

TWENTY-SIXTH ANNUAL

GASEOUS ELECTRONICS CONFERENCE

Topical Conference of the American Physical Society



October 16-19, 1973

**University of Wisconsin—Madison
Madison, Wisconsin**

Twenty-Sixth Annual Gaseous Electronics Conference

PROGRAM AND ABSTRACTS

October 16-19, 1973

Madison, Wisconsin

A topical conference of The American Physical Society

Sponsored by

University of Wisconsin-Madison
The American Physical Society, Division of Electron and Atomic Physics

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PROGRAM
TWENTY-SIXTH ANNUAL
GASEOUS ELECTRONICS CONFERENCE

RECEPTION-MIXER AND REGISTRATION

7:30 PM - 10:00 PM
Monday, October 15
Wisconsin Center

SESSION AA. TRANSPORT AND GLOWDISCHARGE

9:00 AM - 10:40 AM, Tuesday, October 16

Wisconsin Center Auditorium

Chairman: C. F. Gallo, Xerox Research Laboratories

- AA-1 THE EFFECT OF THERMIONIC EMISSION FROM HOT PARTICLES ON THE CONCENTRATION AND CONDUCTIVITY OF A PLASMA (7 min.)
Chih Wu
- AA-2 HIGH FIELD TRANSPORT OF ATOMIC RARE GAS IONS IN THEIR PARENT GASES (7 min.)
Michael E. Fein and Robert A. Schaefer
- AA-3 MOBILITIES AND LOGITUDINAL DIFFUSION COEFFICIENTS OF H^+ , H_3^+ , AND H^- IONS IN HYDROGEN GAS (7 min.)
E. Graham IV, D. R. James, W. C. Keever, D. L. Albritton, and E. W. McDaniel
- AA-4 TRANSPORT PHENOMENA FOR $A \xrightarrow{\alpha} B \xrightarrow{\gamma} C$ TYPE REACTIONS (7 min.)
S. P. Hong and S. B. Woo
- AA-5 DIRECTIONAL PROBE MEASUREMENTS IN MOLECULAR GAS DISCHARGES (7 min.)
A. Garscadden, P. Bletzinger, W. F. Bailey, and W. H. Long
- AA-6 SCALING LAWS FOR THE POSITIVE COLUMN: TWO STEP IONIZATION IN THE RARE GASES (7 min.)
B. E. Cherrington
- AA-7 TRANSIENT BEHAVIOR OF A DIFFUSE GLOW DISCHARGE IN HELIUM AT HIGH PRESSURE (7 min.)
E. F. Jaeger and A. V. Phelps

- AA-8 PROPAGATION OF A FILAMENTARY ARC CHANNEL IN A DIFFUSE GLOW DISCHARGE (7 min.)
Gerald L. Rogoff
- AA-9 RADIAL NEUTRAL GAS TEMPERATURE AND DENSITY PROFILES IN LOW PRESSURE ARGON DISCHARGES (7 min.)
J. G. Eden and B. E. Cherrington
- AA-10 THE EFFECT OF ELECTRON DE-EXCITATION AND SELF-ABSORPTION ON THE INTENSITY OF THE Hg 2537Å RADIATION IN Hg + Ar DISCHARGES (7 min.)
T. J. Hammond and C. F. Gallo

SESSION AB. CO AND ARGON ION LASERS

9:00 AM - 10:25 AM, Tuesday, October 16

Wisconsin Center Lake Shore Room

Chairman: O. P. Judd, Los Alamos Scientific Laboratory

- AB-1 HIGH SPECIFIC ENERGY-HIGH EFFICIENCY CO EDL (7 min.)
M. M. Mann, D. K. Rice, R. G. Eguchi, and G. L. McAllister
- AB-2 MEASUREMENT OF VIBRATIONAL ENERGY TRANSFER RATES IN CO-N₂ AND CO-H₂ MIXTURES FROM 150 TO 500 DEGREES KELVIN (7 min.)
D. F. Starr, J. K. Hancock, and W. H. Green
- AB-3 SATURATION EFFECTS IN BROAD BAND TRANSFER LASERS (7 min.)
William Bailey and William H. Long
- AB-4 A KINETIC-OPTICAL ANALYSIS OF cw CO ELECTRIC-DISCHARGE LASERS (7 min.)
R. J. Hall, L. S. Bender, and A. C. Eckbreth
- AB-5 INFLUENCE OF NITROGEN OXIDES ON CO LASER PERFORMANCE (7 min.)
P. Bletzinger and D. R. Pond
- AB-6 DISTRIBUTION OF VIBRATIONAL ENERGY LEVELS IN A C.W. CARBON MONOXIDE LASER (7 min.)
H. Keren, P. Avivi, F. Dothan, and L. Friedland
- AB-7 KINETIC THEORY OF THE ARGON ION LASER DISCHARGE (20 min.)
C. James Elliott

SESSION BA. NEGATIVE IONS

10:45 AM - 12:25 PM, Tuesday, October 16

Wisconsin Center Auditorium

Chairman: L. W. Anderson, University of Wisconsin

- BA-1 ANGULAR DISTRIBUTION OF MOLECULAR FRAGMENTS FROM ELECTRON INDUCED DISSOCIATION OF DIATOMIC MOLECULES (20 min.)
R. J. Van Brunt

- BA-2 DYNAMICS OF COLLISION-INDUCED DISSOCIATION OF ALKALI HALIDES
(20 min.)
Frank Paul Tully
- BA-3 THE CHEMICAL EQUILIBRIUM OF $\text{OH}^- + \text{C}_2\text{H}_2 \rightleftharpoons \text{C}_2\text{H}^- + \text{H}_2\text{O}$ AND THE
DETERMINATION OF EA(C₂H) (7 min.)
G. I. Mackay, R. S. Hemsworth, H. I. Schiff, and D. K. Bohme
- BA-4 ATTACHMENT IN BORON TRIFLUORIDE (7 min.)
P. J. Chantry
- BA-5 A KINETIC STUDY OF ELECTRON ATTACHMENT TO HBO₂ (7 min.)
W. J. Miller and R. K. Gould
- BA-6 MASS ANALYSIS OF NEGATIVE IONS PRODUCED IN ELECTRON SWARM
EXPERIMENTS: H₂O(D₂O) and NH₃(ND₃) (7 min.)
J. F. Wilson and R. N. Compton
- BA-7 DETACHMENT IN AIR (7 min.)
J. L. Moruzzi

SESSION BB. LASER IONIZATION PROCESSES

10:45 AM - 12:15 PM, Tuesday, October 16

Wisconsin Center Lake Shore Room

Chairman: J. J. Lowke, Westinghouse Research Laboratories

- BB-1[†] UV PHOTOIONIZATION PROCESSES IN SEEDED HIGH PRESSURE LASER
GASES
J. Y. Wada, R. C. Lind, and O. P. Judd
- BB-2[†] GENERATION OF A HIGH ENERGY, LONG PULSE UV SUSTAINED DISCHARGE
IN A CO₂ LASER MIXTURE (20 min.)
R. C. Lind and J. Y. Wada
- BB-3 ELECTRON BEAM SUPPORTED DISCHARGES IN SUPERSONIC FLOWS (20 min.)
W. B. Shepherd, W. M. Brandenburg, D. J. Pistoiresi, and
R. L. Haslund
- BB-4 PARAMETRIC STUDY OF ELECTRON-BEAM CO₂ LASER (7 min.)
G. Fournier, J. Bonnet, and D. Pigache
- BB-5 Abstract withdrawn
- BB-6 ATMOSPHERIC PRESSURE DISCHARGE INITIATION BY EXTERNALLY
EXCITED PHOTOELECTRONS (7 min.)
V. A. Gilson and R. L. Schriever

[†] Combined presentation, total time allotted for both papers 20 minutes.

- BB-7 ENERGY DEPOSITION BY FAST ELECTRONS IN HIGH PRESSURE GAS LASERS (7 min.)
J. H. Jacob

SESSION C. RECOMBINATION AND EXCITATION

2:00 PM - 3:30 PM, Tuesday, October 16
Historical Society Auditorium
Chairman: H. J. Oskam, University of Minnesota

- C-1 ELECTRON-POSITIVE ION RECOMBINATION STUDIES USING ION STORAGE TECHNIQUES (25 min.)
F. L. Walls and G. H. Dunn
- C-2 RECOMBINATION OF MOLECULAR IONS (7 min.)
D. L. Huestis, F. T. Smith, and S. W. Benson
- C-3 EXCITATION TO HIGH VIBRATIONAL STATES IN N_2 , CO, and CO_2 (20 min.)
M. J. W. Boness and G. J. Schulz
- C-4 THEORY OF EXCITATION OF THE ELECTRONIC STATES OF DIATOMIC MOLECULES BY ELECTRON IMPACT - N_2 , CO, and NO (20 min.)
Sunggi Chung

SESSION D. DISTRIBUTION FUNCTIONS

3:45 PM - 5:10 PM, Tuesday, October 16
Historical Society Auditorium
Chairman: D. S. Burch, Oregon State University

- D-1 THE UPFLUX THEORY OF DISTRIBUTION FUNCTIONS (20 min.)
William P. Allis
- D-2 ON THE ENERGY BALANCE IN LOW PRESSURE GAS DISCHARGES (20 min.)
L. Vriens
- D-3 ELASTIC AND INELASTIC CROSS SECTIONS FOR e-Hg SCATTERING FROM Hg TRANSPORT DATA (20 min.)
Stephen D. Rockwood
- D-4 ANISOTROPIC ELECTRON DISTRIBUTIONS IN MOLECULAR GAS DISCHARGES (7 min.)
William H. Long and William F. Bailey

BUFFET SUPPER

6:30 PM - 8:30 PM
 Tuesday, October 16
 Wisconsin Center Alumni Lounge

SESSION EA. EXCITATION TRANSFER

9:00 AM - 10:22 AM, Wednesday, October 17
 Wisconsin Center Auditorium
 Chairman: R. M. St. John, University of Oklahoma

- EA-1 CHEMIONIZATION BY RARE GAS METASTABLE ATOMS (7 min.)
 W. P. West, T. B. Cook, F. B. Dunning, R. F. Stebbings,
 and R. D. Rundel
- EA-2 PRODUCTION OF EXCITED MOLECULAR IONS BY RARE GAS MOLECULAR
 METASTABLES (7 min.)
 P. E. Thiess and G. H. Miley
- EA-3 FORMATION AND REACTIONS OF METASTABLE $N^+(\text{D})$ (7 min.)
 J. A. Rutherford, R. H. Neynaber, and D. A. Vroom
- EA-4 THE DECAY OF KRYPTON $1s_2$ AND $1s_3$ EXCITED SPECIES IN THE LATE
 AFTERGLOW (7 min.)
 R. T. Ku, J. T. Verdeyen, and B. E. Cherrington
- EA-5 ENERGY TRANSFER FROM ARGON RESONANCE STATES TO MOLECULES (20 min.)
 G. S. Hurst and E. B. Wagner
- EA-6[†] AB INITIO POTENTIAL CURVES FOR THE $Ne(3s) - Ne$ INTERACTION WITH
 SEMIEMPIRICAL TREATMENT OF SPIN-ORBIT COUPLING
 J. S. Cohen and Barry Schneider
- EA-7[†] EXCITATION TRANSFER IN $Ne + Ne^*$ COLLISIONS (14 min.)
 Barry Schneider and J. S. Cohen

[†] Combined presentation, total time allotted for both papers 14 minutes.

SESSION EB. HF AND OTHER LASERS

9:00 AM - 10:25 AM, Wednesday, October 17

Wisconsin Center Lake Shore Room

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

- EB-1 HF AND DF NONCHEMICAL ELECTRICAL DISCHARGE LASERS (20 min.)
L. Y. Nelson, S. R. Byron, and G. J. Mullaney
- EB-2 STUDIES CONCERNING AN ELECTRICALLY-EXCITED H_2 -HF LASER (7 min.)
R. M. Osgood Jr.
- EB-3 KINETICS FOR POPULATION INVERSION ON THE 557.7 nm $O(^1S) \rightarrow O(^1D)$ TRANSITION IN ATOMIC OXYGEN (7 min.)
S. D. Rockwood, O. P. Judd, and R. O. Hunter
- EB-4 ENERGY FLOW IN ARGON, N_2 , NO MIXTURES EXCITED BY PULSED ELECTRON BEAM (7 min.)
R. M. Hill, D. J. Eckstrom, R. A. Gutcheck, D. L. Huestis,
D. C. Lorents, D. Mukherjee, and H. H. Nakano
- EB-5 A SPECTROSCOPIC STUDY OF A HIGH FLOW COPPER VAPOR LASER (7 min.)
T. W. Karras, R. S. Anderson, and B. G. Bricks
- EB-6 EVIDENCE OF CHARGE EXCHANGE PUMPING IN CALCIUM-XENON SYSTEM (7 min.)
Donald L. Chubb
- EB-7 EXCITATION MECHANISM IN THE He-Cd AND He-Zn ION LASERS (7 min.)
George J. Collins

SESSION FA. ION-MOLECULE COLLISIONS

10:45 AM - 12:30 PM, Wednesday, October 17

Wisconsin Center Auditorium

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

- FA-1 ION-MOLECULE REACTION AND MOBILITY MEASUREMENTS IN A FLOWING AFTERGLOW-DRIFT TUBE (20 min.)
M. McFarland, D. L. Albritton, F. C. Fehsenfeld, E. E. Ferguson, and A. L. Schmeltekopf
- FA-2 PROTON AFFINITIES OF O_2 , Xe, and C_2H_6 (7 min.)
P. F. Fennelly, R. S. Hemsworth, J. D. Payzant, H. I. Schiff, and D. K. Bohme
- FA-3 THERMAL ENERGY ION MOLECULE REACTIONS INVOLVING NH_3 AND NO (7 min.)
R. S. Hemsworth, J. D. Payzant, P. E. Fennelly, D. K. Bohme,
and H. I. Schiff
- FA-4 REACTION RATE CONSTANTS MEASURED IN A TEMPERATURE VARIABLE FLOWING AFTERGLOW (7 min.)
F. C. Fehsenfeld, A. L. Schmeltekopf, D. B. Dunkin, D. L. Albritton, C. J. Howard, and E. E. Ferguson

- FA-5 FLOWING AFTERGLOW MEASUREMENTS OF NEGATIVE ION REACTIONS (7 min.)
E. E. Ferguson and F. C. Fehsenfeld
- FA-6 TERMOLICULAR AND SATURATED TERMOLICULAR KINETICS FOR Li^+
(7 min.)
Kenneth G. Spears and E. E. Ferguson
- FA-7 BINDING ENERGIES OF ALKALI-METAL IONS WITH INERT GASES (7 min.)
L. G. McKnight and J. M. Sawina
- FA-8 REACTIONS OF IONS IN HYDROGEN (7 min.)
W. T. Huntress Jr., L. P. Theard, and J. K. Kim
- FA-9 CLUSTERING OF H_2O AND NH_3 ABOUT THE MONOVALENT BISMUTH ION
(7 min.)
A. W. Castleman Jr. and I. N. Tang

SESSION FB. CO_2 KINETICS AND EXCITATION TRANSFER

10:45 AM - 12:20 PM, Wednesday, October 17

Wisconsin Center Lake Shore Room

Chairman: J. Y. Wada, Hughes Research Laboratories

- FB-1 THE EFFECT OF NEGATIVE ION PROCESSES ON THE STABILITY OF
MOLECULAR GAS DISCHARGES (25 min.)
W. J. Wiegand and W. L. Nighan
- FB-2 CO_2 LASER DISCHARGES CONTROLLED BY ATTACHMENT (20 min.)
J. J. Lowke and L. J. Denes
- FB-3 ELECTRON EXCITATION OF THE 001 LEVEL OF CO_2 AND THE VIBRATIONAL
LEVELS OF N_2 (7 min.)
B. R. Bulos and A. V. Phelps
- FB-4 KINETIC MODELING OF ELECTRICALLY EXCITED CO_2 LASERS (7 min.)
A. M. Lockett III
- FB-5 STIMULATED EMISSION FROM THE AFTERGLOW OF AN E-BEAM DISCHARGE
IN SEVERAL ATMOSPHERES OF HELIUM (7 min.)
C. B. Collins, B. W. Johnson, and A. J. Cunningham
- FB-6 ELECTRON-BEAM EXCITED CHARGE TRANSFER AT ATMOSPHERIC PRESSURES
AS A SOURCE OF STIMULATED EMISSION (7 min.)
A. J. Cunningham, B. W. Johnson, W. P. Lee, and C. B. Collins

SESSION G. VACUUM ULTRAVIOLET LASERS I

2:00 PM - 3:25 PM, Wednesday, October 17

Wisconsin Center Auditorium

Chairman: M. M. Mann, Northrop Research and Technology Center

- G-1 THE VACUUM-ULTRA-VIOLET MOLECULAR-XENON LASER (20 min.)
J. B. Gerardo and A. Wayne Johnson
- G-2 STIMULATED EMISSION FROM MOLECULAR XENON AND KRYPTON DIMERS
(20 min.)
P. W. Hoff and C. K. Rhodes
- G-3 EXCIMER FORMATION AND DECAY PROCESSES IN ELECTRON EXCITED
HIGH PRESSURE RARE GASES (20 min.)
D. C. Lorents
- G-4 SPONTANEOUS AND SUPERRADIANT EMISSION AT 1730 Å IN XENON GAS
AT LOW TEMPERATURE (7 min.)
Franck Collier and Christian Collet

SESSION HA. ELECTRON-MOLECULE AND CHARGE TRANSFER COLLISIONS

3:45 PM - 5:25 PM, Wednesday, October 17

Wisconsin Center Lake Shore Room

Chairman: W. L. Borst, Southern Illinois University

- HA-1 EXCITATION OF THE $C^3\Pi_u$ STATE OF N_2 BY ELECTRON IMPACT (7 min.)
R. J. Anderson, S. T. Chen, and R. H. Hughes
- HA-2 DISSOCIATIVE EXCITATION OF N_2 BY ELECTRON IMPACT: TRANSLATIONAL
SPECTROSCOPY OF LONG-LIVED HIGH-RYDBERG FRAGMENT ATOMS (7 min.)
Kermit C. Smyth, James A. Schiavone, and Robert S. Freund
- HA-3 DISSOCIATIVE IONIZATION OF N_2 BY ELECTRON IMPACT (7 min.)
J. A. D. Stockdale, Lilliana Deleanu, and R. N. Compton
- HA-4 VIBRATIONAL EXCITATION OF O_2 BY ELECTRON IMPACT (7 min.)
S. F. Wong, M. J. W. Boness, and G. J. Schulz
- HA-5 NEW RYDBERG SERIES IN O_2 AND O_2^- (7 min.)
R. Carbonneau and P. Marmet
- HA-6 LIGHT EMISSION FROM He^+ /RARE GAS COLLISIONS (7 min.)
B. M. Hughes, E. G. Jones, and T. O. Tiernan
- HA-7 KINEMATICS OF CHARGE TRANSFER IN COLLISIONS OF RARE GAS IONS
WITH DIATOMIC MOLECULES (7 min.)
T. L. Budzynski and T. L. Bailey

- HA-8 COMPARISON OF THE EXPERIMENTAL CROSS SECTION FOR $Kr^{++} + Ne \rightarrow Kr^+ + Ne^+$ WITH SOME SIMPLE THEORIES (7 min.)
William B. Maier II
- HA-9 THERMAL ENERGY CHARGE TRANSFER REACTIONS IN Kr/CO AND Xe/O_2 MIXTURES (7 min.)
James B. Laudenslager
- HA-10 CHARGE-EXCHANGE CROSS SECTIONS FOR Ne^+ AND Ar^+ INCIDENT ON Cs (7 min.)
F. W. Meyer and L. W. Anderson

SESSION HB. VACUUM ULTRAVIOLET LASERS II

3:45 PM - 5:15 PM, Wednesday, October 17

Wisconsin Center Auditorium

Chairman: J. B. Gerardo, Sandia Laboratories

- HB-1 EXPERIMENTAL AND THEORETICAL STUDIES OF FLUORESCENCE QUENCHING FROM ELECTRON BEAM EXCITED QUASI-MOLECULAR XENON (20 min.)
D. J. Bradley, L. D. Clements, D. R. Hull, and M. H. R. Hutchinson
- HB-2 VUV EMISSION FROM HIGH-PRESSURE XENON, KRYPTON, AND ARGON EXCITED BY HIGH-CURRENT RELATIVISTIC ELECTRON BEAMS (20 min.)
H. A. Koehler, L. J. Ferderber, and P. J. Ebert
- HB-3 EXCITED STATE KINETICS IN HIGH PRESSURE RARE GAS ASSOCIATION LASERS (7 min.)
P. E. Thiess and G. H. Miley
- HB-4 LIMITATION ON THE GAIN OF A He_2 UV LASER DUE TO PHOTOIONIZATION (7 min.)
T. W. Hartquist and N. F. Lane
- HB-5 ABSOLUTE INTENSITIES IN THE HOPFIELD CONTINUUM (7 min.)
K. M. Sando
- HB-6 LOW-LYING EXCITED ELECTRONIC STATES OF DIATOMIC KRYPTON (7 min.)
Y. Tanaka, K. Yoshino, and D. E. Freeman

SESSION I. VACUUM ULTRAVIOLET LASER WORKSHOP

8:00 PM - 10:00 PM, Wednesday, October 17

Wisconsin Center Lake Shore Room

Chairman: W. A. Fitzsimmons, University of Wisconsin

SESSION JA. ELECTRON-ATOM COLLISIONS

9:00 AM - 10:35 AM, Thursday, October 18
 Wisconsin Center Auditorium
 Chairman: S. Chung, University of Wisconsin

- JA-1 ELECTRON EXCITATION OF THE POTASSIUM ATOM (20 min.)
 Jerry E. Solomon, Dale F. Korff, James O. Phelps, and
 Chun C. Lin
- JA-2 ELECTRON EXCITATION OF THE LITHIUM 6708 Å RESONANCE LINE (7 min.)
 David Leep and Alan Gallagher
- JA-3 ELECTRON EXCITATION OF METASTABLE ARGON AND HELIUM ATOMS (7 min.)
 Walter L. Borst
- JA-4 SIMULTANEOUS IONIZATION AND EXCITATION TO THE 4s,p,d,f STATES
 OF He⁺ BY ELECTRON IMPACT (7 min.)
 William D. Evans, Fred L. Roesler, and Chun C. Lin
- JA-5 SHAPE RESONANCES STUDIED BY ELASTIC SCATTERING OF ELECTRONS
 AT 180° (7 min.)
 P. D. Burrow and L. Sanche
- JA-6 ELECTRON IMPACT CROSS SECTIONS FOR ELASTIC, INELASTIC, AND
 SUPERELASTIC COLLISIONS (7 min.)
 S. Trajmar
- JA-7 METHOD OF ORTHOGONAL RESIDUALS APPLIED TO SINGLE CHANNEL
 SCATTERING OF PARTIAL WAVES FROM IONIC POTENTIALS (7 min.)
 B. W. Shore
- JA-8 COMPARISON OF THEORY AND EXPERIMENT FOR IONIZED AIRLIKE
 MIXTURES (7 min.)
 M. N. Hirsh, F. E. Niles, and K. Raj

SESSION JB. ENERGY TRANSFER

9:00 AM - 10:17 AM, Thursday, October 18
 Wisconsin Center Lake Shore Room
 Chairman: F. A. Franz, Indiana University

- JB-1[†] EXCITED STATE CHEMISTRY OF THE LOW PRESSURE HELIUM AFTERGLOW,
 I. REACTIONS INVOLVING 2³S and 2³Σ
 L. C. Pitchford, K. N. Taylor, and C. B. Collins
- JB-2[†] EXCITED STATE CHEMISTRY OF THE LOW PRESSURE HELIUM AFTERGLOW,
 II. REACTIONS INVOLVING He⁺ and He₂⁺ (14 min.)
 L. C. Pitchford, K. N. Taylor, H. S. Hicks, and C. B. Collins

[†] Combined presentation, total time allotted for both papers 14 minutes.

- JB-3 EXCITATION-TRANSFER IN COLLISIONS OF EXCITED AND GROUND-STATE He ATOMS (7 min.)
W. Steets and N. F. Lane
- JB-4 AFTERGLOW DECAY PROCESSES IN HIGHLY IONIZED HELIUM AND ARGON PLASMAS (7 min.)
J. H. Mountjoy and M. C. Sexton
- JB-5 LIGHT EMISSION FROM AN ARGON DISCHARGE CONTAINING AN ADMIXTURE OF CARBON MONOXIDE (7 min.)
G. Bekefi, P. Avivi, F. Dothan-Deutsch, L. Friedland, J. L. Hirshfield and H. Keren
- JB-6 VIBRATIONAL TEMPERATURE MEASUREMENTS IN NITROGEN (7 min.)
E. E. Wisniewski and A. Garscadden
- JB-7 COLLISIONALLY INDUCED ENERGY TRANSFER IN THE $A^2\Sigma^+$ STATE OF OH (7 min.)
Russell K. Lengel and David R. Crosley
- JB-8 n AND ℓ DEPENDENCE OF ELECTRON TRANSFER FROM A HIGHLY EXCITED (n, ℓ) ATOM TO SF_6 (7 min.)
M. Matsuzawa

SESSION K. INVITED PAPER

11:00 AM - 11:45 AM, Thursday, October 18, 1973
Wisconsin Union Theater

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

ELEMENTARY PROCESSES IN A HELIUM AFTERGLOW
R. Deloche

SESSION L. GEC BUSINESS MEETING

11:45 AM - 12:15 PM, Thursday, October 18, 1973
Wisconsin Union Theater

Chairman: G. L. Weissler, University of Southern California

SESSION MA. AVALANCHES AND STREAMERS

2:00 PM - 3:15 PM, Thursday, October 18

Wisconsin Center Auditorium

Chairman: R. N. Varney, Lockheed Palo Alto Research Laboratory

- MA-1[†] ELECTRON AVALANCHES IN OXYGEN: THEORY
Lothar Frommhold and R. Corbin
- MA-2[†] ELECTRON AVALANCHES IN OXYGEN: EXPERIMENT (20 min.)
R. J. Corbin, D. W. Goodson, and Lothar Frommhold
- MA-3 THE IMPLICATION OF RELIABILITY THEORY FOR INTERPRETATION OF
STATISTICAL TIME LAG DATA (7 min.)
B. M. Lancaster Jr. and K. J. Nygaard
- MA-4 FORMATIVE TIME LAG AND IONIZATION COEFFICIENT MEASUREMENTS IN
CO₂ LASER GAS MIXTURES (7 min.)
E. A. Crawford and A. V. Phelps
- MA-5 CALCULATION OF TOWNSEND'S FIRST COEFFICIENT OF IONIZATION (7 min.)
E. Nasser and H. Parekh
- MA-6 PHOTOMULTIPLIER MEASUREMENT OF IMPULSE STREAMER ONSET (7 min.)
E. Nasser and M. Heiszler
- MA-7 PHOTOGRAPHIC INVESTIGATIONS OF INDIVIDUAL POINT-PLANE STREAMERS
(7 min.)
J. M. Geary and G. W. Penney

SESSION MB. FLOW AND MAGNETIC EFFECTS, STEADY AND NON-STEADY ARCS

2:00 PM - 3:20 PM, Thursday, October 18

Wisconsin Center Lake Shore Room

Chairman: J. R. Mahan, Virginia Polytechnic Institute

- MB-1 STUDY OF LONG ARCS STABILIZED BY A SELF-GENERATED VORTEX (7 min.)
D. C. Watkins, J. D. Cobine, and B. Vonnegut
- MB-2 ON INTERNAL E.M.F. SOURCES APPEARING IN THE BLOWN HEAVY CURRENT
ELECTRIC ARC (7 min.)
V. V. Dementiev, A. I. Zhidovich, A. G. Shashkov, and
O. I. Yas'ko
- MB-3 VISUALIZATION OF SOME FLOW PHENOMENA IN CONSTRICTED ARCS (7 min.)
H. S. Hsia and C. J. Cremers

[†] Combined presentation, total time allotted for both papers 20 minutes.

- MB-4 DENSITY, ELECTRON TEMPERATURE AND SPACE POTENTIAL MEASUREMENTS
USING AN ION BEAM PROBE (7 min.)
R. E. Reinovsky, W. C. Jennings, and R. L. Hickok
- MB-5 TEMPERATURE MEASUREMENTS IN BALANCED RAIL ARCS (7 min.)
D. M. Benenson and J. J. Nowobilski
- MB-6 ENERGY UTILIZATION IN A HIGH-SPEED ROTATING ARC (7 min.)
M. J. Kofoid
- MB-7 ANALYSIS OF ALTERNATING CURRENT ARCS (7 min.)
D. M. Benenson and S. K. Ghose
- MB-8 A PULSED XENON MEGAWATT ARC PLASMA SOURCE (7 min.)
C. J. Michels

SESSION N. NON-EQUILIBRIUM IN ARCS

3:45 PM - 5:20 PM, Thursday, October 18

Wisconsin Center Auditorium

Chairman: R. E. Kinsinger, General Electric Company

- N-1 LIGHT SCATTERING FROM WEAKLY IONIZED ARC PLASMAS (20 min.)
L. Vriens and M. Adriaansz
- N-2 SPECTROSCOPIC MAPPING OF THE NONEQUILIBRIUM BETWEEN ELECTRON AND
EXCITATION TEMPERATURES IN A 1 ATM. HELIUM ARC (20 min.)
T. L. Eddy, E. Pfender, and E. R. G. Eckert
- N-3 TEMPERATURE DETERMINATION IN A Na-Xe DISCHARGE (20 min.)
J. H. Waszink
- N-4 DEPARTURE FROM LTE IN A 200 TORR SODIUM DISCHARGE (7 min.)
J. H. Ingold
- N-5 EXPERIMENTAL CHECK ON ELECTRON-ION ENERGY TRANSFER IN AN ARGON
ARC (7 min.)
B. Van der Sijde

RECEPTION AND BANQUET

6:30 PM, Thursday, October 18 Social Hour

7:30 PM, Thursday, October 18 Banquet

Wisconsin Center Guest House (Lowell Hall)

Chairman: G. L. Weissler, University of Southern California

Speaker: W. F. Fry, University of Wisconsin
"Acoustics of violins - Did Stradivari
have a secret?"

SESSION OA. PHOTON INTERACTION AND BREAKDOWN

9:00 AM - 10:34 AM, Friday, October 19

Wisconsin Center Auditorium

Chairman: F. L. Roesler, University of Wisconsin

- OA-1[†] MULTIPHOTON IONIZATION OF MOLECULAR CESIUM WITH A TUNABLE DYE LASER
C. B. Collins, B. W. Johnson, D. Popescu, G. Musa, M. L. Pascu, and Iovitzu Popescu
- OA-2[†] MULTIPHOTON EXCITATION AND IONIZATION OF ATOMIC CESIUM WITH A TUNABLE DYE LASER (14 min.)
D. Popescu, C. B. Collins, B. W. Johnson, and Iovitzu Popescu
- OA-3[¶] LASER INDUCED PLASMAS IN ELECTRIC FIELDS
George P. Arnold, C. J. Elliott, and Robert G. Wenzel
- OA-4[¶] THE TIME BEHAVIOR OF ARC FORMATION IN DISCHARGES TRIGGERED BY LASER INDUCED PLASMAS (14 min.)
Robert G. Wenzel, C.J. Elliott, and George P. Arnold
- OA-5 LASER PRODUCED BREAKDOWN IN MERCURY VAPOR (7 min.)
J. G. Winans and C. Santaram
- OA-6 IONIZATION AND EXCITATION GROWTH IN HIGH PRESSURE RARE GASES AND MIXTURES (7 min.)
P. E. Thiess and G. H. Miley
- OA-7 THE DYNAMICS OF PARTICLE INDUCED AIR BREAKDOWN (7 min.)
D. E. Lencioni and L. C. Pettingill
- OA-8 THE RARE GAS IONIZATION CHAMBER (7 min.)
J. A. R. Samson and G. N. Haddad
- OA-9 SPIN RELAXATION OF THERMAL ALKALI EARTH IONS IN NOBLE GAS BUFFERS (7 min.)
E. W. Weber, H. Ackermann, N. S. Laulainen, and G. zu Putlitz
- OA-10 TRANSIENT SIGNALS IN THE WHITE LIGHT OPTICAL PUMPING OF CESIUM (7 min.)
F. A. Franz and C. E. Sooriamoorthi

[†] Combined presentation, total time allotted for both papers 14 minutes.

[¶] Combined presentation, total time allotted for both papers 14 minutes.

SESSION OB. PHYSICS OF ARC LIGHT SOURCES

9:00 AM - 10:30 AM, Friday, October 19

Wisconsin Center Lake Shore Room

Chairman: G. L. Rogoff, Westinghouse Research Laboratories

- OB-1 MEASUREMENT OF TEMPERATURE DISTRIBUTION AND CALCULATION OF THE TOTAL SPECTRUM OF A HIGH PRESSURE SODIUM VAPOUR DISCHARGE (20 min.)
J. J. de Groot
- OB-2 THERMAL AND RADIATIVE PROPERTIES OF METAL-HALIDE ARCS (20 min.)
E. Fischer and L. Rehder
- OB-3 THE INFLUENCE OF THE TIN-HALIDE PRESSURE ON THE SPECTRUM OF MERCURY/TIN HALIDE ARCS (7 min.)
P. C. Drop, J. J. de Groot, and A. G. Jack
- OB-4 SELF-ABSORBED ATOMIC LINE RADIATION FROM THE HIGH PRESSURE MERCURY ARC (7 min.)
R. J. Zollweg and R. W. Liebermann
- OB-5 CONTINUUM RADIATION FROM THE HIGH PRESSURE MERCURY ARC (7 min.)
R. J. Zollweg and R. W. Liebermann

SESSION PA. RADIATION

10:45 AM - 11:55 AM, Friday October 19

Wisconsin Center Auditorium

Chairman: J. A. R. Samson, University of Nebraska

- PA-1 RADIATIVE LIFETIMES OF THE $A^2\Sigma^+$ STATE OF OD (7 min.)
David Wilcox and Richard Anderson
- PA-2 LONG-LIVED, EXCITED STATES OF N_2^+ (7 min.)
William B. Maier II and Reduŝ F. Holland
- PA-3 THE MECHANISM FOR THE PRODUCTION OF THE CARBON MONOXIDE FLAME BANDS (7 min.)
Nicholas W. Winter
- PA-4 COLLISIONAL BROADENING OF THE HANLE EFFECT IN IODINE (7 min.)
Lloyd G. Williams and David R. Crosley
- PA-5 RESONANCE BROADENING IN THE SINGLET SPECTRUM OF He (7 min.)
D. M. Camm and G. H. Copley
- PA-6 NON-LORENTZIAN ICR LINE SHAPES DUE TO VELOCITY-DEPENDENT ION-NEUTRAL COLLISION FREQUENCIES (7 min.)
J. H. Whealton and E. A. Mason

PA-7 DETERMINATION OF HIGH FREQUENCY ELECTRIC FIELDS IN PLASMAS
FROM THE HYDROGEN SPECTRUM (7 min.)
Arthur Cohn, P. Bakshi, and G. Kalman

SESSION PB. THERMAL AND RADIATIVE PROPERTIES OF ARCS

10:45 AM - 11:35 AM, Friday, October 19
Wisconsin Center Lake Shore Room
Chairman: E. Pfender, University of Minnesota

PB-1 THE LOWERING OF THE HYDROGEN IONIZATION POTENTIAL IN AN ARGON
ARC PLASMA (7 min.)
S. K. Srivastava and G. L. Weissler

PB-2 ELECTRICAL AND THERMAL CONDUCTIVITY OF IONIZED NITROGEN (7 min.)
R. S. Devoto and M. Capitelli

PB-3 SPECTROSCOPIC STUDIES OF HIGH PRESSURE ARGON PLASMA (7 min.)
U. H. Bauder and D. L. Bartelheimer

PB-4 RADIATIVE PROPERTIES OF XENON (7 min.)
P. W. Schreiber, A. M. Hunter, and P. Taylor

PB-5 SPECTROSCOPIC INVESTIGATION OF DEMIXING EFFECTS IN A WALL-
STABILIZED SF₆ ARC (7 min.)
E. Schulz-Gulde and G. Baruschka

SESSION QB. ELECTRODE EFFECTS IN ARCS

11:35 AM - 12:30 PM, Friday, October 19
Wisconsin Center Lake Shore Room
Chairman: H. Witting, General Electric Company

QB-1 AN EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THE ANODE
PLASMA OF A PULSED VACUUM ARC (20 min.)
F. M. Bacon

QB-2 ANODE HEAT FLUXES IN PULSED HIGH INTENSITY ARCS (7 min.)
J. L. Smith and E. Pfender

QB-3 PLASMA WALL SPACE CHARGE SHEATH (7 min.)
G. Ecker

QB-4 THE TRANSITION FROM VACUUM ARCS TO ARCS AT ATMOSPHERIC
PRESSURE (7 min.)
C. W. Kimblin

SESSION AA

9:00 AM, Tuesday, October 16

Wisconsin Center Auditorium

TRANSPORT AND GLOWDISCHARGE

Chairman: C. F. Gallo, Xerox Research Laboratories

AA-1 The Effect of Thermionic Emission from Hot Particles on the Concentration and Conductivity of a Plasma. Chih Wu, Division of Engineering and Weapons, U.S. Naval Academy, Annapolis, Maryland 21402.-- The electron, ion concentrations and electrical conductivity of a plasma in a non-equilibrium steady state is discussed with consideration of the effects by external electric field to the extent of ionization and by thermionic emission from hot particles in the gas. Potential models of interactions are chosen for the plasma-particle system. A better representation of the concentration and conductivity are calculated, as the contributions of various types of collisions are accounted for.

AA-2 High Field Transport of Atomic Rare Gas Ions in Their Parent Gases. MICHAEL E. FEIN and ROBERT A. SCHAEFER, Owens-Illinois, Inc.--A simple form of Holstein's semiclassical model¹ describes collisions as the sum of pure components; forward, backward, and isotropic. The model allows reinterpretation of some well-known observations of "charge transfer" cross-section, which have not all measured the same thing. Published data for isotropic and backscattering in He, Ne, and Ar are fitted with curves of the form $\sigma_{back} = \sigma_0 v^{-Y}$ and $\sigma_{iso} = r_{iso} \sigma_{back}$. Energy and momentum balance equations are solved approximately to yield mobility and diffusion coefficients. Mobility predictions fit Hornbeck's data² well. For lack of reliable experimental data, longitudinal and transverse diffusion coefficients are compared to Skullerud's Monte-Carlo experiments.³

Data available to test the present theory are twenty years old. Current techniques would permit more accurate measurements, which would improve modeling of the cathode region of glow-like discharges, such as the AC plasma display discharge.

1. T. Holstein, J. Phys. Chem. 56, 832 (1952).
2. John A. Hornbeck, Phys. Rev. 84, 615 (1951).
3. H. R. Skullerud, J. Phys. B 6, 728 (1973).

AA-3 Mobilities and Longitudinal Diffusion Coefficients of H^+ , H_3^+ and H^- Ions in Hydrogen Gas. E. GRAHAM IV, D. R. JAMES, W. C. KEEVER, D. L. ALBRITTON, and E. W. McDANIEL, Ga. Inst. of Technology.--

The mobilities of H^+ , H_3^+ and H^- ions in hydrogen gas have been measured in a drift-tube mass spectrometer. These measurements were made as a function of E/N , where E is the electric field intensity and N is the gas number density, at a temperature of $300^\circ K$. The zero-field reduced mobilities, $K_0(0)$, for H^+ , H_3^+ and H^- in H_2 are 16.0, 11.3, and $43.0 \text{ cm}^2/\text{V-sec}$, respectively. The large difference in $K_0(0)$ for H^+ and H^- in H_2 is unexpected and thus far unexplained.

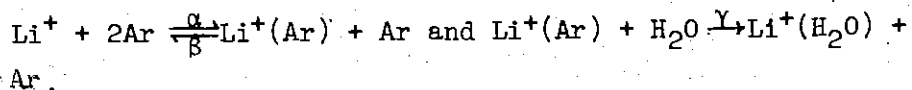
The longitudinal diffusion coefficients of H^+ and H_3^+ in H_2 have been measured over a substantial range of E/N . Diffusion coefficients calculated by the Einstein equation from the zero-field mobility and those measured are in good agreement.

AA-4--

Transport Phenomena for $A \xrightarrow{\alpha} B \xrightarrow{\gamma} C$ Type Reactions.* S.P. Hong and S.B. Woo, Univ. of Del.--The transport phenomena in drift tubes of three converting ion species, where $A \xrightarrow{\alpha} B \xrightarrow{\gamma} C$, were analyzed. The following three coupled partial differential equations were solved:

$$\begin{aligned}\delta n_A / \delta t &= -v_A (\delta n_A / \delta z) - \alpha n_A + \beta n_B \\ \delta n_B / \delta t &= -v_B (\delta n_B / \delta z) + \alpha n_A - (\beta + \gamma) n_B \\ \delta n_C / \delta t &= -v_C (\delta n_C / \delta z) + \beta n_B\end{aligned}$$

n_i and v_i refer respectively to linear ion density and drift velocity of i^{th} ion species. α , β , and γ are respectively reaction rate for $A \rightarrow B$, $B \rightarrow A$ and $B \rightarrow C$ reactions. On account of different distribution of poles in contour integrations, six sets of analytic solution were found, one each according to whether $v_A > v_B > v_C$ or $v_B > v_A > v_C$ or $v_C > v_B > v_A$...etc. Typical arrival spectra of each case will be presented and discussed. Their application to situations where three dimensional effects and diffusion effects are significant will be discussed. The above solutions are useful in analyzing reactions such as



*Work supported in part by ARO-D.

AA-5 Directional Probe Measurements in Molecular Gas Discharges. A. GARSCADDEN, F. BLETZINGER, W. F. BAILEY, and W. E. LONG, Aerospace Research Labs, WPAFB, O.--Experiments have been made using a directional Langmuir probe and second derivative techniques to evaluate the degree of anisotropy of the electron energy distribution in molecular gas discharges. Results are presented for N₂ and N₂-He mixtures over a range of the ratio of electric field intensity to neutral gas number density, E/N. The directionality of the distribution increases with the ratio of inelastic collision frequency to momentum transfer collision frequency. Solutions of the Boltzmann equation, utilizing the standard expansion in spherical harmonics, are used to model probe response. Theory and experiment are compared, and the implications evaluated.

AA-6 Scaling Laws for the Positive Column: Two Step Ionization in the Rare Gases. B. E. CHERRINGTON, Univ. of Ill. at U-C.--The scaling laws for the positive column in rare gases have been studied under the assumption of a two step ionization process through the metastable species. If it is assumed that the dominant metastable loss process is diffusion to the walls and that the electron spatial distribution is approximately the same as for one-step ionization, it is found that E/P should scale directly with IP^3R^2 . Experimental data for discharges in He, Ne and Ar show excellent agreement with this relationship over a wide range of variables. A detailed theoretical analysis for He using Smit's distribution functions and available cross section data shows good agreement with the experimental data. The limitations on the conditions under which the scaling relationship is expected to be valid is discussed.

AA-7 Transient Behavior of a Diffuse Glow Discharge in Helium at High Pressure* E. F. JAEGER and A. V. PHELPS†
Joint Institute for Laboratory Astrophysics.---Numerical calculations have been made of the transient behavior of a cylindrical discharge in helium at high pressure. In contrast with previous calculations,^{1,2} full account is taken of the specific heat of the gas, electronic recombination, and the variation of pressure in both space and time. Excited states of the atoms, energy loss by radiation, and charge separation effects are neglected. An initial constriction of the discharge is followed by a slight expansion of the density profile before steady state is reached. A spatially uniform pressure approximation gives results not far different from the complete solution. Higher recombination coefficients or higher pressures accentuate the constriction.

*Supported in part by Advanced Research Projects Agency.
 †Staff Member, Laboratory Astrophysics Division, N.B.S. and Prof. Adjoint, Department of Physics and Astrophysics, University of Colorado.
¹E. F. Jaeger, J. T. Mariska, L. Oster, and A. V. Phelps, Bull. Am. Phys. Soc. 18, 806 (1973).
²G. Ecker, W. Kröll, K. H. Spatschek, and O. Zöller, Phys. Fluids 10, 1037 (1967).

AA-8 Propagation of a Filamentary Arc Channel in a Diffuse Glow Discharge.* GERALD L. ROGOFF, Westinghouse Res. Labs.--A two-dimensional computer model has been developed to test a process that is proposed for the axial propagation of a highly conducting constricted arc channel in a diffuse positive column. A simple diatomic gas is considered, with the electron temperature increasing with dissociation due to the removal of molecular excitation as an electron energy loss mechanism. In this process a local increase in the electrical conductivity σ causes a distortion of the axial electric field (E) distribution. Among the effects in an adjacent axial region (toward either electrode) are (1) an intensification of E with a resulting increase in the ionization rate and σ and (2) enhanced gas heating and radial gas convection. When the gas thermally dissociates at some location, the local conductivity increases abruptly, and a highly conducting filamentary path extends axially. Contour plots of discharge properties show the filament formation with time in nitrogen discharges at about 300 Torr. Initial results of the calculations are compared with published experimental data on spark development.

* Part of this research was supported by ARPA and was monitored by ONR.

AA-9 Radial Neutral Gas Temperature and Density Profiles in Low Pressure Argon Discharges. J. G. EDEN and B. E. CHERRINGTON, Univ. of Ill. at U-C.--This paper describes the direct measurement of the neutral gas density and the determination of the neutral temperature profiles in a low pressure, weakly-ionized Argon discharge. The measurements were made using a single wavelength coupled cavity laser interferometer to study the neutral density variations in the afterglow of a crowbarred D.C. (steady state) discharge. The temporal and radial variations of the neutral gas density in the afterglow were used to infer the D.C. steady state gas density and temperature profiles, assuming an ideal gas. It is shown that the profiles are strongly current and pressure dependent and that the axial depletion of neutrals can be as high as 25-30%.

AA-10

The Effect of Electron De-excitation and Self-Absorption on the Intensity of the Hg 2537A Radiation in Hg+Ar Discharges. T. J. HAMMOND and C. F. GALLO, Xerox Research Laboratories. - The characteristics of Hg+5 Torr Ar discharges have been measured for AC and DC currents. Due to cataphoresis, the DC behavior is dependent upon whether the anode or cathode was cooled to control the Hg vapor pressure. For all cases, the Hg 2537A intensity initially rises linearly with current, but then tends to bend over and approach an asymptotic limit. These curves have been obtained at constant Hg pressures ranging from 0.2 to 500 millitorr. The non-linear, asymptotic behavior is due to electron de-excitation of the Hg 6^3P_1 state at the higher currents. From a different viewpoint, the Hg 2537A intensity was measured as a function of Hg pressure at various constant currents. The intensity rises to a peak (which defines an optimum Hg pressure) and then decreases with further increase in Hg pressure due to self-absorption. For AC, the optimum Hg pressure is independent of current but varies inversely with the tube diameter. Again the behavior is due to Hg 6^3P_1 de-excitation by electrons and by self-absorbed radiation. The DC behavior is also consistent with the above theory complicated by the cataphoretic feature.

SESSION AB

9:00 AM, Tuesday, October 16

Wisconsin Center Lake Shore Room

CO AND ARGON ION LASERS

Chairman: O. P. Judd, Los Alamos Scientific Laboratory

AB-1
HIGH SPECIFIC ENERGY-HIGH EFFICIENCY CO EDL

M. M. Mann, D. K. Rice, R. G. Eguchi, G. L. McAllister
Northrop Research and Technology Center
Laser Technology Laboratories

An experimental investigation of electron-beam stabilized electric discharge CO lasers has confirmed the optimistic theoretical performance projections which have been made for such devices. A conversion efficiency from electrical input to radiated output of 50% has been obtained from a cryogenic E-beam stabilized electric discharge CO laser. This is the highest value ever achieved in a directly excited laser system. Under the same conditions, the specific energy was approximately 650 J/l atm corresponding to approximately 130 kJ/kg. The effect of parameters such as gas mixture and electrical excitation rate on laser characteristics is discussed.

AB-2
MEASUREMENT OF VIBRATIONAL ENERGY TRANSFER RATES IN CO-N₂ AND CO-H₂ MIXTURES FROM 150 TO 500 DEGREES KELVIN.
D. F. Starr, J. K. Hancock and W. H. Green, Naval Research Laboratory, Washington, D.C. 20375.

Hancock and Green¹ have recently reported room temperature vibrational energy transfer rates in mixtures of CO with various additives (e.g., He, N₂). They employed the frequency doubled lines of a pulsed CO₂ laser to directly excite CO molecules from v=0 to v=1. We have used this method with a variable temperature cell to determine V-V rates in CO-N₂ mixtures and V-R,T rates in CO-H₂ mixtures from 150 to 500 degrees Kelvin.

¹J. K. Hancock and W. H. Green, "The Application of a Frequency Doubled CO₂ Laser to Energy Transfer Measurements in CO," 8th Annual Middle Atlantic Regional Mtg. (ACS), Washington, D.C., Jan. 14-17, 1973.

AB-3 Saturation Effects in Broad Band Transfer Lasers. * WILLIAM BAILEY, WILLIAM H. LONG, Aerospace Research Labs, WPAFB, OHIO.---

A numerical solution of the coupled rate equations governing vibrational energy level populations is presented. The calculations employ electron excitation rates obtained from numerical solutions of the electron distribution function and the most current data available for VV and VT energy transfer rates. Steady state solutions are given for conditions representative of a broad band CO-N₂ laser. The CO distribution saturates above a critical N₂ pumping rate and is merely a function of gas temperature in this regime. Simultaneous gains on a wide range of vibrational transitions are calculated. The effects of CO-N₂ mix, gas temperature, and electron pumping rate are examined. Comparisons are made with recent experimental data.

* Submitted by J. W. BIRKELAND.

AB-4

A Kinetic-Optical Analysis of cw CO Electric-Discharge Lasers, R. J. Hall, L. S. Bender, A. C. Eckbreth, UARL - A rate equation analysis of convective CO EDL's is presented. The axial distribution of CO vibrational levels is governed by a kinetic master equation which contains terms representing electron pumping, V-V and V-T energy transfer, and spontaneous and stimulated emission. Electronic pumping rates are derived by solving the electron Boltzmann equation. Spectral distributions of small-signal gain and optical flux are calculated in terms of the cross-sections for these processes. Good agreement is obtained between predicted and experimentally reported gain and power spectra. For coincident discharge-cavity configurations, the quasi-steady small-signal gain is predicted to depend essentially only on the gas temperature. The predicted power output for a wide variety of bulk gas and plasma properties is found to be correlated by a simple power-time parameter. The performance of devices which involve separate discharge and cavity regions is also examined. The importance of the threshold excitation energy in understanding a variety of configurations is discussed.

AB-5 Influence of Nitrogen Oxides on CO Laser Performance. * P. BLETZINGER, and D. R. FOND, Aerospace Research Labs, WPAFB, OHIO. -- SUART, et.al. I have measured the influence of added N_2O and NO_2 on the performance of the CO chemical laser. We investigated the gain characteristics of cryogenically cooled electric discharge CO laser oscillators and amplifiers on addition of NO , N_2O and NO_2 using single and multiple wavelength lasers. Under certain conditions, we also observed enhanced output power with addition of small amounts of N_2O , indicating vibrational deexcitation of the lower vibrationally excited levels of CO in the electric discharge laser. Addition of 0.3% NO_2 or NO and more than 5% of N_2O decreases laser output to less than 10%.

*Submitted by J. C. CORBIN
1 R. D. SUART, S. J. ARNOLD and G. H. KIMBELL,
Chem. Phys. Lett. 7, 337 (70).

AB-6
Distribution of Vibrational Energy Levels in a C.W. Carbon Monoxide Laser. H. Keren, P. Avivi, F. Dothan & L. Friedland, Racah Institute of Physics, The Hebrew University of Jerusalem. - A general method is presented, by which the population of CO vibrational levels can be computed. This method is based on the experimental knowledge of (a) the spectrum of the lasing lines; (b) the spontaneous emission of the CO molecules in the 5μ or 2.5μ region; (c) the lasing power output. The difference of the spectral composition of the lasing lines between the CW and Q switched mode is explained for various lasing mixtures. It was found experimentally that there is a drastic decrease in the light intensity of the 3rd positive band of the CO molecules, and no change in the 2nd positive band of N_2 between the non lasing and the C.W. lasing operation. It is shown that spontaneous emission and vibrational-translational transitions cannot account for the experimentally found high losses in CO lasers.

AB-7 Kinetic Theory of the Argon Ion Laser Discharge*.
C. JAMES ELLIOTT, Los Alamos Scientific Lab. -- The kinetic theory describing electron and ion distributions found in discharges suitable for operation as a capillary argon ion laser is described. Starting with the Boltzmann equation, the ions are shown to follow local fluid equations while the electrons do not. Two limiting cases for describing the electrons are discussed. The case in which the electrons are trapped in space charge fields gives rise to an isothermal non-local fluid limit; here the electrical conductance is computed by a novel variational principle. The wall of the discharge tube gives rise to sheath regions which are carefully considered in two limiting cases. Predictions are made concerning the radial profiles of the discharge parameters. Of particular interest is the minimum in the ion temperature which occurs on the axis of the discharge tube. Ion drift velocities as a function of filling pressure and characteristic curves are compared with experimental data.

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

SESSION BA

10:45 AM, Tuesday, October 16

Wisconsin Center Auditorium

NEGATIVE IONS

Chairman: L. W. Anderson, University of Wisconsin

BA-1 Angular Distribution of Molecular Fragments from Electron Induced Dissociation of Diatomic Molecules. R.J. VAN BRUNT, University of Virginia.--A general expression is given for the form of the angular distribution of molecular fragments produced by electron induced dissociation of diatomic molecules. A model for parameterizing angular distributions is introduced which permits investigation of electron energy dependence, rotational corrections, and higher order multipole contributions in the expansion of the Born approximation. The model is useful in explaining previously observed deviations from dipole behavior and is used to analyze recent measurements of the angular distribution of O^- from dissociative ion pair formation in O_2 .¹

¹R.J. Van Brunt and L.J. Kieffer, *Bull. Am. Phys. Soc.* 17, 1139 (1972).

BA-2 Dynamics of Collision-Induced Dissociation of Alkali Halides. FRANK PAUL TULLY, Univ. of Chicago.--The dissociation of CsI, CsBr, RbI and KI to ion pairs upon collision with fast xenon and krypton atoms has been studied by the crossed molecular beam method. Relative total dissociation cross sections for the above salts have been obtained up to 10 eV relative kinetic energy. Complete angular and energy distributions of both dissociated ions have been obtained for Xe(Kr) + CsI (CsBr, RbI) collisions at several collision energies. At low collision energies it is found that nearly collinear collisions of the fast atom with the heavy end of the alkali halide are the most efficient means of effecting dissociative ion pair formation. Typically, the light ion is scattered far forward relative to the initial direction of the fast atom, the heavy ion remains near the center of mass, and, from conservation, the Xe(Kr) rebounds backward after impact. At higher collision energies, two distinct, well-separated, asymmetric peaks are observed in the differential cross section of each ion, corresponding to nearly collinear impact with each side of the alkali halide.

BA-3 The Chemical Equilibrium of $\text{OH}^- + \text{C}_2\text{H}_2 \rightleftharpoons \text{C}_2\text{H}^- + \text{H}_2\text{O}$ and the Determination of $\text{EA}(\text{C}_2\text{H})$. G. I. Mackay, R. S. Hensworth, H. I. Schiff and D. K. Bohme, C.R.E.S.S., York University, Downsview, Ontario. Conditions of concentration and time could be established at 297°K in a flowing afterglow system under which the proton-transfer reaction $\text{OH}^- + \text{C}_2\text{H}_2 \rightleftharpoons \text{C}_2\text{H}^- + \text{H}_2\text{O}$ was observed to be in equilibrium. The equilibrium constant determined from equilibrium concentrations was $(3 \pm 2) \times 10^5$. Knowledge of the equilibrium constant allows the determination of $\Delta H_{f, 297}^\circ(\text{C}_2\text{H}^-) = +71 \pm 1$ kcal/mole which leads to a value for the adiabatic electron affinity of C_2H , $\text{EA}(\text{C}_2\text{H}) = 1.9 \pm 0.3$ eV. This result has important implications for published dissociative electron attachment¹ and photodetachment² studies as well as a number of negative ion-molecule reactions recently investigated in this laboratory, viz. reactions of C^- , C_2^- and C_2H^- with H_2 , CH_4 , and C_2H_2 .

1. R. Locht and J. Momigny, Chem. Phys. Letters 6, 273 (1970).
2. D. Feldman, Z. Naturforsch. 25a, 621 (1970).

BA-4 Attachment in Boron Trifluoride. P.J. CHANTRY Westinghouse Research Laboratories--An apparatus¹ which permits total collection measurements, as well as kinetic energy analysis and mass identification of the ions, has been used to study dissociative attachment in BF_3 . Comparison of the total ion current, measured as a function of absolute pressure, with similar measurements of known processes gives a peak cross-section of 2.7×10^{-18} cm^2 occurring at 11.5 eV. The predominant ion is F^- , with F_2^- comprising only a few percent of the total. The two incompletely resolved F_2^- peaks at 10.85 and 11.70 eV both exhibit a linear dependence on pressure, in contrast to the results of MacNeil and Thynne.² Measured kinetic energy distributions of the F^- ion have a peak very close to zero energy, extend past 1 eV, and show virtually no dependence on the electron energy. Hence a large fraction of the ~ 8 eV available excess energy must be absorbed by the neutral fragment, causing either electronic excitation or dissociation of the BF_2 .

¹ P. J. Chantry, Phys. Rev. 172, 125 (1968).

² K.A.G. MacNeil and J.C.J. Thynne, J. Phys. Chem. 74, 2257 (1970).

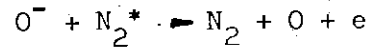
BA-5 A Kinetic Study of Electron Attachment to HBO₂. W.J. MILLER and R.K. GOULD, Aero-Chem Res. Labs., Inc. -- The rate of the dissociative attachment reaction $e^- + \text{HBO}_2 \rightarrow \text{BO}_2^- + \text{H}$ has been determined over the temperature range 1730 - 2250 K. This reaction is representative of a large class of endoergic attachment reactions occurring between electrons and highly electrophilic gaseous acids including HCl, H₂WO₄, H₂MoO₄ and HReO₄. The measurements were carried out in well characterized laminar premixed H₂/O₂/N₂ flames. Alkali metals introduced into these flames provided the source of electrons. The concentration of electrons as a function of reaction (flow) time was monitored using both a microwave resonant cavity method and electrostatic probes; BO₂⁻ profiles were ascertained mass spectrometrically; H atom concentrations and temperatures were determined using previously developed optical spectroscopic techniques. The flames employed comprise two sets: one set of 3 at 760 Torr and another set of 4 at 100 Torr. An Arrhenius plot of the results yields a rate coefficient given by the expression $k = 3.2 \times 10^{-10} \exp(-1100/T)$ ml molecule⁻¹ sec⁻¹.

BA-6 Mass Analysis of Negative Ions Produced in Electron Swarm Experiments: H₂O (D₂O) and NH₃ (ND₃).*

J.F. WILSON and R.N. COMPTON, Oak Ridge Nat'l. Lab. -- Negative ions with masses in the range from zero to 200 a.m.u. produced by electron swarm interactions with H₂O (D₂O) and NH₃ (ND₃) have been studied as a function of E/P from zero to 70 V-cm⁻¹-torr⁻¹ and at total pressures varying from 0.1 to 1 torr. The ions observed are H⁻ (D⁻), OH⁻ (OD⁻), OH⁻ · nH₂O (OD⁻ · nD₂O) where n = 1 to 6, and H⁻ (D⁻), NH₂⁻ (ND₂⁻), NH₂⁻ · nNH₃ (ND₂⁻ · nND₃) where n = 1 to 4. The appearance of ions from D₂O occurred at a lower E/P than from H₂O, in agreement with previous D/μ studies of electron swarms in H₂O and D₂O. The variation of the cluster ion distribution with pressure and E/P supports a sequential clustering scheme.

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

BA-7 Detachment in Air. J.L. MORUZZI, Univ. Liverpool--
Current growth curves in air at pressures between 10 and 100 torr show no evidence of electron attachment in the E/N range 90-150 Td. Attachment in air would be expected, on the basis of its oxygen content to be $3 \times 10^{-19} \text{cm}^2$ thus a rapid detachment mechanism must be operative. Evidence to support this conclusion has been obtained from current growth curves in Air-CO₂ mixtures and from drift-tube mass spectrometer data. Analysis of this data indicate that a reaction with a detachment coefficient of 1300cm^{-1} at a pressure of 100 torr exists in air. The most likely reaction is thought to involve an excited state of nitrogen:



Values of the ionization coefficient have also been measured over the same range of E/N and are found to be in good agreement with earlier published work.

SESSION BB

10:45 AM, Tuesday, October 16

Wisconsin Center Lake Shore Room

LASER IONIZATION PROCESSES

Chairman: J. J. Lowke, Westinghouse Research Laboratories

BB-1 UV Photoionization Processes in Seeded High Pressure Laser Gases. J. Y. WADA and R. C. LIND, Hughes Research Laboratories, and O. P. JUDD, Los Alamos Scientific Laboratory. -- Generation of a stable dense discharge by single and multiple-step UV photoionization processes has been demonstrated in high pressure, seeded CO₂ laser mixtures.¹ Quantitative analysis of these processes (which are often made difficult to predict due to lack of detailed excitation and lifetime data of organic seed gases) have been carried out using NO as a seed gas. This analysis shows that the production of plasma density in excess of 10¹² electrons/cm³ can be accomplished with photon intensities less than 1 kW/cm² using typical UV emission spectra from spark discharges operated in the laser mixture; more than a three order of magnitude increase is required for a two-step process using flashlamps.

* Sponsored by ONR/ARPA Contract N00014-73-C-0287.

¹ J. A. Levine and A. Javan, Appl. Phys. Lett. 22, 55 (1973); R. C. Lind and J. Y. Wada, paper submitted to this conference.

BB-2 Generation of a High Energy, Long Pulse UV Sustained Discharge in a CO₂ Laser Mixture.* R.C. LIND and J.Y. WADA, Hughes Research Laboratories--Generation of a high energy, long pulse UV sustained discharge in a seeded CO₂ laser mixture has been demonstrated. Using a series of spark discharge UV sources placed adjacent to the laser cavity region, we have obtained input discharge energy densities in excess of 200J/l with pulse lengths longer than 50 μ sec in a high pressure CO₂ laser discharge. Photoionization yield measurements of the seeded medium have indicated that single step photoionization is the dominant mechanism responsible for production of the dense plasma. Typically this requires arc UV intensities of less than 1 kW/cm², whereas two to three orders of magnitude higher intensities are required for two-step photoionization using a flashlamp source.¹ The measured results together with scalability concepts will be presented.

*Work supported by ONR/ARPA, N00014-73-C-0287.

¹J.A. Levine and A. Javan, Appl. Phys. Lett. 22, 55 (1973).

BB-3 Electron Beam Supported Discharges in Supersonic Flows*. W.B. SHEPHERD, W.M. BRANDENBERG, D.J. PISTORESI and R.L. HASLUND, Boeing Aerospace Company. -- The properties of electron beam supported discharges in a variety of CO₂ and CO laser mixtures have been studied in Mach 3 flow over a density range from 0.3 to 1 amagat. Measurements were made as a function of gas density, static temperature, applied E/N, gas composition and laser output. The effects of additive gases such as He, H₂ and H₂O have been measured. In general, discharges are predictable and their behavior is similar to that observed in static or subsonic flow environments. However, temperature and mixture dependent gas conductivities are observed in CO₂, N₂ and CO at the low temperatures achieved by supersonic expansion. Increased attachment rates in H₂O mixtures were observed, but, at less than 1% H₂O, the rates are sufficiently small to permit effective power loading of the gas. The effects of supersonic flow on discharge stability are discussed.

*This work was supported in part by AFWL under Contract No. F29601-72-C-0110.

BB-4 Parametric Study of Electron-Beam CO₂ Laser.*† G. FOURNIER, J. BONNET, and D. PIGACHE, ONERA, Châtillon, France.-- Steady-state laser performance can be characterized by small-signal gain, available optical power density and efficiency. These values are given by simple calculations as functions of easily measured plasma properties: mixture composition, gas temperature and pressure, current density and potential gradient. As an interesting feature, the efficiency is found to be nearly independent of He fraction (between 10 and 80%) and to be high at low electron temperature (< 1 eV). In addition time-dependent phenomena were also computed: the effect of temperature rise is clearly shown. In order to assess these results, preliminary experiments were carried out with a 100 keV electron gun. Small-signal gain measurements were made for 200 μs pulses in CO₂/N₂/He mixtures at 30 to 100 Torr. Gain values reach 5% cm⁻¹ in good agreement with recently published results¹.

* Submitted by J. TAILLET.

† Work supported in part by the DRME (Research Department of the French Ministry of Defense).

¹ C.B. Mills, Report LA-5151-MS, Los Alamos, 1973.

BB-5

Abstract withdrawn

BB-6 Atmospheric Pressure Discharge Initiation by Externally Excited Photoelectrons.* V.A. GILSON and R.L. SCHRIEVER, LAWRENCE LIVERMORE LABORATORY, Livermore, CA, 94550--The photoelectric emission from ultraviolet radiation is used to generate the necessary electrons at an aluminum Rogowski cathode to sustain a uniform glow discharge. Two pulsed xenon flashlamps with 1.3 ID x 16 cm long quartz envelopes are used for the μV source to provide radiation wavelengths longer than 2000\AA at the cathode. The main discharge containing a mixture of He:CO₂:N₂ near an atmosphere is pulsed during the μV flash to take advantage of the photoelectrons. The results show a stable glow discharge can be obtained in the two electrode structure if sufficient radiation shorter than 3100\AA is provided. This data is compared with data obtained from a regular Dumanchin type configuration employing an isolated triggering grid structure. It is shown that the delay time before the main glow discharge in both configurations decreases linearly with the voltage applied across the tube. The delay time is found to be $T=R-\alpha V$, where V is the applied voltage, and R and α are functions of the pressures and the cathode-anode separation.

*Work supported by the USAEC.

BB-7 Energy Deposition by Fast Electrons in High Pressure Gas Lasers. * J. H. JACOB, Avco Everett Research Laboratory, Everett, Ma. -- The transport and energy deposition of fast electrons in multilayer targets are investigated. This calculation is general and is motivated by the use of high energy electrons either for direct laser excitation, as in the molecular Xenon laser or as a source of ionization as in the E-beam sustainer lasers. When a highly peaked distribution function of electrons impinges on a target it is necessary to use a high order diffusion theory to adequately represent the distribution function. To a first approximation the energy in each layer is assumed to be constant. However the energy can change from one layer to the next. The average energy loss/layer is calculated using the Bethe stopping power for the average electron trajectory. Once the beam penetrates a distance of about one-fifth the transport mean free path the Bethe age diffusion equations apply, provided the atomic number ≥ 13 and electron energies ≤ 1 MeV. The multilayer theory developed is generalized to include the effects of the electric field.

*This research was supported in part by the ARPA of the Dept. of Defense and was monitored by the Office of Naval Research under Contract N00014-70-C-0427

SESSION C

2:00 PM, Tuesday, October 16

Historical Society Auditorium

RECOMBINATION AND EXCITATION

Chairman: H. J. Oskam, University of Minnesota

C-1

Electron-Positive Ion Recombination Studies using Ion Storage Techniques.

F.L. Walls and G.H. Dunn, Joint Institute for Laboratory Astrophysics, National Bureau of Standards and University of Colorado.

Measurements of the total cross section for two-body electron-positive ion recombination vs electron energy are reported for O_2^+ , NO^+ , H_3O^+ , N_2H^+ , NH_4^+ , and COH^+ over the electron energy range ~ 0.1 to 8 eV with a resolution of 50 - 120 meV. The ions are contained in a static Penning style quadrupole ion trap for periods up to 24 hours. The number of ions for each value of e/m can be nondestructively and independently observed. The natural and the induced decay due to recombination with monoenergetic electrons are separately measured yielding the total cross section for recombination at that electron energy. Values of cross section at 0.3 eV are O_2^+ [8.7×10^{-16}], NO^+ [8.9×10^{-16}], H_3O^+ [1.6×10^{-16}]. Some structure is observed. From the measurements, rate constants are calculated and compared with afterglow measurements in the overlapping temperature interval for O_2^+ and NO^+ .

C-2 Recombination of Molecular Ions.* D. L. HUESTIS, F. T. SMITH, and S. W. BENSON, Stanford Research Institute.--In our study of the recombination of hydrated molecular ions, we have found that the transfer of ion kinetic energy to internal excitation, plays a dominant role. This neutralization mechanism, which combines aspects of both the two-body electron transfer and Thompson three-body energy transfer mechanisms, remains important even for simple molecular ions if one of them has a permanent dipole moment. It must also be considered for low temperature electron-ion recombination. We will discuss the results of our trajectory studies of molecular recombination, including various analytical approximations, and the statistics of ultimate neutralization or escape.

*Supported by Contract F19628-72-C-0121, Air Force Cambridge Research Laboratories.

¹F. T. Smith, D. L. Huestis and S. W. Benson, VIII ICPEAC, Belgrade, 895 (1973).

C-3 Excitation to High Vibrational States in N_2 , CO and CO_2 * M. J. W. BONESS and G. J. SCHULZ, Yale U.-- The vibrational cross section to $v = 8, 9$ and 10 by electron impact on N_2 and CO has been measured in the energy range $2 - 4$ eV. In this energy range, vibrational excitation proceeds predominantly via a compound state and decay into high vibrational states can occur. At the first peak, the ratio of cross sections for $v = 8 : 9 : 10$ is $1 : 0.31 : 0.11$ in N_2 , and $1 : 0.51 : 0.25$ in CO. These ratios are largely determined by the quantum mechanical penetration through the centrifugal barrier. In CO_2 , we find that at least 30 vibrational modes are excited near the center of the ${}^2\Pi_u$ shape resonance, at an electron energy of 3.8 eV. We can distinguish between two progressions, namely pure symmetric stretch, $n00$, and symmetric stretch with one quantum of bending, $n10$. The first of these dies out after about $10,0,0$ whereas the latter mode persists up to $20,1,0$.

*This work was supported by ONR.

C-4 Theory of Excitation of the Electronic States of Diatomic Molecules by Electron Impact - N_2, CO , and NO* SUNGGI CHUNG, Univ. of Wisconsin--The electron-impact excitation cross sections of the $a^1\Pi_g, c^1\Sigma_u^+, a^1\Sigma_g^+, w^1\Delta_u, b^1\Sigma_u^+, b^1\Pi_u, A^3\Sigma_u^+, B^3\Pi_g, C^3\Pi_u, D^3\Sigma_u^+, W^3\Delta_u,$ and $E^3\Sigma_g^+$ states of N_2 ; those of $A^1\Pi, a^3\Pi, E^1\Pi, c^3\Pi, B^1\Sigma^+, b^3\Sigma^+, C^1\Sigma^+, j^3\Sigma^+, D^1\Delta,$ and $d^3\Delta$ states of CO; and that of $B^1\Sigma$ state of NO molecules by means of the Born approximation with Ochkur's and Rudge's scheme of treating electron-exchange scattering amplitude in the energy ranges of $0-1000$ eV for singlet and $0-60$ eV for triplet excitations. Tests with three different sets of wave functions show that the computed cross sections vary typically within 15% when different wave functions are used. Comparison with experiment shows moderate to good agreement in many cases. The computation is greatly simplified by using the Gaussian-type wave functions.

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

SESSION D

3:45 PM, Tuesday, October 16

Historical Society Auditorium

DISTRIBUTION FUNCTIONS

Chairman: D. S. Burch, Oregon State University

D-1 The Upflux Theory of Distribution Functions.
WILLIAM P. ALLIS, Massachusetts Institute of Technology.
 --The inelastic collision term of the Boltzman equation has always been considered too difficult to handle other than by computer. Even by computer it is a lengthy process particularly if de-excitations are to be considered. As any computation of gas laser efficiency requires a knowledge of the distribution of electron energies it is useful to have a method of calculating the latter which yields analytic expressions for the excitation frequencies in terms of two parameters per excitation level considered and E/p . Our method requires that inelastic cross-sections be represented by δ -functions so that the electron flow G along an energy axis is constant between excitation energies u_x with discontinuities at each u_x . The distribution f is then constructed of analytic functions joined at each u_x . This then allows the derivation of analytic expressions for all excitation frequencies ν_x . Replacing inelastic collisions by δ -functions seems naive but the results are worth it.

D-2 On the Energy Balance in Low Pressure Gas Discharges, L. VRIENS, Philips Research Laboratories, Eindhoven, The Netherlands.--In the positive column of low pressure gas discharges, the electron energy distribution can be markedly non-Maxwellian, in particular in the tail of the distribution at low electron densities. A method is described which enables one to account for large deviations from a Maxwellian distribution when calculating collision rates, energy flow terms, excited state densities and the radiation output. Illustrative examples are given for Cs-Ar, Ar and Hg-Ar discharges. As compared to our first report on this topic¹ the method and results are extended by introducing besides the separation in two groups of electrons, a separation in three groups of electrons. Energy conservation is separately required for each group of electrons. The collision rates and the densities obtained converge rapidly to their experimental values.

¹L. Vriens, J. Appl. Phys., Sept. or Oct. 1973.

D-3 Elastic and Inelastic Cross Sections for e-Hg Scattering from Hg Transport Data.* STEPHEN D. ROCKWOOD, Los Alamos Scientific Lab. -- Elastic and inelastic scattering cross sections for low energy electrons in Hg have been obtained through comparison of experimental and calculated transport data. Electron-electron interactions and super-elastic collisions are incorporated into the numerical solution for the electron energy distribution. The electron-electron interactions are shown to have a pronounced effect upon computed drift velocity and characteristic energies at low E/N while super-elastic collisions principally alter the cascade ionization rate. Details of the present method for solving the DC Boltzmann equation, including the above process, are discussed.

* This work supported by the U. S. Atomic Energy Comm.

D-4 Anisotropic Electron Distributions in Molecular Gas Discharges.* WILLIAM H. LONG, WILLIAM F. BAILEY, Aerospace Research Labs, WPAFB, O.--The electron energy distribution in nitrogen and carbon monoxide is shown to be strongly anisotropic for low values of the ratio of electric field to gas number density. In this regime, the expansion in spherical harmonics, commonly used to compute the distribution is no longer valid. The angular dependent electron velocity distribution has been calculated analytically for simple elastic and inelastic cross sections. Numerical solutions, using the measured collision cross sections, are also presented. From these anisotropic distributions, the electron transport properties and vibrational excitation and ionization rates are determined.

* Submitted by W. G. BRAUN

SESSION EA

9:00 AM, Wednesday, October 17

Wisconsin Center Auditorium

EXCITATION TRANSFER

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

EA-1 Chemionization by Rare Gas Metastable Atoms.*
 W.P. West, T.B. Cook, F.B. Dunning, R.F. Stebbings, and R.D. Rundel. Dept. of Space Physics & Astronomy, Rice University, Houston, Texas 77001

A crossed beams apparatus has been used to study thermal energy chemiionization collisions of rare gas metastable atoms with a variety of atomic and molecular targets. Mass analysis of product ions has been carried out, enabling identification of specific reaction channels. Penning ionization, dissociative Penning ionization, associative ionization, rearrangement ionization, and negative ion formation have been observed. Results will be compared where possible with the work of previous investigators.

*Work supported by the Atmospheric Sciences Section, National Science Foundation, Grant No. GA27169, and by the Robert A. Welch Foundation.

EA-2 Production of Excited Molecular Ions by Rare Gas Molecular Metastables.* P. E. Thiess and G. H. Miley, Univ. of Ill. -- Formation of excited molecular ions in collisions of the 2nd kind⁽¹⁾ with rare gas molecular metastables were investigated in high pressure, He, Ne & Ar (to 750 Torr) using an external source of ionization (5.3 MeV alphas). Optical line and band intensities of the noble gas atomic and molecular states and of the molecular species (H₂, N₂, O₂, CO, & NO) were studied as functions of an applied electric field (to 10qa), total pressure, and partial pressure (10⁻⁴ to 10%). While the spectra excited in these mixtures have been extensively investigated in low pressure flowing afterglows⁽²⁾, no detailed studies at high pressures have been reported which resolve the kinetic processes involved nor has any work been reported in a Townsend discharge. The results indicate that the enhanced fluorescence of the molecular ion and dissociation products at low concentrations (<0.1%) above 50 Torr in He and Ne are primarily due to the molecular metastable rather than the atomic metastable or charge exchange. From Stern-Volmer plots of the molecular emissions estimates of the transfer cross section can be made. ---
 (1) R. Meycroff, Phys. Rev., 70, 671 (1946); (2) C. B. Collins and W. W. Robertson, J. Chem. Phys., 40, 701 (1964). *Work supported in part by AEC & NSF.

EA-3 Formation and Reactions of Metastable $N^+(^1D)$.*

J. A. Rutherford, R. H. Neynaber, and D. A. Vroom, Intelcom Rad Tech.--Reactions involving $N^+(^1D)$ have been suggested to be of importance in the calculation of atmospheric deionization. Past experiments in our laboratory have indicated that the amount of $N^+(^1D)$ present in ion beams is very small. In recent experiments we have shown that this species is in fact present in amounts large enough to study. Charge transfer measurements using $N^+(^1D)$ have been performed using a crossed-ion modulated-neutral-beam apparatus. The target particles considered are Kr, Xe, CO and O_2 . Measurements have shown that, for N^+ formed from N_2 by electron impact using 40 eV electrons, approximately 10% of the N^+ particles are in the metastable state.

*This work was supported by the Defense Nuclear Agency under Contract No. DNA001-73-C-0031.

EA-4 The Decay of Krypton $1s_2$ and $1s_3$ Excited

Species in the Late Afterglow*. R.T. Ku, J.T. Verdeyen, B.E. Cherrington, Gasecus Electronics Laboratory, Univ. of Ill. at U-C.--Experimental investigations of the behavior of the Kr $1s_2$ excited state population in afterglow discharge plasmas are described. The number density of Kr $1s_2$ atoms was obtained by performing resonant absorption measurements at 8509 Å (Kr $1s_2 \rightarrow 2p_4$) with a tunable GaAs laser diode. The narrow width laser was tuned and swept through the entire resonant transition. The decay of the $1s_2$ species in the late afterglow was found to depend primarily on the decay processes for the $1s_3$ species. Analysis of the pressure dependent decay curve in the late afterglow has been carried out to derive the diffusion coefficient as well as two-body and three-body destruction frequencies for Kr $1s_3$ excited species. The diffusion coefficient was found to be $49 \text{ cm}^2 \text{ sec}^{-1}$. The two body collisional destruction rate was found to be $9 \times 10^{-15} \text{ cm}^3/\text{sec}$. The three body collisional destruction rate, which presumably indicates the rate of formation of the excited dimer Kr_2 , was found to be $53.6 \times 10^{-33} \text{ cm}^6/\text{sec}$.

Work supported by National Science Foundation.

EA-5 Energy Transfer from Argon Resonance States to Molecules. * G. S. HURST and E. B. WAGNER, Oak Ridge Nat'l. Lab. --Energy transfer from resonance atomic states to molecules is an important subject for understanding energy pathways in the noble gases. We have examined this process experimentally for the $1P_1$ (1048 Å) and the $3P_1$ (1067 Å) states of argon and have made a comparison with the energy transfer theory of Watanabe and Katsuura.¹ The technique involves measuring the rate of decay of resonance photons escaping from a cylindrical cell in which excited states are created by a pulsed beam of 2-MeV protons traveling down the axis of the cylinder. We find, for example, with C_2H_4 that the rate constants are 10.3×10^{-10} and 5.0×10^{-10} $cm^3 sec^{-1}$ for the $1P_1$ and $3P_1$ states of argon, respectively, compared with theory which gives 10.3×10^{-10} and 5.4×10^{-10} $cm^3 sec^{-1}$ for these two rate constants, respectively.

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

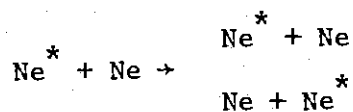
¹T. Watanabe and K. Katsuura, J. Chem. Phys. 47, 800 (1967).

EA-6 Ab Initio Potential Curves for the Ne(3s) - Ne Interaction with Semiempirical Treatment of Spin-Orbit Coupling. * J. S. COHEN AND BARRY SCHNEIDER, Los Alamos Scientific Lab. --Ab initio calculations of the $1^3\Sigma$ and $1^3\Pi$ interactions of Ne(3s) with ground-state 1S_0 Ne have been made using generalized valence-bond wave functions and neglecting spin-orbit coupling. Polarizabilities and dispersion coefficients have been separately estimated. With the introduction of spin-orbit coupling, these states split into two 0^+ , two 0^- , three 1, and one 2 [Hund's case c] states. Neglecting the effects of high lying states, the spin orbit splittings can be calculated from two coupling matrix elements, which have been determined empirically from the known splittings of the $3P_{2,1,0}$ and $1P_1$ levels of atomic neon. The coupling matrix elements should have little dependence on the internuclear distance since the atomic cores overlap little even near the equilibrium separation. Making this assumption, the spin-orbit coupling matrices have been diagonalized separately for each value of m_j yielding the Ω -quantized wave functions and potential curves as linear combinations of the Λ -quantized wave functions and potential curves. Several interesting avoided curve crossings due to spin-orbit effects are noted.

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

EA-7 Excitation Transfer in Ne + Ne* Collisions.[†]
BARRY SCHNEIDER AND J.S. COHEN, Los Alamos Scientific Lab

--From the curves discussed in the preceding abstract, we have determined differential and integrated cross sections for elastic and transfer processes in the collision



Both semi-classical and quantum mechanical methods have been used to integrate the equations of motion and determine the necessary phase shifts. The cross sections were determined in two ways: 1) by averaging over the appropriate cross sections for Σ and Π states and, 2) by averaging over the appropriate states including spin-orbit effects in the Hamiltonian, weighting by the appropriate angular momentum statistics in each case. Results will be presented for each type of potential curves.

[†]Work supported by the U.S. Atomic Energy Commission.

SESSION EB

9:00 AM, Wednesday, October 17

Wisconsin Center Lake Shore Room

HF AND OTHER LASERS

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

EB-1 HF and DF Nonchemical Electrical Discharge Lasers.
 L.Y.NELSON, S.R.BYRON and G.J.MULLANEY, Mathematical Sciences NW, Seattle.--Using a high current, long pulse, e-beam stabilized electrical discharge, laser oscillation has been observed on several vibration-rotation bands of HF and DF: 3 \rightarrow 2 P(6,7,8,9), 2 \rightarrow 1 P(7,8,9,10) and 1 \rightarrow 0 P(9) lines in HF, and the 3 \rightarrow 2 P(8,9) and 2 \rightarrow 1 P(9,10) lines in DF. Laser output generally shifted from simultaneous emission on the lower J values early in the discharge to higher J values near the end of the pulse. Cascade coupling of 3 \rightarrow 2 to 2 \rightarrow 1 lines was evident from the time sequencing of the laser emission. A plasma diode⁽¹⁾ e-beam provided an average current density of 30 ma/cm², for a time duration of 50 μ sec. An electric field ($E/N = 0.1$ to 1.0×10^{-16} volts/cm²) was applied to the laser gas (200 Torr) and resulted in a discharge current of 3-10 amps/cm². A high-Q laser cavity was used with a 50 cm active path length. By observing laser action in HF/Ar mixtures with 10% added N₂, H₂ or D₂ it was established that HF is vibrationally pumped by direct electron impact and also by vibrational energy transfer from H₂. Probe laser measurements confirm the V-V pumping mechanism in Ar/H₂/HF mixtures and indicate no significant V-V transfer from N₂ to HF.
 (1) B.B.O'Brien, Jr., Appl. Phys. Lett. 22,503(1973).

EB-2 Studies Concerning An Electrically-Excited H₂-HF Laser.*
 R. M. Osgood, Jr., M.I.T. Lincoln Laboratory.--A technique for achieving a completely electrically-pumped pulsed HF laser is described. The gas mixture in the laser consists of a majority percentage of H₂ and a minority of HF. The H₂ acts as a long-lived reservoir of vibrational energy, while the HF is added in such a quantity as to provide sufficient gain, thus enabling much of this stored energy to be extracted as laser light at 3 μ m. An important consideration is that the exothermicity of the vibration change process $H_2(V=1)+HF(V=0) \rightarrow H_2(V=0)+HF(V=1)+\Delta E$ causes the vibrational temperature of the HF to be greater than that of H₂ by the Boltzmann factor $e^{\Delta E/KT}$, where T is the gas translational temperature. This fact allows one to achieve a partial inversion in HF with a relatively vibrationally cold H₂ bath.
 A computation which considers both the kinetics of the H₂-HF energy exchange process and the steady state electron energy distribution shows that both practically high gains and extraction energies can be realized in this system. Finally, some preliminary measurements of HF vibrational temperature in electrically excited H₂-HF mixtures will be described.

*Submitted by D. E. LENCIONI.

EB-3 Kinetics for Population Inversion on the 557.7 nm $O(^1S) \rightarrow O(^1D)$ Transition in Atomic Oxygen.* S.D. ROCKWOOD, O.P. JUDD, Los Alamos Scientific Laboratory, and R.O. HUNTER, Maxwell Laboratories.---Using current data for the production of $O(^1S)$ and $O(^1D)$ by uv photolysis coupled with their measured deactivation rates by numerous gases, a complete kinetics analysis is developed which demonstrates the attainment of large inversion densities between $O(^1S)$ and $O(^1D)$. Four of the most promising configurations for producing large population inversions are examined in detail. The results of fluorescence measurements performed in both transverse and longitudinal electrical discharges in mixtures of (Kr, N_2O), (Ar, Xe, N_2O), (Ar, O_2), and (He, O_2). From the results of these experimental data, previously unclear advantages and disadvantages of the proposed laser configurations are discussed.

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

EB-4 Energy Flow in Argon, N_2 , NO Mixtures Excited by Pulsed Electron Beam.* R. M. HILL, D. J. ECKSTROM, R. A. GUTCHECK, D. L. HUESTIS, D. C. LORENTS, D. MUKHERJEE, and H. H. NAKANO, Stanford Research Institute.--We have studied by experiment and modelling the molecular kinetics of high pressure gas mixtures excited by short, intense pulses of high energy electrons. The energy initially deposited in the argon can be transferred rapidly into the excited triplet states of N_2 which are monitored by first and second positive radiation and by transfer of $N_2(A)$ metastable energy to $NO(A)$ which can then radiate. Large populations of $N_2(A)$ can be achieved. Subsequent transfer to $NO(A)$ may lead to lasing in the γ band system.

*Supported by Contract N00014-72-C-0478, ARPA and ONR.

EB-5 A Spectroscopic Study of a High Flow Copper Vapor Laser. T. W. Karras, R. S. Anderson, and B. G. Bricks, GE, Space Division--An efficient, high flow velocity, copper vapor generator used as a source for a copper vapor laser is described. Generator operating time of ~ 100 minutes at copper densities within the laser cavity of $10^{15}/\text{cm}^3$ have been achieved; densities of the order of $10^{17}/\text{cm}^3$ have been reached for short durations. Lasing has been demonstrated with this source using both longitudinal and transverse electrical discharges of 8 and 4 cm gain lengths, respectively. Power measurements imply that up to 33 percent of the copper atoms in the cavity participate in the lasing action. Low inductance transverse discharge current pulses of 50 ns FWHM permit investigation of the effects of discharge parameters and ambient gas on time dependence and delays of spontaneous emission and laser radiation relative to current. The results are compared with current models, and an interpretation of excitation processes based on the time dependence of electron energy is presented.

EB-6 Evidence of Charge Exchange Pumping in Calcium-Xenon System. DONALD L. CHUBB, NASA Lewis Research Center.--The charge exchange reaction, $\text{Xe}^+ + \text{Ca} \rightarrow \text{Xe} + \text{Ca}^+(5s^2S_{1/2})$ may produce an inversion in CaII . A low power flowing xenon plasma was seeded with calcium to determine if charge exchange or electron collisions pump the $5s^2S_{1/2}$ level. The dependence of the density ratios n_u/n_l and n_u/n_l' (there are two possible lower levels, $\lambda = 4p^2P_{1/2}$, $\lambda' = 4p^2P_{3/2}$) on input power was determined by measuring the spontaneous emission intensities of the appropriate transitions. The density ratios vary inversely with input power to the plasma source, as they should if charge exchange is the pumping mechanism. If electron collisions are the predominate mechanism, then these ratios should increase with power. Also, the density ratios obtained using argon and krypton are lower than in xenon. Since the argon and krypton plasmas should be at higher electron temperatures than the xenon plasma, the density ratios in these gases should be higher if electron collisions are the predominate pumping mechanism.

¹Chubb, D. L., Rose, J. R.; Applied Phys. Lett. Vol. 22, pp. 417-418 (1973).

EB-7 Excitation Mechanism in the He-Cd and He-Zn Ion Lasers. GEORGE J. COLLINS, Colorado State University--

Experimental evidence from pulsed afterglow studies is presented which demonstrates that thermal energy charge transfer is the primary source of excitation for the high-lying Zn II and Cd II laser levels, with configurations of the type $3d^{10}nx$ and $4d^{10}nx$, respectively. Whereas, the main source of excitation of the Zn II and Cd II laser levels, with configurations of the type $3d^94s^2$ and $4d^95s^2$, is Penning ionization. The total velocity-averaged cross-sections for thermal energy charge exchange and for Penning ionization are measured to be of order 10^{-15}cm^2 .

The intensity of spontaneous emission from laser levels excited in a flowing afterglow by charge transfer reactions is broken down into the component contributions: direct charge-transfer excitation; radiative cascade; and collisional cascade excitation. The results are used to estimate the values of the individual cross-sections for direct charge transfer into Zn II and Cd II laser levels.

SESSION FA

10:45 AM, Wednesday, October 17

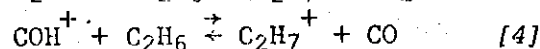
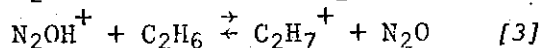
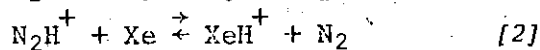
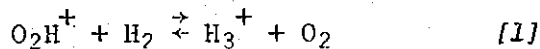
Wisconsin Center Auditorium

ION-MOLECULE COLLISIONS

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

FA-1 Ion-Molecule Reaction and Mobility Measurements in a Flowing Afterglow-Drift Tube. M. McFARLAND*, D. L. ALBRITTON, F. C. FEHSENFELD, E. E. FERGUSON*, and A. L. SCHMELTEKOPF, NOAA Research Labs.--A drift tube has been combined with a flowing afterglow system for ion-neutral reaction measurements from thermal energy (300°K) to several eV ion kinetic energy. This system combines the chemical versatility of a flowing afterglow with the energy range of a drift tube for both mobility and reaction rate measurements. The mobility of He⁺ in He agreed precisely with previous measurements over the 7 to 175 Td range of E/N. The mobilities of He₂⁺, H⁺, D⁺, O⁺, N⁺, N₂⁺, H⁻, O⁻, and OH⁻ in helium have been obtained, agreeing with previous measurements where they exist. The reaction O⁺ + O₂ → O₂⁺ + O has been measured from thermal to 3 eV (center of mass), the reaction O⁺ + N₂ → NO⁺ + N has been measured from 0.2 to 3 eV, and the reactions of N⁺ and N₂⁺ with O₂ from thermal to 3 and 2 eV, respectively. The reaction of O⁻ + H₂ to give H₂O + e and OH⁻ + H has been obtained from thermal to 0.5 eV, the similar O⁻ + D₂ from thermal to 0.9 eV, the reaction O⁻ + CO → CO₂ + e from thermal to 2.7 eV, and O⁻ + NO → NO₂ + e from thermal to 1.1 eV. These data will be compared with previous beam, drift tube, and afterglow measurements.
*Also Chemistry Department, Colorado University.

FA-2 Proton Affinities of O₂, Xe and C₂H₆. P. F. Fennelly, R. S. Hemsworth, J. D. Payzant, H. I. Schiff and D. K. Bohme, C.R.E.S.S., York University, Downsview, Ontario. The approach to and attainment of equilibrium for the following proton transfer reactions were investigated in a flowing afterglow at 297⁰ K:



An analysis¹ of the data yielded the following values of the equilibrium constant: $K_1 = 1.1 \pm 0.2$, $K_2 = 59 \pm 12$, $K_3 = (1.6 \pm 0.3) \times 10^3$, and $K_4 = 13 \pm 5$. These values allow the determination of the differences in the proton affinities of the neutral species in each reaction. Absolute values for the proton affinities of O₂, Xe and C₂H₆ can be calculated from the previously established proton affinities of H₂, N₂, and N₂O or CO.

*Present address: Aerochem Research Laboratories, Princeton, New Jersey.

I. D. K. Bohme, R.S.Hemsworth, H.W.Rundle and H.I.Schiff, J.Chem.Phys. 58, 3504 (1973).

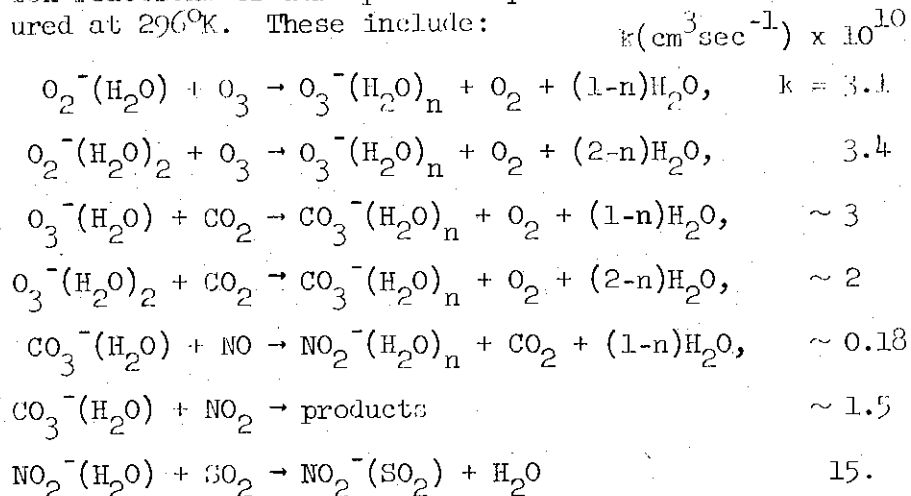
FA-3 Thermal Energy Ion-Molecule Reactions Involving NH₃ and NO. R. S. Hemsworth, J. D. Payzant, P. F. Fennelly*, D. K. Bohme and H. I. Schiff, C.R.E.S.S., York University, Downsview, Ontario. The flowing afterglow technique has been used to measure rate constants at 300° K for the reactions of various ions with ammonia and nitric oxide. Rate constants for proton transfer reactions between H₃⁺, NH₃⁺, CH₅⁺, H₃O⁺, COH⁺, N₂H⁺, C₂H₅⁺, C₂H₇⁺, C₃H₇⁺, N₂OH⁺ and C₁₁H₉⁺ and NH₃ are found to lie between the values predicted by the Langevin and 'locked-dipole' models. No correlation was apparent between the reaction probability and the exothermicity of the reaction. The rate constants for the reactions between O⁺, O₂⁺, C⁺, and CO⁺ with NH₃ were also found to lie between the two theoretical extremes. The system has also been used to measure reaction rate constants for various ions with NO; these include C⁺, CO⁺, N⁺, N₂⁺ and N₃⁺. Many of the above reactions are of astrophysical interest.

*Present address: Aerochem Research Laboratories, Princeton, New Jersey

1. E. Herbst and W. Klemperer, Ap. J., in press.

FA-4 Reaction Rate Constants Measured in a Temperature Variable Flowing Afterglow. F. C. FEHSENFELD, A. L. SCHMELTZKOPF, D. B. DUNKIN, D. L. ALBRITTON, C. J. HOWARD, E. E. FERGUSON, NOAA Environmental Research Labs. Boulder, Colo. 80302.--The NOAA temperature variable flowing afterglow has been modified to cover an extended temperature range from 80°K to 900°K. The system will be briefly described. Using this apparatus several reactions have been studied including: (1) $D^+ + H_2 \rightleftharpoons H^+ + HD$ at 280°K and below and (2) $O^+ + CO_2 \rightarrow O_2^+ + CO$, (3) $O^+ + O_2 \rightarrow O_2^+ + O$, and (4) $O^+ + N_2 \rightarrow NO^+ + N$ at 280°K and above. The rate constants for these reactions will be reported as a function of temperature. Comparison will be made with other experiments in which ion kinetic energy alone was varied. No other experiments encompassing the present wide range of gas temperature exist. Reaction mechanisms implied by the observed energy variations will be discussed.

FA-5 Flowing Afterglow Measurements of Negative Ion Reactions, W. E. FERGUSON and F. C. FEHSENFELD, NOAA Research Labs., Boulder, Colo. 80302.--A series of negative ion reactions of atmospheric importance have been measured at 296°K. These include:



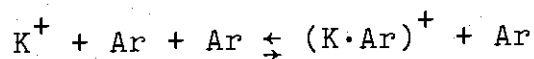
These results imply that hydration will not seriously modify the NOAA D-region negative ion reaction scheme. The last reaction (and others which we have measured) shows that SO₂ replaces H₂O in negative ion clusters.

FA-6 TERMOLECULAR AND SATURATED TERMOLECULAR KINETICS FOR Li⁺

Kenneth G. Spears and E. E. Ferguson. Department of Chemistry, Northwestern University, Evanston, Illinois 60201 and Aeronomy Laboratory, NOAA, Boulder, Colorado, 80302

The termolecular association of Li⁺ with nineteen molecules was observed in helium at 0.3-1.0 Torr. The molecules included N₂, CO₂, SO₂, NH₃, substituted methanes, and substituted ethylenes. The rates ranged from 8(-31) to 5(-27) cm⁶ molecule⁻² sec⁻¹. Six molecules were observed to have a transition from termolecular to saturated termolecular kinetics in the 0.3 to 1.0 Torr pressure range and C₄F₈, C₂Cl₂F₄, and C₂F₆ were saturated termolecular at 0.2 Torr in both helium and argon buffer. The overall importance of such measurements as a "tunable" probe of kinetics is emphasized.

FA-7 Binding Energies of Alkali-Metal Ions with Inert Gases. L. G. MCKNIGHT, and J. M. SAWINA, Bell Telephone Laboratories, Murray Hill, New Jersey.--A drift tube measurement has been made of the equilibrium constants for the clustering of alkali metal ions with inert gases of the general type:



at temperatures between room temperature and -110°C . By using calculated values of ΔS° , the binding energies of the ion clusters can be estimated:

	ΔH° (e.v.)			
	He	Ne	Ar	Kr
Li ⁺	<.07	.13	.25	
Na ⁺		<.11	.17	.19
K ⁺			.11	.12
Cs ⁺			.09	

FA-8 Reactions of Ions in Hydrogen. W. T. HUNTRESS, JR., L. P. THEARD and J. K. KIM, Jet Propulsion Laboratory. -- A combination of ion cyclotron resonance (ICR) trapped ion and cyclotron ejection methods have been used to identify and measure the rate constants for the reactions of CH_4^+ , CH_3^+ , CH_2^+ , CH^+ , NH_3^+ , NH_2^+ , H_2O^+ , OH^+ , H_2S^+ , C_2H_2^+ , CH_3NH_2^+ and CH_3OH^+ ions with H_2 molecules. Some of these hydrogen atom abstraction reactions are not observed at all, even though they are highly exothermic and have only one available reaction pathway. Ion-molecule reactions in hydrogen-helium mixtures have also been reexamined using the ICR trapped ion method. Deactivation of vibrationally excited H_2^+ ions in non-reactive collisions with He atoms has been identified, and the rate constant for the reaction of HeH^+ with H_2 has been measured.

FA-9

Clustering of H₂O and NH₃ about the Monovalent Bismuth Ion.*

A. W. Castleman, Jr. and I. N. Tang, Brookhaven National Laboratory--Clustering of the polar molecules H₂O and NH₃ about Bi⁺ has been studied under equilibrium conditions. The measurements were made over the temperature range 10^o to 350^oC and at total pressures ranging from 5 to 40 torr. Nitrogen or Argon was used as a buffer gas for introducing reactants and for thermalizing the primary ions. Bond energies obtained for the clusters Bi⁺(H₂O)_n, n ≤ 6 are 22.8, 17.7, 14.0, 12.0, 10.5 and 9.7 kcal/mole, respectively. Likewise, the bond energies for Bi⁺(NH₃)_m, m ≤ 3 are 36, 23 and 9 kcal/mole. The observation that the first two ammonia clusters possess bond energies larger than the corresponding water clusters cannot be explained solely on the basis of electrostatic bonding. Instead, the nature of the chemical bonding of these clusters is discussed in terms of the electronic structure of the central ion as well as the clustering molecules.

* This work was performed under the auspices of the U. S. Atomic Energy Commission and partially supported by the National Science Foundation (AG 423)

SESSION FB

10:45 AM, Wednesday, October 17

Wisconsin Center Lake Shore Room

CO₂ KINETICS AND EXCITATION TRANSFER

Chairman: J. Y. Wada, Hughes Research Laboratories

FB-1 The Effect of Negative Ion Processes on the Stability of Molecular Gas Discharges*. W. J. WIEGAND AND W. L. NIGHAN, United Aircraft Research Laboratories.-- Analysis of the factors causing electric discharge instability has shown that several types of instability are possible. The occurrence of these instabilities depends in a central way on the response of the electron density to a local disturbance in plasma properties. Processes resulting in the production and loss of negative ions have been found to affect the nature of electron density fluctuations, and thus plasma stability. The present investigation focuses attention on explaining the effects on discharge behavior of electron attachment and detachment processes for mixtures of molecular gases representative of CO₂ laser applications. Plasma conditions leading to the development of both ionization and thermal instability have been determined, and it has been shown that negative ion processes exert a dominant influence in many circumstances of interest. *This work was performed in part through the sponsorship of the Office of Naval Research, the Naval Ordnance Systems Command, and the Air Force Aerospace Research Laboratories.

FB-2 CO₂ Laser Discharges Controlled by Attachment. J. J. LOWKE and L. J. DENES, Westinghouse Research Labs.--The voltage-current dependence is investigated for pulsed, self-sustained, uniform-glow discharges using commercial-grade mixtures of CO₂, N₂ and He at near atmospheric pressures. For a given mixture, the discharge is found to stabilize at a value of $E/N = E_G/N$ which is independent of discharge current density, total pressure and electrode spacing; E is the electric field and N the number density of the gas. We find that these values of E_G/N are consistent with theoretical predictions where the voltage-current dependence is obtained after equating ionization rates with electron loss by attachment and recombination. To explain the independence of E_G/N on variations of current density of more than 3 orders of magnitude,³ the recombination coefficient must be less than $10^{-8} \text{ cm}^3 \text{ sec}^{-1}$ and then E_G/N is given simply by the value of E/N for which ionization and attachment coefficients are equal. Water vapor impurities of ~0.4% also slightly influence E_G/N . When account is taken of attachment to H₂O as well as CO₂ theoretical and experimental values of E_G/N agree to within 5%.

FB-3 Electron Excitation of the 001 Level of CO₂ and the Vibrational Levels of N₂.* B. R. BULOS and A. V. PHELPS†
Joint Institute for Laboratory Astrophysics.-- A drift tube technique has been used to measure the number of vibrationally excited CO₂ (001 level) and N₂ molecules produced per cm of electron drift. An InSb photovoltaic detector was used to measure the 4.3 μm radiation escaping from the gas. Theoretical calculations were used to correct for self absorption. The N₂ measurements were made using small admixtures of CO₂ to sense the degree of vibrational excitation of the N₂. The measured excitation coefficients for N₂ are in good agreement with the expectation that about 95% of the electron energy is expended in vibrational excitation. For pure CO₂ the excitation coefficients at the lower E/N are significantly larger than expected on the basis of proposed¹ sets of vibrational excitation cross sections.

*Supported in part by the Defense Nuclear Agency through the Air Force Cambridge Research Laboratories.

†Staff Member, Laboratory Astrophysics Division, N.B.S. and Prof. Adjoint, Dept. of Physics and Astrophysics, University of Colorado.

¹J. J. Lowke, A. V. Phelps and B. W. Irwin, J. Appl. Phys. (September) (1973).

FB-4 *Kinetic Modeling of Electrically Excited CO₂ Lasers. A.M. LOCKETT, III, Los Alamos Scientific Lab. -- A detailed multitemperature kinetics model describing the behavior of electrically excited CO₂ lasers has been developed and quantitative comparison with experimental data from the LASL electron beam controlled CO₂ amplifier has been obtained. The results are absolute in the sense that there are no adjustable parameters in the theory. Previous reported results using this model,¹ indicated a possible discrepancy between theory and experimental data in that the measured zero flux gain in pure CO₂ was 30-40% lower than that predicted theoretically. This discrepancy was initially attributed to a low value for the accepted electronic vibrational excitation cross section to the (00°1) level in CO₂.² The experimental measurements have since been repeated with better accuracy and now yield values for the gain in pure CO₂ that are within 10% of the theory using the published value for this cross section. A detailed comparison of the theory with the experimental data will be presented at both low and high levels of electronic pumping.

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

¹A.M. Lockett, III, Paper NB5, GEC, London, Ont., Can. '72

²A.V. Phelps, private communication.

FB-5 Stimulated Emission from the Afterglow of an E-beam Discharge in Several Atmospheres of Helium.*
C. B. COLLINS, B. W. JOHNSON, and A. J. CUNNINGHAM,
U. of Texas at Dallas--The collisional-radiative recombination of hydrogenic ions with electrons offers the possibility of producing significant population inversions.¹ Evidences of such inversions have been observed at 7065, 6400, 5875, 5130 and 4400 Å in the afterglow of a 3 nsec., 8KA., 500 KeV e-beam discharge in helium at 3 atmospheres pressure. An optical gain of 0.05 cm^{-1} has been found in the 6400 Å band of He₂ of recombination origin.

*This research was supported by the U.S. Advanced Research Projects Agency of the Department of Defense and monitored by ONR under Contract No. N00014-67-A-0310-0007.

FB-6 Electron-Beam Excited Charge Transfer at Atmospheric Pressures as a Source of Stimulated Emission.*
A. J. CUNNINGHAM, B. W. JOHNSON, W. P. LEE, and C. B. COLLINS, U. of Texas at Dallas--Charge transfer at atmospheric pressures provides a mechanism for the selective excitation and inversion of excimer states in plasmas directly excited by pulsed electron beams of high power. Evidences of stimulated emission have been observed in He+N₂ and He+CO systems at 3 atmospheres total pressure excited by a Gigawatt electron beam. The $\nu+\nu+1$ components of the 1st Negative Bands of N₂⁺ and elements of the CO⁺ spectrum around 4200 Å, respectively have shown evidence of small signal optical gain.

*This research was supported by the U. S. Advanced Research Projects Agency of the Department of Defense and monitored by ONR under Contract No. N0014-67-A-0310-007.

SESSION G

2:00 PM, Wednesday, October 17

Wisconsin Center Auditorium

VACUUM ULTRAVIOLET LASERS I

Chairman: M. M. Mann, Northrop Research and Technology Center

G-1 The Vacuum-Ultra-Violet Molecular-Xenon Laser.*
 J. B. GERARDO and A. WAYNE JOHNSON, Sandia Laboratories.
 --The molecular xenon laser radiates near 1721 Å with a bandwidth of (20 ± 4) Å. Evidence is presented which proves that the stimulated-emission cross-section of the excited xenon molecule is larger than the photo-ionization cross section. Our measured values of the parameters of importance to this laser are the spontaneous-emission lifetime $((50 \pm 20)$ nsec), the pressure quenching cross-section $((3.3 \pm 1.3) \times 10^{-18}$ cm²), the mutual ionization rate of two excited xenon molecules $((3.5 \pm 1.4) \times 10^{-10}$ cm³ sec⁻¹), and the effective stimulated-emission cross section $((1.0 \pm .5) \times 10^{-18}$ cm²). Using these measured parameters and the general rate equations describing the wavelength-dependent photon density $\rho(\lambda)$ in the optical resonator, we found qualitative agreement between the measured $\rho(\lambda)$ and the calculated $\rho(\lambda)$. Other rare-gases and mixtures with xenon have also been examined and these results will be discussed.

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

G-2

STIMULATED EMISSION FROM
 MOLECULAR XENON AND KRYPTON DIMERS *

P. W. Hoff and C. K. Rhodes

ABSTRACT

Stimulated emission has been observed at ~ 1720 Å in high pressure xenon gas originating from the bound-free continuum of the xenon dimer and at ~ 1457 Å in high pressure krypton gas from the corresponding transition of the krypton molecule. Under appropriate conditions these transitions exhibit strong spectral narrowing, spatial coherence corresponding to a few times the diffraction limit, and a sharp oscillation threshold. Energy transfer processes and operation of the xenon system have been explored in argon/xenon mixtures.

*This work was performed under the auspices of the United States Atomic Energy Commission.

G-3 Excimer Formation and Decay Processes in Electron Excited High Pressure Rare Gases. D. C. LORENTS
Stanford Research Institute. -- A theoretical model has been developed to describe excited dimer formation and decay in rare gases at pressures above 1 atm. The model is based on available knowledge of the electronic energy deposition processes, and collisional association, recombination and relaxation reactions occurring in excited rare gases. Excimer formation and decay rates in Ar and Xe are calculated as a function of atom and excitation density. The importance of excimer-excimer deactivation by Penning ionization is evident at high excimer densities. The results are compared with recent experimental measurements of excimer decay following pulsed excitation under conditions of both high and low excitation density. The application of the results to the development of uv lasers based on the rare gas excimer bands will be discussed.

G-4 Spontaneous and Superradiante Emission at 1730 Å in Xenon Gas at Low Temperature. Franck Collier and Christian Collet, Laboratoires de Marcoussis--
Spectral and time dependent studies of vacuum ultraviolet (V U V) continuum ($\lambda_0 = 1730 \text{ \AA}$) of electron excited gaseous xenon are presented for quasi-atmospheric pressures (1 - 3 Atm) and low temperatures : $-50^\circ \text{ C} < t < + 25^\circ \text{ C}$. At low temperature, large increase in intensity, spectral narrowing and higher conversion efficient (of about 60 %) are achieved. Population inversion is easier. Superradiant characteristic parameters are given.

SESSION HA

3:45 PM, Wednesday, October 17

Wisconsin Center Lake Shore Room

ELECTRON-MOLECULE AND CHARGE TRANSFER COLLISIONS

Chairman: W. L. Borst, Southern Illinois University

HA-1 Excitation of the $C^3\Pi_u$ State of N_2 by Electron Impact* R.J. Anderson, S.T. Chen and R.H. Hughes, University of Arkansas.--Time-resolved spectroscopy has been used to study the excitation of the $C^3\Pi_u$ state of N_2 by low-energy electron impact. Measurements were carried out on the $\lambda=3371 \text{ \AA}$ spectral line, corresponding to the $(0,0) C^3\Pi_u \rightarrow B^3\Pi_g$ transition, at 50eV incident electron beam energy and pulse widths of 0.3 and 5 μsec and for gas pressures in the range ~ 4 to 300 mtorr. The lifetime of the $C^3\Pi_u$ ($v=0$) level is determined to be 39 ± 4 nanoseconds which is in agreement with other experimental results. In the case of the 5 μsec excitation pulse width the $\lambda=3371 \text{ \AA}$ radiation was observed to contain a long-lived component ($\tau \geq 1 \mu\text{sec}$) which comprises less than $\sim 15\%$ of the total radiation and which exhibits a dependence upon the target gas pressure. Secondary excitation of the $C^3\Pi_u$ state by collisional transfer from metastable states is being investigated as a function of the gas pressure, electron beam current, excitation pulse width, and collision chamber size.

*This work supported in part by the National Science Foundation and the Research Corporation.

HA-2-

Dissociative Excitation of N_2 by Electron Impact: Translational Spectroscopy of Long-Lived High-Rydberg Fragment Atoms. Kermit C. SMYTH, James A. SCHIAVONE, and Robert S. FREUND, Bell Laboratories, Murray Hill, New Jersey 07974.

Nitrogen atoms in long-lived high-Rydberg states have been produced in the dissociative excitation of N_2 by electron impact. Four principal features were found in the time-of-flight distributions of the dissociation fragments and in the corresponding translational (kinetic) energy distributions. Appearance potentials and excitation functions were measured for the high-Rydberg atoms; for the slowest fragments the excitation function exhibits sharp, resonance-like structure near threshold. The core-ion model of high-Rydberg dissociation, which treats the Rydberg electron essentially as a spectator in the dissociation process, is used to interpret the data in terms of the dissociative core ion states of N_2^+ and the appropriate dissociation limits. In addition, the high-Rydberg kinetic energy distributions are found to be in reasonable qualitative agreement with the kinetic energy distributions of N^+ measured by dissociative ionization experiments.

HA-3 Dissociative Ionization of N_2 by Electron Impact.*

J.A.D. STOCKDALE, LILIANA DELEANU, and R.N. COMPTON, Oak Ridge National Laboratory. --An apparatus employing crossed molecular and pulsed electron beams has been used to study dissociative ionization of N_2 . Product ions were mass analyzed by a quadrupole mass spectrometer after drifting through a field-free region. Their energies were estimated from analysis of time-of-flight spectra. N^+ and N^{++} energy distributions have been obtained for electron energies from threshold to 300 eV. These will be presented with total and differential N^+ angular distributions for electron beam-detector angles from 30° to 110° .

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

HA-4 Vibrational Excitation of O_2 by Electron Impact.*

S. F. WONG, M. J. W. BONESS and G. J. SCHULZ, Yale U.--Vibrational excitation of O_2 by electron impact in the energy range 4 - 15 eV has been studied with a crossed-beam double electrostatic analyzer. The scattering angle is fixed at 25° and the resolution is 60 meV. The differential vibrational cross sections for the $v = 1 - 4$ levels of the ground $X^3\Sigma^-$ state are found to have similar bell-shaped energy dependences, with a broad peak near 9.5 eV. The maximum differential vibrational cross section for $v = 1$ is approximately 4.6×10^{-18} cm^2/sr and the peak cross sections to consecutive higher vibrational states diminish by a factor of about two. The differential cross sections at 25° for the excitation to the $a^1\Delta_g$ and $b^1\Sigma_g^+$ metastable states are in substantial agreement with the results of Trajmar et al¹, and show peaks near 8.0 eV and near 9.0 eV respectively. The vibrational and electronic cross sections in the range 4 - 15 eV are interpreted in terms of the resonant contributions of excited O_2^- states.

*Work supported by NSF and by DNA through AROD.
¹S. Trajmar, D. C. Cartwright, and W. Williams, Phys. Rev. A 4,1482 (1971).

HA-5

New Rydberg series in O_2 and O_2^- .

R. CARBONNEAU and P. MARMET, Laval U., Canada -- New 3σ Rydberg states from series converging to the recently observed $^1O_2 + ^2\Pi_u$ state (at ~ 24 eV) have been detected in the electroionization spectrum of O_2 . The $3s\sigma$, $3p\sigma$ and $3d\sigma$ states lie respectively at 20.73, 21.75 and 22.28 eV. The O_2^- resonance, associated to the parent states $3s\sigma$ and $3p\sigma$, are respectively measured at 20.21 and 21.22 eV. The linewidth, shape factor "q" and cross-section of these states have been determined by best-fitting the experimental data.

¹ O. Edqvist, E. Lindholm, L.E. Selin and L. Åsbrink, Physica Scripta 1, 25 (1970).

HA-6 Light Emission from He^+ /Rare Gas Collisions. B. M. HUGHES, E. G. JONES, and T. O. TIERNAN, Chemistry Research Laboratory, Aerospace Research Laboratories. -- A new apparatus developed in our laboratories has been employed to study optical excitation produced by low energy (1.0 - 180 eV) charge transfer processes. A mass and energy analyzed beam of He^+ ions is impacted on a rare gas target (He, Ne, Ar, Kr or Xe), and optical emissions are detected with a one-meter monochromator and a photomultiplier operated in pulse-counting mode. The dispersed spectra from these collisions in both the vacuum-UV (500-1200Å) and visible (3000-8000Å) regions have been obtained. Reactions with Ar, Kr and Xe predominantly yield emissions from the ionic products. At energies up to 180 eV, however, collisions of He^+ with Ne produce only neutral Ne and He atom emissions. Excitation functions for the major emissions have been measured, with emphasis on accurate determinations of energy thresholds, and observation of undulatory structure in the vicinity of the maxima.

HA-7 Kinematics of Charge Transfer in Collisions of Rare Gas Ions with Diatomic Molecules.* T.L. BUDZYNSKI and T.L. BAILEY, U. of Florida -- Investigations of charge transfer in collisions of Ne^+ , Ar^+ , and Kr^+ ions with H_2 , D_2 , O_2 , N_2 and NO molecules have been carried out in a variable scattering-angle tandem mass spectrometer, at incident ion energies in the range 30-373 eV. Distributions in kinetic energy E of the product ions were measured, and were used to obtain information concerning the energy defects Q of the various transfer reactions, and the internal states of the product ions. Most of the experiments were carried out at the observation angle $\theta = 90^\circ$; in this case, coupling between primary and product ion energies is at a minimum, but the measurements give direct information concerning exothermic reaction channels only. The dominant feature in all the distributions was a sharp (0.3-0.4 eV FWHM) peak located near $E = 0$; Q -values calculated from these peaks were in all cases small (for example, for $\text{Ar}^+ - \text{O}_2$, $Q = +0.16 \pm 0.07$ eV, and for $\text{Ne}^+ - \text{N}_2$, $Q = 0.29 \pm 0.15$ eV). Dissociative transfer reactions in the systems $\text{Ne}^+ - \text{O}_2$ and $\text{Ar}^+ - \text{H}_2$, D_2 have also been studied, using the same technique.

* Supported by the U.S. Office of Naval Research

HA-8 Comparison of the Experimental Cross Section for $\text{Kr}^{++} + \text{Ne} \rightarrow \text{Kr}^+ + \text{Ne}^+$ with Some Simple Theories.* WILLIAM B. MAIER II, Los Alamos Scientific Laboratory. -- Experimental cross sections for $\text{Kr}^{++} + \text{Ne} \rightarrow \text{Kr}^+ + \dots$ are exhibited for energies E_0 in the center-of-mass between 0.4 and 1000 eV. The cross section measured for $\text{Kr}^{++} + \text{Ne} \rightarrow \text{Ne}^+ + \dots$ is given for $0.1 < E_0 < 0.4$ eV. These data may represent the cross section σ for $\text{Kr}^{++} + \text{Ne} \rightarrow \text{Kr}^+ + \text{Ne}^+$ with fair accuracy when $0.1 \lesssim E_0 \lesssim 1000$ eV. The measured cross section is nearly constant for $E_0 \gtrsim 1$ eV and increases as E_0 is decreased below 1 eV. Theoretical representations of σ have been obtained from Langevin theory, Landau-Zener theory, and a semiempirical method. These simple methods do not adequately represent the data over the whole energy range. The Langevin cross section is consistent with the data for $E_0 \lesssim 2$ eV. The Landau-Zener cross section is too large for $E_0 \gtrsim 0.5$ eV and has the wrong dependence on E_0 .

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

HA-9 Thermal Energy Charge Transfer Reactions in Kr/CO and Xe/O₂ Mixtures. JAMES B. LAUDENSLAGER, Jet Propulsion Laboratory.--The near resonant charge transfer reactions occurring in Kr/CO and Xe/O₂ mixtures has been studied using an ion cyclotron resonance spectrometer with a trapped ion analyzer cell¹. The rates for each charge transfer system Kr⁺/CO, CO⁺/Kr, Xe⁺/O₂, and O₂⁺/Xe were measured by observing the intensity of one ion versus trapping time and continuously ejecting the other ion from the cell to prevent the back reaction. The absolute rate constants in each system were found to be smaller than the classical Langevin collision rate^{2,3} even though the energy defect for each reaction system was less than 0.1eV.

¹T. B. McMahon and J. L. Beauchamp, Rev. Sci. Inst. 43, 509 (1972)

²P. Langevin, Ann. Chim. Phys. 5, 245 (1905)

³G. Gioumouisis and D. P. Stevenson, J. Chem. Phys. 29, 294 (1958)

HA-10 Charge-Exchange Cross Sections for Ne⁺ and Ar⁺ Incident on Cs.* F. W. MEYER, and L. W. ANDERSON, Univ. of Wisconsin, Madison--Total charge exchange cross sections have been measured for Ne⁺ and Ar⁺ incident on Cs vapor. A surface ionization detector inside the cesium target chamber was used to measure the Cs target density. Ion beam energies for Ne⁺ incident on Cs were in the range 1.72-40.18 keV. The cross section σ_{+0} for the incident Ne⁺ ions has the almost constant value of $540 \pm 60 \times 10^{-17} \text{cm}^2$ in the energy range 1.72-7.0 keV. The cross section increases from 7 to 20 keV, reaching another plateau of $1010 \pm 70 \times 10^{-17} \text{cm}^2$ in the energy range 20-40.18 keV. Ion beam energies for the Ar⁺ ions incident on Cs were in the range 1.44 to 28.7 keV. The cross section σ_{+0} for incident Ar⁺ ions is $710 \pm 63 \times 10^{-17} \text{cm}^2$ at 1.44 keV. The cross section increases between 1.44 and 8.6 keV, reaching a plateau of $1020 \pm 90 \times 10^{-17} \text{cm}^2$ in the energy range 8.6 to 28.7 keV. Using previously published data¹ on σ_{+0} for Ar⁺ incident on Cs, together with the data of the present experiment, the cross section σ_{+0} of Ar⁺ incident on Cs is now known in the energy range 11 eV to 28.7 keV.

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

¹J. Peterson, and D. Lorents, Phys. Rev. 182, 152 (1969)

SESSION HB

3:45 PM, Wednesday, October 17

Wisconsin Center Auditorium

VACUUM ULTRAVIOLET LASERS II

Chairman: J. B. Gerardo, Sandia Laboratories

HB-1 Experimental and Theoretical Studies of Fluorescence Quenching from Electron Beam Excited Quasi-Molecular Xenon. D.J. BRADLEY, L.D. CLEMENTS, D.R. HULL and M.H.R. HUTCHINSON, Imperial College, London - A pressure dependent quenching of the VUV broad-band fluorescence (15 nm centred at $\lambda 173$ nm) from high pressure Xenon previously reported⁽¹⁾ has been further investigated employing a short duration ($\ll 3$ ns) electron-beam excitation pulse. Excitation processes and loss mechanisms including the quenching of excited species by atomic and molecular collisions have been studied in detail employing a semi-empirical model. Good agreement has been obtained between theoretical calculations and experimental measurements of fluorescence decay, spectral narrowing and pulse shapes. The implications of these results for the design of high power VUV quasi-molecular lasers are discussed.

(1) D.J. Bradley, M.H.R. Hutchinson and H. Koetser, Opt. Commun. 7, 187 (1973).

HB-2 VUV Emission from High-Pressure Xenon, Krypton, and Argon Excited by High-Current Relativistic Electron Beams.* H. A. Koehler, L. J. Ferderber, and P. J. Ebert, Lawrence Livermore Laboratory

The pressure-dependence (0.2 to 61 atm) of the spectra, buildup and decay time constants, output efficiency, and attenuation coefficient of the Xe continuum radiation ($\sim 1700\text{\AA}$) is discussed and the results can be related to high-pressure VUV Xe lasers. Similar results are presented for the Ar ($\sim 1260\text{\AA}$) and Kr (1500\AA) continua.

*Work performed under auspices of the USAEC.

HB-3 Excited State Kinetics in High Pressure Rare Gas Association Lasers. * P. E. Thiess and G. H. Milcy, Univ. of Ill. -- Studies have been conducted to determine the dominant processes and estimate reaction rates in high pressure noble gas association lasers⁽¹⁾ in order to construct a plasma model to predict population inversion. A 5.3 MeV He⁺⁺ ion source was used to produce ionization (and excitation) in a cylindrical gas volume of pure He, Ne, & Ar (to 750 Torr) and in mixtures of these gases with small amounts of N₂, O₂, H₂, Kr & Ar. With field multiplication studies of optical line intensities vs total pressure and concentration (10⁻⁴ to 10%) of the additive were measured (20-Å resolution). This included the near-ir atomic 2p-1s transitions which have not previously been included in studies of high purity high pressure rare gases. The results indicate that both the 2p and 1s atomic states are quenched by two and three body collisions with ground state atoms to form excited rare gas molecules the same as higher states form molecular ions. Hence the model for high pressure plasmas created by external high energy ionization sources⁽³⁾ must be modified to include the 2p atomic states and at least two excited molecular states. (1) J. B. Gerardo & A. W. Johnson, IEEE J. Q. E., QE-9, 748 (1973). (2) W. R. Bennett, Jr., Ann. Phys., 18, 367 (1962). (3) D. B. Rees, C. B. Leffert & D. J. Rose, J. Appl. Phys. 40, 1184 (1964). *Supported in part by the AEC & NSF.

HB-4 Limitation on the Gain of a He₂ UV Laser Due to Photoionization* -- T.W. Hartquist[†] and N.F. Lane, Physics Dept., Rice U. Photoionization of the A¹Σ_u⁺ state is found to severely limit the possible gain of the proposed He₂ UV laser. We have applied the single-channel quantum defect method to a physical model of the He₂ system, obtaining photoionization cross sections varying from $\sigma_i \approx 7 \times 10^{-18} \text{ cm}^2$ at threshold to $\approx 4 \times 10^{-19} \text{ cm}^2$ at 700 Å. These lie slightly below σ_i for the separated-atom 2¹S state of He. Using the experimental value¹ $\sigma_s \approx 3.6 \times 10^{-19} \text{ cm}^2$ for the stimulated emission cross section at 800 Å and our result of $\sigma_i \approx 5 \times 10^{-19} \text{ cm}^2$, we obtain a negative gain for this system.

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

[†] NSF Undergraduate Research Fellow.

¹M. Stockton, L.A. Rosocha, F.J. Soley, J.W. Keto, and W.A. Fitzsimmons, Bull. Am. Phys. Soc. 18, 612 (1973).

HB-5 Absolute Intensities in the Hopfield Continuum.
 K. M. SANDO, University of Iowa.-- Accurate absolute intensities for continuous emission from the first excited singlet state of He₂ are calculated. The most recent results for the transition dipole¹ and the repulsive ground state potential² are incorporated along with an RKR fit to the spectroscopic constants of the excited state.³ The radial wave functions and oscillator strengths are evaluated numerically. The intensities may be used to help predict favorable conditions for constructing a helium "molecular association" laser. Comparison of the calculated intensities for an isolated molecule with those observed from liquid helium may give information about interactions between excited dimers and the bulk liquid.

¹P. L. DeVries, Master's Thesis, University of Texas, Austin, Texas (1973).

²B. Liu and A. D. McLean, private communication (1973).

³K. M. Sando, *Mol. Phys.* 23, 413 (1972).

HB-6 Low-Lying Excited Electronic States of Diatomic Krypton*. Y. TANAKA, K. YOSHINO, and D. E. FREEMAN, AFCRL, Bedford, MA --Low-lying excited molecular states of Kr₂, relevant to the operation of vacuum ultraviolet (VUV) lasers, have been investigated by high resolution VUV spectroscopy. Eight band systems, four well-developed and four rather fragmented, are observed in the region 1260-1050Å. Vibronic analyses of the former four systems reveal that their upper states are correlated to separated atom limits involving one krypton atom at the ground level and one at various levels of configuration 4p⁵5s; these excited molecular states are assigned, in order of increasing energy, as 1_u, 0_u⁺, 0_u⁺, and 1_u, and are derived from the separated atom limits 4p⁶ 1S₀ plus, respectively, 5s(3/2)₂, 5s(3/2)₁, 5s'(1/2)₁ and 5s'(1/2)₁. The four fragmented band systems are correlated to separated atom limits 4p⁶ 1S₀ plus one or another KrI level of configuration 4p⁵5p.

*A preliminary account was presented at the Symposium on Molecular Structure and Spectroscopy, Ohio State University, June 1973.

SESSION JA

9:00 AM, Thursday, October 18

Wisconsin Center Auditorium

ELECTRON-ATOM COLLISIONS

Chairman: S. Chung, University of Wisconsin

JA-1 Electron Excitation of the Potassium Atom.*

JERRY E. SOLOMON[†], DALE F. KORFF[¶], JAMES O. PHILIPS, AND CHUN C. LIN, Univ. of Wisconsin--Electron excitation functions of states in the n^2S , n^2P , n^2D , and n^2F series have been measured, and their characteristic shape may be explained by a generalization of the results of helium and consideration of the strength of coupling. Theoretical excitation cross sections have been obtained by means of the Born approximation and by a series of close-coupling calculations including a 10-state and a 15-state one. The Born approximation is found to overestimate the 4^2P cross sections (because of the superstrong 4s-4p coupling) and underestimate the $2D$ cross sections (because of neglecting the indirect coupling via the $2P$ states). Use of the close-coupling method improves the theoretical results and gives better agreement with experiment.

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

[†]Now at California State University at San Diego.

[¶]Now at Air Force Cambridge Research Laboratories.

JA-2 Electron Excitation of the Lithium 6708Å Resonance Line.* DAVID LEEP and ALAN GALLAGHER,[†] Joint Institute for Laboratory Astrophysics.--We have measured the relative optical excitation function and the polarization of the 6708Å line, using crossed beams of electrons and lithium-6, for electron energies from threshold to 1400 eV. The electron-energy resolution was ~ 0.3 eV; the lithium-beam optical depth was small and varied. We have normalized our excitation function by using the Born theory in the high-energy region, from 50-750 times the threshold energy, where the energy dependence converges to the theoretical behavior. Our results agree within 20% with 2-state close-coupling theories in the energy range 2-5 eV. The expected threshold polarization is not observed with our energy resolution.

*Work supported in part by Advanced Research Projects Agency.

[†]Staff Member, Laboratory Astrophysics Division, National Bureau of Standards, and Professor Adjunct, University of Colorado.

JA-3 Electron Excitation of Metastable Argon and Helium Atoms.* WALTER L. BORST, Southern Illinois University at Carbondale and University of Pittsburgh.-- Electron excitation of Ar and He metastables was studied with a time-of-flight technique from threshold to 50 eV. Using a trapped electron method, the He cross section was calibrated near threshold and found to be $(4.0 \pm 1.5) \times 10^{-18} \text{ cm}^2$ at the first peak at 20.3 eV. At higher energies, the He cross section contains both the 2^3S_1 and 2^1S_0 metastables. Using the secondary electron "yield curve" of the metastable detector, the combined cross section for the $3P_2$ and $3P_0$ argon metastables was found to have a peak value of $3.7 \times 10^{-17} \text{ cm}^2$ at 22 eV within a factor of two. In order to further test the internal consistency of the detector yield curve, the Ar cross section was determined by normalizing to the He cross section and using the relative yield ratio $\gamma_m^{\text{Ar}}/\gamma_m^{\text{He}}$. The resulting cross section had a peak value of $3.4 \times 10^{-17} \text{ cm}^2$. The present Ar cross section is of the same magnitude as that for the two Ar resonance lines.

*Work supported by SIU-C Office of Research and Projects and by NASA and ARPA.

JA-4 Simultaneous Ionization and Excitation to the 4s,p,d,f States of He* by Electron Impact.* WILLIAM D. EVANS, Naval Research Laboratory, FRED L. ROESLER AND CHUN C. LIN, Univ. of Wisconsin.--The simultaneous ionization and excitation process of He by electron impact has been studied by observing the 4686 Å radiation from He⁺ in the 4s,4p,4d,4f states at electron energies of 80-300 eV and gas pressure 2-140 mTorr. Because of the hydrogenic-type near degeneracy of the 4s,p,d,f states, a high-resolution, high-luminosity scanning Fabry-Perot interference spectrometer was used to resolve the thirteen components of the 4s,p,d,f → 3s,p,d transitions. Pressure dependence was observed for the excitation cross sections of the 4s → 3p and 4f → 3d lines down to a few mTorr. The ionization-excitation cross sections of the 4s states are in reasonable agreement with the theoretical values. The 4p cross sections are the largest, the 4s and 4d cross sections are of comparable magnitude, and the 4f cross sections are much smaller.

* Supported in part by the Air Force Office of Scientific Research and National Science Foundation.

JA-5

Shape Resonances Studied* by Elastic Scattering of Electrons at 180° . P. D. Burrow and L. Sanche,[†] Yale U. Elastic scattering of electrons from molecules at 180° offers a number of advantages for the detection of resonant structure which occurs in the scattering cross section due to the formation of temporary negative ion states. We have devised an apparatus to study scattering at this angle with good energy resolution and have used it to observe the shape resonances in a number of common molecules. The results for N_2 , CO, and three linear triatomic molecules, CO_2 , OCS, and CS_2 will be presented.

*This work supported by Research Corporation.

[†]Present address: University of Sherbrooke, Sherbrooke, Canada.

JA-6 Electron Impact Cross Sections for Elastic, Inelastic and Superelastic Collisions. S. TRAJMAR, Jet Prop. Lab., Calif. Inst. of Tech.—In systems where free electrons are present (plasma and laser devices, ionosphere, etc.) electron-atom (molecule) collision processes play an important role in determining the behavior of the system, and the knowledge of the cross sections for these processes is necessary. A brief summary of the present status of electron impact cross section measurements will be given, and examples of recently determined cross sections will be presented for He, Xe, Cu, N_2 , and O_2 .

JA-7 Method of Orthogonal Residuals Applied to Single Channel Scattering of Partial Waves from Ionic Potentials. B. W. SHORE, Lawrence Livermore Laboratory.*--I will describe techniques for numerical construction of scattering radial wavefunctions based on discrete quadrature approximations to the Galerkin procedure of orthogonal residuals. As basis functions I use asymptotic scattering functions (e.g. sine and cosine) augmented by a succession of overlapping cubic B-splines covering the region where the potential acts. A simple quadrature produces matrix elements to convert the radial Schrödinger equation into a set of simultaneous linear equations. Applied to low energy (e.g. electrons less than 10 eV) single-channel scattering, the solving of a 10 x 10 matrix equation typically allows 3-5 decimal places accuracy in phase shifts. I will exhibit illustrative examples appropriate to scattering of electrons by atoms and ions.

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

JA-8 Comparison of Theory and Experiment for Ionized Airlike Mixtures.* M. N. HIRSH†, U. Minnesota, Morris, F. E. NILES, US Army Ballistic Research Laboratories, and K. RAJ, The Dewey Electronics Corporation.--Laboratory measurements of positive and negative ions produced during the megavolt-electron irradiation of airlike mixtures (80% N₂, 20% O₂, 0.6 to 6.0 ppm H₂O, and total pressures of 1, 2, and 5 Torr) have been compared with the predictions of the multispecies atmospheric-chemistry computer code AIRCHEM. Although the total ionization rate is well known, the individual rates for the production of such chemically important species as N⁺, N₂⁺, O⁺, O₂⁺, N(⁴S), N(²D), O(³P), and O(¹D) by the energetic electrons have not been measured directly. The predicted ion spectra are very sensitive to the values chosen for some of these production rates. With physically reasonable production rates, good agreement has been obtained between the computed and observed ion spectra for the assumption that the mass spectrometer is free from mass discrimination.

*Supported in part by the Defense Nuclear Agency.

†Supported by the Laboratory Research Cooperative Program of the US Army Research Office.

SESSION JB

9:00 AM, Thursday, October 18

Wisconsin Center Lake Shore Room

ENERGY TRANSFER

Chairman: F. A. Franz, Indiana University

JB-1 Excited State Chemistry of the Low Pressure Helium Afterglow, I. Reactions Involving 2^3S and $2^3\Sigma$.
L.C. PITCHFORD, K.N. TAYLOR and C.B. COLLINS, U of Texas at Dallas--This work concerns the quantitative modeling of the chemistry of the $He(2^3S)$ and $He_2(2^3\Sigma)$ metastables in a pulsed helium afterglow at 1.86 Torr. A comprehensive 10-term model is used to fit spectroscopic measurements of the time dependent evolution of metastable concentrations. Rate coefficients obtained agree with previous values where such prior measurements have been made. Additionally, a value of $(3.8 \pm 0.5) \times 10^{-9} \text{cm}^3 \text{sec}^{-1}$ has been found for the reaction $He_2(2^3\Sigma) + He_2(2^3\Sigma)$; a value of $(1.7 \pm 0.4) \times 10^{-9} \text{cm}^3 \text{sec}^{-1}$ for $He_2(2^3\Sigma) + e$; and an upper limit of $0.8 \times 10^{-9} \text{cm}^3 \text{sec}^{-1}$ for $He(2^3S) + He_2(2^3\Sigma)$.

JB-2 Excited State Chemistry of the Low Pressure Helium Afterglow, II. Reactions Involving He^+ and He_2^+ .
L.C. PITCHFORD, K.N. TAYLOR, H.S. HICKS, AND C.B. COLLINS, University of Texas at Dallas--A model of the chemistry of He^+ and He_2^+ in a pulsed afterglow at 1.86 Torr is presented which is consistent with a previous investigation of the metastable $He(2^3S)$ and $He_2(2^3\Sigma)$ and electron behavior. In particular it is established that both He^+ and He_2^+ are produced from the mutual metastable ionizing collisions and branching ratios are determined. The value of the molecular recombination rate coefficient is found to be $2.25 \times 10^{-18} [e].814 \text{cm}^3 \text{sec}^{-1}$ at 300°K .

JB-3 Excitation-Transfer in Collisions of Excited and Ground-State He Atoms.*--W.Steets and N.F.Lane, Physics Dept., Rice U. Theoretical studies of several of the excited-state He₂ potential energy curves have been carried out with special emphasis on n=3 separated-atom states. Several avoided crossings are observed and are consistent with existing cross section measurements.^{1,2} In particular, crossings in the 1,3 Σ_g^+ system are felt to be important to the 1p-1s and 3p-3s transfer processes. Our results also predict very small 1,3D-1,3S cross sections, as observed.

* Supported in part by the U.S. Atomic Energy Commission and Robert A. Welch Foundation

¹H.F. Wellenstein and W.W. Robertson, J. Chem. Phys. 56, 1411 (1972)

²W.W. Hunter, Jr. and T.E. Leinhardt, J. Chem. Phys. 58, 941 (1973)

JB-4
Afterglow decay processes in highly ionized helium and argon plasmas* J.H.MOUNTJOY and M.C.SEXTON, University College, Cork, Ireland.

A HCN laser interferometer was used to monitor electron densities from 10^{15} to 10^{12} cm⁻³ in He and Ar afterglows in which electron and neutral gas temperatures were also monitored. Binary electron-atom (collisional) recombination was clearly identified as the principal decay mechanism, with coefficients within the range 10^{-9} to 10^{-11} cm³ sec⁻¹. Excellent agreement with theory was obtained by including elevated and time-varying gas temperatures into the calculations. Moreover, the formation of Ar₂⁺ at higher pressures was dependent on the input discharge power.

* Work supported in part by AFOSR and UKAEA (Culham)

JB-5 Light Emission from an Argon Discharge Containing an Admixture of Carbon Monoxide. G. BEKEFI*, P. AVIVI, F. DOTHAN-DEUTSCH, L. FRIEDLAND, J. L. HIRSHFIELD† and H. KEREN, The Hebrew University of Jerusalem--An experimental study is made of the optical line spectrum emanating from the positive column of a discharge in Argon (pressure 0.5 to 15 Torr) containing minute admixtures (partial pressures from zero to 10^{-2} Torr) of Carbon Monoxide. Throughout the experiments, the current is maintained at a fixed value (30 mA). At Argon pressures below approximately 2 Torr the presence of CO diminishes the intensities of the ArI lines, in accord with expectations. However, at higher Argon pressures, CO causes an unexpected increase in the lines. As little as one part in ten thousand of CO impurity results in a two-fold enhancement. Tentative explanations for this anomalous increase are advanced. Amongst these, the possibility of vibrational quanta of CO being transferred to the Argon atom is being investigated.

*Present address: Dept. of Physics, Massachusetts Institute of Technology, Cambridge, Mass. 02139.

†Present address: Mason Laboratory, Yale University, New Haven, Conn. 06511

JB-6 Vibrational Temperature Measurements in Nitrogen. E. E. WISNIEWSKI, Technology Incorporated, Dayton, Ohio and A. GARSCADDEN, Aerospace Research Laboratories, WPAFB, Ohio.--Measurements of the degree of vibrational excitation produced in nitrogen discharges were made using the Helium Metastable - Penning ionization method. Vibrational temperatures in excess of several thousand degrees at gas temperatures of typically less than 400°K were measured. Energy considerations indicate that the N_2 vibrational distribution is not of a fully developed - modified - Treanor form. The vibrational temperature evolution which was determined from First Negative intensity ratios as a function of power input and time in the afterglow is used to determine the integrated decay rate for the lower vibrational levels.

JB-7 Collisionally Induced Energy Transfer in the $A^2\Sigma^+$ State of OH.* RUSSELL K. LENGEL and DAVID R. CROSLLEY, University of Wisconsin.--OH molecules, chemically produced in a flow system, are excited to individual rotational levels of the $v'=0$ and 1 vibrational levels of the $A^2\Sigma^+$ state, using a frequency doubled tunable dye laser. Addition of foreign gases (H_2 , N_2 , Ar) at pressures of up to ~ 1 torr gives rise to collisions populating states other than the one initially excited. Level populations are determined using rotationally resolved fluorescence emitted by molecules in both the initially pumped and vibrationally relaxed levels. Vibrational transfer in collisions with N_2 is quite rapid and only slightly less efficient than rotational transfer; a preliminary value for the $v'=1 \rightarrow 0$ cross section is $\sim 15 \text{ \AA}^2$. The vibrational transfer is accompanied by rotational transfer with large values of ΔJ , but some retention of the initially pumped rotational distribution is evident. Within a given vibrational level, rotational transfer involving a change of the spin doublet component is less probable than that maintaining it, but the doublet components are scrambled in a vibrational transfer collision.

*Supported by the National Science Foundation.

JB-8 n and ℓ Dependence of Electron Transfer from a Highly Excited (n, ℓ) Atom to SF_6 .* M. Matsuzawa, Argonne Nat'l Lab.-- Reactions of a highly excited atom with a molecule can be largely understood in terms of information on inelastic scattering of a slow electron by a molecule. This comes from that an excited electron in high Rydberg orbit behaves as if it were a free and slow electron except that it is characterized by a momentum distribution. Thus rate constant of the electron transfer from the highly excited (n, ℓ) atom to SF_6 is related to that of thermal electron attachment to SF_6 .¹ Based on an assumed form of velocity dependence of the attachment cross section $\sigma \propto v^\alpha$, the rate constant of the electron transfer is evaluated. For example, there is no n and ℓ dependence of the rate constant for usual s wave threshold law (namely, $\alpha = -1$). The possibility of learning about the velocity dependence of thermal-electron attachment to SF_6 from the measurement of the n and ℓ dependence of the electron transfer will be discussed.

*Work supported by Atomic Energy Commission

¹M. Matsuzawa, J. Phys. Soc. Japan 32 1088 (1972).

SESSION MA

2:00 PM, Thursday, October 18

Wisconsin Center Auditorium

AVALANCHES AND STREAMERS

Chairman: R. N. Varney, Lockheed Palo Alto Research Laboratory

MA-1 Electron Avalanches in Oxygen: Theory.* Lothar Frommhold and R. Corbin, Univ. of Texas at Austin.-- A model of the electronic and ionic reactions occurring in O_2 for pressures from 1-32 torr and for electric field strength to pressure ratios from 35-90 V/cm torr is outlined.¹ The primary negative ion, atomic O^- , is formed by dissociative attachment. It may undergo the competing reactions of charge transfer to O_3^- , three body ion conversion to O_3^- , or electron detachment. The diatomic ion O_2^- , is considered to be unstable and account is made for three body ion conversion to O_4^- and for electron detachment. O_3^- and O_4^- are considered to be stable. Account is also made of the primary negative ion O^- obtaining its reaction energy from the dissociation of O_2 as well as the applied electric field. Expressions for effective attachment rates of O^- , O_2^- , and O_3^- are derived from the continuity equations for the various charge carriers and approximate solutions for slow and fast time resolution are found.¹ The effective attachment rates predicted exhibit a characteristic pressure dependence, which is experimentally verifiable.

- *) Supported by NSF Grant GP 28489 and Joint Services Electronics Program Contract F44620-71-C-0091.
 1) Lothar Frommhold, R. J. Corbin, and D. W. Goodson, Phys. Rev. A 8 (In print) 1973.

MA-2 Electron Avalanches in Oxygen: Experiment.* R. J. Corbin, D. W. Goodson, and Lothar Frommhold, Univ. of Texas at Austin.--In order to justify the model of the electronic and ionic reactions occurring in O_2 as outlined in the preceding abstract, a time resolved drift tube study of electron avalanches in uniform electric fields in O_2 was undertaken. By using slow time resolution the effects of fast reactions can be nearly ignored and the slow (effective) reaction rates accurately measured. The rates for the fast reactions are then obtained by a study at increased time resolution, with the slow rates accounted for as a correction. Measurements have been made at pressures from 4 to 32 torr and at electric field strength to pressure ratios (E/p) from 35 to 90 V/cm/torr. The effective attachment rates for O^- , O_2^- , and O_3^- show a pressure dependence consistent with those of the theory. Specifically, effective attachment rates divided by pressure for O_3^- increase with increasing pressure, and those of O^- and O_2^- decrease. The detachment rates attributed to O^- and O_2^- are found to depend linearly on pressure, and are approximately the same, $v/p_{20} = 10^4 (\text{sec torr})^{-1}$ at an E/p_{20} of 35 V/cm/torr, with the atomic ion detachment rate increasing more rapidly with energy (E/p).

- *) Supported by NSF Grant GP28489 and Joint Services Electronics Program Contract F44620-71-C-0091.

MA-3 The Implication of Reliability Theory for Interpretation of Statistical Time Lag Data.* B.M. LANCASTER JR., AND K.J. NYGAARD, Univ. of Missouri-Rolla--When an electrical discharge gap is subject only to random breakdowns, the reliability $R(t)$ of the gap is defined by $R(t)=\exp(-\lambda t)$, where λ is a constant called the failure rate. More generally, the reliability¹ can be written as

$$R(t)=\exp\left[-\int_0^t \lambda(t')dt'\right],$$

where $\lambda(t')$ can be any function of time. This principle has been used to analyze an experiment for determining metastable fluxes by means of statistical time lags².

*Supported in part by Aerospace Research Laboratories, Wright-Patterson Air Force Base.

1. Igor Bazovsky, Reliability Theory and Practice (Prentice-Hall, Inc., Englewood Cliffs, 1961).
2. L.B. Loeb, Basic Processes of Gaseous Electronics (University of California Press, Berkeley, 1965).

MA-4 Formative Time Lag and Ionization Coefficient Measurements in CO₂ Laser Gas Mixtures.* E. A. CRAWFORD, University of Colorado, and A. V. PHELPS[†], Joint Institute for Laboratory Astrophysics.--Measurements have been made of the formative time lags as a function of electric field to gas density ratio E/N for typical CO₂ laser gas mixtures, i.e., CO₂:N₂:He ratios of 1:1:8 and 1:2:3. These data show reasonable agreement with a simple avalanche model of ionization growth¹ using calculated Townsend ionization coefficients.² The apparatus used Rogowski profile, copper electrodes and a concentric wire trigger. A 700 ns square voltage pulse of measured amplitude is supplied from a Blumlein type pulse generator. The formative lag time is determined from the current wave form.

*Supported in part by the Air Force Special Weapons Laboratory.

[†]Staff Member, Laboratory Astrophysics Division, N.B.S. and Professor Adjunct, Department of Physics and Astrophysics, University of Colorado.

¹P. Felsenthal and J. M. Proud, Phys. Rev. 139, 1796, (1965).

²J. J. Lowke, A. V. Phelps and B. W. Irwin, J. Appl. Phys. (September 1973).

MA-5 Calculation of Townsend's First Coefficient of Ionization. E. NASSER and H. PAREKH, Iowa State U. --
 A theoretical expression for Townsend's first coefficient of ionization, α , under uniform electric field and at low values of field-magnitude-to-pressure ratio, E/p , has been derived using Huxley's rigorous approach to motion of slow electrons in gases.^{1/}
 The expression for α is obtained in terms of experimentally measurable collision cross sections of gas molecules as a function of electron energy. The values of α at E/p between 15 and 24 volt/cm-Torr are calculated using a digital computer by iterative techniques. Hydrogen is selected to test the derived equation by computing α for H_2 and comparing the computed values with those measured independently by other workers. A good agreement is found to exist especially below 22 volt/cm-Torr.

^{1/} E. Nasser, Fundamentals of Gaseous Ionization and Plasma Electronics, Chapt. 6, Wiley-Interscience, New York, 1971.

MA-6 Photomultiplier Measurement of Impulse Streamer Onset. E. NASSER and M. HEISZLER*, Iowa State U. --
 In nonuniform fields in atmospheric air, the onset of the streamer mode of corona breakdown under a short voltage pulse is difficult to detect because of the short duration of the weak ionization.^{1/} Sensitive photomultipliers were used with image conduits placed in close proximity of the streamer path to detect both streamer onset voltage and streamer range. Results were correlated with digital calculations of the field and its gradient in anode vicinity and the length of the initial electron avalanche.

* Now at Isarwerke, Munich, Germany.
^{1/} E. Nasser, Fundamentals of Gaseous Ionization and Plasma Electronics, Chapter II, Wiley Interscience, New York, 1971.

MA-7

Photographic Investigations of Individual Point-Plane Streamers J.M. GEARY and G. W. PENNEY, Carnegie-Mellon Univ. -- A sensitive photographic system is used to obtain distinct photographs of individual streamers in a positive point-plane gap in atmospheric air. The streamers are produced by the application of either (1) a single impulse voltage or (2) a single small triggering pulse superimposed on a larger DC gap voltage. The streamers are seen as curving branched filaments on the photographs which have an appearance substantially different from that of the patterns seen in Lichtenberg figures. In many of the photographs, the path of one streamer branch can be seen to curve toward the path of another streamer branch and to join with it. The genuineness of this surprising effect is confirmed by a supplementary experiment in which the joining phenomenon is reproduced by artificial means. The "secondary streamer" is also observed on the photographs. This observation is confirmed by an additional experiment in which streamer photographs are correlated with photo-multiplier oscillograms of the "secondary streamer". A third additional experiment is presented which compares the Lichtenberg figure technique with the direct photographic technique presented here.

SESSION MB

2:00 PM, Thursday, October 18

Wisconsin Center Lake Shore Room

FLOW AND MAGNETIC EFFECTS, STEADY AND NON-STEADY ARCS

Chairman: J. R. Mahan, Virginia Polytechnic Institute

Study of Long Arcs Stabilized by a Self-Generated Vortex. D.C. Watkins, J.D. Cobine, B. Vonnegut, St. U. of New York at Albany.--Original work with long (=50cm) arcs utilized a forced spiral gas flow in a tube to stabilize the arc¹. More recent work has dealt with long (=100cm) discharges stabilized by a non-restricting vortex powered by the discharge heat alone². It was unknown whether this discharge, which is being studied as a phenomena associated with tornadoes, was a glow or an arc. A comparison of the characteristics of this vortex-discharge to those of previously studied short arcs and vortex-arcs, shows that the self-generated vortex-discharge is an arc. The vortex stabilizes the arc sufficiently to promote study without appreciably modifying the characteristics of the arc. Probes were used to determine some of the arc characteristics. Studies of the voltage and the current in the exponentially decaying tail of a current surge through the discharge, show that the voltage gradient is essentially constant from 5 to 100 amperes, and increases with current from 100 to at least 400 amperes.

¹W. Grotrian, ANNALEN DER PHYSIK, IV folge, 47, 10, 141, 1915

²R.T. Ryan and B. Vonnegut, Science, vol 168, 1349, 1970

Work supported by the Nat. Sci. Found.-grant # A036100

MB-2

ON INTERNAL E.M.F. SOURCES APPEARING IN THE
BLOWN HEAVY CURRENT ELECTRIC ARC

V.V. Dementiev, A.I. Zhidovich, A.G. Shashkov,
O.I. Yas'ko

The negative intensities of the electric field earlier found in the heavy current arc blown by hydrogen are explained by the onset of the internal e.m.f. sources in blown arcs due to expansion and compression jumps in the ionized gas. The value of negative intensity calculated by the theory of Finkelburg and Mecker

$$E = 56 \rho_L (\vec{V} \nabla) (\vec{V}_L - \vec{V})$$

achieves hundreds volts per 1 cm in hydrogen arcs and agrees with the experimental results.

MB-3 Visualization of Some Flow Phenomena in Constricted Arcs H. S. Hsia and C. J. Cremers, University of Kentucky, Lexington. An experimental investigation on the flow downstream of the cathode regime in a constricted arc plasma is described. Gas flow in the heating region was dynamically modeled by slow water flow over a Reynolds number range between 500 and 2000 in order to examine the shear layer separation and reattachment length. A tellurium dye trace method was used for visual observation of the flow patterns in a lucite model. Observation revealed the nature of the flow and aided in a qualitative understanding of the occurrence of the maximum wall heat flux near the cathode which has been observed by several investigators.

MB-4 Density, Electron Temperature and Space Potential Measurements using an Ion Beam Probe,* R. E. REINOVSKY, W. C. JENNINGS, and R. L. HICKOK, Rensselaer Polytechnic Institute--An ion beam probe diagnostic system has been designed and operated to make both space and time resolved measurements of important plasma parameters in the Rensselaer hollow cathode discharge. The system is based on directing a non-perturbing beam of singly charged ions (Li, Na, K, Rb) normal to the confining magnetic field. The rate at which doubly charged ions are produced by electron impact ionization is measured to determine the charged particle density. The energy of the doubly charged ions is analyzed to yield the only direct measure of plasma space potential presently available. In addition, a new multiple-beam technique has been developed to measure electron temperature. Spatial resolution is better than 4mm in each dimension, and the system time response is ~ 10 μ sec. Data in a 2KW helium arc at 10^{-3} torr show densities from 10^{12} - 10^{14} cm^{-3} , electron temperatures from 5-10eV, and space potential variations from 1-30 volts. AC measurements of coherent oscillations in density and space potential have also been made up to 100 KHz.

*Work Supported by AFOSR Grant 72-2191

MB-5 Temperature Measurements in Balanced Rail Arcs.*

D.M. BENENSON and J.J. NOWOBILSKI, State Univ. of N.Y. at Buffalo -- Using techniques previously developed for cross-flow plasmas, temperature distributions and arc profiles have been obtained for balanced rail cross-flow argon arcs. Arc operating conditions included: current 100A, pressure level ~ 800 Torr, rail spacing, 12.5 mm, mainstream velocity ~ 3.7 m/s to ~ 7.3 m/s, magnetic field ~ 3 Gauss to ~ 60 Gauss. The cathode and anode electrodes were tantalum and copper, respectively. Both electrodes were water-cooled to permit continuous operation. At various horizontal locations, the arc cross-section (determined from isotherm distribution) varied from nearly circular to elliptical with major axis in the direction of flow. The elongation increased with mainstream velocity. Such results are in contrast to those previously reported for balanced cross-flow pin electrode configurations. Arc profiles were found to be straight or slanted depending upon the flow and magnetic fields. With slant, the arc attachment at the cathode rail was upstream. This result was probably associated with the relative "stickiness" associated with localized melting of the tantalum. * Research supported by Air Force Office of Scientific Research Grant 70-1928.

MB-6 Energy Utilization in a High-Speed Rotating Arc, M. J. Kofoid, The Boeing Company, Seattle, Washington. The utilization of the input power IV is considered in a d-c arc existing between concentric circular electrodes and rotating rapidly due to an axial magnetic field B . The arc-plasma power IV_{arc} is taken to include radiated power and heat lost to the electrodes. Neglecting the arc-root "sticking" forces as relatively small, the mechanical power IV_0 is that used to overcome the aerodynamic forces on the arc column. The column usually has both a non-assessable time-variable cross-section and involute-like shape; the mechanical power cannot be accurately calculated from aerodynamic principles. The applied voltage V is the sum of the arc-plasma voltage V_{arc} and the arc-rotation induced voltage V_i . It is found useful to recognize that the total electrical energy converted into mechanical energy under both steady and transient conditions is precisely IV_i . V_i is independent of arc shape and is determinable. With very high speed arcs and large B , $IV_i > IV_{arc}$ or $IV_i \gg IV_{arc}$ can exist. IV_i , not IV_{arc} , is then the main factor which increases the total power. V_{arc} of these high current arcs increases much slower than V_i . Taking V_{arc} as simply an extrapolation of lower speed values enables useful estimates of IV to be obtained as $(IV_{arc} + IV_i)$ at very high speeds.

MB-7 Analysis of Alternating Current Arcs.* D. M. BENENSON and S. K. GHOSE, State Univ. of N.Y. at Buffalo
 -- The two-dimensional non-steady Navier-Stokes equations have been applied to the analysis of an alternating current argon arc. Real gas properties and optically thin radiation have been employed; the effects of turbulence have been included. The arc channel is 1cm diameter, 10cm long; the channel is connected through a 6.5cm long nozzle to an upstream reservoir (\approx 4.7cm inlet diameter). Constant mass flow rate and uniform conditions were assumed at the nozzle inlet. Solutions have been obtained in both the laminar flow ($\dot{m}=0.1\text{g/s}$) and turbulent flow ($\dot{m}=5.0\text{g/s}$) regimes. Initially, a 100A steady-state arc is assumed. Following switch-on of the ac arc, current zero is assumed to occur $200\mu\text{s}$ later--equivalent to a current of 938A rms. Numerical solutions for the space and time dependent fields, e.g., flow, temperature, pressure, and electric, as well as for the dynamic arc radius, were obtained in the interval $\pm 200\mu\text{s}$ about the first current zero.

* Research supported by National Science Foundation Grant GK-24292.

MB-8 A Pulsed Xenon Megawatt Arc Plasma Source.
 C. J. MICHELS, NASA Lewis Research Center.--The exhaust of the source flowing into vacuum was measured by Thomson scattering diagnosis. Electron temperature and density were found to be 4-8 eV and of order 10^{13} cm^{-3} respectively. Radial and temporal profiles show these conditions over the 8 cm exhaust diameter at 30 cm from the source. Large shot to shot variations were noted. After a transient spike passes, the conditions persist over the power time, 125 μsec . The exhaust is at minimal conditions to be used to evaluate a proposed near resonant charge exchange pumped laser media theory.¹

¹D. L. Chubb and J. R. Rose, Appl. Phys. Lett. 22, 417 (1973).

SESSION N

3:45 PM, Thursday, October 18

Wisconsin Center Auditorium

NON-EQUILIBRIUM IN ARCS

Chairman: R. E. Kinsinger, General Electric Company

N-1 Light Scattering from Weakly Ionized Arc Plasmas. L. VRIENS, and M. ADRIAANSZ, Philips Research Laboratories, Eindhoven, The Netherlands.--Rayleigh scattering has been used to obtain the radial gas density and temperature distributions in low current Ne, Ar and Xe arcs. Possible contributions to the scattered light intensity at the laser wavelength due to (i) plasma electrons and (ii) excited atoms have been found to be negligible or have been corrected for by measuring (i) the wavelength dependence of the scattered light and (ii) depolarized Rayleigh scattering and Raman scattering. Comparisons made with spectroscopic results give direct information on departures from LTE. Characteristic axis gas temperatures obtained from Rayleigh scattering are 2500 K for a 1 atm, 2 A Ne arc, 4300 K for a 3 atm, 2 A Ne arcs, 4000 K for a 1 atm, 2 A Ar arc and 3600 for a 0.3 atm 3 A Xe arc. Characteristic corresponding spectroscopic "temperatures" are 7000 K and 5400 K for Ne and 9000 K for Ar.

N-2 Spectroscopic Mapping of the Nonequilibrium between Electron and Excitation Temperatures in a 1 Atm Helium Arc. T.L. EDDY, West Virginia Inst. of Tech., E. PFENDER and E.R.G. ECKERT, U. of Minnesota — The nonequilibrium thermodynamic states of a 100 amp, 1.016 bar, free burning helium short arc with a 10 mm electrode gap as obtained from spectrometric measurements are presented at cross sections 1, 2, 5, 7, 8, 9 and 9.5 mm from the cathode. The diagnostic methods employ a multifluids model extended to consider nonequilibrium between electron and excitation temperatures, as well as simple nonequilibrium among excited electronic levels. Seven He lines yield population densities and upper level excitation temperatures T_{exp} . The electron density is calculated from continuum intensity measurements using the relation of Anderson and Griem plus the electron-atom bremsstrahlung relation of Firsov and Chibisov. The electron temperature T_e is calculated using the experimental electron density and excited level densities with a method suggested by the work of Athay and Menzel. The effective total atom excitation temperature T_{exa} is obtained by iteration. The results indicate $T_{exa} = T_{LTE}$; T_e up to three times T_{exa} near both electrodes and 1.5 T_{exa} in the middle; heavy particle temperatures T_a appear to follow T_e except near the anode where $T_a \sim T_e/6$; and $n_e \sim 10n_{e, LTE}$ near the cathode.

N-3 Temperature determination in a Na-Xe discharge.
 J.H.WASZINK, Philips Research Laboratories, Eindhoven,
The Netherlands. Time-resolved measurements have been
 made of the profiles of the Na 5890/96 Å ($^2S - ^2P$) and the
 8183/94 Å ($^2P - ^2D$) lines emitted by a 50 Hz Na-Xe
 discharge ($p(\text{Na})=0.3$ atm; $p(\text{Xe})=0.03$ atm at filling).
 The section of the discharge envelope through which the
 measurements have been made is a ruby cylinder (ϕ 7.5 mm).
 The radiation from a cylindrical volume (ϕ 0.5 mm)
 perpendicular to the axis was recorded. The temperature
 distribution in the discharge has been derived from a
 comparison with calculated line profiles. The
 calculation is based on a non-equilibrium model¹. For
 a current of 5 A and a wall temperature of 1500 K the
 temperature at the axis is found to be 4300 K. The
 emitted intensity at the minimum of the self-absorbed
 lines is consistent with an electron temperature of
 2200 K near the wall, which confirms the deviation from
 equilibrium derived from the model.

xSubmitted by R.Bleekrode.

¹J.H.Waszink, J.Phys.D, 6, 1000 (1973).

N-4

Departure from LTE in a 200 Torr Sodium Discharge.
 J.H. INGOLD, General Electric Co. -- A three-level so-
 dium atom is assumed for the purpose of calculating the
 departure from LTE of the excited atom density in a nar-
 row cylindrical sodium discharge. Electrons and ions
 are assumed to be in LTE at the prescribed parabolic gas
 temperature. It is concluded that LTE is valid in the
 center of the discharge ($r/a < 0.6$), but breaks down
 near the wall ($0.6 \leq r/a \leq 1$). For $0.6 \leq r/a \leq 1$, the
 excited atom density is higher than given by LTE, due
 to copious absorption of photons which originate near
 the center of the discharge. Consequently, calculations
 of radiated power may be low by about 5% when LTE is
 assumed to hold all the way to the wall.

N-5 Experimental Check on Electron-Ion Energy Transfer in an Argon Arc*. B. VAN DER SIJDE, UNIV. EINDHOVEN, NETHERLANDS--Temperatures and densities of electrons, ions and neutral particles in a hollow cathode argon arc with a hot cathode (2500 K) have been calculated from spectroscopic and microwave measurements. Typical values of the temperatures were 4, 1 and .5 eV, while the densities were 10^{19} , 10^{19} and $5 \cdot 10^{18} \text{ m}^{-3}$, respectively. The discharge current ranged from 10 to 70 A, the background pressure from $.75 \cdot 10^{-3}$ to $1.5 \cdot 10^{-3}$ torr and the confining axial magnetic field from 10^{-2} to $12.5 \cdot 10^{-2}$ T. Combining an energy transfer model used by Hudis et al.¹ with our experimental data enables us to verify quantitatively the electron-ion energy transfer formula of Spitzer. Agreement with this formula is found within +10 and -100 per cent for appropriate conditions, i.e. magnetic fields $> 10^{-1}$ T. These results are compared with Chandrasekhar's formula, containing an extra factor T_i/T_e (ion, electron temperature respectively). It will be discussed whether accounting for losses of ions due to diffusion and drift phenomena before these particles transfer their energy to neutral particles, can still improve the results.

*Submitted by H.L.HAGEDOORN

¹M.Hudis, K.Chung and D.J.Rose, J.Appl.Phys. 39, 3297 (1968).

SESSION OA

9:00 AM, Friday, October 19

Wisconsin Center Auditorium

PHOTON INTERACTION AND BREAKDOWN

Chairman: F. L. Roesler, University of Wisconsin

OA-1 Multiphoton Ionization of Molecular Cesium with a Tunable Dye Laser.* C. B. COLLINS, B. W. JOHNSON, D. POPESCU, G. MUSA, M. L. PASCU and IOVITZU POPESCU, U. of Texas at Dallas, Inst. of Physics of Bucharest, and U. of Bucharest--Observation of the two-photon ionization of molecular cesium has been made as a continuous function of laser wavelength in the 6200 Å to 6600 Å region with a tunable dye laser having 0.18 cm⁻¹ linewidth. This work serves to illustrate the extension to neutral molecular species of the important techniques of resonant multiphoton photodetachment spectroscopy¹. The resulting two-photon photoionization spectrum is interpreted in terms of the vibrational structure of the resonant intermediate molecular state.

*This work was conducted as part of the U.S.-Romanian Co-operative Program in Science and Technology in association between the University of Texas at Dallas and the Institute of Physics of Bucharest. Financial support was provided in part by the U.S. National Science Foundation Grant GF443 and in part by the Romanian CSEN and CNST.

1. W. C. Lineberger and T. A. Patterson, Chem. Phys. Lett. 13, 40 (1972).

OA-2 Multiphoton Excitation and Ionization of Atomic Cesium with a Tunable Dye Laser.* D. POPESCU, C. B. COLLINS, B. W. JOHNSON, and IOVITZU POPESCU, U. of Texas at Dallas, Inst. of Physics of Bucharest, and U. of Bucharest--The two-photon excitation and three-photon ionization of atomic cesium is investigated over the 6550 Å - 6950 Å wavelength region with a tunable dye laser source having a 0.08 Å linewidth and a space charge ionization detector sensitive to a few ions per second. The resulting dispersion curve for photoionization is interpreted in terms of the two-photon transitions from the ground 6²S level to resonant n²D and n²S intermediate states. Transitions from n=9 through 13 have been recorded for the S-D series and from n=11 through 14 for the S-S series.

*This work was conducted as part of the U.S.-Romanian Co-operative Program in Science and Technology in association between the University of Texas at Dallas, and the Institute of Physics of Bucharest. Financial support was provided in part by the U.S. National Science Foundation Grant GF443 and in part by the Romanian CSEN and CNST.

1. W.C. Lineberger and T.A. Patterson, Chem. Phys. Lett. 13, 40 (1972).

OA-3 Laser Induced Plasmas in Electric Fields.* GEORGE P. ARNOLD, C. J. ELLIOTT, ROBERT G. WENZEL, Los Alamos Scientific Laboratory. -- Using an HF chemical laser, the energy dependence of laser induced plasma formation in air on applied electric field is investigated. The threshold energy is found to increase monotonically with gap voltage to within a few kilovolts per cm of the spontaneous breakdown field. The possibility that this dependence may be due to precipitation of particulate matter was investigated, and was not found to be consistent with the observations. One alternate mechanism, in which free electrons drift out of the focal volume under the influence of the external field, is consistent with the experiment.

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

OA-4 The Time Behavior of Arc Formation in Discharges Triggered by Laser Induced Plasmas.* ROBERT G. WENZEL, C. J. ELLIOTT, GEORGE P. ARNOLD. Los Alamos Scientific Laboratory -- Streak and framing camera photographs, as well as oscillograms, were used to study the time behavior of arc formation in discharges triggered by laser induced plasmas. The laser plasmas were formed at various points within a 1.6 cm gap, as well as outside the gap. Low-jitter time delays ranging from 70 nsec to 3 μ sec were observed, the latter being significantly greater than the 150 nsec laser pulse. The time delays are characterized by lack of observable current flow and luminosity. The arc formation is completed in a time which is invariably short compared to the delay. Possible mechanisms are considered.

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

Laser Produced Breakdown in Mercury Vapor
 J. G. Winans and C. Santaram* State Univ. of
 N.Y. at Buffalo**. A ruby laser, Q switched
 with cryptocyanine solution, was used to
 produce electrical breakdown in quartz tubes
 containing Hg vapor at pressures up to 30 atm.
 Laser produced breakdown spectra, compared to
 Tesla discharge spectra at the same pressure,
 showed a continuous spectrum; Hg I lines
 broadened in the manner expected for the Stark
 effect; several lines due to Hg II; and no
 trace of Hg₂ bands. Hg 2537 was much weaker
 compared to other Hg I lines than in Tesla
 produced spectra. A number of lines in laser
 produced spectra were due to silicon and
 calcium. These could be excited separately by
 focussing the laser beam on a flat fused
 quartz plate.

*Now at Union College, Barbourville, Ky.

** Some of these observations were made at
 Banaras Hindu University, Varanasi, U.P. India
 in cooperation with Ran. B. Singh, now at
 Central Forensic Science Lab. Calcutta, India.

OA-6 Ionization and Excitation Growth in High Pressure
 Rare Gases and Mixtures. P. E. Thiess and G. H. Miley,
 Univ. of Ill. -- Studies of current and excited state
 multiplication [$\int \alpha/p$ & $\int \epsilon/p$] in high pressure pure He, Ne,
 & Ar and N₂, O₂, H₂, Ar, Kr, & Xe in Ne & He and N₂, Kr,
 & Xe in Ar have been investigated in cylindrical geometry
 between 10 Torr and 750 Torr, up to E/p = 30, and with
 minority gas concentrations from 10⁻⁴ to 10%. Initial
 ionization, i₀, was produced in the gas by an external
 source (5.3 MeV He⁺⁺ ions). In addition to measuring the
 current multiplication, selected optical transitions were
 studied in detail by photon counting using a 3/4m mono-
 chrometer. These included the near-ir 2p-1s lines of Ne
 & Ar, the He n = 3 lines, and molecular emissions. Only
 the 5852-Å Ne line⁽¹⁾ and the H_α line⁽²⁾ have been previ-
 ous investigated in such a Townsend discharge. The re-
 sults are in general agreement with theoretical predic-
 tions of Dryvesteyn and Penning⁽³⁾ which indicate an opti-
 mum E/p for production of excited states. An optimum im-
 purity concentration was also found, the value of which
 depends on the gas species and excited state of interest.
 (1) Buursen, et al., Physica, 60, 244 (1972). (2) Corri-
 gan and vonEngel, Proc. Roy. Soc., A245, 335 (1958),
 Blasberg and deHoog, Physica, 54, 468 (1971). (3) Druy-
 vestyn and Penning, Rev. Mod. Phys., 12, 102 (1940).
 *Supported in part by the AEC & NSF.

The Dynamics of Particle Induced Air Breakdown

D. E. Lencioni and L. C. Pettingill, M.I.T.
Lincoln Laboratory. -- A 5 joule e-beam laser with pulse length ≈ 200 nsec was used to study air breakdown induced by a single $50 \mu\text{m}$ carbon particle positioned at the center of a focused laser beam. The threshold for 50% probability of breakdown was $\approx 5 \times 10^7 \text{ W/cm}^2$ for focal spot diameters from .05 to 0.4 cm. Particle motion during the pulse was found to be $\leq 1 \mu\text{m}$ at near threshold intensities. The dynamics of plasma formation were studied with an image converter camera and are compared to the radial dependence of the transmitted laser intensity. Near threshold the plasma grew as an axisymmetric volume surrounding the particle with an absorption length $\approx 5 \times 10^{-2} \text{ cm}$. The axial and radial velocities were $\approx 2 \times 10^5 \text{ cm/sec}$ and $\approx 1.4 \times 10^5 \text{ cm/sec}$. At higher intensities the plasma formed as a thin disk with an absorption length $\leq 1.5 \times 10^{-2} \text{ cm}$ which propagated towards the laser and grew radially within the beam. The axial velocity varied with intensity in accord with the planar theory for laser supported detonation waves but with a reduced magnitude. Comparison is made to a model which includes the energy relaxation due to radial expansion.

OA-8 The Rare Gas Ionization Chamber.

J. A. R. SAMSON and G. N. HADDAD, Univ. of Nebraska--The rare gas ionization chambers have been used primarily to determine the absolute photon flux of vacuum ultraviolet radiation down to a short wavelength limit of about 300 \AA . The work reported here describes how they can be used to extend this limit down into the soft x-ray region. In addition it is shown how the rare gas ion chambers can be used to obtain electron ionization cross sections and W-values (energy loss per ion pair produced). The W-values are obtained in the energy range 0-100 eV where no results have been reported.

OA-9 Spin Relaxation of Thermal Alkali Earth Ions in Noble Gas Buffers. E. W. WEBER, H. ACKERMANN, N. S. LAULAINEN*, and G. zu PUTLITZ, I. Phys. Inst., U. of Heidelberg.-- Direct optical pumping was used to study collisions between Sr^+ (Ba^+) ions, electrons and noble gas atoms.¹ From measurements of transient signals, the Sr^+ $^2\text{S}_{1/2}$ depolarization cross sections for binary noble gas collisions were derived, in \AA^2 : $2 \cdot 10^{-5}$ (He), $4 \cdot 10^{-5}$ (Ne), $5.7 \cdot 10^{-3}$ (Ar), $1.8 \cdot 10^{-2}$ (Kr), and $4.0 \cdot 10^{-2}$ (Xe). These cross sections are about two to three orders of magnitude larger than the corresponding ones of the isoelectronic Rb atom. For the spin exchange cross section $\sigma_{\text{SE}}(\text{Sr}^+ - e^-)$ a value of about $3 \cdot 10^3 \text{\AA}^2$ was obtained ($\sigma_{\text{SE}}(\text{neutral alkali} - e^-) \approx 3 \cdot 10^2 \text{\AA}^2$). The increase of the cross sections for the ions compared to the neutral atoms for both processes indicate the drastic influence of the additional ionic charge.

* Present address: Geophysics Group-AK50, U. of Washington, Seattle.

¹E.W. Weber, Z. Physik 256, 1 (1972).

OA-10 Transient Signals in the White Light Optical Pumping of Cesium.* F.A. Franz and C.E. Sooriamoorthi, Indiana University, Bloomington, Ind. - - Optical pumping transients have been measured in Cs vapor at pressures of He buffer gas ranging from 1.0 to 620 Torr, utilizing a new white light optical pumping technique. At low He pressures the transients are effectively single exponential and yield a value for the Cs-He diffusion coefficient of $0.32 \text{ cm}^2/\text{sec}$ at 15°C . At high pressures the transients are double exponential, and yield a value of $2.4 \times 10^{-23} \text{ cm}^2$ for the nuclear spin independent cross section for collisional relaxation of $\langle S_z \rangle$ in binary collisions of Cs $^2\text{S}_{1/2}$ state atoms with He atoms, and a value of 11.8\AA^2 for the nuclear spin independent cross section for the relaxation of $\langle J_z \rangle$ in the $^2\text{P}_{1/2}$ state. The experiment also provides strong experimental evidence for the existence of bound Cs-He van der Waals molecules, the formation and destruction of which makes a small contribution to the measured relaxation rates.

* Work supported in part by the Air Force Office of Scientific Research, Office of Aerospace Research, USAF, under grant No. 69-1686.

SESSION OB

9:00 AM, Friday, October 19

Wisconsin Center Lake Shore Room

PHYSICS OF ARC LIGHT SOURCES

Chairman: G. L. Rogoff, Westinghouse Research Laboratories

MEASUREMENT OF THE TEMPERATURE DISTRIBUTION AND
CALCULATION OF THE TOTAL SPECTRUM OF A HIGH
PRESSURE SODIUM VAPOUR DISCHARGE.

J.J. de Groot, Light Division, N.V. Philips'
Gloeilampenfabrieken, Eindhoven, The Netherlands.

The temperature distribution in a high pressure sodium discharge is determined from the intensity maximum of a non-resonant sodium line; the sodium vapour pressure is determined from the wavelength difference between the maxima of the self-reversed D-lines. This is achieved via an iterative solution of the radiative transfer equation. Values for the axis temperature derived from the electrical conductivity, are in agreement with the present measurements.

With the help of the radiative transfer equation the total spectrum has been calculated. The calculated spectrum agrees with the measured spectrum. The influence of the buffer gases xenon, helium and mercury has also been investigated.

OB-2 Thermal and Radiative Properties of Metal-Halide
Arcs. E. FISCHER AND L. REIDER, Philips Forschungs-
laboratorium Aachen GmbH. --Based on the energy balance a theoretical model has been developed for arcs in which the main energy transfer mechanism is the transport of chemical reaction energy associated with strong radial diffusion fluxes. For the example of an arc in tin-halide atmospheres detailed calculations have been carried out. The resulting electrical, thermal and radiative data are compared with electrical and spectroscopic measurements. The very good agreement between calculated and measured quantities indicates that the present model gives a realistic description of such arcs. Furthermore, the different emission and absorption mechanisms determining the spectral properties of these arcs will be briefly discussed.

OB-3 The influence of the tin-halide pressure on the spectrum of mercury/tin-halide arcs.

P.C. DROP, J.J. de GROOT and A.G. JACK, Light Division, Philips, Eindhoven, Netherlands.

The temperature profile in a mercury/tin-iodide arc changes in form as the tin-iodide pressure increases. From emission profile measurements the source of the continuum has been shown to be mainly due to SnI molecules. Similar measurements have been performed on mercury/tin-iodide-chloride arcs with different I/Cl-ratios and tin-halide pressures. The continuum absorption is due to tin-dihalide molecules. For SnCl_2 molecules the visible and near-UV absorption coefficient has been found to be an order of magnitude less than that for SnI_2 molecules. The arcs were burned horizontally and stabilized magnetically. This eliminates axial inhomogeneities and arc instabilities, the latter arising at high tin-halide pressures. The measured spectra at various tin-halide pressures are compared with a theoretical model which includes continuum emission from tin-monohalide molecules and continuum absorption due to SnI_2 molecules.

OB-4 Self-Absorbed Atomic Line Radiation from the High Pressure Mercury Arc. R. J. ZOLLWEG and R. W.

LIEBERMANN, Westinghouse Research Labs.--The formulae of Holstein¹ predicting the escape of strongly self-absorbed (imprisoned) resonance radiation have been generalized to permit application to atomic lines of arbitrary optical density for a cylindrical arc. By combining these results with the concept of an equivalent isothermal arc² of effective temperature and effective radius a relatively simple, yet reliable means has been found to predict the net radiation emitted by each of several self-absorbed lines in the high pressure mercury arc. Calculated results are compared with Rössler's measurements³ for the "uv-Standard" mercury arc [pressure 1.6 atm., effective temperature 5700°K, arc diameter 18 mm]. Agreement is generally within 20-40% except where lines overlap.

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

²W. Elenbaas, The High Pressure Mercury Vapour Discharge, North-Holland Pub. Co., Amsterdam (1951).

³F. Rössler, Ann. Physik 10, 177 (1952); Z. Physik 133, 80 (1952).

OB-5 Continuum Radiation from the High Pressure Mercury Arc. R. J. ZOLLWEG and R. W. LIEBERMANN, Westinghouse Research Labs.---The contributions of various radiation mechanisms to the continuum radiation of the "uv-Standard" mercury arc have been calculated. The electron-neutral bremsstrahlung, obtained through use of the electron elastic scattering cross section, is the dominant continuum mechanism in the near infrared. In the visible electron-neutral bremsstrahlung and recombination radiation (responsible for some observed structure) are comparable. The quasistatic theory¹ of line broadening is used to account for molecular effects in the wings of the resonance lines which become relatively important because of strong self-reversal effects. A radiative transport calculation is used with an assumed parabolic temperature profile. The results generally agree within 20-40% with Rössler's measurements² of the spectral distribution of the continuum and within 15% for the total power radiated.

¹R.E.M. Hedges, D.L. Drummond and A. Gallagher, Phys. Rev. A6, 1519 (1972).

²F. Rössler, Ann. Physik 10, 177 (1952); Z. Physik 133, 80 (1952).

SESSION PA

10:45 AM, Friday, October 19

Wisconsin Center Auditorium

RADIATION

Chairman: J. A. R. Samson, University of Nebraska

PA-1
 RADIATIVE LIFETIMES OF THE $A^2\Sigma^+$ STATE OF OD*
 David Wilcox and Richard Anderson, Dept. of
 Physics, Univ. of Missouri-Rolla, Rolla, MO
 65401.

The lifetimes of approximately 100 lines of
 the 3065A (0,0) band of OD were measured.
 Data was taken at five different pressures
 for each line with a pulsed rf discharge and
 delayed coincidence apparatus. Variation of
 lifetimes of the rotational lines over the
 band will be reported.

Supported by ONR Contract N00014-69-A-0414-0004

PA-2 Long-Lived, Excited States of N_2^+ . * WILLIAM B.
 MAIER II and REDUS F. HOLLAND, Los Alamos Scientific
 Laboratory. -- Long-lived, excited states of N_2^+ have
 been detected in ion-neutral reactions and in emission
 spectra. The identities of these states are discussed.
 Present evidence from electron and ion impact work and
 from spectroscopy suggests that electron impact popu-
 lates groups of N_2^+ states ~ 17 eV, $\sim 19-22$ eV, and 23.8-
 25.6 eV above the ground state of N_2 . The first group
 of states is easily identified to be low $A^2\Pi_u$ vibra-
 tional levels. The second group is probably $A^2\Pi_u$ vibra-
 tional levels having $v' \geq 10$ and populated by autoioni-
 zation. The final group may be quartet states, such as 1
 $^4\Pi_u$, or doublet states, such as those found by Cartwright
 and Dunning.²

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

¹J.C. Lorquet and M. DeSouter, Chem. Phys. Lett. 16, 136
 (1972).

²Thomas Dunning and D. C. Cartwright (private Communi-
 cation).

PA-3

The Mechanism for the Production of the Carbon Monoxide Flame Bands. Nicholas W. Winter, Jet Propulsion Laboratory. The recombination of $O(^3P)$ and $CO(^1\Sigma^+)$ has been studied theoretically by calculating the potential energy surfaces for the five lowest states of CO_2 . In contrast to earlier mechanisms, four states were found to be bound relative to the above dissociation limit. These surfaces are in agreement with the CO_2 emission as observed from an afterglow source and suggest a new mechanism for the chemiluminescent reaction.

PA-4 Collisional Broadening of the Hanle Effect in Iodine.* LLOYD G. WILLIAMS and DAVID R. CROSLY, University of Wisconsin.--A study has been made of the collisional broadening, by the rare gases, of the Hanle effect signal in the $(5p^46s) ^4P_{5/2}$ state of iodine. The cross sections for the destruction of alignment in this state are (in \AA^2): He, 9.8 ± 1.1 ; Ne, 19.5 ± 1.6 ; Ar, 37.6 ± 3.1 ; Kr, 38.7 ± 3.6 ; Xe, 49.2 ± 3.1 . The relative values of these cross sections are in good agreement with predictions made using a van der Waals interaction between the excited iodine and the rare gases. In particular, this result for the helium broadening cross section may be described by such a mechanism without invoking additional effects due to shorter range collisions.

*Supported by the National Science Foundation.

PA-5
 RESONANCE BROADENING IN THE SINGLET SPECTRUM OF He
 D.M. Camm and G.H. Copley
 Institute of Astronomy and Space Science
 University of British Columbia, Vancouver, Canada

Resonance broadening of the 7281 Å and 6678 Å He lines emitted from a gas discharge at pressures around 1 atmosphere has been measured at a temperature of about 500°K. Temperatures in the discharge were obtained by recording the intensity distribution of the $^3\pi_g \rightarrow ^1\Sigma_u$ ($v'=0, v''=0$) band of He₂ at 4650 Å and the $^2\Sigma_u^+ \rightarrow ^2\Sigma_g^+$ ($v'=0, v''=0$) band of N₂ at 3914 Å. Analysis of the asymmetry of the He line profiles shows that the impact approximation is no longer a valid description of the collision process at the He densities encountered in this experiment. The self broadening constant of the 2¹P state in He was derived from the widths of the resonance broadened profiles after correction for residual van der Waals broadening.

PA-6 Non-Lorentzian ICR Line Shapes due to Velocity-Dependent Ion-Neutral Collision Frequencies. *
 J. H. WHEALTON⁺ and E. A. MASON, Brown U. --An asymptotic solution of the Boltzmann equation has been developed for steady-state ion cyclotron absorption in a uniform, unbounded, weakly ionized gas, with no restriction on the velocity dependence of the collision frequency or on the ion-neutral mass ratio. The method uses the expansion of the collision term of the Boltzmann equation in Burnett functions, and solution by a moment method. Velocity dependence of the collision frequency causes deviations from Lorentzian line shape. Particular types of deviations are interpreted in terms of the nature of the ion-neutral force law. General features of line shapes that cannot be attributed to the nature of the force law are skewness and central dips.

*Supported in part by NASA Grant NGL-40-002-059.

⁺Present address: JILA, Boulder, Colorado 80302.

PA-7 DETERMINATION OF HIGH FREQUENCY ELECTRIC FIELDS IN PLASMAS FROM THE HYDROGEN SPECTRUM Arthur Cohn, AFCRL, P. Bakshi and G. Kalman, Boston College.--In a plasma there are high frequency electric fields due to Langmuir electron oscillations in conjunction with other low frequency fields. The combination of these fields determine the shifted position of the spectral components of the hydrogen lines.¹ Thus from measurements of the spectral positions only, without the difficulty of measuring the line intensities, the strength, direction, and frequency of the Langmuir oscillation field can be determined. Calculations for the Balmer series are compared to the experimental profiles² observed from discharges in the TORMAC device during turbulent heating. The high frequency electric field is determined to have a strength of $1.3 \cdot 10^7$ V/cm at a frequency of $2 \cdot 10^{12}$ hertz.

1. A. Cohn, P. Bakshi and G. Kalman, Phys. Rev. Lett. 29 324 (1972).
2. C.C. Gallagher and M.A. Levine, Phys. Rev. Lett. 30 897 (1973).

SESSION PB

10:45 AM, Friday, October 19

Wisconsin Center Lake Shore Room

THERMAL AND RADIATIVE PROPERTIES OF ARCS

Chairman: E. Pfender, University of Minnesota

PB-1 The Lowering of the Hydrogen Ionization Potential in an Argon Arc Plasma:* S.K. Srivastava and G.L. Weissler, Dept. of Phys., U. of So. Calif., Los Angeles.--Hydrogen was flowed into a wall-stabilized high current arc, using argon as a carrier gas. The advance or the Inglis and Teller shift towards longer wavelength of the series limit was observed for different electron densities and temperatures, and the results are in good agreement with theoretical work,^{1,2,3} which takes into account both the microfield and the polarization terms.

*Supported by ONR, Contract #N00014-67-A-0269-0014

¹D.R. Inglis and E. Teller, *Astrophys. J.* 90, 439 (1939);
B.H. Armstrong, *J. Quant. Spectrosc. Radiat. Transfer* 4, 207 (1964).

²G. Ecker and W. Kröll, *Z. Naturforsch.* 21a, 2023 (1966);
G. Ecker and W. Weizel, *Ann. Physik* 17, 126 (1956).

³A. Unsöld, *Z. Astrophys.* 24, 355 (1948);
P. Debye and E. Hückel, *Z. Physik* 24, 185 (1923).

PB-2 Electrical and Thermal Conductivity of Ionized Nitrogen. R.S. DEVOTO, Georgia Inst. of Technol., and M. Capitelli, U. Bari -- The electrical and thermal conductivity of nitrogen at atmospheric pressure have been computed theoretically with expressions from the Chapman-Enskog method. Intermolecular potentials judged to be most accurate were used for computing cross sections among molecules, atoms and ions. e-N₂ cross sections were taken from an analysis of drift measurements; e-N cross sections were inferred from a single measurement and theory neglecting the ³P resonance. Generally satisfactory agreement between theory and experiments for electrical conductivity was noted, although the former appears slightly high at 10000-13000K. Incorporation of the ³P resonance could improve agreement at these temperatures. The thermal conductivity is also in generally reasonable accord with measurements, but lies somewhat higher than most experiments at 13000-18000K. In this range the ion-atom charge-transfer cross is of critical importance for the reactive thermal conductivity. Increasing this cross section would improve agreement.

Spectroscopic Studies of High Pressure Argon Plasma, U. H. Bauder, Georgia Inst. of Tech. and D.L. Bartelheimer Systems Res. Lab. Profiles of several lines of the neutral and singly ionized argon were recorded at different particle densities and temperatures. In particular the profiles of AI 4300 and AII4806 are presented for a range of electron number densities, $n_e: 3.6 \times 10^{16} - 2.8 \times 10^{17}$ and temperatures, $T: 10050^\circ - 13500^\circ$ as achieved by a variation in gas pressure from $p: 1 \text{ atm} - 20 \text{ atm}$. Values of the line - halfwidth and line - shift are determined and compared to GRIEM's* theoretical predictions. The plasma used for the investigations is generated in a cascade arc of 5 mm diameter, operating steady state at pressure levels up to 250 atm. The temperature profiles of the arc column are presented for the pressure range 1-200 atm. The line - profile measurements were performed with a 0.8 m grating spectrograph viewing a side-on projection of the plasma. At predetermined wavelength settings a friction-free scanning mechanism is used to sweep the arc projection across the spectrograph entrance slit. Curve fitting of theoretical line profiles to the measured profiles shows that of the various broadening mechanisms Stark broadening is the dominant effect. *H. Griem, Plasma Spectroscopy. McGraw Hill 1965

PB-4 Radiative Properties of Xenon. P. W. SCHREIBER, A. M. HUNTER, and P. TAYLOR, Aerospace Research Laboratories, Wright-Patterson AFB, Ohio - A free-burning arc facility was designed and used to study the radiative characteristics of Xenon plasma at a pressure of one atmosphere. To obtain a pure plasma, the system was evacuated to less than 10^{-4} Torr before introducing the test gas. Xenon was cryogenically pumped through the arc chamber during runs. The Xenon was then purified and used for additional measurements. A very stable arc was obtained for the duration of the Xenon supply which lasted for several hours. Plasma temperature distributions were experimentally determined by measuring the absolute emission coefficients of spectral lines of known transition probabilities. The continuum emission coefficient was measured from 3900\AA to 6500\AA and correlated with the plasma temperature.

PB-5 Spectroscopic Investigation of Demixing Effects in a Wall-Stabilized SF₆ Arc. E. SCHULZ-GULDE, G. BARUSCHKA, Inst. f. Plasmaphys. Techn. Univ. Hannover, Federal Republic of Germany.

A wall-stabilized arc having a canal diameter of 3.2 mm was operated in SF₆ at atmospheric pressure at a current of 40 A. Except for the edge of the arc column, all SF₆ molecules were fully dissociated. Photoelectric measurements were carried out for the S I 4695 Å and S II 5454 Å lines for which the plasma was optically thin. By using known sulfur line transition probabilities the radial distribution of the sulfur to fluorine concentration ratio was determined from the Abel inverted line data under the assumption that a Saha-Boltzmann relationship exists between neutral and ionized sulfur atoms. The measured S to F concentration ratio within the arc is lower by a factor of up to 3.3 than that of the gas admitted to the arc, as a result of a diffusive separation or demixing of gaseous species due to large radial temperature gradients. Also, the measured concentration ratio is lower than that theoretically predicted by Frie.

SESSION QB

11:35 AM, Friday, October 19

Wisconsin Center Lake Shore Room

ELECTRODE EFFECTS IN ARCS

Chairman: H. L. Witting, General Electric Company

QB-1 An Experimental and Theoretical Investigation of the Anode Plasma of a Pulsed Vacuum Arc.* F. M. BACON, Sandia Laboratories, Albuquerque, N.M. 87115--A spectroscopic investigation has been made of the plasma near anode spots of a pulsed vacuum arc with an Al anode. The arc was driven by a 150 A, 10 μ sec current pulse. Temporal and spatial distributions of excited levels of Al I, Al II, and Al III were measured. As the arc discharge was extinguished, the plasma electron temperature was shown to decrease through the Al III, Al II, and Al I norm temperatures sequentially. Peak Al III excited state densities of 10^{11} - 10^{12} cm^{-3} were measured. The Boltzmann distribution temperature of the Al III excited levels was determined to be 2.0 ± 0.5 eV. A one-dimensional, non-LTE model of the aluminum plasma has been developed. Quantitative agreement was obtained between the theoretical values and the measured values of the distribution temperature and the Al III excited state densities for $N_e = 10^{15}$ cm^{-3} , $T_e = 30$ eV and τ , the time the aluminum spends in the anode plasma, of 10^{-7} sec. The results of this model show that the plasma is not in LTE and that Al III and Al IV ions are produced in approximately equal quantities in agreement with other experimental results.

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

QB-2
Anode Heat Fluxes in Pulsed High Intensity Arcs*

J.L. Smith and E. Pfender
Dept. of Mech. Eng.
Univ. of Minnesota

A method for measuring very high heat fluxes to solid surfaces is described and applied to the evaluation of anode heat fluxes in pulsed high current arcs. Light emission from the rear surface of a very thin anode is measured with a calibrated light fiber probe. The resulting time-temperature profiles are compared with calculated profiles for various assumed heat fluxes. By matching experimental and theoretical profiles the heat flux is deduced. Results for atmospheric pressure 5,000 amp arcs in argon and nitrogen using Cu, W, and Mo as anode materials reveal heat fluxes in the order of 10^5 watts/cm².

* This work was supported by the USAF under Contract F33615-72-C-1869/

QB-3

Plasma Wall Space Charge Sheath.

G. ECKER, Institut für Theoretische Physik, Ruhr-Universität Bochum. -- The plasma space charge region in front of a wall has been analysed matching the "inertia limited model" with the "undisturbed plasma". The extension of the space charge region is - if one cannot avoid it - identified with the mean-free-path of one of the particle kinds. The problems of this approach have been recognized but not resolved. We show that the potential drop in front of the plasma wall cannot be calculated from a boundary value problem but must be determined from a stability consideration. Its value is mainly determined by the electron temperature in the plasma. Moreover, the extension of the space charge region is not characterized by the mean-free-path of one of the particle components but rather by the value of the Debye-length of the plasma electrons.

QB-4 The Transition From Vacuum Arcs to Arcs at Atmospheric Pressure, C. W. KIMBLIN, Westinghouse Research Laboratories--DC arcs in the current range

50-1000 A have been established between pairs of Cu, Ag and C electrodes. Ambient pressures of N_2 , He or Ar in the range 10^{-3} to 350 torr have been admitted to the arc chamber, and the arc properties have been studied by (a) high speed photography, (b) measurements of the cathode erosion rate and (c) measurements of the ion current to cylindrical metal collectors surrounding the electrodes. Metal-ion collisions with the ambient gas result in a decrease in the ion current. This decrease is unaffected by the cathode diameter, but occurs at lower pressures for gases of high atomic weight and for large radius collectors. The measured erosion rate also decreases with increasing pressure, and a comparison with the ion current reduction indicates redeposition of cathode spot evaporated material on the cathode. With increasing pressure the cathode spots on Ag and Cu (i) decrease slightly in luminosity, (ii) move more rapidly over the cathode surface, and (iii) become more numerous. Further, at the high end of the pressure range the cathode spots are grouped together beneath the arc column giving the appearance of a single cathode spot.

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