon.* J. C. Morris, AVCO Wilmington, Mass. The continuum radiation of doubly ionized argon emitted in the vacuum ultraviolet region of the spectrum has been measured for a plasma pressure of one atmosphere up to temperatures of 28000°K. The data have been put into the form of spectral absorption coefficients and given versus temperature. These are compared with theoretical calculations that have been made using hydrogen like cross sections for the recombination continuum. The plasma used in this study was generated in a pulsed mechanically constricted arc generator. Temperatures of the plasma were measured using the 3311.25AIII multiplet. The continuum radiation measurements were put on an absolute basis using a nitrogen arc and viewing the blackbody radiation emitted by several atomic nitrogen lines in the wavelength region of interest.

*Work supported by Aerospace Research Laboratories, Office of Aerospace Research of the U. S. Air Force, (Contract No. F336.5-70-C-1360).

B2. Measurements of Electron Broadened Widths of Atomic Nitrogen Lines*. R. U. Morris and J. C. Morris, AVCO Wilmington, Mass. The half-widths of 26 atomic nitrogen lines of seven multiplets have been measured for an electron number density of $1.6 \times 10^{17}/cm^3$ and a temperature of 13000°K. The results are compared with the theoretical predictions of Griem. The data were obtained under optically thin conditions by using constricted argon arc seeded with nitrogen. Temperature were measured using the absolute intensities of a number of atomic and ionic argon lines. Electron concentrations were determined by using trace amounts of hydrogen beta.

*Work supported by Aerospace Research Laboratories, office of Aerospace Research of the U. S. Air Force, (Contract No. F33615-68-C-1081).

B3. Transistion Probabilities for Sulfur Lines From Wall-Stabilized Arc Measurements. E. SCHULZ-GULDE, Westinghouse Research Laboratories. A new type of analysis has been developed to determine transition probabilities of spectral lines emitted from optically thin, multi-element, arc plasmas in local thermodynamic equilibrium (LTE). Provided the plasma contains one element whose ionization energy is considerably lower than that of the other elements, this method is independent of demixing effects for a fairly wide temperature range. The technique has been applied to spectroscopic data obtained from wall-stabilized arcs operated at atmospheric pressure, first in a mixture of argon and sulfurhexafluoride (SF_6), and second in SF_6. A trace of hydrogen is added in both experiments in order to determine the electron density from the measured H_β hydrogen line width. The experimental data do not contradict the assumption of LTE. The transition probabilities for the SI 4695 Å, SI 5279 Å, SII 5320 Å, and SII 5454 Å lines are in agreement with those listed in the NBS critical data compilation.[1]

[1]Wiese, W. L., Smith, M.W., and Miles, B. M., Atomic Transition Probabilities, Vol.II, Nat. Bur. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.), 22 (1969).

B4. Spectral Characteristics of the High Current, Low Pressure Mercury Discharge. PETER D. JOHNSON, General Electric R&D Center, Schenectady--The dependences of the relative intensities of the HgI 1849 and 2537 A and the HgII 1942 A resonance lines on current density (up to about 100 a/cm^2), Hg pressure (10^{-3} to 0.5 Torr) and arc tube diameter (10 to 25 mm) have been measured. The HgI line intensities saturate at about 2 a/cm^2. Absolute output at 1849, measured photochemically, is consistent with the results of B.T. Barnes. In the Hg-A discharge the intensity of the 1942 A line varies as the 1.75 power of the current density up to about 100 a/cm^2. There is evidence for volume recombination, which is inhibited when A is replaced by Kr. A mechanism for this effect will be proposed.

SESSION C

Tuesday Afternoon, 20 October

2:00 p.m.

VACUUM ARCS

Chairman: G. Frind, General Electric, Philadelphia

C1. Energy Distributions of Ions from Pulsed Vacuum Arcs.* J.T. GRISSOM and G.W. McCLURE, Sandia Laboratories.--Recent work at Sandia Laboratories has been aimed at a better understanding of the physics of pulsed vacuum arcs as used in high-voltage switching tubes. The energy distributions of ions emitted from pulsed vacuum ambient arcs of 5 μsec duration have been measured using a cylindrical electrostatic analyzer. The arc characteristics include initiation rise times of less than 1 μsec, a total arc potential after initiation of approximately 50 volts, and arc currents of 50-60 amps. The ion species present in the arc plasma have been determined spectroscopically. The measured energy spectra display low energy cut-offs corresponding to the arc potential in the region of extraction. The peaks of the distributions occur consistently at an energy significantly higher than the arc voltage. In addition, a substantial fraction of the ions have energies greater than the total arc potential drop. Various sources of possible experimental bias in the measurements will be discussed.

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

C2. Plasma Expansion Into a Field-Free Vacuum Environment.* D.L. MANGAN, Sandia Laboratories.--The free expansion of a two-component plasma sphere into a vacuum background is examined theoretically using Monte Carlo techniques. Initially the small sphere (~ 20 microns) of moderate temperature (7.5 eV) and moderate density (10^{15} cm^{-3}) is assumed electrically neutral. Spherical symmetry of the expanding sphere is assumed. The time development of the self-consistent electric field at the outer edge of the sphere is evident, affecting the rate of expansion of the ion component. Transfer of energy from the electrons to the ions through the self-consistent electric field is observed. Three cases are compared: the collisionless expansion, expansion with collisions, and a collisionless neutral gas expansion. The plasma model is described along with techniques used in obtaining the dynamics of the plasma.

The collision model based upon the two Fokker-Planck coefficients is discussed.

Research supported by the U.S. Atomic Energy Commission

C3. The Temperature Measurement of Cathode Spots in Vacuum Arcs. T. UTSUMI, Bell Telephone Laboratories.--Temperatures of the cathode spots of various metals in vacuum arcs have been measured for the first time on the basis of the velocity distribution of the vapor atoms emanating from the cathode spot region by employing the combined technique of time of flight and quadrupole mass analysis. The measured velocity distribution exhibits a large Maxwellian type peak, superimposed with a small non-Maxwellian type for higher velocities. The temperatures of the cathode spots were measured from this Maxwellian type velocity distribution under the assumption that the cathode spot is at thermal equilibrium with the vapor in front of the spot. The measured temperatures of the cathode spots for Au, Ag, Pd, W and Pt-Rh alloys indicate that the temperatures are much higher than the boiling temperatures of these materials at atmospheric pressure, implying that the vapor pressure in the front of the cathode spot amounts to several times the atmospheric pressure.

C4. A Model for the Vacuum Arc. M. F. HOYAUX Univ. of Pittsburgh.---A model is presented for the vacuum arc without anode spot, on grounds of the concept of near ambipolar diffusion [1]. The arc "column" is divided between Region I, in which there is a non-zero carrier pair generation rate, and Region II, in which this rate is essentially zero. A large fraction of the ions generated in Region I move parallel, not antiparallel to the electrons, as in ordinary arcs. (Region I,which is very small, is essentially equipotential, but Region II and the anode sheath have "reversed" voltage drops.) The relative importance of their number compared to those returning to the cathode is discussed on grounds of Steenbeck's minimum principle and of experimental data of various origins. When the relative number of ions impinging on the anode increases, the difference in potential between the anode itself and an electrically inert electrode (e.g. vapor shield) tends to vanish, which is confirmed by experiments.

[1] M. F. Hoyaux, Arc Physics, N. Y. Springer-Verlag 1968, p. 112.

SESSION D

Tuesday Afternoon, 20 October

4:20 p.m.

TRANSIENT ARCS

Chairman: W. C. Roman, United Aircraft Research Laboratories

D1. Time Resolved Spectroscopic Investigation of Short Gap Discharges. Jacques A.Augis and Eoin W.Gray. Bell Laboratories, Columbus, Ohio.--Using a high speed photomultiplier, monochromator and a sampling oscilloscope, variable duration, 4 to 12 amp, coaxial cable discharges in air have been studied with nanosecond resolution. ($pd < 10$ torr cm). The initial high current, high voltage regime of the discharges was identified as being a high pressure glow. The transition to the arc regime corresponded to the appearance of the metal lines in the spectrum. In the arc regime the gas bands were observed less than 1 nsec from the onset of a measureable current. The metal lines were observed to have a delay which depended on the metal and corresponded to the time required to reach the arc current from the glow regime. The shapes of the metal lines were found to be similar to that found by Sigmond[1] using W electrodes in 2 atmospheres of hydrogen.An interpretation of the maximum observed in the time resolved metal lines is proposed,and is consistent with the cathodic damage as observed using a scanning electron microscope.

[1] Sigmond,R.S. 'Nanosecond Arcs in Hydrogen.' Proc. 7th Int.Conf.Phen.Ion.Gases. Beograd 1 611, (1965)

D2. Line Intensity Behavior in a Decaying Arc Plasma. J. B. SHUMAKER, JR., and W. H. VENABLE, JR., National Bureau of Standards.--Under certain conditions of non-equilibrium, the intensity of spectral lines observed in an arc increases upon removal of the electric field powering the arc. To provide a basis for quantitative investigation of the effect, space- and time-resolved measurements of the absolute intensity of Argon I lines, particularly the 4s-4p' line at 696.5 nm, were made using an atmospheric pressure arc operating in the range 15 to 60 A. These measurements agree qualitatively with a previously advanced[1] two-temperature model. The usefulness of the effect in detecting departures from equilibrium will be discussed.

[1]V.Ya.Alexandrov, D.B. Gurevich, and I.V. Podmoshenskii, Optics and Spectroscopy 23, 282 (1967).

D3. The transient behaviour of a D.C. arc relevant to a D.C. "switching off" problem. V. Fuchs, Hydro-Quebec Institute of Research, Varennes, Quebec.--The arc is forced by a transverse magnetic field into a chamber and cut by a system of floating electrodes into a sufficient number of short subarcs to prevent stable operation. The energy equation of a short subarc assuming conductance losses to the electrodes is formulated and an equation of the "Cassie" type for current and arc resistance is derived. The solution of the simultaneous nonlinear dynamic arc and circuit equations suggests that in the pre zero-current period the transient behaviour is dominated by the circuit time constant rather than by the so-called arc time constant. The analysis is dimensionless in order to allow for scaling.

D4. Rates of Excitation and Ionisation in Arcs. A. R. FAIRBAIRN, Air Force Cambridge Research Lab. If the relaxation time for excitation and ion-isation of an atom injected into an arc source intended for quantitative spectroscopy is comparable with its dwell time corrections must be applied to the number of emitters estimated from the rate of injection times dwell time. This paper presents simple estimates for these relaxation times and shows that only ionisation effects will be experimentally important in air arcs at 5000 K and electron densities of around 10^{15} cm^{-3}. Allowances are made for both levels involving allowed and forbidden transitions but the radiation is considered to be thin.

SESSION E

Wednesday Morning, 21 October

8:30 a.m.

STEADY-STATE AND RF ARCS

Chairman: D. R. Keefer, University of Florida

E1. Thermodynamics and Kinetics of Chloride Arcs.

D. M. SPEROS and R. M. CALDWELL, General Electric Lighting Research Laboratory, Cleveland, Ohio 44112.--Thermodynamic analysis shows that, while metal chlorides, MCl_x, will attack severely arc tube electrodes, the addition of excess metal M to the arc atmosphere will reduce this attack by several orders of magnitude. In addition, it is necessary to control the free and/or bound oxygen impurity content because the formation of oxychlorides and the operation of kinetic effects involving differential diffusion of species in the convective arc flow affects electrode life and the transport of electrode material to and from the arc tube walls.

A thermodynamic corollary is that the monochloride, MX, is an important radiating specie.

It is found, and further corroborated (1), that the theoretical predictions are fully consistent with the results of arc tube experiments.

(1) R. H. Springer and R. P. Taylor, accompanying Arc Symposium paper.

E2. Tin Chloride Arc Temperature Measurements.

R. H. SPRINGER and R. P. TAYLOR, General Electric Lighting Research Laboratory, Cleveland, Ohio 44112.--Arc discharges containing tin chloride ($SnCl_2, SnI_2, Hg, A$), operated at an average of 20 watts/cm^3 have been studied to isolate the major source of continuum radiated from these arcs. We have measured the center temperature to be about 5700°K with a radial distribution similar to the pure Hg discharge.

We have identified the spectrum of the SnCl molecule from our radiation measurements in the near uv. Thermodynamic calculations[(1)] have indicated that the SnCl molecule should be the dominant molecule at high temperatures. Results which support the belief that a low lying band transition from SnCl (e.g. $A^2\Sigma^+ \rightarrow X^2\Pi$) accounts for a large fraction of the continuous radiation will be presented.

(1) D. M. Speros and R. M. Caldwell, accompanying arc symposium paper.

E3. Mode Shift in Molecular Vapor Arcs. R.J. ZOLLWEG, Westinghouse Research Labs, Pittsburgh, Penna.--A pronounced shift from constricted to diffuse mode is observed for wall-stabilized arcs containing mercury plus cesium and thallium iodides or mercury plus cesium, thallium and dysprosium iodides as the reservoir temperature is raised to 1000-1150°C (achieved by operation of the arc in a furnace). The arc core increases abruptly from about 1 mm to 11-14 mm in diameter as the reservoir temperature is slowly raised through the transition region or as the input power is slowly reduced. In a restricted range both modes can be achieved simultaneously in the arc column--diffuse in the center and constricted near the electrodes. The constricted mode is characterized by largely atomic radiation and relatively high arc temperature and electrical conductivity, while the diffuse mode yields nearly continuous (molecular) radiation and has lower arc temperature and electrical conductivity. This transition can be understood qualitatively in terms of a maximum in the temperature dependence of the thermal conductivity and/or of the ratio of radiative emittance to conductivity.

E4. The Mason Dark Space and High Pressure Arc Re-ignition. JOHN E. WHITE, G.E. Lamp Research Lab. — A solid object immersed in the plasma of a high pressure arc is surrounded by a dark sheath. The sheath is at plasma temperature along one boundary, and near thermal equilibrium with the solid object at the other boundary. Cooling by the electrodes sets up such a sheath at current zero of an ac arc; breakdown of the sheath insulation determines the re-ignition process of high pressure mercury arcs with thermionic electrodes. The process requires about 0.6 joule/cm^3 in a channel adjacent to the electrodes, heating the vapor there to approximately 4400°K.

E5. Local Heat Transfer to Wires Immersed in an Arc Plasma.* T.W. PETRIE and E. PFENDER, Univ. of Illinois and Univ. of Minnesota--An experimental technique is developed to measure local heat transfer rates to bare and ceramic-coated metal wires from an atmospheric pressure argon plasma in LTE. Wire probes are swept in planes parallel to the anode through the plasma of a free-burning arc without drawing a net current. For plasma and probe parameters of this study, the layer between the undisturbed plasma and the probe surface is very thin so that electrons directed toward the probe essentially retain their energy. The data show that heat transfer in this situation is dominated by energy transport associated with electron and ion partial currents which, however, are not locally balanced due to variation of the floating potential over the arc cross section. The technique is then applied for a plasma in non-LTE at atmospheric pressure. Its sensitivity to electron temperature is especially evident in this test. With data obtained using this technique, a simple physical model of the heat transfer process between a plasma and a solid immersed in it is obtained and verified.

*Research supported by the AWS and the NSF under Grant GK 1728.

E6. Effects of Electron Temperature Variations on Spectral Line Intensity Ratios. R.F. WEBER, AFWL, Kirtland AFB, and A. GARSCADDEN, Aerospace Rsch Labs, WPAFB, Ohio.--Time-varying a.c. arcs or positive columns are used in discharges in gas mixtures, or a d.c. discharge may spontaneously support oscillations or turbulence. An analysis has been made of the errors which arise in line-intensity measurements due to the experimental averaging of the time-varying intensities caused by electron temperature fluctuations. These calculations have been made both for coherent and for random electron temperature fluctuations. It is shown that in the usual method of measuring the line intensities with a monochromator, averaging may cause the true mean temperature to be overestimated by typically 15% and similar magnitudes of errors occur in line intensity measurements for estimation of relative transition probabilities or excited state populations. However the method of instantaneous ratioing and averaging using a polychromator and appropriate circuitry is shown to allow the errors to be reduced an order of magnitude.

E7. Computer Model of a Wall-Stabilized Metal Vapor Arc. A.J. FROELICH, D.S. BECKER, and F.C. FRANCL, The Hallicrafters Company--A series of computer programs has been employed to obtain the temperature profiles and radiation spectra of cesium and potassium metal vapor arcs operating at pressures of 0.3-3.0 atm and axial field gradients of 10-30 V/cm. The temperature profiles are obtained by iteration until a power balance is achieved between ohmic heating and radiant absorption as input power, and radiant emission and heat flux as output power. Radiant emission as a function of temperature and pressure is deduced from integration of calculated spectral line and continuum intensities over the wavelength region 0.35-5.5 μm. Electrical and thermal conductivities employed as inputs are based on the calculations of Eastlund.[1] Radiation in the visible and near infrared regions predominates in determining the overall power balance of the arc. The field gradient-arc current characteristics corresponding to the static solutions obtained are presented, and predicted radiant conversion efficiencies in some spectral bands of interest are presented.

[1] B. J. Eastlund, J. of Nucl. Energy Part C 8, 31 (1966).

E8. EXPERIMENTAL STUDY OF AN ARGON PLASMA VORTEX SEEDED WITH XENON* A.E. Mensing, United Aircraft Research Laboratories. An experimental investigation is discussed in which an r-f induction heated argon plasma was seeded with xenon. The plasma was of the confined vortex type approximately 2 cm in diameter and 8 cm long. The total plasma pressure was 1.3 atm. Spectroscopic measurements were made of several argon and xenon spectral lines. The Abel inversion technique was used to calculate both the radial temperature distribution and the radial xenon partial pressure distribution. Measurements were also made of the xenon partial pressure at the wall of a 3.2-cm-dia water-cooled fused silica tube surrounding the plasma. The data showed that local xenon partial pressures as large as 0.3 atm were obtained within the plasma while maintaining wall xenon partial pressures of approximately 10^{-4} atm. Some theoretical studies of the effect of the temperature gradient (approximately 20,000 K/cm) on the vortex momentum equations are also discussed.

*This research was supported by the joint AEC-NASA Space Nuclear Propulsion Office under Contracts NASw-847 and SNPC-70.

E9. INVESTIGATION OF A HIGH-INTENSITY R-F RADIANT ENERGY SOURCE* W.C. Roman, United Aircraft Research Lab. This paper describes experiments to develop an intense radiant energy source capable of producing radiant energy fluxes corresponding to equivalent black-body radiating temperatures of 8000 to 15,000R. R-F energy was supplied by a 1.2-megw r-f induction heater operating at 5.5 MHz to an argon plasma contained within a radial-inflow vortex. The test chamber (2.24-in.-ID) was formed by concentric, water-cooled, fused silica tubes and copper end walls. Tests were conducted at pressures up to about 20atm and up to 223 kw of power was deposited in the ellipsoidally shaped (2 in. long) discharge. The maximum power density was 0.57 megw/in.^{3}. The maximum radiant energy flux achieved was 48 kw/in.^{2}, (T_{BB}=10,800 R). The diagnostics included measurements of (1) plasma size and shape, (2) total radiation in various wavelength bands, (3) calorimetric power losses, and (4) radial temperature distributions. The effects of several important parameters on: radiation losses, convection losses, and plasma size are presented.

*Work supported by joint AEC-NASA SNPO; Contracts NASw-847 and SNPC-70.

E10. Measurement of the rf Magnetic Field Distribution in a Thermal Induction Plasma.* H. U. ECKERT, The Aerospace Corporation. --The radial distribution of the rf magnetic field is measured with a water-cooled search coil of 3-mm diam in the midsection of an argon induction plasma flame maintained at 2.6 MHz in a 150-mm-wide tube. Over most of the flame section, the field is reduced from an unperturbed value of 15 A/cm to 0.5 A/cm. The skin depth is about 1 cm. In the annular space between the flame and the inductor coil, the field is increased by 10%. The effects of signal averaging, current obstruction, and plasma cooling by the probe are discussed and found to be of minor consequences.

*This work was supported by the U. S. Air Force.

SESSION F

Wednesday Afternoon, 21 October

2:00 p.m.

FLOW EFFECTS

Chairman: D. M. Benenson, State University of New York, Buffalo

F1. Experimental Investigation of Flow in an Induction Plasma. J. D. CHASE, American Cyanamid Co., Stamford, Conn.---An experimental investigation of flow in and around a thermal, 4.7 MHz induction plasma is made. The existence of the predicted[1] flow out from both ends of the plasma is confirmed by flow visualization and stagnation pressure measurements on an ambient pressure, vortex-free, argon plasma in a 28 mm tube. Flow visualization and gas velocities are obtained by high speed photography of injected 1μ diamond particles. Axial velocities at the upstream end of the plasma were measured in the range of 2-10 m/sec, depending on discharge power. Velocity varies linearly with discharge power over the range investigated (up to 4.7 kW). A simple model of the plasma is devised to enable the maximum velocity of magnetically pumped flow to be calculated from the static magnetic pressure. Agreement between predicted and measured velocities is within 20% at high powers. The calculation of thrust enables magnetic and expansion pressures to be separated.

[1] J. D. Chase, J. Appl. Phys. 40, 318 (1969).

F2. Non-Vortex Stabilized Electrodeless Arcs.* D. R. KEEFER, P. J. GROSS, R. E. MARTIN and J.C. SWINGLE, University of Florida--Electrodeless arcs have been operated in argon at 1-2 atmospheres pressure without the usual vortex flow. The arc is stabilized by a bluff body placed in the entering flow. Spectroscopic measurements indicate temperature profiles similar to those for vortex flow but arc stability is improved. The arc is stabilized by the recirculation region downstream of the bluff body in a manner analogous to a flame holder. Conduction front velocities have been calculated for cylindrical arcs and blow-off velocities determined based on a model similar to those used in flame holder theories.

*The research reported in this paper was sponsored by Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, Tennessee, under Contract No. F40600-70-C-0003. Further reproduction is authorized to satisfy the needs of the U. S. Government.

F3. Turbulent Characteristics of a Plasma Jet Produced by a Vortex-Stabilized Arc*. A.K. GHOSH, C. RICHARD† AND T.W. JOHNSTON**, RCA Limited., Montreal.-- An experimental facility in which a vortex-stabilized argon arc has been used to produce a plasma jet (laminar or turbulent) is described. The turbulent plasma parameter has been measured with electrostatic probes over an extended range of such a jet. The nature of turbulence is observed to depend on the operation condition of the arc. At low arc current the spatial electron density correlation functions (transverse and along the mean flow) show scalar isotropy. The one dimensional wave number spectra deduced from the frequency spectra and flow velocities using Taylor's hypothesis bunch together indicating wave-number isotropy. At relatively high current significant anisotropy in space correlations is observed which is also associated with assymetric "spiky" electron density fluctuations towards the edge of the plume. The observed decay of the space time cross correlation functions has been accounted for by convolving space correlations with time dependent velocity fluctuation decay functions.

* Supported by ARPA/SAMSO.

† Now at Inst. de Recherche de l'Hydro-Quebec, Quebec.

** Now at Dept. of Physics, Univ. of Houston, Texas.

F4. A Relaxation Method of Calculating Properties of Convection Stabilized Electric Arcs. J.J. LOWKE, Ion Diffusion Unit, Australian National Univ. -- A relaxation method, based on the time dependent energy balance equation, coupled with the continuity and momentum balance equations, enables properties of arcs stabilized by convection to be calculated, provided that radial convection can be neglected in the momentum balance equation. It is assumed that flow is laminar and that the electric field is uniform with radius. Recirculation effects are neglected. Required input material functions are the specific heat, viscosity, density, radiation emission coefficient and the thermal and electrical conductivity as a function of temperature. Calculations have been made for vertical arcs in air, stabilized by natural convection, but neglecting pressure effects due to the self magnetic field. Theoretical predictions are made of the radii of free burning arcs by doing calculations for an arc confined in tubes of successively larger radii. For a given electric current, results are obtained for temperature and axial velocity as a function of radius and axial position z, the electric field and pressure gradient as a function of z, and the rate of axial mass flow.

F5. A Voltage Correlation for Free-Burning Arcs With Transpiration-Cooled Anodes. J. R. MAHAN and C. J. CREMERS, Univ. of Kentucky--An energy balance on the transpiration-cooled anode of a free-burning dc arc discharge provides a basis for correlating the overall potential drop with the fluid transpiration rate and discharge current. For an arc of fixed geometry the anode heat flux depends only on the discharge current and the flow of transpirant through the porous anode. A characteristic potential based on the anode energy balance is used to non-dimensionalize the overall arc potential, and a dimensionless mass flux is derived from the momentum balance between the cathode jet and the counter flow of transpirant through the anode surface. Experimental data are then used to demonstrate that the dimensionless arc potential depends only on the dimensionless mass flux for the range of operating conditions of engineering interest.

SESSION G

Wednesday Afternoon, 21 October

3:45 p.m.

MAGNETIC FIELD EFFECTS

Chairman: H. O. Schrade, Aerospace Research Laboratories, WPAFB

G1. HEAT TRANSFER FROM A MAGNETICALLY-BALANCED ELECTRIC ARC TO A CROSS-FLOW STREAM* L.S. Han, Ohio State Univ., W.C. Roman, United Aircraft Research Lab., and D.H. Kihara, Univ. of Hawaii. This work describes the experiments and analysis on a steady-state d-c arc held stationary in an external cross-flow field and a transverse magnetic field. The arc's cross-sectional shape was optically observed to become elliptical (major axis perpendicular to flow direction) under the combined effects of increasing cross-flow and stronger magnetic fields. Velocity profiles and energy flux measurements were obtained in the arc wake using probe techniques. The arc's shape change was postulated to be the effect of a twin-vortex driven by the non-conservative part of the J x B force and the viscous interactions with the external flow. In a heuristic analytical study of representing the arc by an impermeable fluid cylinder the internal flow and its convective effects on the arc temperature distributions were calculated. The resulting isotherms exhibit an oval pattern consistent with the optical observations. The calculated drag on the arc surface and the separation points for a solid cylinder are also in reasonable agreement with the experiments.

*Work accomplished as part of arc technology program of ARL, WPAFB, Ohio.

G2. Experiments on Magnetically Balanced Cross-Flow Arcs.* A. J. BAKER and D. M. BENENSON, State Univ. of N. Y. at Buffalo--Experiments were conducted upon magnetically balanced, 1.1 atmosphere, 80 amp. and 130 amp., argon cross-flow arcs in the range of magnetic field $48 \leq B_{gauss} \leq 585$ and mainstream velocity $1.82 \leq U_{m/s} \leq 13.13$. Temperature distributions were obtained in several horizontal planes within the plasma; cross-sectional shapes and profiles were determined. Isotherms indicated arcs to be clearly non-circular with major axis in direction transverse to flow. Two types of stable operation were found: colinear mode (arc attachment on upstream side of electrodes). Below critical velocity, about 5 m/s. The upstream mode was markedly more uniform along its length and exhibited much greater lateral broadening than the colinear mode. At mid-height between the electrodes, the ratio of major to minor axes was about 1.1 for the colinear mode and about 2.4 for the upstream mode. The principal effect of velocity upon the upstream mode was to decrease slightly the above ratios.

*Work supported by National Science Foundation Grants GK-1174 and GK-2886.

G3. Analysis of Magnetically Balanced Cross-Flow Arcs.* V. R. MALGHAN and D. M. BENENSON, State Univ. of N. Y. at Buffalo--A straight, balanced cross-flow plasma is considered wherein the flow and temperature fields and arc boundary are determined as results of the analysis. The fluid mechanic and thermodynamic interactions are coupled in a consistent fashion. Phenomenological relations are employed to determine the flow and arc parameters for the balanced arc. The analysis uses some of the concepts of Lord and of Kihara and Han. The linear discontinuous model is employed for electrical conductivity. Other gas properties are assumed constant appropriate to the respective regions interior and exterior to the arc. The method of Galerkin is employed. The results show that the effect of Reynolds number is to change the flow pattern from "complete flow-through" type to "closed streamline" type, with the location and shape of the bounding streamline a function of Reynolds number. Isotherm distributions obtained for the various closed streamline flows agree qualitatively with experiment.

*Work supported by National Science Foundation Grants GK-1174 and GK-2886.

G4. Magnetic Pumping Effects in Gas-Blown SF_6 Arcs. J. F. PERKINS and L. S. FROST, Westinghouse Research Laboratories--Experimental measurements of the rate of recovery of dielectric strength of gas-blown SF_6 arcs following current interruption in a small polycarbonate nozzle have been performed. The experiments were carried out with a 1 cm electrode spacing and 400 μsec duration current pulses whose amplitude was varied between 20 A and 1000 A. The upstream arc chamber pressure was either 35 psia or 60 psia, which ensured that critical pressure and sonic velocity occurred near the nozzle throat. An anomalous behavior of the dielectric recovery characteristics was observed, in which the recovery rate following a 1000 A arc was faster than that following a 350 A arc. This is contrary to expected behavior, which is that recovery times should increase with arc current. With the aid of an empirical linearization of the recovery characteristics, the anomalous results have been analyzed using a model of magnetic arc pumping; this model predicts an acceleration of the gas, which increases with the square of the current, away from any arc constriction.

G5. "Hot" Electrode Studies in a Supersonic Plasma Stream with a Magnetic Field. MARIS A. MANTENIEKS, NASA-LeRC - Electrode phenomenon were studied in a supersonic plasma flow with a magnetic field (MHD generator). A single pair of carbonized Th-W electrodes immersed into the stream were used. The following measurements were taken: floating potential profiles of the electrode gap (from which the electrode drops were determined), electrode temperature, V-I characteristics. At the maximum available magnetic field of 0.54 Tesla, generated voltages of about 21 volts and current of up to 34 amps were attained. The cathode drops increase from about 0.75 volts for zero discharge current conditions to up to 10.2 volts for high current. Anode drops increase negatively from about 1.35 volts to -4.7 volts. Electrode temperatures range from 2135° to 2500° K. It was found that: (1) electrode drops are independent of magnetic field, (2) the discharge may exist in the self-sustaining or nonself-sustaining arc mode depending on the cathode temperature, (3) there is an electrode temperature (about 2250° K) for which a minimum cathode drop is found, (4) a cooling effect for low discharge current is found at the cathode and, (5) the cooling at the cathode depends on the magnetic field.

ABSTRACTS

TWENTY-THIRD ANNUAL

GASEOUS ELECTRONICS CONFERENCE

21–23 OCTOBER

1970

HARTFORD HILTON HOTEL

HARTFORD, CONNECTICUT

SESSION H

Wednesday Morning, 21 October

8:30 a.m.

GLOW DISCHARGES

Chairman: W. J. Weigand, United Aircraft Research Laboratories

H1. Radial Density Distribution Measurements of Neutral Cs in the Positive Column of a Cs-Ar d.c. Discharge, H.v.TONGEREN and C.v.TRIGT, Philips Research Laboratories, Eindhoven, The Netherlands.-- The radial distribution $N_{Cs}(r)$ of neutral Cs in a Cs-Ar discharge (tube radius R=17 mm, P_{Ar}=5 Torr, $N_{Cs}(R)=2.3\times10^{18}m^{-3}$) was determined by measuring the absorption A(y) at 852.1 nm ($6^2S_{1/2}-6^2P_{3/2}$) of a light beam perpendicular to the tube axis ($y=\sqrt{r^2-R^2}$). $N_{Cs}(o)/N_{Cs}(R)$ is found to be 0.3 and 0.1 in a discharge with currents of 50 mA and 63 mA respectively. The Abel inversion required has been performed by means of a new technique[1] essentially based on expansion of $N_{Cs}(r)$ and A(y) in Legendre polynomials. The problem is reduced to a matrix inversion, which can be performed analytically. The expansion coefficients are least squares fits. Furthermore the noise can be handled explicitly. This method proves to be accurate and stable for the addition of noise.

[1].C.v.Trigt, J.Opt.Soc.Am. to be published.

H2. The Radial Distribution of Ga atoms in a GaJ_3-Ar Discharge. J.H.WASZINK, Philips Research Laboratories, Eindhoven, Netherlands. In the positive column of a discharge in 3×10^{-5}Torr GaJ_3 and 10 Torr Ar the radial distribution of Ga atoms in the $^2P_{1/2}$ and $^2P_{3/2}$ states has been measured by optical absorption. At the tube wall the density is practically zero. For discharge currents below 15 mA there is a maximum at the axis, at higher currents a minimum at the axis and a maximum between the axis and the wall. At the maximum, the density is about $2\times10^{17}m^{-3}$. The Ga density profile is determined mainly by dissociation of the GaJ_3 (a two-step process) and ionization of the Ga. A continuity equation for the Ga density is obtained. It has solutions which are zero at the tube wall and have a maximum at the axis. Also possible are solutions which are zero at the wall and have a minimum at the axis and a maximum between the axis and the wall. The parameters for the dissociation and ionization processes determine the type of solution.

H3. Microwave and Langmuir Probe Measurements of CO_2 Plasmas. L.A. SCHLIE*, P. BLETZINGER, and A. GARSCADDEN, Aerospace Rsch Labs, WPAFB, Ohio --A study of CO_2 plasmas was made by comparing microwave radiometer and second derivative Langmuir probe results. In a discharge tube 24 mm i.d. 0.9<pR<5 torr cm, with discharge current to 100 mA, the probe method showed that the electron energy distribution is non-Maxwellian. The microwave measurements gave radiation temperatures of about 1.3 eV. The probe data, uncorrected for finite probe size and pressure effects, gave average energies ∿1 eV higher. The observed radiation temperature is directly related to the average electron energy, and the electron density can be determined by resonant cavity perturbation methods. These boundary conditions allow calibration of probe curves. Comparison is made with curves corrected using an extrapolation near space potential. These results are compared with collisional probe theories.

*Research Associate from the Ohio State Univ. Research Foundation, Columbus, Ohio

H4. V-I Characteristics and Depletion Effects in a Multicomponent Gas Discharge. GERALD L. ROGOFF, Westinghouse Res. Labs.--A negative V-I characteristic is usually associated with an electrical discharge in a weakly ionized gas mixture of a few Torr containing a minority component with significantly lower excitation and ionization potentials than the majority components. If the current is increased sufficiently, however, the characteristic may become positive due to depletion of the minority component; eventually the excitation of a majority component can become appreciable. A theory of an ambipolar-diffusion-controlled positive column with a minority component having one excited state yields expressions relating current, voltage gradient, average electron energy, and minority ground state density. In the case of stepwise ionization, excited atom loss by radiation and diffusion, and electron energy loss by elastic collisions the expressions simplify and predict the negative and positive characteristics. A criterion for the change in slope is determined. Expressions are obtained for the current at the voltage minimum and the current at which excitation of the majority gas becomes significant. The latter is compared with data for cesium-noble gas discharges.

H5. Solutions to the Continuity Equation with Variable Transport Coefficients in a One-Dimensional Negative Glow and Faraday Dark Space.* W. B. HURT, U. of Texas at Dallas--The one-dimensional charged particle continuity equation has been solved in a negative glow, Faraday dark space environment allowing for the field dependence of the electron mobility, electron diffusion coefficient, and electron-ion recombination coefficient. The values used for the mobility and diffusion coefficient were for electrons in helium, and the values used for the recombination coefficient were compatible with a collisional-radiative recombination mechanism. The resulting solutions are shown to be significantly different than those obtained assuming constant transport and recombination coefficients. In particular, it is seen that recombination is not necessarily negligible in the Faraday dark space.

*Work supported in part by the National Aeronautics and Space Administration, NASA Grant NGL44-004-001

H6. Plasma Diagnostic Technique Using a Beam of Slow Positrons. GUNTER H. LOHNERT, MICHAEL W. SCHIKORR, and RICHARD T. SCHNEIDER, Univ. of Florida--Interactions of positrons with a plasma allows investigations of plasma parameters such as density, temperature, and velocity distribution of the electrons. Theoretical consideration for the positron-plasma interactions show that a beam of slow positrons has to be used in order to obtain detectable effects. The measurement of positron lifetime in the plasma and of the angular correlation of the annihilation radiation yield information on electron density and temperature. A parallel beam of slow positrons injected into a plasma will be spread into an angle α after leaving the plasma due to the cumulative effect of small angle scattering. In measuring α the electron density n_e can be found. A device was designed and constructed which is capable of producing a beam of slow positrons. In order to verify the theoretical beamspread measurements and to demonstrate the feasibility of the new technique a He plasma (14 cm diameter) was built. The slow positrons were injected into the plasma through an ultrathin window (200Å). Spectroscopic and probe measurements were carried out. The results compared well with the beamspread measurements.

SESSION I

Wednesday Morning, 21 October

8:30 a.m.

IONIZATION

(PANEL)

Chairman: C. E. Kuyatt, National Bureau of Standards

I1. Threshold Ionization of Krypton by Electron Impact. N. SWANSON, J.W. COOPER and C.E. KUYATT, National Bureau of Standards--The near-threshold ionization region in krypton has been studied by making measurements in a new mode of operation (Ionian mode) in which scattered electrons of constant energy are observed as the incident energy is varied. The energy resolution was $\approx$0.1 eV and results were obtained for final energies in the range 0.1-4 eV and incident energies in the range 10-20 eV. The electron spectrometer is similar to others used in this laboratory but was designed specifically for operation in the near threshold region. All measurements were made with the analyzer at 15° relative to the incident beam. Preliminary results are: 1) We observe a rise in the scattered electron current at the first ionization threshold (14 eV) for final electron energies in the range 0.1-0.5 eV. The rise is believed to be the contribution of the ejected electrons. 2) The scattered electron current rises gradually between the $^2P_{3/2}$ and $^2P_{1/2}$ thresholds (0.65 eV splitting) presumably due to the autoionizing states between these two thresholds. 3) The scattered current drops off rapidly for incident energies approximately 1-1.5 eV above the first threshold indicating that few slow electrons are either scattered or ejected at 15°.

I2. Energy and Angular Distributions of Electrons Ejected from N_2 by Electron Impact.* G. C. TISONE, Sandia Laboratories--Energy distributions and angular distributions of electrons that have been ejected from N_2 after ionization by electrons with energies of 500, 750, and 1000 eV have been measured using crossed molecular and electron beams. The ejected electron spectra, at selected angles, were measured for ejected energies up to 500 eV with an energy resolution of $\Delta E = 0.015$ E at FWHM. The energy spectra have been measured between 40° and 90° where a maximum in the number of ejected particles occurs. The spectra were measured at 5° intervals with an angular resolution of 1°. Absolute cross sections, differential in energy and angle, were obtained by normalization to the absolute elastic scattering cross sections of Bromberg.[1]

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

[1] J.P. Bromberg, J. Chem. Phy. 50, 3906 (1969)

I3. Secondary Electron Distribution from He and N_2.* W. K. PETERSON, C. B. OPAL, AND E. C. BEATY, Joint Institute for Laboratory Astrophysics, Univ. of Colorado, Boulder, Colorado.--The energy and angular distributions of secondary electrons resulting from electron impact ionization of helium and molecular nitrogen have been measured using a crossed-beam apparatus. The secondary energies between 4 and 200 eV were measured with a hemispherical analyzer having an angular acceptance of approximately 15° and an energy resolution of approximately 10%. The primary electron energy was varied from 200 to 2000 eV and the angle between the primary beam and the analyzer was varied between 30° and 150°. For ejected electron energies less than about twice the ionization potential the angular distribution is isotropic to within a factor of 2 for both gases. At higher energies a maximum occurs between 45° and 90°, as expected from kinematic effects in electron-electron collisions. The observed N_2 spectrum integrated over angles agrees reasonably well with the semi-empirical formulas which have been used in auroral model calculations.

*Work supported in part by Advanced Research Projects Agency.

I4. Distributions in Energy and Angle of Electrons Ejected From Hydrogen by Fast Protons,* L.H. TOBUREN, W.E. WILSON, Battelle-Northwest -- Cross sections, differential in electron energy and emission angle were measured for electron ejection from molecular hydrogen by proton impact. The energy range of the incident protons was from 0.3 to 1.5 MeV. At 0.3 MeV, our doubly differential cross sections are compared to measurements of Rudd,[1] et al., and to the calculations of Macek.[2] After integration over angle, our results were compared to cross sections differential in electron energy calculated by means of binary encounter theory. In general, the results of binary encounter theory are 20 to 50% smaller than the measured values; estimated experimental uncertainties are 25%. The total ionization cross sections obtained by integration of our measured values over emission energy and angle are in close agreement with results reported by Hooper, et al.[3]

*This paper is based on work performed under United States Atomic Energy Commission Contract AT(45-1)-1830.

[1]M.E. Rudd, et al., Phys. Rev, 151, 20 (1966).
[2]J. Macek, Phys. Rev. A-1, 235 (1970).
[3]J.W. Hooper, et al., Phys. Rev. 121, 1123 (1961).

I5. Electron Distributions from Hydrogen for 0.6,1.0 and 1.5 MeV Hydrogen Ions,* W. E. WILSON, L. H. TOBUREN, Battelle-Northwest -- Electron yields, differential in energy and angle of emission, have been measured for 0.6, 1.0 and 1.5 MeV hydrogen ions incident upon hydrogen. Energy distributions of electrons from a few eV to approximately 1500 eV were recorded at 9 angles between 20 and 130 degrees. The experimental method employed was that used by Toburen.[1,2] The electron distributions are characterized by strong forward peaking, a broad peak about an energy corresponding to an electron with velocity equal the velocity of the incident ion, and at all angles, a decreasing yield for increasing ion energy. By integrating the distributions with respect to angle and comparing the resulting energy distributions with similar ones for equal-velocity-proton ejection of electrons from H_2 target, a measure of the cross section for the process $H_2^+ \rightarrow H^+ + H^+ + e^-$ is obtained. We find this breakup cross section to be 3.2, 1.8 and 1.2 x $10^{-17} cm^2 \cdot molecule^{-1}$ at 0.6, 1.0 and 1.5 MeV respectively.

*This paper is based on work performed under United States Atomic Energy Commission Contract AT(45-1)-1830.
[1]L.H. Toburen, Phys. Rev., in press.
[2]L.H. Toburen, W.E. Wilson, this conference.

I6. Multiple Ionization of Ne, Ar, and Kr, by Soft X-Rays. G.S. Lightner*, R.J. Van Brunt, and W. D. Whitehead, Univ. of Virginia -- The relative abundances of multiply charged ions of Ne, Ar, and Kr due to photoionization by monoenergetic X-rays of energies 279 eV, 1.49 KeV, 5.4 KeV, and 8.05 KeV have been measured with a linear pulsed time-of-flight mass spectrometer. The ion charge spectra were obtained by a matched filters differencing technique, in which two filters of matching transmission at all energies except at the K line of the X-ray tube target material were alternately placed in the X-ray beam. The difference in the two charge spectra thus produced is then due to the K line. The data were corrected for charge dependent discrimination effects associated with the mass spectrometer. The results are generally consistent with previous experiments and with calculations which include the "electron shake-off" mechanism in addition to Auger transitions.[1]

* Present address: Westminster Col.,New Wilmington,Pa.
1 For example: T.A. Carlson and M.O. Krause, Phys. Rev., 137, A1655 (1965).

SESSION J

Wednesday Morning, 21 October

10:15 a.m.

ELECTRON SCATTERING

(PANEL)

Chairman: L. J. Kieffer, JILA, University of Colorado

J1. Measurements of the total cross sections for the scattering of low energy electrons for K, Cs and Rb.* K. Rubin, P.J. Visconti, and J.A. Slevin, City College of the City University of N.Y.- Recently there have been a number of reasons, both theoretical and experimental, to question the validity of the low energy electron alkali total cross sections that have existed in the literature for the past forty years. We therefore decided to remeasure the cross sections for K, Cs and Rb in the energy range .3ev- 9ev using the atom beam recoil technique. Through the use of an automatic data acquisition system and a careful analysis of all sources of systematic error, we obtained cross section values with an estimated error of less than 10%. We also investigated the effect of the finite resolution of our apparatus on the measured cross sections. All our results differ significantly from those of Brode, both in magnitude and variation with energy, while our potassium data agrees quite well with those of Collins et al.[1] as well as the calculations of Karule[2] and Karule and Peterkop.[3]

*Work supported by the National Science Foundation.

[1] R.E. Collins, B. Bederson and M. Goldstein (submitted to the Physical Review A)

[2] E.M. Karule and [3] E.M. Karule and Peterkop, JILA Info. Center Report No.3, University of Colorado.

J2. Dependence of Generalized Oscillator Strengths on Momentum Transfer and Effective Nuclear Charge for s, p, and d Atomic Transitions.* K. J. Miller, Rensselaer Polytechnic Institute.--Generalized Oscillator Strengths, f(K), for atomic transitions are studied within the first Born Approximation. A one electron model employing hydrogen-like orbitals is used with appropriate effective nuclear charges. For single electron excitations, the Born matrix element $f(K) = (2/3)K^{-2} \Delta E \left| \int \phi_a e^{iK \cdot r} \phi_b \, dV \right|^2$ can be scaled so that f(K) depends on the ratio of effective nuclear charges z (final)/z (initial) and a reduced momentum transfer K/z (initial). Transitions to a Rydberg series exhibit extrema in f(K) which are nearly the same for all members, whereas excitations to different series exhibit a different number and positioning of the extrema. These trends suggest that transitions to different types of electronic states can be identified.

*Supported by the Petroleum Research Foundation.

J3. Elastic Scattering of Electrons by a Freely Rotating Electric Dipole: Effect of Closed Channels.* W. R. GARRETT, Oak Ridge National Laboratory. -- Calculations have been made for elastic scattering of extremely low energy electrons by a free-rotator electric dipole system where no inelastic processes are energetically possible. The effects of rotational transitions are included as closed channels in the close coupling calculations, and the overall effects of open and closed channels in the dipole problem are analyzed.

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

SESSION K

Wednesday Morning, 21 October

10:15 a.m.

HEAVY PARTICLE EXCITATION

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

K1. Rotational Excitation of N_2^+ Produced in Na^+-N_2 Collisions.* R.E. MICKLE and R.P. LOWE, Univ. of Western Ontario.--Rotational line intensities from spectra of the (0,0) First Negative band of N_2^+ have been used to obtain the population distribution of the rotational levels of $N_2^+(B^2\Sigma_u^+)$ excited in collisions of 3 to 9 keV sodium ions on nitrogen target gas. Lines with K' up to 80 were used. After correction for branch overlapping, Boltzmann distributions were found at all energies, contrary to previous results on the same system excited by other ions[1]. Deduced rotational temperatures decreased from 9700°K at 3 keV to 4600°K at 9 keV.

*Supported in part by the National Research Council of Canada.

[1]J.H. Moore and J.P. Doering, Phys. Rev. 174, 178 (1968); 177, 218 (1969).

K2. Excitation of N_2^+ In Ion-Molecule Collisions At Low-Energy. S. H. NEFF*, Morehouse College, N. H. TOLK, C. W. WHITE, Bell Telephone Laboratories--We have measured absolute emission cross sections for the production of N_2^+ first negative radiation in collisions of He^+, Ne^+, and Ar^+ ions with N_2. The energy range of these measurements extends from 10eV to 3keV in the laboratory system. Pronounced structure is evident in the cross section for the emission of the (0,0) band as a function of ion energy. In all cases, a low energy peak is observed at energies less than 100eV, followed by a broad minimum between 100 and 200eV, and a monatomic increase with energy above 200eV. The location of the low energy peak scales with velocity, occurring in all cases at $\sim 1.7 \times 10^6$ cm/sec. These cross sections show rotational and vibrational enhancement over the measured energy range. The population of levels of the $B^2\Sigma_u^+$ state with $\nu > 0$ is velocity dependent and particle independent for energies above 100eV as reported by previous investigators[1], but becomes dependent upon the nature of the bombarding particle below that energy.

[1] J. H. Moore and J. P. Doering, Phys. Rev. 177, 218 (1969).

* Present address: Earlham College, Richmond, Indiana.

K3.
Excitation of the 2^3S Metastable State Helium by 50 keV Helium Ions.* D. R. SCHOONOVER, Corning Electronics and JOHN T. PARK, Physics Department, University of Missouri-Rolla. The cross section for excitation of the 2^3S metastable state of helium has been measured by heavy ion energy loss spectrometry. The method and apparatus have been described in earlier publications[1,2]. The data was taken from inelastic energy loss spectra of helium ions incident on a gaseous helium target. The spectra were obtained with a resolution of 0.6-0.8 eV. Contributions from the 2^1S and 2^3P states were eliminated by detailed study of the spectra curve shapes. The cross section for excitation of the optically forbidden 1^1S-2^3S transition in Helium by 50 keV Helium ion Impact is nearly as large as the cross section for excitation of the optically allowed 1^1S-2^1P transition.

*Research Supported by the National Science Foundation.

1. J. T. Park and F. D. Schowengerdt, Phys. Rev. 185, 152 (1969).
2. J. T. Park and F. D. Schowengerdt, Rev. Sci. Instrum. 40, 753 (1969).

K4. Spectral Excitation by Collisions of the He^+ + H_2 and H_2^+ + He Systems.* R.D. NATHAN and R.C. ISLER, Univ. of Florida--Emission spectra which arise from He^+ + H_2 and H_2^++He collisions have been investigated in the region from 3500Å - 7500Å at bombarding energies f from 10 eV to 800 eV. The Balmer series of hydrogen and lines of neutral helium are produced strongly in both processes. Relative cross sections for excitation as a function of energy have been measured for several lines. The dependence of these cross sections upon the energy of the electrons which are used to produce ions will be discussed

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

K5. Cross Sections for Emission of Lyman-α Radiation in Collisions of 1-30 keV Hydrogen Atoms with Inert Gases.* J. H. Birely and R. J. McNeal, The Aerospace Corporation.--Cross sections are reported for emission of Lyman-α (L_α) radiation in collisions of 1-30 keV H atoms with He, Ne, Ar, Kr and Xe. An H atom beam is prepared by electron-capture collisions of a fast proton beam with Ar. The H atoms interact with the low-pressure target gas in a differentially-pumped, essentially field-free collision chamber after electrostatic removal of residual H^+ and quenching of metastable H. L_α from collisions of either the parent H^+ beam or the H beam with the target gas is viewed at 90° with respect to the beam direction by an oxygen-filtered solar-blind photomultiplier. Relative cross sections for emission of L_α in H atom collisions are made absolute by normalizing to previous measurements of the H^+ bombardment emission cross section.[1,2] The processes producing L_α radiation in H^+ and H collisions will be discussed.

*Work conducted under USAF Contract No. F04701-70-C-0059

1. E. P. Andreev et al., Sov. Phys.-JETP 23, 375 (1966).
2. T. D. Gaily et al., Phys. Rev. 167, 81 (1968).

SESSION L

Wednesday Afternoon, 21 October

2:00 p.m.

ATOMIC AND MOLECULAR PROPERTIES

(PANEL)

Chairman: H. H. Michels, United Aircraft Research Laboratories

L1. Transition Probabilities for the CO 4^{th} Pos System. G. M. LAWRENCE, Joint Institute for Laboratory Astrophysics.--A factor-of-two discrepancy between CO radiative lifetimes and electron impact oscillator strengths is largely explained by allowing the electronic transition moment, R_e, to vary with internuclear separation r (in Å). Hesser's[1] radiative lifetimes for the CO fourth positive system are used to determine the variation of R_e. The result, $R_e = 3.73\ (1-0.67r)$, obtained from an iterative least square process,[2] yields an oscillator strength $f_{20} = 0.037$. Constant R_e yields $f_{20} = 0.022$. Thus there is improved agreement with the electron impact oscillator strength,[3] $f_{20} = 0.0429$. Lifetime measurements are being made to examine rotational perturbations, etc.

[1] J. E. Hesser, JCP, 48, 2518 (1968).

[2] Vibrational integrals by D. Albritton, A. Schmeltekopf, and R. Zare, to be published.

[3] E. N. Lassettre, A. Skerbele, V. D. Meyer (private communication).

L2. Measurement of Transition Probabilities for O I in the Vacuum Ultraviolet* W.R. Ott, NBS.--Transition probabilities were obtained using a wall-stabilized arc discharge operating in a mixture of argon and oxygen. The following values were obtained for lines in the resonance transition array: $A(^1D_2 - {}^1D_2^\circ, \lambda = 1152\ Å) = 5.5\times10^8$/sec; $A(^1S_o - {}^1P_1^\circ, \lambda = 1218\ Å) = 1.8\times10^8$/sec; $A(^3P_o - {}^3S_1, \lambda = 1306\ Å) = 0.66\times10^8$/sec; $A(^3P_{2,1,0} - {}^3S_1^\circ, \lambda = 1303.5\ Å) = 5.9\times10^8$/sec. These values were obtained under optically thin conditions and are in excellent agreement with theoretical calculations by Garstang[1] and with recent lifetime measurements.[2] Existing discrepancies in the literature concerning previous arc determinations of the OI VUV oscillator strengths will also be discussed.

[1] Garstang, R.H., Proc. Cambridge Phil. Soc. 57, 115 (1961).

[2] Lawrence, G.M., to be published

*Research supported by the Advanced Research Projects Agency of the Department of Defense under the Strategic Technology Office.

L3. Lifetime Measurements in Metallic Vapors.* A.R. SCHAEFER and R.G. FOWLER, Oklahoma Univ.--The invertron excitation source developed at the University of Oklahoma by T.M. Holzberlein has been modified for use in measuring atomic lifetimes of metallic vapors via a delayed coincidence technique. Measurements have been made and results are presented for about sixty excited states of magnesium, cadmium, barium, and their first ionized species. Interesting trends in the lifetimes of series are noted, including that of the ^1D series in magnesium, of interest in astrophysics. The lifetime of the doubly excited state used in the helium cadmium laser was also measured.

*Work supported by the National Science Foundation.

L4. Hydrogen Balmer Lifetimes. R.A. MICKISH and R. G. FOWLER, Oklahoma Univ.--An experimental measurement of the H_α, H_β, H_γ, and H_δ hydrogen Balmer lifetimes has been carried out by use of the invertron (a bright hollow cathode source) and a delayed coincidence technique of photon counting. The lifetimes were found to be 63 ± 6, 39 ± 9, 71 ± 10, and 105 ± 21 nanoseconds, respectively. Considering the mode of excitation, and decay, these values agree well with theory and the experimental values obtained by other investigators. It was found that when prepared by electron dissociation of hydrogen molecules the degenerate ℓ levels of the hydrogen atoms are populated in proportion to their degeneracies and radiate according to ordinary ℓ selection rules.

L5. Lifetimes of Metastable CO and N_2 Molecules.* WALTER L. BORST and E. C. ZIPF, University of Pittsburgh.-- The radiative lifetime of N_2 molecules in the $a^1\Pi_g$ and $E^3\Sigma_g^+$ states were found to be (115 ± 20) μsec and (190 ± 30) μsec, respectively, in a time of flight experiment which used a diffuse gas source at low pressure. The primary lifetime data were obtained by normalizing to the time of flight distribution for N_2 molecules in the metastable $A^3\Sigma_u^+$ state for which $\tau \approx 2$ sec $\approx \infty$. The lifetimes were also obtained directly from the nearly Maxwellian time of flight distributions. Using these techniques radiative lifetimes of CO molecules in the metastable $a^3\Pi$ state were found to lie between 0.7 and 1.3 msec. In the course of this work a careful assessment of potential momentum recoil problems was made and, as a consistency check on our method, the lifetimes of metastable helium atoms were estimated. The total metastable excitation functions were also measured from threshold with high energy resolution.

*Work supported, in part, by NASA and ARPA.

L6. Energies of Metastables Produced in Electron Impact Dissociation of Atmospheric Gases.* WALTER L. BORST and E. C. ZIPF, University of Pittsburgh.-- Gases of atmospheric interest - O_2, N_2, CO, and CO_2 - were dissociated by electron impact and the metastable dissociation products O^m, N^m, and CO^m were energy analyzed. The energy spectra of these metastables exhibit characteristic structure that can be associated with the molecular structure of the parent molecules. In all cases studied, the energies of the dissociation products ranged up to several eV. Threshold studies of the dissociation process were made and extended up to primary electron energies of about 50 eV. Emphasis was put on the dissociation of O_2. The apparatus designed for this experiment will be discussed briefly.[1] Implications of the measured energy spectra concerning repulsive molecular states and reactions in the upper atmosphere will be discussed.

*Work supported, in part, by NASA and ARPA.

[1]See also following paper.

L7. Autoionization in the UV Photo-Absorption of Atomic Calcium.* V. L. CARTER, R. D. HUDSON† and E. L. BREIG, Aerospace Corp.--Results are presented of a combined theoretical and experimental investigation of the absorption spectrum for the allowed dipole transitions $^1S_0 \rightarrow ^1P_1^o$ of Ca near the first (4sEp, λ<2028Å) and beyond the second (3dEp, λ<1589Å) ionization limits. Absorption spectra[1] were obtained with a bandwidth of .075Å. The theoretical calculations made allowance for configuration interaction through an analysis of series perturbations according to the multi-channel quantum defect theory.[2] For wavelengths near the ionization threshold, significant improvements have been achieved in the agreement between experiment and the two-channel theory, both in the general shape of the absorption profile, and in its magnitude at threshold and at the first resonance peak. Experimental results for λ<1589Å indicate σ<3 Mb, in sharp contrast to the large (σ>12 Mb) peaks predicted by Moores.[2] Application of the three-channel theory to the latter region will be briefly discussed.

*Work performed under USAF Contract F04695-67-C-0158.
†Present address: NASA/MSC, Houston, Texas.

[1] R.D. Hudson and V.L. Carter, Phys.Rev. 137, A1648(1965)
[2] D.L. Moores, Proc.Phys.Soc. 88, 843 (1966)

L8. Autoionization Levels in Cesium.* Y. HAHN, K.J. NYGAARD, D.R. KASTELEIN, and L.A. ROE, Univ. of Missouri at Rolla--Most of the present knowledge on autoionization levels and mechanisms in Cs originates from spectroscopic data[1,2]. Our contribution has been to study autoionization levels by electron impact. A retarding potential difference (RPD) electron gun was used to produce an electron beam with energy spread of about 0.1eV. The scattered beam electrons were analyzed by means of the trapped-electron method. About 15 levels above the Cs ionization potential have been resolved and identified. An additional peak at 12.85 eV is probably due to the quartet states observed by Feldman and Novick[3].

*Work supported in part by the National Science Foundation.

[1] H. Beutler and K. Guggenheimer, Z. Physik 88, 25 (1934)
[2] J. P. Connerade, Astrophys. J. 159, 685 (1970)
[3] P. Feldman and R. Novick, Phys. Rev. 160, 143 (1967)

SESSION M

Wednesday Afternoon, 21 October

2:00 p.m.

AFTERGLOWS

Chairman: C. Lineberger, JILA, University of Colorado

M1. <u>Behavior of $He(2^3S)$ Metastables in Helium Plasmas</u>.* P.A.MILLER, J.T. VERDEYEN, and B.E. CHERRINGTON, <u>Univ. of Ill</u>.--Investigations concerning the behavior of the $He(2^3S)$ population in active discharge and afterglow helium plasmas are described. Good quantitative agreement is obtained between measured $He(2^3S)$ metastable densities in active discharges and predicted values based on the solution of a nonlinear rate equation. The rate coefficient for ionizing metastable-metastable collisions is measured in afterglow helium plasmas for the pressure range 10 to 40 Torr; close agreement is obtained with the value reported by Phelps. The electron temperature decay in the afterglow is measured and found to agree closely with the decay expected on the basis of the energy source and loss processes which affect the electron gas. In this work, measurement of the metastable density is accomplished by the novel use of a He-Ne laser operating at 1.0798μ in an interferometer as well as by the conventional optical absorption method.

*Work supported by Aerospace Research Laboratories, Wright Patterson Air Force Base, under contract AF 33(615)5248.

M2. <u>Investigation of the $Ne(1s_5)$ Metastable Atom Concentration in the Early Afterglow of Pulsed Neon Plasmas</u>.* E.E.WISNIEWSKI, J.T.VERDEYEN, B.E.CHERRINGTON, <u>Univ. of Ill</u>.--Interferometric studies at 6401Å of the spatial and temporal behavior of the $Ne(1s_5)$ atom density in pulsed neon plasmas indicate a build-up in metastable atom concentration in the early afterglow. Over the range of investigation; pressures between 5 and 20 Torr, pulsed current densities between 0.2 and 2.0 amperes/cm^2, a rapid increase in $Ne(1s_5)$ atom density to a value several times larger than attained during the pulse was observed. This build-up is followed by an interval of rapid metastable decay whose rate decreases in time and approaches the value of final decay frequency reported by Phelps.[1] We attribute this build-up to electronic recombination since it is affected by selective heating of the electrons with microwaves. The rapid initial decay is believed to be due to collisions of the second kind.

*Work supported by Aerospace Research Laboratories, Wright Patterson Airforce Base under contract AF33(615)5248.

[1]A.V.Phelps, Phys.Rev. <u>114</u>, 1011 (1959).

M3. Stabilization of the Recombination of He^+ and He_2^+ in a High Pressure Helium Afterglow.* H.S.HICKS, W.E.WELLS, and C.B.COLLINS, U. of Texas at Dallas--The time dependent net rate of stabilization of the recombination with electrons of both He^+ and He_2^+ has been measured in a pulsed helium afterglow at a neutral pressure of 44.6 Torr. Simultaneous measurement of the electron density with a 35 Gc microwave interferometer has given the stabilization rates as functions of electron density without the need of a priori assumptions about the functional form. In contradiction to theory little similarity of stabilization rates is found for the two ions over the range of electron densities, 10^{10} - 10^{12} cm^{-3}, spanned by these measurements.

*Work supported in part by the Atmospheric Sciences Section, National Science Foundation, NSF Grant GA-15434

M4. The Rotational Distribution of He_2^* Resulting from Recombination of He_2^+ and He_3^+ in a Helium Afterglow.*A. WAYNE JOHNSON, Sandia Labs.--At temperatures below 300°K, the molecular spectra in a helium afterglow plasma results primarily from the dissociative recombination of the He_3^+ ion. A statistical analysis of the rotational distribution of He_2^* resulting from He_3^+ dissociative recombination predicts that which is observed in a helium discharge tube cooled with liquid nitrogen. At 300°K and above, the rotational distribution of He_2^* in an afterglow is produced by more complicated recombination processes. A model including pressure dependent recombination of He_2^+ is presented to describe the rotational distribution which is observed in a 300°K helium afterglow.

*Work supported by U. S. Atomic Energy Comm.

M5. Role of He_3^+ in the Recombination of 300°K Helium Plasma.* M. A. GUSINOW, R. A. GERBER, and J. B. GERARDO, Sandia Labs.--Data will be presented which shows that the net electron-ion recombination coefficient in room temperature helium plasmas may be predominantly accountable to a two-body recombination with the minority ion He_3^+ for pressure greater than a few Torr. The measured equilibrium constant of the He_2^+-He_3^+ reaction at 300°K is

$$0.5 \times 10^{21} < [He_2^+]^*[He]^*/[He_3^+]^* < 1.0 \times 10^{21}\ cm^{-3}\ .$$

Using the He_3^+ recombination coefficient,[1] and $[He_3^+]^*/[He_2^+]^*$ a pressure dependent term in the net recombination coefficient is obtained,

$$1.2 \times 10^{-11}\ p \leq \alpha' \leq 7.1 \times 10^{-11}\ p\ cm^3/sec$$

where p is in Torr. This is to be compared with the measured pressure dependent term[2]

$$(6.4 \pm 1.6) \times 10^{-11}\ p\ cm^3/sec.$$

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

[1] J. B. Gerardo and M. A. Gusinow (submitted for publication.

[2] Jacques Berlande, et al., Phys. Rev. A1, 887 (1970).

M6. Afterglow Behavior of the 4s,p,d,f → 3s,p,d Lines of He^+ by High-Resolution Interferometry.* WILLIAM W. KUHLOW,† FRED L. ROESLER, AND CHUN C. LIN, University of Wisconsin -- The relative intensities of ten components of the group of 4s,p,d,f → 3s,p,d transitions of He^+ have been measured in a liquid-nitrogen-cooled, pulsed hollow cathode discharge of helium at various afterglow time increments over a period of 20 μsec. A high-resolution, high-luminosity scanning Fabry-Perot interference spectrometer with double etalon was used. Over a range of gas pressure from 0.3 to 3 Torr and of peak discharge current from 0.4 to 1.6 A, the observed relative intensities remain fairly constant giving the relative populations of the 4s, 4d, and 4f states of He^+ as typically 2:67:100. The decay time varies appreciably under different conditions ranging from 1 to 4.5 μsec. Analysis of the emission intensities and their time-variation indicates that the three-body recombination of He^{++} with subsequent cascade is mainly responsible for the observed population of the n = 4 levels of He^+.

*Work supported by the National Science Foundation.
†Present Address: Glenville State College, Glenville, West Virginia.

M7. Mass Spectrometric Study of Low Pressure Rare Gas Afterglow Plasmas. A. K. BHATTACHARYA, General Electric Lighting Research Laboratory, Cleveland, Ohio 44112.--The results of mass identified measurements of the decay of atomic positive ion number densities in low pressure rare gas afterglow plasmas are reported. At high gas pressures the loss of the atomic ions is due to conversion into molecular ions and by ambipolar diffusion to the walls of the container. Extrapolation of the high pressure data to zero pressure yields the following reduced mobilities of ions in their parent gases, $\mu_0 = 4.1$, 1.5, 1.0 and 0.67 $cm^2\ V^{-1}\ sec^{-1}$ for Ne^+, Ar^+, Kr^+ and Xe^+ respectively. At low pressures the contribution of the diffusion loss of ions to the walls is modified by the diffusion cooling of electrons[1-3], and it approaches the limit determined by $D_a \simeq D_+$. However, for all the rare gases studied, at very low pressures the rates of change of atomic ion number densities in time were nonexponential and very slow which is not explained.

1. M. A. Biondi, Phys. Rev. 93, 1136 (1954).
2. H. J. Oskam and V. R. Mittelstadt, Phys. Rev. 132, 1435 (1963).
3. R. Hackam, J.Phys.B(Atom.Molec.Phys.)[2],2,790(1969).

M8. Diffusion Cooling. J. H. INGOLD, General Electric Lighting Research Laboratory, Cleveland, Ohio 44112.--The energy balance equation for electrons in a diffusion-controlled afterglow plasma is analyzed in the ambipolar limit. It is shown that there are three contributions to the energy loss caused by the diffusion of electrons to the walls (in addition to the loss caused by elastic collisions). The largest of these losses (several kT per electron) is due to electrons escaping over the wall sheath, as proposed by Biondi.[1] Theoretical results for the final electron temperature are shown to be in good agreement with electron decay measurements of Oskam and Mittelstadt[2] and ion decay measurements of Bhattacharya[3] in Ne afterglows. Comparisons with Ar, Kr, and Xe measurements are also given.

1. M. A. Biondi, Phys. Rev. 93, 1136 (1954).
2. H. J. Oskam and V. P. Mittelstadt, Phys. Rev. 132, 1435 (1963).
3. A. K. Bhattacharya, Private Com., 1970.

M9. Decay of Low Pressure Neon Afterglows. K. V. Narasinga Rao, Air Force Cambridge Research Laboratories, Bedford, Mass. --The decay of pulsed r-f (12MHz) discharges in low pressure neon (0.4 to 7.0 Torr) is probed by the simultaneous measurement of (1) floating double-probe saturation current (2) microwave cavity perturbation and (3) intensity of several spectral lines. A plot of p/τ_c versus p^3, where τ_c is the characteristic time constant associated with the decay of the probe saturation current, showed a linear relationship. This plot, yielded value for the ambipolar diffusion coefficient $D_a p = 151$ cm^2 sec^{-1} torr and a conversion frequency of Ne^+ to Ne_2^+ $\nu_c = 41p^2$ sec^{-1}, compared to corresponding values obtained by Sauter et al* of 178 cm^2 sec^{-1} torr and 52 p^2 sec^{-1} from mass spectrometric studies. The double probe data is also compared with the data obtained from electron density decay measurements and the decay of spectral line intensities.

* G.F. Sauter, R.A. Gerber and H.J. Oskam, Physica 32 (1966) 2173.

M10. A New Afterglow Technique for the Measurement of Electron Attachment in Gases. L.J. Puckett, M.D. Kregel and M.W. Teague, Ballistic Research Laboratories. By means of stationary afterglow techniques, a decaying plasma has been observed to exhibit a transition[1,2] from ion-electron to ion-ion ambipolar diffusion domination. For purposes of this model it is assumed at times prior to the transition that the densities of the positive ions (n_+), negative ions (n_-) and electrons (n_e) are related by $n_e = n_+ - n_-$, $dn_+/dt = -\nu_d n_+$, $dn_-/dt = \nu_a n_e$, where ν_d and ν_a are the diffusive loss frequency and reactive loss frequency, respectively. It is further assumed at the time (t) of the transition that $n_e \ll n_+ \simeq n_-$. From these relationships one can obtain $t(\nu_a - \nu_d) = \ln(\nu_a/\nu_d)$. Numerical solution of this expression, with t and ν_d measured in the afterglow, yields rate constants for electron-attachment in NO and NO_2 within a factor of 2 of published values.

[1] L.J. Puckett and W.C. Lineberger, *Phys. Rev.* 1, 1635 (1970).

[2] M.D. Kregel, *J. Appl. Phys.* 41, 1978 (1970).

SESSION N

Thursday Morning, 22 October

8:30 a.m.

HEAVY PARTICLE COLLISIONS: EXPERIMENTAL

Chairman: W. W. Smith, University of Connecticut

N1. Excitation in Li^+ + He Collisions.* D. C. LORENTS and G. CONKLIN, SRI--The scattering of Li^+ by He has been remeasured to resolve a discrepancy between observed and calculated elastic cross sections and to observe the inelastic interactions between two filled K shells. Extension of the earlier measurements to higher energies revealed the onset of strong electronic excitation for $E\theta \sim 8$ keV·deg. With increasing $E\theta$ (decreasing impact parameter) the excitation probability rapidly builds up to dominate the exit channels and reduce the intensity in the elastic channel. This confirms the suggestion[1] that the calculated elastic cross section is in error due to neglect of excited states. The observed energy loss spectrum displays two discrete lines, whose centers yield excitation energies of 21.0 and 60.5 eV, corresponding to the $1s2s\,^1S$ or $1s2p\,^1P$ states and to the $2s2p\,^1P$ autoionizing state of He, respectively. No other excitation is observed in the $E\theta$ range up to 30 KeV·deg. Cross sections for each of the three exit channels measured at 1.0, 1.5 and 2.0 keV and over a wide angular range will be presented.

*Work supported by AEC, Division of Biology and Medicine

[1]B. F. Junker and J. C. Browne, VI ICPEAC, Boston

N2. Charge Transfer Between Li^+ and Alkali Metal Atoms.* JULIUS PEREL and HOWARD L. DALEY, Electro-Optical Systems, Pasadena, Ca.--Measured total cross sections for the five Li^+ + alkali metal atoms illustrate the role of the energy defect (ΔE) in determining the degree of competition between electron transfer to the ground state and the first excited state of Li. The magnitude and shape of the cross sections as a function of velocity, particularly at the velocity of the maxima, is found to be determined by the minimum energy defect and the binding energy of the electron in its initial state. Measurements of the transfer-excitation radiation produced in charge transfer collisions show the dominance of transfer to the first excited state of Li when the incident atoms are K, Rb, and Cs where the minimum ΔE occurs for the reaction. The effects of competition between ground and excited states are illustrated when the energy defects are comparable in value. Oscillatory structure, observed with all other alkali metal charge transfer cross sections, are very clear for the Li and Na cases, less clear for Cs, uncertain for Rb, and absent for K. The attenuation of this structure is correlated with the degree of competition for transfer to the two states.

*This work was supported by U.S. ARO-Durham.

N3. Ion-Ion Mutual Neutralization Cross Sections for $O_2^+ + NO_3^-$ and $NO^+ + NO_3^-$.* JOHN MOSELEY, WILLIAM ABERTH, and JAMES R. PETERSON, SRI--Cross sections have been measured for the two-body mutual neutralization of NO^+ and O_2^+ in collisions with NO_3^-, using a superimposed beams technique to cover a relative velocity range of about $0.1 - 4 \times 10^{-6}$ cm/sec (barycentric energies between 0.15 and 200 eV). For O_2^- the cross section Q has close to a v^{-1} velocity dependence over this range, with the product $vQ \simeq 1.2 \times 10^{-7}$ cm^3/sec. However, for NO^+, vQ falls steadily from about 3×10^{-7} cm^3/sec at 0.15 eV to less than 5×10^{-8} cm^3/sec above 10 eV. Some similarities are noted between the cross sections for the neutralization of O_2^+ by NO_2^- and NO_3^-, and also between the neutralization of NO^+ by NO_2^- and NO_3^-. Thermal rate constants are obtained from extrapolations of the low energy data.

*This work was sponsored by the DASA Reaction Rate Program through AFCRL.

N4. Electron Transfer from O^- to Na^+ at Low Collision Energies.* J. WEINER*, W.B. PEATMAN, and R.S. BERRY, Univ. of Chicago--A merged beams technique is used to measure radiative charge transfer cross sections for $Na^+ - O^-$ collisions in the energy range 0 - 7 e.v. Specifically, total cross sections for electron transfer into the 3d, 3p, and 4p levels of sodium are reported. Structure in the cross section vs. collision energy curves indicate inelastic channel contributions to the cross sections due to excitation of oxygen to its ^1D and ^1S states.

*Present address, Department of Physics, Yale University, New Haven, Connecticut

N 5. Reactions between H^+ and D_2.* William B Maier II, Los Alamos Scientific Laboratory.--Cross Sections for the endothermic reactions

$$H^+ + D_2 \rightarrow D_2^+ + H \quad (1)$$
$$\rightarrow HD^+ + D \quad (2)$$
$$\rightarrow D^+ + (HD?) \quad (3)$$

have been measured for barycentric ion energies E between 0.3 and 80 eV. The total cross section σ for reactions of H^+ with D_2 can be represented by $\sigma = 1.54\ E^{-0.7} (\text{Å}^2)$ for $8 \leq E \leq 80$ eV and by $\sigma = 2.11\ E^{-1.43} (\text{Å}^2)$ for $0.3 \leq E \leq 2$ eV. σ appears to have a relative maximum at $E \approx 4.5$ eV. The branching ratios $r_i = \sigma_i/\sigma$, where $\sigma_i \equiv$ cross section for reaction (i), are given. At $E \approx 80$ eV, $r_1 \approx 0.7_2$; $r_2 \approx 0.2_5$; and $r_3 \approx 0.0_3$. At $E \approx 3.5$ eV, $r_1 \approx r_2 \approx r_3$. For $E \leq 3.5$ eV, $r_1 \approx r_2$. For $E \leq 1.8$ eV, $r_3 = 1$.

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

N6. Low Energy Elastic Differential Scattering for Proton-Rare Gas Atom Systems. S.M. BOBBIO, W.G. RICH, R. CHAMPION and L. DOVERSPIKE, College of William and Mary--Elastic differential scattering experiments have been performed for the systems p+Kr, p+Ar, p+Ne, and p+He over the energy range $3 \leq E \leq 50$ eV. The measured cross sections are compared to the results of JWKB calculations. For the first three systems an analytical form was used for the interatomic potential and parameters (e.g., the well depth and the internuclear separation for which the potential is a minimum) were varied until a satisfactory fit to the data is achieved. For the p+He system, the results of two *ab initio* calculations* were available for the potential and were used in the JWKB calculation. Comparison to the data is seen to provide a critical test for such potentials when they exist.

* H.H. Michels, J. Chem. Phys. 44, 3834 (1966), and L. Wolniewicz, J. Chem. Phys. 43, 1087 (1965).

N7. Elastic Perturbations in the Low Energy Differential Scattering of He^+ by Rare Gas Atoms. W. G. RICH, S. M. BOBBIO, L. DOVERSPIKE, and R. CHAMPION, College of William and Mary--Perturbations in the elastic differential scattering of He^+ by rare gas atoms have been investigated over the collision energy range $3 \leq E \leq 240$eV and the angular range $0 \leq \theta_{lab} \leq 90°$. These perturbations are attributed to the crossing of molecular electronic-energy curves, an effect which has been observed and discussed previously.* For the systems He^++Ar and He^++Ne, experiments have been performed at a sufficiently low collision energy such that the effects of curve crossing are not observed for $\theta_{lab} < 90°$. As the collision energy is increased, the perturbations on the differential elastic scattering are clearly resolved and can be attributed to a single crossing. These experimental cross sections are compared to the results of semi-classical calculations. The He^++Kr and He^++Xe systems are rich in structure indicating the possibility of many crossings. An interesting feature due to nuclear symmetry is observed in the low energy, large angle scattering of He^++He.

*e.g., see R. P. Marchi, Phys. Rev. 183, 185 (1969) and papers cited therein.

N8. Total Cross Section Measurements for the Scattering of He by He from 300 to 3000 eV.* W.J.SAVOLA, JR., F.J.ERIKSEN, and E.POLLACK, University of Connecticut--The total cross section for the scattering of He by He is measured in an energy range of from 300 to 3000 eV. The incident neutral beam is formed by resonant charge exchange of a mass analyzed He^+ beam, and attenuation measurements are made with detectors having geometrical angular resolutions of 0.056° and 0.260°. Total cross section values of from 4.94×10^{-16} to $12.29 \times 10^{-16} cm^2$ and from 2.69×10^{-16} to $6.83 \times 10^{-16} cm^2$ are obtained respectively for these angular resolutions as the energy is decreased from 3000 eV. A classical analysis of the data yields values of the He - He potential for interatomic separations between 0.93 and 1.72 A. In addition to the above measurement differential data are taken out to 1.0° at several energies. The angular distributions obtained show an essentially monotonic decrease in signal as the scattering angle increases.

*Work supported by the Connecticut Research Commission, A.R.O.D., and the University of Connecticut Research Foundation.

N9. Energies of Formation of H^- by H^+ Impact at 4 KeV on Various Gases. FRED C. WITTEBORN and DOLORES E. ALI, NASA Ames Research Center--The kinetic energy lost by incident 4 KeV protons in producing H^- by impact with He, A, Kr, Xe, H_2 and N_2 was measured by electrostatic analysis of the protons and the forward scattered H^-. In the case of impact with He, the emerging H^- ions were monoenergetic. The H^- current varied approximately as the square of the pressure indicating that two collisions were required. In each of the other gases two values of energy loss were observed. The current at one value of energy loss varied approximately linearly with pressure and at the other it varied quadratically. These energy losses correspond to H^- formation by double charge exchange (a one-step process) and successive single charge exchanges (a two-step process) respectively. Measurements of the differences between formation energies show that the ions formed from the target gas were predominately in or near their ground states. In the one-step reactions with Ar and Kr some of the low lying levels of Ar^{++} and Kr^{++} may have been excited but excitations above 4 eV were not observed. In the two-step reactions with H_2 and N_2 it appears that vibrational levels of H_2^+ and N_2^+ were excited by up to 2.5 eV.

N10. Comparison of Inelastic Scattering of Hydrogen and Deuterium Atoms in Nitrogen.* C. F. BARNETT, J. A. RAY, ORNL, and H. H. FLEISCHMANN, Cornell Univ.--Scattering from electron capture and electron loss collisions has been determined for hydrogen and deuterium atoms in nitrogen gas in the 0.5-5 keV energy region. For electron stripping collisions the differential scattering cross section for H and D are identical at the same energy whereas, the deuterium atom scatters less than hydrogen atoms at the same velocity. For electron capture collisions the differential scattering cross section is different for H^- and D^- at equal particle velocity or energy.

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

N11. Coincidence Study of Ar^+ - Kr at 15 to 230 KeV.*

R. Del Boca and H. Hayden, Department of Physics, University of Connecticut.

Inelastic energy losses ($\overline{Q}_{mn}$) and average ionization probabilities $\overline{P}'_m$ and $\overline{P}''_n$ are measured for $Ar^+ + Kr \rightarrow Ar^{+m} + Kr^{+n} + (m+n-1)e$ using coincidence techniques. Incident ion energies and scattering angles are varied from 15 to 230 Kev and from 10° to 40°, respectively. The energy lost to inelastic processes, averaged over all charge states of both particles ($\overline{Q}_{TT}$), increases steadily with decreasing distance of closest approach from about 50 eV at .39Å to 2 Kev at .065 Å. The average inelastic energy $\overline{Q}_{mn}$ can be considered as the sum of the average scattered ion (Ar^{+m}) inelastic energy $\overline{E}'_m$, and the average recoil ion (Kr^{+n}) inelastic energy $\overline{E}''_n$ ($\overline{Q}_{mn} = \overline{E}'_m + \overline{E}''_n$), and is linearly related[1] to the spectroscopic energy deficits ($\overline{Q}_{mn} = A + BU'_m + CU''_n$). From probability data and the estimate that the term A is equally divided between the two colliding partners, it is apparent that the Krypton receives 55% (50 Kev, 10°) to 65% (100 Kev, 20°) of the inelastic energy $\overline{Q}_{TT}$.

*Work sponsored by U.S.A.F.O.S.R.

[1] H. C. Hayden and E. J. Knystautas, Analysis of the N^+- Ar and O^+- Kr Collision, submitted to Phys. Rev.

N12. Fast Electron-Slow Electron Coincidence Studies of the Violent Argon Ion-Atom Collision.*

G.M. Thomson,+ P.C. Laudieri, and W.W. Smith, Univ. of Connecticut

The collision $Ar^+ + Ar \rightarrow Ar^{+m} + Ar^{+n} + (m+n-1)e^-$ at 25 keV may eject electrons by processes that fill vacancies either in the inner or outer shell. The former are characterized by electron energies of from 100eV to 200eV (fast), while the latter produce electrons mostly in the 0eV to 100eV range (slow). To test for relationships between these processes we determined the energy distribution of slow electrons ejected from those collisions that produce a fast electron of known energy. Fast and slow electrons were collected at angles of 90° and 21° to the beam axis respectively and energy analyzed electrostatically. A coincidence circuit produced a count whenever a fast and a slow electron arrived from the same event. Preliminary results for fast electron energies between 150eV and 190eV indicate that within our error little relation exists between the fast electron energy and the energy spectra of the slow electrons.

*This work supported by U.S.Army Research Office,Durham

+Present address; Physics Dept. Georgia Institute of Technology, Atlanta, Georgia 30332

N13. Delayed-Coincidence Study of O^{+} + Ne Collisions.*

F. W. BINGHAM, Sandia Laboratories--This study investigates details of O^{+}+ Ne collisions by measuring, in addition to several other quantities, the function $\bar{Q}(r_o)$, where $\bar{Q}$ is the average energy transferred to inelastic processes in collisions characterized by a distance of closest approach r_o. The r_o values range from 0.014 A to 0.15 A and correspond to collisions in which the incident O^{+} ion has energies between 50 and 200 keV and scatters at angles between 5° and 35°. Over most of this r_o range the $\bar{Q}(r_o)$ function remains almost constant and varies only slowly with bombarding energy. Also, the average charges of the particles after collision show little variation with r_o. These results imply that the collisions produce excitations only among L-shell electrons and do not make the inner-shell vacancies that some other collision systems produce in this r_o range. However, some data describing inelastic-energy distributions and electron-removal energies indicate that K-shell excitations may occur infrequently among collisions that produce O^{+4} ions.

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

SESSION O

Thursday Morning, 22 October

8:30 a.m.

TRANSPORT PROPERTIES

Chairman: J. H. Ingold, General Electric Company

01. <u>Motion of Gaseous Ions in a Uniform Electric Field.</u>* John H. Whealton, <u>University of Delaware</u>--The steady-state velocity distribution function of ions traveling under the influence of a uniform electric field and interacting with a gas under a polarization attraction is found analytically in compact form. This is done by a reformulation of the Boltzmann Equation in terms of the distribution function just after a collision. By a judicious choice of an initial velocity distribution, the steady state ion velocity distribution found is valid at low as well as high E/N. The ion velocity distribution is found to be skewed in the field direction. It tends to depart sharply from a suitably displaced Maxwellian under conditions of high fields or low gas temperatures, non-extreme mass ratios, and low polarizability. Under some combinations of opposing conditions, this distribution behaves like a suitably displaced ion temperature Maxwellian. The calculation of ion-molecule reaction cross-sections from reaction rate data in drift tubes is best done with a distribution having these properties.

*Work supported in part by an NDEA fellowship.

02. <u>Interpretation of Drift Tube Rate Constants in Terms of Cross Sections.</u>* S. B. WOO and S. F. Wong, <u>University of Delaware</u>--The basic definition of the rate constant of a two-body reaction,

$$\varkappa = \int_{\vec{v}_g} \int_{\vec{v}_i} f_{gas}(\vec{v}_g) f_{ion}(\vec{v}_i) v_r \sigma(v_r) d\vec{v}_i d\vec{v}_g$$

is used to infer cross section from rate constant of ion-molecule reactions measured in drift tubes as a function of E/p_o. $\varkappa$, v_r, and σ are rate constant, relative velocity, and cross section respectively. The Maxwellian distribution at gas temperature is used for f_{gas}. A displaced Maxwellian, having a temperature parameter defined by the diffusion coefficients, and a displacement defined by $< v_z > = v_d$, is used for f_{ion}. v_d is the drift velocity. Justifications are given. The advantage of this approach is in the interpretation of rate constant of endothermic reactions. Examples are cited. A way for calculating rate constant of ion-molecule reactions under thermal equilbrium conditions is proposed. Its limitations are significances for ionospheric model calculations are discussed.

*Research supported in part by Ballistic Research Laboratories, Aberdeen, Maryland.

03. Microwave Conductivity of an Electron Gas Exciting Compound States in Atoms and Molecules.* J.L. HIRSHFIELD and ALAN S. RATNER, Yale Univ. and J.M. WACHTEL, Yeshiva Univ.--We have previously reported[1] measurements of microwave conductivity near cyclotron resonance for an electron beam colliding elastically with atoms of the noble gases. Negative conductivities were reported for energies in the vicinity of Ramsauer minima, in accord with theory. The apparatus has been refined so as to permit observations near electron energies for which excitation of compound states is possible in atomic and molecular systems.[2] The resulting structures in the energy-dependence of the elastic cross section causes sharp variations in the observed microwave conductivity, as well as relaxation oscillations of the electron gas.

* This work supported in part by NSF.

[1] J. M. Wachtel and J. L. Hirshfield, Phys. Rev. Letters 19, 293 (1967).

[2] H.S. W. Massey, E. H. S. Burhop and H. B. Gilbody, ELECTRONIC AND IONIC IMPACT PHENOMENA Vol. 1 (The Clarendon Press) 1969.

04. Excitation and ionization of neutral species in a dense discharge. C. DEUTSCH and L. HERMAN. D.R.P. Faculté des Sciences, Paris, France.

The excitation and the ionization of the ground state of H, He, Cs, Na, Li and Ar by electron impact is systematically investigated with the aid of accurate closed expressions for the electron-atom cross-sections. The various processes : ionization, excitation of forbidden and allowed transitions, are quantitatively compared for $kT_e = E_i/10$ and $E_i/20$, E_i being the first ionization energy. The excitation and ionisation functions[1] $\langle\sigma v\rangle$ are given for a Maxwellian and a Druyvesteyn distribution, respectively. Then, it is confirmed that ionization is a much more temperature dependent process than excitation. On the contrary, excitation processes are seen to be strongly influenced by the atomic spectrum and the electron distribution function. Numerical data are derived for the existence of complete local thermodynamic equilibrium. Argon shows a behavior very similar to the Hydrogen one.

[1] C. DEUTSCH.- Phys. Letters, 28 A, 525, 742, 1969.

05. Bistable Electron Temperature in Vibrationally Excited Gases. A.COHN, AFCRL.--The effect of elevated vibration temperature on the electron temperature is analyzed. It is found (using present estimates of cross-sections) for a mixture of N_2 with a few per cent H_2O with the N_2 vibration temperature, T_v,>2000° K while all other molecular modes have a temperature T≐300° K that the electron temperature, T_e, can have two stable values. There is an upper value just below T_v and a lower value just above T. If on the upper branch T_e will move discontinuously to the lower branch if T_v is lowered below the minimum value for bistability for the given per cent of H_2O. Conversely if on the lower branch T_e will move discontinuously to the upper branch if T_v is raised beyond the maximum value for bistability for the given per cent of H_2O.

SESSION P

Thursday Morning, 22 October

10:15 a.m.

ELECTRON DISTRIBUTIONS

(PANEL)

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

P1. Electron Velocity Distributions in a Pulsed Low-Pressure Arc Discharge. J. POLMAN, Philips Research Laboratories, Eindhoven, Netherlands.-- The time-dependent Boltzmann equation for electrons in a weakly ionized plasma, subject to a suddenly applied electric field, has been solved numerically. The solution gives the relaxation of the electron velocity distribution towards the equilibrium, belonging to the value of E. It is found that the number of electrons in the tail of the distribution is larger during the heating process than in a steady state with the same average energy. This is caused by a forced drift in velocity space and increases the rate of excitation of atomic levels (up to a factor of 10, depending on the parameters used). The results of the computations may explain the enhancement of the light emission by pulsing a low pressure arc discharge with a period between the diffusion time and the energy relaxation time of the electrons[1].

1. J.Polman, J.E. van der Werf, Appl.Phys.Letters, to be published.

P2. Energy Distributions of Electrons in Argon Townsend Discharges, D.S. Burch and Jon Losee, Oregon State University, Corvallis, Oregon. Measured energy distribution functions of electrons from d.c. Townsend discharges in argon show considerable structure. The distributions are obtained by retarding potential analysis of the effusive electron current from apertures in the anode of a Townsend discharge cell. The retarded current is measured at a platinum-blacked spherical collecting electrode. The overall shapes of the distributions are consistent with theoretical work, but show significant low-level fine structure. Especially noteworthy are variations which appear near the first excitation and ionization potentials of argon.

P3. Effects of Non-Maxwellian Electron Energy Distribution in Low-Voltage Neon Discharges.* D. T. Shaw, State University of New York at Buffalo--The electron energy distribution function in a neon discharge is determined from the Boltzmann equation with electron-electron Coulomb interactions, elastic and inelastic collisions taken into account. The plasma is assumed to be homogeneous and is under the influence of a constant electric field. It was found that the electron energy distribution function is non-Maxwellian at high electric fields and low electron density, especially in the high-energy tail region of the distribution. Such deviations have significant effects on the ionization mechanisms. Three ionization rates were determined: namely, the molecular ion generation from collisions between excited atoms H_G, the one-step direct ionization H_I and multi-stage ionization H_E. At moderately high pressures, if the electron density is high enough such that the deviation from the Maxwellian function is negligible, then H_G is the most important ion-generation process. However, at low pressures, the electron density is usually too low to maintain the Maxwellian distribution. In this case, contributions from H_I and H_E become as important as that from H_G.

*Supported in part by the National Science Foundation.

P4. On the Spatial Electron Relaxation to Equilibrium near Plasma Boundaries.* F. T. Wu and D. T. Shaw, State University of New York at Buffalo.--The spatial relaxation of steady-state distribution is obtained for electrons initially injected into the plasma and subsequently drift under the influence of a constant electric field. The Boltzmann equation is formulated for a spatially non-uniform plasma composed of electrons, ions, and neutrals and numerically integrated for the relaxation of Gaussian-like distributions initially peaked about some particular energies. Cesium discharges are used as a numerical example and the effects of electron-electron Coulomb interactions and inelastic collisions on the spatial relaxation of energy distribution are discussed. It was found that in the low energy region the distribution rapadily becomes Maxwellian in 4 or 5 mean-free-paths. The rate of Maxwellization in the high-energy region depends primarily on the electron-electron Coulomb interaction in the present paper. Since the electron density is usually low near the boundary, the electron population depression of the high-energy tail can be seen even after 20 mean-free-path.

*Supported in part by the National Science Foundation.

P5. Effect of Superelastic Collisions on the Electron Velocity Distribution in Nitrogen.* J. H. NOON, M. FOSTER, W. C. JENNINGS, Rensselaer Polytechnic Institute.--To show how electron temperatures ten times that of the neutral gas can persist in the nitrogen afterglow, we have modelled mathematically the effect on the electron velocity distribution of electrons gaining energy by superelastic collisions with a vibrational state of the nitrogen molecule. Assuming $f(v) \propto e^{-bv^2}$, an initially Maxwellian form, we perturb this by a multiplicative factor resonant at a chosen value of electron energy. Computations show that, depending on whether the perturbation is introduced above or below the average electron energy, the apparent form of $f(v)$ changes to look more like $\exp(-bv^4)$ or $\exp(-bv^1)$ respectively. Clearly a non-Maxwellian form for $f(v)$ derived empirically by fitting theoretical curves to experimental data cannot be interpreted without considering the various energy interchange processes which can occur. Theory and experimental results, (using a microwave technique to measure radiation temperature), are compared.

*Work supported by the National Science Foundation.

P6. Electron Energy Distributions and Collision Rates in Electrically Excited N_2, CO, and CO_2.* W.L. NIGHAN, United Aircraft Research Laboratories.--Electron energy distributions have been obtained for electrically excited N_2, CO, CO_2, and their mixtures by numerically solving the Boltzmann equation for conditions typical of electric discharges. Reported electron cross section data have been used in the calculation. The calculated distribution functions were found to be markedly non-Maxwellian, having energy variations which reflect the important electron-molecule energy exchange processes. Solution of the electron energy conservation equation using these distribution functions revealed that vibrational and electronic excitation of N_2, CO, and CO_2 dominates electron-molecule energy exchange processes for average electron energy in the 1-3 eV range typical of electric discharges. Electron-molecule vibrational excitation rates were also evaluated for a variety of gas mixtures and discharge conditions.
*Portions of this work were supported by the Office of Naval Research under Contract N00014-69-C-0309.

SESSION Q

Thursday Afternoon, 22 October

2:15 p.m.

BREAKDOWN

Chairman: T. L. Churchill, United Aircraft Research Laboratories

Q1. Reduction of Breakdown Voltages at Conditions Below Paschen's Minimum Due to a Magnetic Field Parallel to the Axis of Rod Electrodes. M. J. KOFOID, Boeing Scientific Research Laboratories.--Type 321 stainless steel round rod electrodes with flat ends were aligned on the same axis in a Pyrex glass vacuum chamber. They were completely insulated by close fitting glass except for the 1.0cm^2 area ends which faced each other to form a 2.5cm long spark gap. Breakdown voltage (B.V.) tests were made at 5μ and/or 40μ in Kr, Ne, He, N_2 and air. An unexpected dramatic and sudden decrease in B.V. occurred in all gases when a modest steady uniform magnetic field of intensity B_o was applied parallel to the axis of the electrodes; e.g. with He at 5μ, from greater than 60kV with B_o<200 gauss to ∿8kV with B_o=300, leveling off at ∿6kV for B_o>400. Although the magnetic field was parallel to the electrode axis, a crossed-field situation did exist to a minor and varying degree within the gap since the electric field was non-uniform. It is suggested that the lowering of the B.V. may have occurred because cycloiding of electrons in the crossed fields caused electrons to make an increased number of collisions in traveling between the electrodes.

Q2. A Magnetic Memory Effect in Vacuum Breakdown, ALAN WATSON,* The University of Western Ontario, London, Canada - A factorially designed voltage breakdown (<300kV) experiment with spherical aluminium and copper electrodes of differing size was performed in weak crossed magnetic fields of up to 400 gauss. The magnetic field strength was raised from zero in five steps, measuring the breakdown voltage, V_B, each time. Subsequent repetition of the initial measurement showed that the magnetic influence upon the breakdown immediately previous to this was retained. Slow decay of the oxide surface field effect is thought to influence Fowler-Nordheim emission and hence V_B.

*Partially sponsored by USAECOM under Contract No. DA-28-043-AMC-00394(E).

Q3. Analysis of Prebreakdown Current Growth due to Two Emission Mechanisms*. E. P. OPPENHEIMER, A. N. MICHEL, and ESSAM NASSER, Iowa State University. --When a pulse of electrons is released photoelectrically from a cathode, avalanches of electrons and positive ions are produced in the gas. The current rise is a function of the coefficient of ionization and of the mobility of the various carriers. New electrons are emitted from the cathode by gas-produced photons and/or positive ion impact. Mathematical solution of the time and space dependent electron and ion current discontinuous functions has always been considerably difficult. A digital technique was contrived to calculate the current functions. The linear first-order hyperbolic partial differential equations were represented by a finite difference method which was examined for convergence and stability of round-off errors. The curves obtained for the current growth with each emission mechanism acting separately were in good agreement with measured oscillograms. The current initially rises exponentially and then drops suddenly as first-generation electrons are absorbed by the anode. The effect of the cathode was studied by varying the cathode work function and solving the current equations. *Supported by National Science Foundation.

Q4. AC Electrical Breakdown of Neon with External Electrodes. H. VERON and C. C. WANG, Sperry Rand Res. Ctr.--Results are presented of an experimental and theoretical investigation of ac electrical breakdown of neon in glass cells with external electrodes. The calculations are based upon a Townsend avalanche model that takes into account the effect of both the space charge and the surface charge on the glass walls that separate the electrodes from the gas. The experimental and theoretical results give a total discharge current pulse in each half-cycle of the applied sine wave that are in agreement. Profiles are calculated of the electric field-to-pressure ratio as a function of position in the discharge gap with time as a parameter. These profiles exhibit a linear dependence on distance from the cathode wall as the discharge current reaches its peak, a behavior similar to that which occurs in the cathode fall region of dc glow discharges. Under the present set of operating conditions, the Townsend avalanche model for breakdown is adequate to account for the discharge mechanism.

Q5. Transient Microwave Breakdown of Low Pressure Gases.* S. E. El-Khamy, S. F. Marlier, and R. E. McIntosh, Univ. of Massachusetts.--Experiments have been performed to determine the transient breakdown time of low pressure (1 - 50 Torr) gas by high power (> 1.0 kw) microwave pulses propagating along a coaxial line in which the region between the inner and outer conductor is filled with a test gas. The effects of microwave breakdown on the envelope of S-band pulses and the ionization time are observed to depend on peak signal power, signal time duration and the background pressure and ionization potential of the transmission medium. Relaxation oscillations have also been observed in the experiments which can be ascribed to the alternate ionization and deionization of the gas due to absorption of the transmitted field. These oscillations are interesting because they provide a diagnostic tool for measuring the transient breakdown time. The measurements are compared with results obtained from a simple theoretical model which includes RF ionization due to electro-neutral collisions and electron attachment.

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

Q6. Optical breakdown in colored gases. W. HOLZER, P. RANSON and P. PERETTI, Faculté des Sciences, PARIS, FRANCE.

Optical breakdown has been studied in colored gases (I_2, Br_2, ICl, Cl_2 and NO_2) with a Q-switched ruby laser. In these gases breakdown occurs at pressures of several torr, under experimental conditions to produce just breakdown in air at 1 atm. pressure. The thresholds have been measured relative to the ones of air and argon as a function of pressure. The observed thresholds are correlated to the ionization potentials, of these gases ; consequently I_2 has the lowest threshold. Also, the spark life time has been studied in several gases as a function of gas pressure and laser power giving values in the order of 50-200 n sec.

Finally, the effect of impurities will be discussed.

Work supported by C.N.R.S., FRANCE.

Q7. Glass Fiber Optics in the Investigation of Corona Discharges. A. J. SCHWAB, Univ. of Karlsruhe.-- Electrical measurements made in the external circuit of corona discharges contain only information of the total spacially integrated value of the discharge current, whereas measurement of the associated radiation provides selective data for different discharge regions along the gap axis. Scanning the discharge with a glass fiber optic connected to a wideband photomultiplier yields new information about the basic ionization process of corona discharges. Depending on the fiber diameter (0.1 mm to 3 mm) and the gain of the photomultiplier, intensity ratios of 1 : 10^6 could be detected. Thin diameter glass fibers permit high local resolution and do not interfere with the discharge. As an example for the application of this technique, the discontinuities in the rise of Trichel pulses could be studied and explained.

Q8. Observations of the Competition of Trichel Pulses from Negative Corona Needles. W.L. LAMA and C.F. GALLO, Xerox Research Labs. - The interaction of negative needle-to-plane coronas was investigated as a function of point separation (X). The Trichel frequency which characterizes negative corona is determined by the ratio of the electric field to the spatial clearing length L. For a single point, the frequency increased with the voltage (V) and decreased with increasing spacing to the plane (S). Since the clearing field is proportional to V and inversely related to S, we conclude that L is, approximately, proportional to S and independent of V. The interaction between two negative point coronas was measurable at large separation ($X \cong 10S$). As the separation was decreased below ~ 1cm, both frequencies decreased with decreasing X and approached the random Trichel pulse regime. We found some evidence for frequency locking, with the establishment of a phase relationship, indicating a definite Trichel-space-charge interaction. The relative phase approached 180° with decreasing X. At X ~ 1mm, one discharge extinguished while the other re-entered the regular Trichel pulse regime. This "critical" separation varied linearly with S and inversely with V. As X was decreased even further, the still active discharge also terminated.

Q9. The Transition from Primary Streamer through Thermalization to the Arc in Positive Point-to-Plane Corona.* TOSHIO SUZUKI, Univ. of Calif., Berk.--Using diverse approaches, including two-photomultiplier and current dual-scope measuring techniques, temporal development of the spark from primary streamer through thermalization to the arc in various point-to-plane corona gaps above and below conventional sparking threshold was investigated. At high ($\approx$ 30%) overvoltage, thermalization follows in a very few microseconds from ionization in the secondary streamer which results from a succession of ionizing waves following the primary. At lower overvoltages, ionization in the secondary streamer is inadequate; consequently, decline to a dark phase of hundreds of microseconds results. In this time, space charge distortion caused by positive and negative ion movement in the channel leads to increase in anode region field strength. A succession of one or two very fast, luminous waves of ionization then leads to adequate electron densities and temperature with thermalization following in 40 to 60 nsec.

*Supported by U.S. Office of Naval Research and Central Research Institute of Electric Power Industry, Tokyo.

SESSION R

Thursday Afternoon, 22 October

2:15 p.m.

ELECTRON AFFINITIES: O_2, ETC.

(PANEL)

Chairman: P. J. Chantry, Westinghouse Research Laboratories

R1. Vibrational Excitation of O_2 and NO by Electron Impact.* D. Spence, G. J. Schulz, Yale University--The trapped electron method[1] has been applied to the study of vibrational excitation by electron impact in the energy range 0-1 eV. Both O_2 and NO form stable parent negative ions and the vibrational levels of these negative ions provide compound states thru which vibrational excitation of the neutral molecule is enhanced. Resonances in the elastic scattering cross sections in O_2 and NO are measured and give the vibrational spacing of the negative ions, in good agreement with previous data.[2] It is found that the vibrational excitation cross sections for both NO and O_2 consist of a series of spikes whose spacings are equal to the spacing of the vibrational levels of the respective negative ions (approximately 0.12 eV for O_2 and 0.16 eV for NO). The spikes are superimposed on a slowly rising cross section resulting from "direct" vibrational excitation, which is larger in NO than in O_2.

* Work supported by DASA thru ARO-D and ARPA thru ONR.

1. G. J. Schulz, Phys. Rev. 112, 150 (1958).
2. M. J. W. Boness, J. B. Hasted, I. W. Larkin, Proc. Roy. Soc. A305, 493 (1968).

R2. Vibrational Excitation and Attachment by Slow Electrons Bombarding O_2, C. J. Chapman, A. Herzenberg, Yale Univ.-- Two reactions of electrons with E<1eV bombarding O_2 molecules are $e+O_2 \rightarrow O_2^-$(unstable), followed by (1) O_2(unstable)$\rightarrow O_2^*$(excited)+e, or (2) O_2^-(unstable)+$O_2 \rightarrow O_2^-$(stable)+O_2+energy. Reaction (1) has been observed by Spence and Schulz[1] by the trapped electron method; they see discrete resonances spaced about 0.11 eV. However, an angular momentum barrier favors the emission of the most energetic outgoing electrons which cannot be observed by the trapped electron method. We have fitted a potential energy curve for O_2^- to the experiment and used it to calculate the channels, as yet unobserved. The calculation takes the electron affinity and the curvature from experiment and adjusts the separation ΔR of the minima for O_2 and O_2^- to minimize the difference between theory and experiment. An upper bound for the rate constant for reaction (2) can also be calculated from the model; the bound is in rough agreement with the experimental value for E<1eV.

1 D. Spence and G. J. Schulz, to appear in Phys. Rev A, November 1970.

R3. Electron Affinity of O_2 by Laser Photodetachment.* R. CELOTTA, R. BENNETT, J. HALL, J. LEVINE, and M. W. SIEGEL, JILA, Univ. of Colo., Boulder, Colo.--A beam of O_2^- ions, extracted from a glow discharge in N_2O, is crossed with the linearly polarized intracavity photon beam of an argon ion laser (4880Å). Electrons photodetached perpendicular to the crossed beams are energy filtered by a hemispherical analyzer. The electron energy spectra are characteristic of photodetachment from the v=0 state of O_2^- to the X $^3\Sigma_g^-$ and a $^1\Delta_g$ states of O_2. Vibrational state analysis is facilitated by the use of isotopes. The vertical detachment energy for the O_2^-(v=0) to O_2X $^3\Sigma_g^-$(v=0) transition is 0.430±.030 eV. A final result, four times more precise is expected. Additionally, we have measured the relative transition probabilities and angular distributions of the ejected electrons. The angular distributions, of the form $1+\beta P_2(\cos\theta)$ are fit by β's near -0.9. [Here θ is the angle between electron k vector and laser E vector.] The corrected relative intensities, through Franck-Condon factor analysis, determine an O_2^- potential energy curve in reasonable agreement with that given by Schulz.[1]

*Work supported in part by Advanced Research Projects Agency.

[1]D. Spence and G. J. Schulz, Phys. Rev. (in press).

R4. Doppler Broadening in Beam Experiments.* P. J. CHANTRY, Westinghouse Research Laboratories--The distribution in center-of-mass energy caused by the thermal motion of the target gas molecules has been rigorously derived for the case of a monoenergetic beam interacting with molecules having an isotropic Maxwellian velocity distribution corresponding to temperature T°K. Provided the nominal CM beam energy E_0 exceeds a few kT the FWHM of the distribution is given by $W_{1/2} = (11.1\ \gamma kTE_0)^{1/2}$, where $\gamma = m/(m+M)$, m and M being the projectile and target masses. If, for example, m=M, E_0=2 eV, and T=300°K, then $W_{1/2}$ = 0.535 eV. This is significantly greater than the beam spread achieved in recent experiments**. Its effect on the appearance curves for endothermic reactions has been investigated by convolution with idealized cross section functions. It is found that the error ΔE_T arising from the commonly used linear extrapolation technique for estimating a threshold, E_T, depends on the rapidity with which the cross section approaches a maximum, and in general lies within the range $1.5\ \gamma kT < \Delta E_T \lesssim 2(\gamma kTE_T)^{1/2}$. The theory has been applied to recent measurements** of the reaction $I^- + O_2 \rightarrow O_2^- + I$.

*Work supported in part by ARPA through ARO (Durham).

**J. Berkowitz, W. A. Chupka, and D. Gutman, J. Chem. Phys. (submitted).

R5. Drift Tube Measurements of the O^- + O_2 Reaction from Thermal Energy to ~ 3 eV. R. JOHNSEN, H. L. BROWN, and MANFRED A. BIONDI, Univ. of Pgh. - The endothermic charge transfer and ion atom interchange reaction O^- + O_2 has been investigated in a drift tube - mass spectrometer apparatus as function of the ions' mean energy by means of the "additional residence time technique"[1]. The experiments have been carried out in helium as buffer gas rather than in pure oxygen to make use of the narrower velocity distribution attainable when heavier ions drift in a light gas which is particularly desirable when a strongly energy dependent reaction is studied. The rate constant is found to rise from an immeasurably small value at thermal energy (300°K) to about 10^{-11} cm^3/sec at a mean ion energy of about 1 eV and to level off at higher energies. This result appears to be compatible with a difference of about 1 eV between the electron affinities of the oxygen atom and the O_2 molecule. The mean ion energy was calculated from Wannier's[2] formula.

[1]J. Heimerl, R. Johnsen, and Manfred A. Biondi, J. Chem. Phys. 51, 5041 (1969).
[2]G. H. Wannier, Bell System Tech. J. 32, 170 (1953).

R6. Molecular Electron Affinities Derived From Collisional Ionization of Alkali Atoms. K. LACMANN and D. R. HERSCHBACH, Harvard University

A fast (1-100 eV) potassium beam from a resonance charge exchange source is sent through a scattering chamber containing a target gas and the negative ions are observed with a mass filter. From the thresholds for ion-pair formation, electron affinities of the halogens, O_2, NO_2, and SO_2, have been determined. Fluorescence from electronically excited potassium atoms is also observed and the form of the excitation functions are related to the ion-pair cross sections in terms of crossing of potential curves.

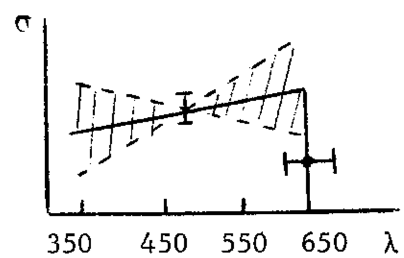
R7. Charge Exchanging Collisions between Cs and NO_2.* S. J. NALLEY,† R. N. COMPTON, and P. W. REINHARDT, Oak Ridge National Laboratory. -- The relative cross section for the production of NO_2^- resulting from collisions of Cs^o and NO_2 has been studied as a function of the incident Cs^o energy from 0 to 15 eV. The threshold for the charge exchange reaction occurs at 1.67 ± .1 eV (c.m.). Assuming that at threshold the NO_2^- is in its ground state, an electron affinity of 2.22 ± .1 eV is obtained. Considerations of Doppler motion of the target neutral are expected to lower this value by ~ 0.25 eV at most. The charge exchange cross section increases steeply above threshold and exhibits a broad peak at 2.57 eV (c.m.). O^- production is observed above 5.82 eV (c.m.) and increases slowly with energy above threshold. The energy of the Cs^o beam is determined from a time-of-flight analysis. For laboratory energies of 7 eV the beam has a FWHM of 0.15 eV.

*Research sponsored by the U.S. Atomic Energy Commission under contract with Union Carbide Corporation.
†USPHS Radiological Health Physics Trainee.

R8. Photodetachment of O_3^-. S. F. WONG, T. V. VORBURGER, and S. B. WOO, University of Delaware.*-- The threshold energy for photodetachment of O_3^- is measured in a drift tube. The ions undergo approximately 10^6 collisions at thermal energies before being guided into the photodetachment region. A white light source is used together with a set of 13 sharp cut-off color filters to determine the photodetachment cross section as a function of wavelength. The photodetached electron current is measured. A sharply rising photodetachment cross section is observed with a threshold at 1.92±.13 eV. An approximate shape for the relative cross section is determined by least-square-fitting the data to a straight line. It is:

$\sigma = 0$, above λ = 650 mμ(1.91 eV)

$\sigma = (0.9 \pm 2.0 \times 10^{-2})(\lambda - 500) + (7.0 \pm .6)$, for $350 < \lambda <$ 650 mμ (arbitrary units for σ).



*Work supported in part by the U. S. Ballistic Research Laboratories, Aberdeen, Maryland.

SESSION S

Friday Morning, 23 October

8:30 a.m.

ION CLUSTERS

(PANEL)

Chairman: E. E. Ferguson, ESSA Research Laboratories

S1. The Reaction of NO^+ and $NO^+\cdot(H_2O)_n$ with H_2O and NH_3. F. C. FEHSENFELD and E. E. FERGUSON. ESSA Research Laboratories, Boulder, Colorado 80302.

The association of H_2O with NO^+ has been measured to be (5.6, 19 and 23) x 10^{-29} cm^3/sec at 300°K with a helium, argon and nitrogen buffer respectively. The reaction sequence produced by the addition of H_2O to form the heavier $NO^+\cdot(H_2O)_n$ ion clusters has been studied. This sequence is terminated by the reaction of $NO^+\cdot(H_2O)_3$ with H_2O to form $H_3O^+\cdot(H_2O)_2$ and HNO_2. The rate constants for these reactions will be reported and the techniques used to obtain them discussed briefly. It has also been found that the $NO^+\cdot(H_2O)_n$ sequence may be terminated at any time by NH_3. In this case $NO^+\cdot(H_2O)_n$ reacts with NH_3 to yield $NH_4^+\cdot(H_2O)_{n-1}$ and HNO_2. For n = 1 the rate constant for this reaction is $1.0 \pm 0.3 \times 10^{-9}$ cm^3/sec.

S2. Three-Body Clustering of NO^+ with O_2, N_2 and CO_2. E. E. FERGUSON, D. B. DUNKIN, AND F. C. FEHSENFELD. ESSA Research Laboratories, Boulder, Colorado 80302

The reaction $NO^+ + CO_2 + N_2 \rightarrow NO^+\cdot CO_2 + N_2$ is found to have a rate constant 3 x 10^{-29} cm^6 sec^{-1} at 197°K. It is found that the reactions $NO^+\cdot CO_2 + H_2O \rightarrow NO^+\cdot H_2O + CO_2$ and $NO^+\cdot CO_2 + NO \rightarrow NO^+\cdot NO + CO_2$ are very fast, consistent with reasonable bond energy estimates, $D(NO^+\cdot CO_2) \approx 0.48$, $D(NO^+\cdot NO) \approx 0.63$, and $D(NO^+\cdot H_2O) \approx 0.85$ eV. Association of NO^+ with O_2 or N_2 was observed to be very slow, upper limits will be reported. The $NO^+(NO)_2$ trimer was observed. It has been found that N_3^+ reacts with O_2 to produce (about equally) NO^+, O_2^+, and NO_2^+. This may explain the observation of NO_2^+ in laboratory discharges. The rate constant for $N_4^+ + O_2 \rightarrow O_2^+ + 2N_2$ was found to be 4 x 10^{-10} cm^3 sec^{-1} at 197°K.

S 3. Rates of Formation of Water Clusters for O_2^+ and NO^+.* C. J. HOWARD, H. W. RUNDLE, and F. KAUFMAN, University of Pittsburgh.--The clustering reactions of O_2^+ and NO^+ with water were studied at 296°K in a flowing afterglow system. The rate constants, k_1^m, for the first step in the clustering sequence were obtained using conventional flowing afterglow analysis for measurements made in He, Ar, O_2 and N_2 carrier gases; for $O_2^+ + H_2O + M$: $k_1^{He} = 8.7\times10^{-29}$, $k_1^{O_2} = 1.9\times10^{-28} cm^6/sec$ and for $NO^+ + H_2O + M$: $k_1^{He} = 3.2\times10^{-29}$, $k_1^{Ar} = 6.5\times10^{-29}$, $k_1^{O_2} = 8.6\times10^{-29}$ and $k_1^{N_2} = 1.4\times10^{-28} cm^6/sec$. Rate constants for the subsequent clustering reactions of NO^+ up to and including the bimolecular step, $NO^+\cdot 3H_2O + H_2O \rightarrow H_2O^+\cdot 2H_2O + HNO_2$, were obtained by matching experimental ion profiles obtained by moving the point of water addition with computer generated profiles.

*Work supported by the Advanced Research Projects Agency.

S4. Drift Tube Studies of Carbon Dioxide Clustering to Potassium and Sodium Ions. G. E. KELLER and R. A. BEYER, Ballistic Research Laboratories. -- A drift tube-mass spectrometer has been used to investigate the clustering of CO_2 to alkali ions. The reaction

$$K^+ + CO_2 + CO_2 \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} K^+\cdot CO_2 + CO_2 \qquad (1)$$

has been studied from E/N = 6 Td to E/N = 21 Td at 310K. From E/N = 6 Td to E/N = 12 Td, $k_1 = 4^{+4}_{-2} \times 10^{-30}$ cm^6/sec and $k_{-1} = 2.5^{+2.5}_{-1.3} \times 10^{-13}$ cm^3/sec. Both constants then increase with increasing E/N. K^+ and $K^+\cdot CO_2$ are both found to have a zero-field, reduced mobility of $1.43 \pm .05$ cm^2/V sec. The reactions

$$Na^+ + CO_2 + CO_2 \underset{k_{-2}}{\overset{k_2}{\rightleftharpoons}} Na^+\cdot CO_2 + CO_2 \qquad (2)$$

and

$$Na^+\cdot CO_2 + CO_2 + CO_2 \underset{k_{-3}}{\overset{k_3}{\rightleftharpoons}} Na^+\cdot 2CO_2 + CO_2 \qquad (3)$$

have been studied at E/N = 12 Td and 310K.

S 5. Clustering of Cs^+ Ions in Atmospheric Gases. L. G. McKNIGHT and J. M. SAWINA, Bell Telephone Laboratories, Whippany, N. J. -- A drift tube study of Cs^+ ions drifting in atmospheric gases has been conducted at temperatures between 310° and 325°K and at $E/N < 30\times10^{-17}$ (V cm^2) for total pressures between 0.5 and 8 Torr. Mobilities (μN) of the Cs^+ ions were 5.9, 6.0, and $5.7\times10^{+19}$ (volt sec cm)$^{-1}$ in N_2, O_2 and Ar respectively. No evidence was seen for reaction of the ions with any of these gases indicating a reaction rate of less than 3×10^{-34} cm^6/sec or, alternatively, an equilibrium constant less than 10^{-19} cm^3 over our range of temperatures. Clustering of the Cs^+ with water was found to take place producing a series of water vapor cluster ions: $Cs^+ \cdot nH_2O$, with equilibrium concentrations of the clusters with two and three water molecules different from those found by Dzidic and Kebarle.[1] The rate for the clustering of Cs^+ with water with N_2 as the third body:

$$Cs^+ + H_2O + N_2 \rightarrow Cs^+ \cdot H_2O + N_2$$

was found to be about 2×10^{-29} cm^6/sec.

[1] I. Dzidic and P. Kebarle, J. Phys., Chem. 74, 1466(1970)

S6. Hydration of Oxygen Negative Ions.* J. L. PACK and A. V. PHELPS+, Westinghouse Research Laboratories-- A combination drift tube and quadrupole mass spectrometer has been used to make measurements of the rate coefficients for the hydration of oxygen negative ions at low partial pressures of water vapor in oxygen at 300°K. The mass spectrometer is also used to measure the partial pressure of water. Measured thermal rate coefficients for the reactions are:

Reaction		Rate Coefficient
$O_2^- + 2O_2$	$\rightleftarrows O_4^- + O_2$	4×10^{-31} cm^6/sec
		2.7×10^{-14} cm^3/sec
$O_4^- + H_2O$	$\rightarrow O_2^- \cdot H_2O + O_2$	1.4×10^{-9} cm^3/sec
$O_2^- + H_2O + O_2$	$\rightarrow O_2^- \cdot H_2O + O_2$	3×10^{-28} cm^6/sec
$O_2^- \cdot H_2O + H_2O + O_2$	$\rightleftarrows O_2^- \cdot (H_2O)_2 + O_2$	4×10^{-28} cm^6/sec
		7.1×10^{-15} cm^3/sec
$O^- + 2O_2$	$\rightarrow O_3^- + O_2$	1.2×10^{-30} cm^6/sec
$O^- + H_2O + O_2$	$\rightarrow O^- \cdot H_2O + O_2$	1.0×10^{-28} cm^6/sec
$O_3^- + H_2O + O_2$	$\rightarrow O_3^- \cdot H_2O + O_2$	2.1×10^{-28} cm^6/sec

*Work supported in part by ARO and AFCRL.
+Present address: J.I.L.A., University of Colorado, Boulder, Colorado 80302.

S7.

Reactions of NO^+ in $NO-H_2O$ and $NO-NH_3$ Gas Mixtures.

L.J. Puckett and M.W. Teague, Ballistic Research Laboratories. Stationary afterglow techniques have been employed to determine the complete set of rate constants governing the sequence of reactions with NO^+ ions as the precursor in $NO-H_2O$ gas mixtures. The main channel of the reaction sequence can be represented as $NO^+ \rightleftarrows NO^+\cdot NO \rightleftarrows NO^+\cdot H_2O \rightleftarrows NO^+\cdot 2H_2O \rightleftarrows NO^+\cdot 3H_2O \rightarrow H_3O^+\cdot 2H_2O \rightleftarrows H_3O^+\cdot 3H_2O \rightleftarrows H_3O^+\cdot 4H_2O$. The same techniques used in $NO-NH_3$ gas mixtures reveal the rate constants for the reactions $NO^+ \rightleftarrows NO^+\cdot NO \rightarrow NO^+\cdot NH_3 \rightarrow NH_4^+ \rightarrow NH_4^+\cdot NH_3 \rightleftarrows NH_4^+\cdot 2NH_3 \rightleftarrows NH_4^+\cdot 3NH_3$.

SESSION T

Friday Morning, 23 October

8:30 a.m.

COLLISION PROCESSES IN GASEOUS LASERS

Chairman: W. L. Nighan, United Aircraft Research Laboratories

T1. Discharge and Gain Properties of the CO_2 Laser*. W.J. WIEGAND, M.C. FOWLER, AND J.A. BENDA, United Aircraft Research Laboratories.--A modified Schottky analysis has been used to obtain the radially dependent discharge properties of a conventional CO_2 laser. Input to the calculation includes electron transport properties calculated from the non-Maxwellian electron energy distributions[1] and the temperature dependence of the thermal conductivity. The discharge current-electric field variations and the radial gas temperature profiles compare favorably with those obtained experimentally. Radial profiles of electron density and gas temperature were used as input to a steady state analysis of the CO_2 vibrational levels to calculate the radial variation of small signal gain. Analytic and experimental results are in very good agreement suggesting that the analysis accurately reflects the various processes occurring in the discharge.

[1] W. L. Nighan and J. H. Bennett, Appl. Phys. Letters 14, 240 (1969).

*Portions of this work were supported by the Office of Naval Research under Contract No. N00014-69-C-0309.

T2. A Quantitative Analysis of the Dependence of CO_2 Laser Performance on Electric Discharge Properties*. M.C. FOWLER, United Aircraft Research Laboratories--Reported values of electron molecule energy transfer rate constants are combined with atom/molecule-molecule and radiative energy transfer rate constants in a comprehensive analysis of the conversion of electron energy to optical energy at 10.6 microns in an electric discharge containing CO_2, N_2, and He. Small signal gain and saturation intensity are calculated as functions of the electron density and gas temperature in the discharge. The calculated values of these quantities are consistent with experimentally determined values. The detrimental effect of increasing gas temperature on small signal gain is found to be the single most important factor influencing the efficiency of the discharge plasma as an energy conversion medium.

*Portions of this work were supported by the Office of Naval Research under Contract No. N00014-69-C-0309.

T 3. Plasma Properties of an Electric Discharge Convection Laser.* C. O. BROWN, United Aircraft Research Laboratories--Measurements of plasma properties of a N_2-CO_2-He, high-mass flow electric discharge convection laser (EDCL) have been made, and the experimental results are compared to the results of an analytical study. At typical EDCL operating conditions, the E/N of the plasma was found to be in a range required for efficient vibrational excitation. In addition, results of experiments utilizing a high-Q optical resonator to determine the effect of flow conditions and discharge parameters on laser performance at the multikilowatt level are described. Also, the performance characteristics of the EDCL in open- and closed-cycle operation are compared. In closed-cycle operation, the time constant for dissociation of CO_2 to an equilibrium level has been determined by monitoring the intensities of the CO Angstrom bands.

*Research described herein was sponsored in part by the United States Army Missile Command and the Advanced Research Projects Agency under Contract DAAH01-68-C-2056.

T4. The CO Laser Plasma. P. BLETZINGER and A. GARSCADDEN, Aerospace Rsch Labs, WPAFB, Ohio.-- An analysis has been made of the CO laser plasma using second derivative Langmuir probe methods. As these discharges have large amplitude fluctuations it has been necessary to use floating potential compensation[1] methods to obtain meaningful results. Measurements have been made of the average electron energy, the electron density and the electric fields for CO, CO-He, CO-N_2, CO-N_2-He systems at pressures of a few torr and at room temperature. It has also been found that less than 0.15 torr xenon additive to these discharges is sufficient to take over the ionization in the plasma and modify the electron energy distribution. The relationship of these results to the laser efficiency and the suggested CO laser mechanisms will be discussed.

1. H.M. Musal, Jr., J. Appl. Phys., 41, 2605 (1970)

T 5. Excitation Processes in the Cathode Region of a Glow Discharge Through Metal-Vapor-Noble-Gas Mixtures. A.J. Palmer and J.William McGowan, The Univ. of Western Ontario, London, Canada.- This paper reports recent observations on the behavior of spontaneous emission intensities from laser transitions in the He-Zn and He-Cd systems in the cathode region of a rectangular-electrode glow discharge, along with their interpretations. The dependence of the intensities on tube temperature is found to be similar to the behavior in the positive column. These results are explained on the basis of scaling arguments applied to the theory of electron groups in the negative glow. Observations on the partial profile of the intensities across the cathode region show practically all the emission occurring in the negative glow. This result is accounted for by comparing the rate at which He ions diffuse into the dark space from the negative glow with the rate of their conversion, by charge-transfer, to metal-vapor ions, the latter of which turns out to be faster. Calculations are presented which show that the action of a grid placed adjacent to the negative glow may serve to increase the former rate over the latter.

T6. Microwave Density Measurements in Ion Laser Plasmas.* L.D.PLEASANCE and E.V.GEORGE, M.I.T.--Measurements have been made of the electron density in a cw argon-ion laser discharge. The electron density was obtained from the frequency shift of a C band ($\sim$ 6 GHz) microwave cavity excited in the TE_{011} mode. In the past measurements of high electron densities using this mode were limited to $\omega_p^2/\omega^2 \leq 10$ by the restrictions of the perturbation theory employed in the analysis. Here we will present a more complete theory based on the detailed fields in the cavity. We will show that for thin plasma columns the TE_{011} mode may be used up to $\omega_p^2/\omega^2 \sim 1000$ before details of the density profile must be considered. The laser discharge was formed in a liquid cooled quartz capillary. Current densities up to 500 A/cm^2 over a pressure range of 0.1 Torr. to 10.0 Torr. were used. At high pressures the maximum frequency shift measured corresponded to an $\omega_p^2/\omega^2 \sim 500$. These measurements were found to be in good agreement with a discharge theory based on electron-neutral collisions.

*This work was supported by the Joint Services Electronics Programs (U.S. Army, U.S. Navy, and U.S. Air Force) under Contract DA 28-043-AMC-02536(E).

T7. Vacuum Ultraviolet Perturbation Spectroscopy on The He-Ne Laser.* H.MERKELO and R.C.QUINN, Univ.of Ill. Urbana.--A modified version of the system recently reported as suitable for carrying out vacuum ultraviolet perturbation spectroscopy on lasering plasmas[1] is adapted to the He-Ne, 3.39μm laser for simultaneous monitoring of the entire 3s-3p-1s-ground state cascade--both radiatively and collisionally induced. Direct monitoring of the laser-induced resonance radiation (736 and 743Å) gives evidence of collision-induced pumping of metastables into radiating states. The composite dependence (function of collision-induced pumping, diffusion, and resonance trapping) of the yield of vacuum ultraviolet radiation on pressure is determined and is shown to be consistent with a p^2 law in the pressure regime of 0.5 to 5 Torr (7:1 He-Ne ratio). Other results and observed deviations from predictions will be discussed.

*Work supported by the National Science Foundation.
[1]H.Merkelo, R.H.Wright, J.P.Kaplafka, and E.P.Bialecke, Appl. Phys. Letters 13, 401 (1969).

SESSION U

Friday Morning, 23 October

10:30 a.m.

THEORY OF HEAVY PARTICLE COLLISIONS
(PANEL)

Chairman: N. Lane, Rice University

U1. Low Energy Elastic and Fine-Structure Excitation Scattering of $C^+(^2P)$ by $H(^2S)$.* JON C. WEISHEIT** and NEAL F. LANE, Rice Univ. -- Cross sections have been computed for the elastic and fine-structure excitation scattering of $C^+(^2P)$ by low energy (less than 0.1eV) $H(^2S)$. A close coupling formalism was employed and included for the first time both spin change and long-range electrostatic interactions. In addition, the scattering equations were solved in a coupled angular momentum representation to allow for the energy defect between the $C^+(^2P)$ fine-structure levels. The calculated C^+-H excitation cross section varies from 48.8×10^{-16} cm^2 at 0.01 eV to 28.7×10^{-16} cm^2 at 0.085eV, and the maximum of almost 56.0×10^{-16} cm^2 occurs near 0.015eV. The spin-change process was found to dominate the scattering. The sensitivity of the computed cross sections to various approximations and numerical techniques will be discussed.

*Work supported in part by the U.S. Atomic Energy Commission.
**Present address: Harvard College Observatory.

U2. Close Coupling Study of Excitation in Low-Energy Atom-Atom Scattering.* S.A.EVANS, J.S.COHEN, N.F.LANE, Rice University.--A theoretical study of an inelastic atom-atom collision problem has been carried out for a two-state model based on $2^3S\rightarrow2^3P$ excitation in He(2^3S)-He(1^1S) collisions. Full quantum mechanical, close coupling calculations have been carried out in both the adiabatic and diabatic representations[1]. Matrix elements were obtained from a modified valence-bond calculation[2] of the first and second excited $^3\Sigma_g{}^+$ states of He_2, a case involving a strong avoided crossing. In the diabatic representation, where only potential coupling is present, the coupling matrix element is arbitrarily scaled by a factor $f\leq1$ in order to compare the cross section behavior. As f is decreased from 1.0 to 0.1, the $2^3S\rightarrow2^3P$ cross section at 10 eV(C.M.) is increased from 6.0×10^{-20}cm^2 to a maximum of 1.2×10^{-16}cm^2, respectively. The Landau-Zener approximation is very poor for f=1.0 but improves with decreasing f. Additional results and interpretation will be given.

*Work supported in part by the U.S. Atomic Energy Comm.
1F. T. Smith, Phys. Rev. 179, 111 (1969).
2J. C. Browne, J. Chem. Phys. 42, 2826 (1965).

U3. Electronic Transitions between s and p States in Slow Atomic Collisions.* P.G. CABLE, Univ. of Maryland--A model based on the Landau-Zener theory is developed for electronic transitions between s and p states in slow atomic collisions. Because of angular coupling of levels having different magnetic quantum number, the model predicts a larger total transition probability than that given by the Landau-Zener formula (which applies only to s-s transitions). The range of validity of the model is discussed in terms of application to electron transfer processes involving diabatic curve crossings.

*Work supported in part by the Office of Naval Research under Grant N00 - 01467A0239 0008.

U4. Long Range Forces in Near-Resonant Charge Transfer.* FELIX T. SMITH and RONALD E. OLSON, SRI--Near-resonant charge transfer in asymmetric collisions is often dominated by long range forces due to polarization and sometimes ion-quadrupole interactions. These interactions can lead to curve crossings at large distances, which can result in very large cross sections at low energies. The necessary parameters for estimating cross sections by the Landau-Zener formula can be obtained from a knowledge of simple atomic and molecular properties such as ionization potentials and polarizabilities. The results can be applied to the prediction of likely laser excitation processes by reactions producing excited metallic ions.

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

U5. Obtaining Interatomic Potentials From Elastic Scattering Data.* R. KLINGBEIL, Univ. of Maryland--A general procedure for obtaining spherically symmetric interatomic potentials V(r) from elastic differential cross section data $\sigma(\theta)$ is described. Details of an integral equation method for inverting semiclassical phase shifts $\delta(\ell)$ to a numerical interatomic potential are presented. As an example of the procedure, calculated phase shifts corresponding to H_2-Hg scattering are inverted to a numerical potential.

*Work supported by the National Science Foundation under Grant NSF-GP-8325. The computing time was granted by the Computer Science Center of the University of Maryland.

U6. Comparison of Numerical Capture Cross Sections with Reaction Cross Sections for NH_3 and H_2O Targets. JOHN V. DUGAN, JR., NASA-LeRC, and JOHN L. MAGEE, Univ. of Notre Dame - Numerical capture cross sections have been calculated for $NH_3^+ + NH_3$ and ions + H_2O by trajectory solutions of randomly generated collisions. The results are compared with Ryan's measurements[1] of the NH_3-parent ion reaction cross section from thermal to 1 eV. The vibrational distribution of reactant ions is such that only 60% of the capture should result in reaction. The experimental cross section, $\approx$ Langevin, is .45 to .65 of the σ_c value over the range of relative translational energy ϵ. The σ_c dependence is $\epsilon^{-.7}$ whereas $\sigma_{exp} \sim \epsilon^{-.8}$. Thermal collision coefficients (maxwell averaged) are $\approx 10^{-8}\sigma(kT)^{2-n}\Gamma(2-n)$ where n = .7 and .8. The σ_c values for thermal collisions involving H_2O targets are compared with Ryan's results and those of the ESSA group. Generally the σ_c values $> \sigma_{exp}$ but a bit less than the maximum cross section.[2]

[1]K. R. Ryan, paper presented at 18th Conf. of Mass Spect., San Francisco, Calif., May, 1970.

[2]J. V. Dugan, Jr. and J. L. Magee, J. Chem. Phys., 47 (1967) 3011.

U7. Vibrational Effects on Ion-Dipole Capture Cross Section; Computer Movies of Classical Tunneling. JOHN V. DUGAN, JR. and R. BRUCE CANRIGHT, JR., NASA-LeRC - Computer-plotter studies of ion-dipole collisions have been extended to effects of thermal oscillators on capture cross sections σ_c. In some cases the capture ratio C_R is lowered by the oscillator at intermediate and large impact parameters b. The $\sigma_c \equiv \int_0^\infty C_R(b)d(b^2)$ can be lowered to < 50% of the pure rotational value. Two sets of oscillators with different dipole moment variations $\mu(x)$ have been studied;[1] the lifetime of the ion-molecule complex is relatively insensitive to $\mu(x)$.[2] The movies and plots suggest that the dipole phase is critical in determining the ion turning points. "Classical tunneling" of the oscillator is observed in the movies at small separations when the ion-dipole orientation angle is $\approx \pi/2$. Preliminary results of elastic and inelastic angular scattering are also reported for CO, HCl, and CH_3CN targets.

[1] J. V. Dugan, Jr. and R. B. Canright, Jr. (submitted to Chem. Phys. Lett.).
[2] J. V. Dugan, Jr., R. W. Palmer, and J. L. Magee, Chem. Phys. Lett. 6 (1970) 158.

SESSION V

Friday Morning, 23 October

10:30 a.m.

NEGATIVE IONS

Chairman: J. F. Paulson, Air Force Cambridge Research Laboratories

V1. The Detachment of Electrons from F^- Ions in a Shock-Heated Cesium Fluoride-Argon Mixture.* A. MANDL and B. KIVEL, AVCO Everett Research Laboratory, Everett, Massachusetts and E. W. EVANS, Univ. of Missouri, Columbia, Mo.--Electron detachment rates from F^- have been measured in shock-heated mixtures of cesium fluoride and argon. The detachment rate is found to increase exponentially with temperature, indicating an activation energy comparable to the electron affinity of F^-. The rate constants for the reactions

$$F^- + Ar \xrightarrow{K(Ar)} F + Ar + e \quad \text{and} \quad F^- + Cs^+ \xrightarrow{K(Cs^+)} F + Cs^+ + e$$

have been found to be $1.2 \times 10^{-11}\, e^{-40,000/T}\ cm^3/sec$ and $2.8 \times 10^{-9}\, e^{-40,000/T}\ cm^3/sec$ respectively, where T is in degrees Kelvin. The temperature range covered was between 3800^oK - 6000^oK.

*This research was supported by the Advanced Research Projects Agency of the Department of Defense and Space and Missile Systems Organization.

V2. Negative Ion Production from SF_6 and N_2O at High Temperatures.* J. H. MULLEN and J. M. MADSON, McDonnell Douglas Research Laboratories, St. Louis.--An investigation of negative ions produced when SF_6 and N_2O react with electrons in a 1550-3000K rf generated argon plasma has been made. Supersonically injected gas molecules react with a flowing argon plasma after which the plasma undergoes a free jet expansion. In the expansion chamber the electron density is measured with a Ka-band interferometer and the ions are sampled by a quadrupole mass spectrometer[1]. The dominant negative ion formed from SF_6 in this temperature range is F^-, consistant with previously reported measurements in SF_6 up to 1200K[2]. O^- production from N_2O yields a rate constant about two orders of magnitude higher than that at room temperature in agreement with recent attachment cross section measurements[3].

*Research conducted under the McDonnell Douglas Corporation Independent Research and Development Program.

[1]J. H. Mullen, J. M. Madson, L. N. Medgyesi-Mitschang, T. C. Peng and P. M. Doane, to be published Rev. Sci. Instr., Dec. (1970).

[2]C. L. Chen and P. J. Chantry, Bull. Am. Phys., Soc., 15, 418 (1970).

[3]P. J. Chantry, J. Chem. Phys., 51, 3369 (1969).

V3. Determination of Thermal Electron Diffusion (D) and Attachment Rate (αw) Coefficients for Oxygen.* D. R. NELSON and F. J. DAVIS, Oak Ridge National Laboratory.-- Important differences among reported results have been noted for the magnitude and energy dependence of the momentum transport cross section, Q_m, of electrons in oxygen at thermal and near-thermal energies.[1] We have determined a preliminary thermal (300°K) value for DP = 1.02 $cm^2 \mu sec^{-1}$ torr with a drift-dwell-drift electron swarm time-of-transport technique.[2] This DP value corresponds to a Q_m value which is in good agreement with the lowest values from microwave determinations.[1] A preliminary determination of the thermal electron attachment rate $\alpha w = 2.1 \times 10^{-30}$ cm^6 sec^{-1} is in excellent agreement with a value recently reported.[3] These attachment and diffusion studies will be extended above thermal energies.

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

[1]R. D. Hake, Jr. and A. V. Phelps, Phys. Rev. 158, 70 (1967).
[2]D. R. Nelson and F. J. Davis, J. Chem. Phys. 51, 2322 (1969).
[3]J. L. Pack and A. V. Phelps, J. Chem. Phys. 44, 1870 (1966).

V4. Mobilities of Large Size Ions. P. L. PATTERSON, Sylvania Electric Products - Measurements of the mobilities of the polyatomic ions SO_2F^-, $SO_2F_2^-$, SF_5^-, SF_6^-, $F^-(SF_6)$, and $SO_2F_2^-(SO_2)$ in a He carrier gas were presented at this conference last year. These data are now compared with existing theories of ion mobilities. As a consequence of the low polarizability of He and the large size of the ions, these mobilities are dominated primarily by the interaction of ion-neutral repulsive cores rather than the conventional point charge - induced dipole interaction. Differences in the sizes of the repulsive cores of the above ions are manifested in readily measured differences in their mobilities. For a series of ions such as SF_5^-, SF_6^-, and $F^-(SF_6)$, the different repulsive cores refer to species differing by the addition of one atom at a time. The results suggest that mobility measurements of this type might be a valuable means of studying short range collisional forces of large molecules.

V 5. Negative Ion Decay in Photoionized Bromine.* FRANK K. TRUBY, Sandia Laboratories--The loss processes of negative ions created in photoionized Br_2 have been studied using quadrupole mass analysis of ions in the afterglow. The most abundant initially observed negative ion was Br^-. The decay rate of the Br^- ion was found to increase with Br_2 pressure. It was found that in addition to loss by ambipolar diffusion the Br^- ion decays by a three-body ion conversion process with the formation of Br_3^-. The ion conversion process is as follows: $Br^- + 2Br_2 \rightarrow Br_3^- + Br_2$. The measured rate constant for this process is $k_c = 2.9 \times 10^{-29}$ cm^6/sec at 296°K. The value of $D_{a}p$ for the Br^- ion is 12.9 cm^2 Torr/sec at the same temperature. The error for these measurements is estimated at ± 10%. The diffusion coefficient for Br_3^- was measured such that $D_{a}p = 7.6$ cm^2 Torr/sec at 296°K for this ion with an estimated error of ± 10%.

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

V 6. Electron Impact Studies of Acetone and Halogenated Acetone.* W. T. NAFF† and R. N. COMPTON, Oak Ridge National Laboratory. -- A time-of-flight mass spectrometer and a trapped electron apparatus were used to study threshold electron impact excitation and negative ion formation in acetone, chloroacetone, and hexafluoroacetone. Threshold excitation spectra were obtained using the SF_6-scavenger and trapped electron techniques. An intense energy loss peak at 1.25 eV observed in both spectra was positively identified as a temporary negative ion resonance (TNIR) by the observation of dissociative attachment in chloroacetone (dissociation from a TNIR state producing Cl^- was observed at 0.5 eV). Electronic states were observed in both the scavenger and trapped electron spectra at 4.2 ± .05, 6.3 ± .05, and 7.5 ± .05 eV. Hexafluoroacetone captures slow electrons (~ 0 eV) into a long-lived temporary negative ion state with an autodetachment lifetime of 66 ± 10 μsec.

*Research sponsored by the U.S. Atomic Energy Commission under contract with Union Carbide Corporation.
†ORAU Graduate Fellow.

V7. Dissociative Electron Attachment to Brominated Aliphatic Hydrocarbons.* A. A. CHRISTODOULIDES,† L. G. CHRISTOPHOROU, P. M. COLLINS,‡ and J. G. CARTER, Oak Ridge National Laboratory.--A swarm-beam study has been made at room temperature of brominated hydrocarbons of the form n-$C_NH_{2N+1}Br$ (N = 2, 3, 4, 5, 6, 8, and 10). At energies below 3 eV the most abundant ion found was Br^-. The cross section $\sigma_{da}(\epsilon)$ peaked at 0.76, 0.74, 0.73, 0.70, 0.72, and 0.13 eV, and had peak values equal to 3.95, 4.14, 5.50, 6.13, 7.41, and 32×10^{-18} cm^2, for N = 2, 3, 4, 5, 6, and 8, respectively. For bromodecane (N = 10) $\sigma_{da}(\epsilon)$ from 3/2 kT to 0.85 eV could be represented by A_γ/ϵ^γ with γ = 1.398 and $A_\gamma = 1.141 \times 10^{-34}$ $(ergs)^\gamma cm^2$. A small decrease has been observed in the cross section width with increasing reduced mass of the R(= C_NH_{2N+1})-Br system. This and the increase in σ_{da} with the reduced mass of the "diatomic-like" R-Br molecules will be discussed within the resonance scattering theory.

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

†Graduate student from the University of Tennessee.

‡ORAU student from the University of Tennessee.

SESSION W

Friday Afternoon, 23 October

2:00 p.m.

ELECTRON EXCITATION

(PANEL)

Chairman: E. C. Zipf, University of Pittsburg

W1. Absolute Experimental Cross Sections for the Excitation of Ba^+ Ions by Electron Impact.* M.O. Pace and J.W. Hooper, Georgia Institute of Technology.-- Absolute emission cross sections have been measured for electron impact excitation of the resonance transitions in the Ba^+ ion. Transitions between the $6^2P_{\frac{1}{2}}{}^\circ$ and $6^2P_{\frac{3}{2}}{}^\circ$ levels and the $6^2S_{\frac{1}{2}}$ ground state with emission of photons with wavelengths of 4934 Å and 4554 Å have been studied over the energy ranges of 3-98 eV and 8-98 eV, respectively. Polarization fractions have been determined for electron energies of 3, 4, 6, and 8 eV. The experimental method involves crossing modulated beams of ions and electrons in a well defined collision volume. A portion of the radiation from excited ions is detected by direct observation of the collision volume with a photomultiplier tube operating in the counting mode. A single resonance line is selected with a narrow band interference filter. The cross sections are made absolute, in the sense that the optical measurements are related to the light standard.

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

W2. Excitation of Resonance States in Electron Impact on Atomic Oxygen and Nitrogen.* E. J. STONE and E. C. ZIPF, University of Pittsburgh.-- Absolute cross sections for the excitation of the resonance states $OI(^3S)$ and $NI(^4P)$ have been measured in electron impact on atomic oxygen and nitrogen. A microwave discharge was used to dissociate the parent molecular gas. The atomic products then flowed into a cylindrical collision chamber where they attained a uniform spatial distribution. This was verified by vacuum ultraviolet absorption measurements which were also used to determine the absolute density of O and N atoms in the collision chamber. A one meter normal incidence monochromator was used to observe the resonance radiation. The excitation cross sections were measured from threshhold to 140 eV using these techniques. The peak value of the excitation cross section is $(3.2\times10^{-17}\pm30\%)\,cm^2$ for the $OI(^3S)$ state and $(1.7\times10^{-16}\pm30\%)\,cm^2$ for the $NI(^4P)$ state.

*Work supported, in part, by NASA and ARPA.

W3. Electron Excitation Functions of Argon.* JAMES K. BALLOU, CHUN C. LIN, University of Wisconsin and F. E. FAJEN, Los Alamos Scientific Lab -- Electron excitation functions have been measured for a series of states associated with the $3p^5ns$, $3p^5np$, and $3p^5nd$ configurations of argon. The s_3, s_5, p_9, d_6, and d_4' states (Paschen's notation) which are purely triplet states within the one-configuration approximation, exhibit narrow peaks in the excitation functions, whereas broad excitation curves were found for the following optically dipole-allowed states: s_2, s_4 ($3p^5ns$, $J = 1$), and d_2, s_1' ($3p^5nd$, $J = 1$). Although the $4d_5$, $5d_5$, and $6d_5$ ($3p^5nd$, $J = 1$) states also satisfy the dipole selection rules, they are found to have sharply peaked excitation functions characteristic of the triplet states. Calculations of intermediate-coupling wavefunctions in terms of LS-eigenfunctions show that the $^1P_1$ components in the d_5 states are indeed very small.

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

W4. Close-Coupling Calculation of Electron Excitation Cross Sections of the 3^2D State of Sodium.* DALE F. KORFF, S. CHUNG, AND CHUN C. LIN, University of Wisconsin -- Because of the strong coupling between the 3s and 3p states and between the 3p and 3d states of the sodium atom, the electron excitation cross sections of the 3^2D state may be expected to be influenced markedly by the indirect coupling between 3^2S and 3^2D (via the 3^2P state) as well as the usual direct one. The use of the Born approximation for calculating these cross sections may therefore result in an under-estimation. We have calculated the electron excitation cross sections of the 3^2D state by the method of close coupling with the inclusion of the 3s, 3p, and 3d states. At an incident energy of 16.8 eV the close-coupling cross section of 3^2D is 16.0 a_0^2 which is considerably larger than the Born value of 9.5 a_0^2 and compares well with 14 a_0^2 obtained from experiment. The introduction of the 3d state decreases substantially the $3^2S \rightarrow 3^2P$ cross section from the 3s-3p close-coupling value.[1]

*Work supported in part by the Air Force Cambridge Research Laboratories, Office of Aerospace Research.
[1]L. L. Barnes, N. F. Lane, and C. C. Lin, Phys. Rev. 137, A388 (1965).

W5. Excitation of OI 1304A and NI 1493A Lines by Electron Impact on Oxygen and Nitrogen Molecules.

W. A. BROWN and J. N. BRADBURY, Lockheed Palo Alto Research Lab.

The vacuum UV spectra of nitrogen and oxygen have been obtained by bombarding the gases (separately) with magnetically confined electron beams at energies from 6 to 300 eV. In nitrogen, the atomic lines at 1493 and 1743A are prominent, along with the LBH bands of the molecule. The appearance potential of these atomic lines, which originate in the $3s^2P$ state of NI, was found to be 21±0.5 eV. This energy is almost equal to the sum of the N_2 dissociation energy and the excitation energy of the upper state in the atom, thus suggesting the presence of a new bound state of the nitrogen molecule with dissociation limit at 20.4 eV corresponding to $N(^4S) + N(^2P)$. The excitation cross section is about $10^{-18} cm^2$ at its peak near 90 volts, with structure at 32 volts. In oxygen, the appearance potential of the 1304A triplet was found to lie at 14.5±1 eV, again suggesting the existence of a new bound state of O_2 which dissociates to $O(^3P) + O(3s\,^3S^o)$.

W 6. Excitation of the $a^1\Pi_g$ State of the Nitrogen Molecule by Electron Impact.* S. CHUNG AND CHUN C. LIN, University of Wisconsin -- The electron excitation cross sections of the $a^1\Pi_g$ state of the nitrogen molecule have been calculated by the Born approximation. The electronic wavefunctions of the ground state and the $a^1\Pi_g$ state were calculated by the self-consistent-field method with thirteen s-type and seven p-type Gaussian-type orbitals as basis functions. At electron energy of 100, 900, and 2000 eV, the calculated cross sections are respectively 11.8, 1.32, and 0.60 ($\times 10^{-18}$ cm^2) in good agreement with the corresponding experimental values (apparent cross section) of 6.7, 1.1 and 0.52. Above 200 eV, the theoretical cross sections are inversely proportional to the incident energy. The sensitivity of the calculated cross sections with respect to the accuracy of the molecular wavefunctions has been examined.

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

W7. Excitation of the CO Fourth Positive Band System by Electron Impact on CO and CO_2. M. J. MUMMA*, E. J. STONE AND E. C. ZIPF, Univ. of Pittsburgh--Absolute excitation cross-sections for five vibrational bands of the $CO(A^1\pi - X^1\Sigma^+)$ Fourth Positive band system have been measured for electron impact on CO and CO_2 over an energy range 0-350 eV. The explicit dependence of the electronic transition moment on the r-centroid was determined via intensity measurements on 28 bands. This permitted the calculation of the absolute transition probabilities for all bands in this system. We have also used the dependence of the electronic transition moment on the r-centroid to correct Hesser's measurement of the total f-value for the $CO(X^1\Sigma^+ - A^1\pi)$ system, which becomes 0.15. The peak cross-section for excitation of the $CO(A^1\pi)$ state was $6.6 \times 10^{-17} cm^2$ (at 25 eV) when CO was the parent molecule, and greater than $2.6 \times 10^{-18} cm^2$ (at 40 eV) when CO_2 was the parent molecule.

*Present address: Goddard Space Flight Center Laboratory for Extraterrestrial Physics, Greenbelt, Md.

W8. Dissociative Excitation of O_2 by Electron Impact with the Formation of Metastable ^5S and High-Rydberg Atoms. ROBERT S. FREUND, Bell Telephone Labs.--Metastable $3s^5S°$ and high Rydberg oxygen atoms are formed by dissociative excitation of O_2. The molecular beam time-of-flight method is used to measure their translational kinetic energy distributions and excitation functions. It is found that the kinetic energy distribution of high Rydberg atoms is similar to that for O^+ from dissociative ionization of O_2. This shows that dissociation of high molecular Rydberg states is governed by the dissociation behavior of their O_2^+ core ions. The fragment kinetic energy distributions are discussed in terms of known and predicted states of O_2 and O_2^+.

W9. Rotational-Vibrational Excitation of H_2 by Low-Energy Electrons.* RONALD J.W.HENRY, Louisiana State Univ., and EDWARD S. CHANG, Univ. of Chicago--Integral and differential cross sections for pure vibrational excitation and simultaneous rotational-vibrational excitation of H_2 by slow-electron impact are calculated using frame transformation theory. They are compared with close-coupling calculations and experiments for energies $E \leq 10$ eV. The interaction potential for e-H_2 system used in the calculations includes static-field, electron-exchange effects, long-range quadrupole, and an effective polarization potential.

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

SESSION X

Friday Afternoon, 23 October

2:00 p.m.

PENNING EXCITATION AND IONIZATION

(PANEL)

Chairman: L. D. Schearer, Texas Instruments, Incorporated

X1. Studies of Penning and Charge-Transfer Collisions Between Noble Gases and Group II Atoms. L. A. Riseberg and L. D. Schearer, Texas Instruments, Incorporated.--Results are reported for a program of investigation of Penning and charge-transfer collisions between noble gas atoms and Group II atoms in an rf-excited binary plasma. Total cross-sections for the $He(2^3S_1)$ - Cd, $He(2^3S_1)$ - Zn, and $Ne(3^3P_2)$ - Cd Penning collisions and He^+ - Zn charge transfer collision are reported and compared. These cross-sections are, respectively, 4.5×10^{-15} cm^2, 2.91×10^{-15} cm^2, 4.61×10^{-15} cm^2, and 2.08×10^{-15} cm^2. Conclusions are presented regarding the roles of these processes in generating population inversions in the He-Cd and He-Zn lasers.

X2. Polarization of Molecular Ions via Penning Collisions with Optically Oriented Metastable Helium Atoms. L. D. Schearer and L. A. Riseberg, Texas Instruments, Incorporated.--Polarization transfer from optically oriented $He(2^3S_1)$ atoms to the electronically excited levels of $N_2^+(B^2\Sigma_u)$ as a result of Penning collisions has been observed in a flowing He afterglow. The N_2^+ polarization is detected by monitoring the polarized optical emission at 3914 Å, $N_2^+(0,0)$. The effects of the spin-rotational coupling in the excited ion result in a considerable reduction in the attainable polarization of the ion and a change in the sign of the optical polarization depending upon whether P or R branch transitions are observed. Applications of this technique to the study of coupling constants, g-factors, lifetimes, and collisional effects in excited molecular ions will be discussed. This method in effect extends the optical pumping process to molecular ions, a field relatively untouched.

X3. Direct Observation of the Spin Dependence of Ionizing Collisions between He(2^3S_1) Metastable Atoms. L. D. Schearer and L. A. Riseberg, Texas Instruments, Incorporated.--The spin-dependence of the Penning ionization process He(2^3S_1) + He (2^3S_1) → He(1^1S_0) + He$^+$($1^2S_{\frac{1}{2}}$) + e has been directly observed by detection of the electron density in an optically pumped He afterglow. When the metastable helium atoms are optically oriented, the process violates spin conservation, and a decrease of 5% in the electron density is observed. The observations indicate that a large fraction of the electrons in the afterglow result from metastable-metastable collisions and demonstrates the value of an optically pumped He afterglow as a source of monochromatic polarized electrons. The polarization of the electrons is detected by observing the polarization induced in a sodium vapor by spin-exchange collisions while the polarization of the He$^+$ is detected by monitoring the polarized optical emission from Zn$^+$($5^2D_{5/2}$) following charge transfer collisions.

X4.

ANGULAR DISTRIBUTION OF PENNING ELECTRONS

H. Hotop and A. Niehaus, Univ. of Freiburg, Germany

Penning electrons produced in the crossing of a collimated He-metastable beam, emerging from a hot cathode dc-discharge, and a broad Ar atom beam are measured with an electron analyzer consisting of a retarding field and a 127^o-cylindrical electrostatic condensor which is rotatable about the scattering center in a plane containing the metastable beam. The angular distributions obtained are asymmetric with respect to 90^o angle between detector and metastable beam and different for ionization by He(2^1S)- and He(2^3S)-metastables.

X5.
Determination of Interaction Potentials from Penning Electron Energy Distributions. H. Hotop and A. Niehaus, Univ. of Freiburg, Germany.-- The energy distributions of electrons arising from Penning ionization of $Na(^2S)$ and $K(^2S)$ atoms by $He(2^1S, 2^3S)$ metastables in thermal collisions are reported. It is shown that under fairly general conditions the well depth ε^* of the interaction potential between the metastable and the target atom can be obtained directly from the measured electron distributions. In this way ε^*-values are determined for the diatomic systems: $He(2^1S)$-Na $(^2\Sigma)$, $He(2^3S)$-Na $(^2\Sigma)$, $He(2^1S)$-K $(^2\Sigma)$, $He(2^3S)$-K $(^2\Sigma)$, and - based on earlier measurements [1] - for $He(2^1S)$-$Hg(^1\Sigma)$ and $He(2^3S)$-Hg $(^3\Sigma)$.

1) H. Hotop, A. Niehaus, Z. Phys. 228(1969) 68

X6. Selective Excitation of the 3^3S Level of Atomic Oxygen in a Flowing Helium Afterglow.* W. B. HURT and W. C. GRABLE, U. of Texas at Dallas-- The reaction flame due to the addition of O_2 downstream in a flowing helium afterglow has been investigated in the vacuum ultraviolet region. One of the most striking features is the appearance of an intense triplet at 1300 Å that has naturally been attributed to the resonance transition, $3^3S \rightarrow 2^3P$, in neutral atomic oxygen. The intensity ratios of the individual lines also correlate with this identification. Both the 2^3S helium metastable and the molecular ion appear responsible for producing the 3^3S level in atomic oxygen. The metastable atom apparently excites a neutral dissociative state of O_2 and the molecular ion apparently excites a level of O_2^+ which then dissociatively recombines.

*Work supported in part by the National Aeronautics and Space Administration, NASA Grant NGL44-004-026

X7. Collisional Dissociation of Associative Ions.*

H.L. KRAMER and E.E. MUSCHLITZ, JR., Univ. of Florida.

--Measurements of the dependence of the ratio of associative to Penning ionization on the target gas pressure have been carried out for thermal beams of He and Ne metastables in collision with Ar and Kr. The apparatus used, except for minor improvements, has been described previously.[1] The results indicate that the associative ions are formed in vibrational states near the dissociation limit. The cross section for dissociation of $NeAr^+$ is roughly five times that for dissociation of $HeAr^+$ on collision with Ar.

*Supported by the National Science Foundation.

[1] J.A. Herce, J.R. Penton, R.J. Cross, and E.E. Muschlitz, Jr., J. Chem. Phys. 49, 958 (1968).

INDEX TO AUTHORS OF CONTRIBUTED PAPERS

S = "senior" author