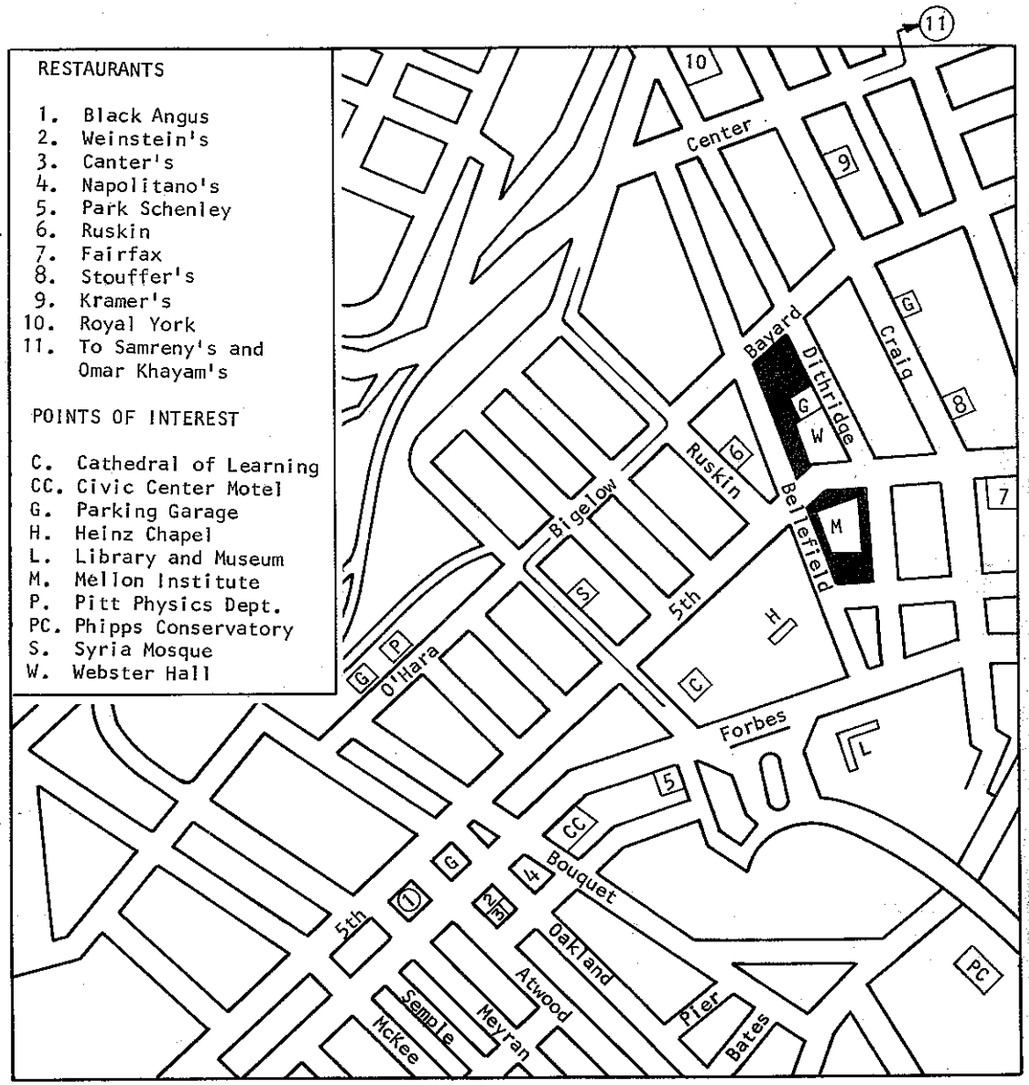


Map of Oakland

OCT. 1963

16TH annual GASEOUS ELECTRONICS CONFERENCE

WESTINGHOUSE Research Laboratories & University of PITTSBURGH

TOPICAL CONFERENCE OF
THE AMERICAN PHYSICAL SOCIETY

Dr. John J. McClure
Northrop Space Labs.
3401 W. Broadway
Hawthorne, Calif.

The conference gratefully acknowledges
the assistance received from the
U. S. Army Research Office (Durham).

16th ANNUAL
GASEOUS ELECTRONICS CONFERENCE

PROGRAM AND ABSTRACTS OF PAPERS

October 16-18, 1963

Jointly Sponsored by
Westinghouse Research Laboratories
And
The University of Pittsburgh

Held At
Mellon Institute
Pittsburgh, Pennsylvania

CONFERENCE COMMITTEE

M. A. Biondi (Chairman)
University of Pittsburgh

E. C. Beaty
Joint Institute for
Laboratory Astrophysics

J. H. Cahn
University of Illinois

L. H. Fisher
General Telephone and
Electronics Laboratories, Inc.

J. M. Richardson
National Bureau of Standards

S. Schneider
Signal Corps Laboratories

G. L. Weissler
University of
Southern California

D. Whitehouse
Massachusetts Institute
of Technology

G. J. Schulz (Secretary)
Westinghouse Research
Laboratories

LOCAL COMMITTEE

A. G. Engelhardt

W. H. Kasner

J. F. Nolan

J. L. Pack

Westinghouse Research Laboratories

PROGRAM

SIXTEENTH ANNUAL GASEOUS ELECTRONICS CONFERENCE

Tuesday, October 15

7:30 P. M. Advance Registration, Georgian Room, Webster Hall Hotel

Wednesday, October 16

8:00 A. M. Registration, Bellefield Lobby, Mellon Institute

9:00 A. M. SESSION A: BREAKDOWN; STRIATIONS; DISCHARGE MECHANISMS
Chairman: D. J. Rose, Massachusetts Institute of Technology

SESSION A

WEDNESDAY, OCTOBER 16
9:00 A. M.

BREAKDOWN; STRIATIONS; DISCHARGE MECHANISMS

CHAIRMAN

D. J. ROSE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A-1

FURTHER CALCULATIONS OF CURRENT GROWTH AND VOLTAGE BREAKDOWN

A. L. Ward
Harry Diamond Laboratories

This paper presents further results in a series of calculations on the dynamic growth of current in gases.[1] A number of calculations have been made to determine the effect of a delayed photoemission from the cathode. One paradoxical result is the reduction of the breakdown time with an increase in the photon delay under conditions of low overvoltages. This anomaly is a consequence of the motion of the positive ions to distort the electric field and thereby increase the ionization rate. Other calculations have been made to compare with the experimental measurements of Seifert[2] of the effect of dV/dt, rate of voltage rise, upon the breakdown voltage. These calculations show that the pressure-distance product for minimum breakdown voltage increases with increasing dV/dt, as Seifert observed. A photon delay proportional to the gap distance seems necessary to fit the experimental data in argon. The calculations will provide a test of the ionization coefficient of hydrogen in the controversial region of high field over pressure, when ion-to-photon secondary-coefficient ratios are determined.

1. A. L. Ward, Bull. Am. Phys. Soc. 6, 390(1961); 7, 634(1962).
2. H. E. Seifert, Proc. 5th Int. Conf. Ion. Phen. in Gases, North Holland, Amsterdam (1962) p. 742.

A-2

BREAKDOWN POTENTIAL OF NEON BELOW THE PASCHEN MINIMUM

H. Craig Miller
General Electric Research Laboratory

The breakdown potential of neon has been measured as a function of pd (pressure times gap) for $0.75 \leq d \leq 34.6$ mm. Emphasis was placed upon measuring the portion of the Paschen curve below the voltage minimum. Breakdown occurred between the ends of 24.6 mm diameter copper cylinders sliding in 25.0 mm I.D. Pyrex tubing. In the region $dV/d(pd) < 0$ the Paschen curve for non-monatomic gases is concave upwards[1] whereas the observed neon curve has the segment $0.4 < pd < 0.9$ cm-torr concave downwards, the remainder of the curve being concave upwards. Cataphoretic purification was used. Deliberate contamination (N_2 or Ar) of the neon showed that the observed behavior was not due to impurities (being somewhat insensitive to their presence). The effect of changing d was less than experimental error for $1.8 \leq d \leq 10.8$ mm, variation of d beyond these limits affecting the curve in a manner indicating that the electrode diameter/spacing ratio change was the major contributor to the observed changes. Associated work has indicated that the observed effect is not due to the particular electrode geometry and material employed.

1. J. M. Meek and J. D. Craggs, Electrical Breakdown of Gases, (Oxford, London, 1953) Chapter II.

A-3

THE VELOCITIES OF STREAMER TIPS IN IMPULSE POINT-TO-PLANE CORONA IN AIR AT ATMOSPHERIC PRESSURE AS A FUNCTION OF POSITION IN THE GAP AND POTENTIAL USING LICHTENBERG FIGURE TECHNIQUES*

G. Waidmann and L. B. Loeb
University of California, Berkeley

Using the Lichtenberg figure technique reported by us at the 15th Annual Gaseous Electronics Conference, a study has been made of the velocity of the streamer tips and tip potentials as these proceed across the gap at various voltages and gap lengths in air at atmospheric pressure. It is observed that the velocity is high near the streamer tip in a long gap but declines as the streamers attenuate in crossing the gap. At higher potentials or with shorter gaps nearer breakdown, streamers crossing the gap have their velocity again increased as they approach the cathode. For a fixed gap the same increase can be observed as point potential is raised to values where vigorous streamers are crossing.

* Work supported by Office of Naval Research and Research Corporation.

A-4

ELECTRICAL BREAKDOWN IN HIGH VACUUM

D. Alpert, D. Lee, E. M. Lyman and H. Tomaschke
University of Illinois

Despite intensive investigation in recent years of the mechanisms of electrical conduction between metal electrodes in high vacuum, there has remained great diversity in both the nature and the interpretation of the observations. This paper presents recent experimental results together with alternative theories for the initiation of electrical breakdown. For clean refractory metals in ultrahigh vacuum, several experimenters have obtained results which are here correlated in terms of a single picture. This picture predicts breakdown when the maximum effective electric field at the cathode reaches a critical value. The effective field, which for broad area electrodes is considerably enhanced by the presence of sharp points, is deduced from observations of field emission prior to breakdown. When properly analyzed, data obtained in this laboratory and in several others[1, 2, 3] give a breakdown field, E_B, which is independent of gap-spacing or geometrical configuration (for tungsten, $E_B \cong 7 \times 10^7$ V/cm). This picture also gives physical insight concerning the observed dependence of prebreakdown current and of breakdown voltage on pressure.

1. Boyle, Kisliuk and Germer, J. Appl. Phys. 26, 720 (1955).
2. I. I. Gofman, et al., Soviet Physics – Solid State 2, 1203 (1960).
3. Dolan, Dyke and Trolan, Phys. Rev. 91, 1054 (1953).

A-5

VACUUM ARC RECOVERY PHENOMENA

J. A. Rich and G. A. Farrall
General Electric Research Laboratory

The general problem of arc interruption and recovery is extremely complex and has yielded only partially to theoretical analysis. The problem is considerably simplified in the case of the vacuum arc. To uncover the mechanism operative in the recovery of electrical strength in a vacuum gap an analysis has been carried out for a simplified, well controlled experiment in which only the contact area and gap length were allowed to vary. The recovery times for various gap proportions were calculated by following the decay of the metal vapor density in the gap from an initial density, present at arc extinction, to a final critical density characterizing full gap recovery. The initial density is obtained from vacuum arc erosion data and the final density from the condition that, for full recovery, the atom mean free path be of the order of the gap length. Two cases are considered: (1) no condensation of metal vapor on the electrodes; (2) condensation. It is the latter case which gives by far the best agreement with experiment and accounts for the very rapid recovery of electrical strength.

A-6

RECENT RESEARCH ON MOVING STRIATIONS

N. L. Oleson
U. S. Naval Postgraduate School

(Review Paper)

A-7

EFFECT OF GAS FLOW ON ELECTRICAL PROPERTIES OF A POSITIVE COLUMN*

K. U. Ingard, G. Bekefi and K. Gentle
Department of Physics and Research Laboratory of Electronics
Massachusetts Institute of Technology

Preliminary experimental studies of the influence of gas flow on some properties of the positive columns in argon and helium are reported. An interesting feature is that when the gas flows in the direction from the cathode to the anode the column becomes striated. This appears when the flow velocity is of the order of the ion drift velocity. If the flow direction is reversed, no such effect is noticed. Probe measurements of the voltage-current characteristics of the column for different flow speeds are presented for different gas pressures, both with and without an axial magnetic field. An apparent decrease of the conductivity with increased flow speed is found, and this effect is somewhat enhanced by a magnetic field, at sufficiently low pressures. Data on the fluctuations in the potential gradient, both parallel and transverse to the magnetic field, are also included. The ion current carried by the jet that protrudes past the cathode (or anode) has been measured as a function of the flow velocity.

* This work was supported in part by the U. S. Army, the Air Force Office of Scientific Research, the Office of Naval Research, the U. S. Atomic Energy Commission and the U. S. Air Force (Electronic Systems Division).

A-8

ARC DISCHARGES IN METAL-IODIDE VAPORS

J. F. Waymouth, F. Koury and W. C. Gungle
Sylvania Electric Products Inc.

Many metal iodides have vapor pressures of millimeters to atmospheres at temperatures of 700-800^{o}C. Arc discharges can be operated in quartz tubes containing such vapors. At the temperature of the arc axis, iodide molecules are all dissociated, and free metal atoms are ionized and excited to emit their characteristic spectra. Partial pressures of metal vapors at the arc axis are comparable to vapor pressures of the metal iodides at the tube wall temperature. We have operated such arcs in the vapors of several dozens of different metal iodides, including sodium, cadmium, indium, thallium, thorium, tungsten and many of the rare earth metals. For maximum efficiency of generation of radiation, it is desirable to have several atmospheres of mercury vapor present also. The high pressure retards diffusion of free atoms to the wall, reducing energy losses due to molecular recombination. Moreover, maintaining the iodine-to-mercury ratio in the system at somewhat less than unity reduces the concentration of I_2 molecules in the cooler gas surrounding the arc in favor of HgI. This substantially reduces absorption loss and increases efficiency.

A-9

STUDIES OF THE MECHANISM OF THE HOLLOW CATHODE DISCHARGE*

D. J. Sturges and H. J. Oskam
University of Minnesota

The hollow cathode discharge has been studied in helium and neon. Two parallel electrodes, the separation of which could be varied, served as the cathode. In order to have the possibility to eliminate the influence of the anode fall on the measurements, the distance between the planar anode and the cathode assembly could be changed. Pulse techniques were used for measuring the current-voltage characteristics since it was found essential to maintain the cathode at a constant temperature. This temperature was monitored by means of a thermocouple. The results obtained are (a) the hollow cathode mechanism is very pronounced in both helium and neon, (b) the efficiency of the hollow cathode mechanism shows a maximum for two values of the distance between the planar cathodes and (c) the value of these distances depends on discharge current and gas pressure. An explanation of the phenomena observed will be given.

* Work supported by the Air Force Cambridge Research Laboratories.

A-10

ON THE EMISSION OF ELECTRONS FROM SOLIDS IN GAS DISCHARGES

D. M. Speros and P. R. Buccilli
Lamp Research Laboratory, General Electric Company

Cathode behavior is examined during the first few microseconds after the ignition of the discharge.[1] The discharge is extinguished a few milliseconds later. The cathode is allowed to recover before a new measurement is made. The results thus obtained are reproducible and give an idea of (i) the capability of the cathode system while in a thermochemically definable state,[2] and (ii) voltampere characteristics of the cathode-discharge system, which are nearly independent of undeterminable variations in the cathode component. The application of this method to low pressure discharges has led to: (a) the determination of the condition of zero field, whereby the work function of the cathode material is accurately determined, (b) volt-ampere characteristics[3] expressible in terms of $\ln J \propto V^{1/2}$, the proportionality constant being a function of the gas and (c) the correspondence between vacuum and gas discharge emission from the same tungsten cathode, where it has been shown that the true zero-field emission in gas is the same as the Schottky zero-field emission in high vacuum.

1. D. M. Speros and P. R. Buccilli, J. Electrochem. Soc. 109, 940 (1962).
2. D. M. Speros, J. Electrochem. Soc. 106, 791 (1959).
3. D. M. Speros and P. R. Buccilli, J. Electrochem. Soc. 110, 748 (1963).

SESSION B

WEDNESDAY, OCTOBER 16
2:15 P. M.

RADIATION PROCESSES; EXCITATION BY IONS

CHAIRMAN

T. M. DONAHUE
UNIVERSITY OF PITTSBURGH

B-1

A HIGH IMPACT CURRENT METHOD FOR MEASURING LIFETIMES OF EXCITED ATOMIC ENERGY LEVELS AND ITS APPLICATION TO HELIUM*

T. M. Holzberlein and R. G. Fowler
University of Oklahoma

A direct method of measurement has been applied to atomic energy level lifetimes in helium. A radially directed electron beam of the order of two amperes impact current has been cut off by a sharply impressed counter potential, and the decay of radiative transitions is observed with fast photomultiplier oscillography. The method is capable of wide applicability, but has been tested only in helium. Good agreement with theory and with the results of Heron, McWhirter and Rhoderic[1] and with Bennett and Dalby[2] is obtained for several lifetimes, but there are interesting exceptions. The extent and significance of cascading is a by-product of the method and accidental evidence has also been found that the population of the triplet levels does not follow the same mechanism as that of the singlets.

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

1. S. Heron, R. W. P. McWhirter, and E. H. Rhoderic, Proc. Roy. Soc. (London) 234, 565 (1956).
2. R. G. Bennett and F. W. Dalby, J. Chem. Phys. 31, 434 (1959).

B-2

ABSORPTION SPECTRA OF THE PINK AFTERGLOW OF NITROGEN IN THE 1070-1600 Å REGION

M. Nakamura, Y. Tanaka, A. S. Jursa, and F. R. Innes
Air Force Cambridge Research Laboratories

Absorption spectra on many vibrational levels of the ground state appear in the nitrogen afterglow with intensities dependent on the pink afterglow location.[1] Spectrograms were made on a flow system at points upstream, downstream and within the pink afterglow. A three-meter normal incidence vacuum spectrograph was used at 1070-1600 Å with argon and krypton continua for background. A large number of strong bands were observed in absorption over this entire region.[2] Analysis indicates neutral nitrogen bands of several electronic systems from high vibrational levels of the ground state to excited states at energies of 12 - 14 eV. Conspicuous transitions are: $X^1\Sigma_g^+$ (to v = 21)$\rightarrow b^1\Sigma_u^+$ (v = 0 to 6), $j^1\Sigma_u^+$ (v = 0) $b^1\pi_u$ (v = 0 to 6), $m^1\pi_u$ (v = 0, 1). Upstream of the pink afterglow these bands appeared with little intensity change. Downstream there were almost no absorption bands. Atomic lines at 1200 Å ($2p^3\,{}^4S \rightarrow 2p^2\,3s\,{}^4P$) and 1134 Å ($2p^3\,{}^4S \rightarrow 2p^4\,{}^4P$) appeared strongly throughout. Also the Lyman-Birge-Hopfield bands appeared weakly. Considerable energy is evidently removed from vibrational levels of the ground state at the pink region.

1. G. E. Beale, Jr. and H. P. Broida, J. Chem. Phys. 31, 1030 (1959).
2. Observed also and discussed by A. M. Bass (private communication).

B-3

TIME-DELAYED FLUORESCENCE FROM EXCITED IONIC STATES OF CO, CO_2, O_2, AND N_2O*

D. L. Judge, A. L. Morse, S. Furmanski, and G. L. Weissler
University of Southern California

Recent studies of the fluorescence of several atmospheric gases excited by vacuum ultraviolet radiation[1] have led to an investigation of delayed fluorescent emission from excited ionic states of these gases. It is observed that CO has a most pronounced delay, on the order of several microseconds. The other gases investigated have delays ranging from a few μ sec down to the limit of detectability of $1/2\,\mu$ sec. Both the pressure dependence and excitation energy were parameters in this investigation. Quenching is particularly noticeable in CO at pressures above $100\,\mu$, where the mean free time between collisions becomes comparable to the fluorescence decay time, indicating non-radiative de-excitation. Knowing the threshold excitation energy and the wavelength-resolved spectra of the fluorescence, it is possible to determine which states are involved, at least in the case where only excited states of the molecular ion are involved. The delayed fluorescence data are interpreted in terms of the parameters of this experiment and the previously determined fluorescence spectra.[2]

* The support of this work by both AF 19(628)-2452 and NASA Grant No. NsG-178-61 is hereby gratefully acknowledged.

1. R. I. Schoen, D. L. Judge, and G. L. Weissler, Proc. of the Fifth Int'l. Conf. on Ionization Phenomena, Munich, Vol. I, p. 25; North-Holland Publishing Co., Amsterdam: 1962.
2. D. L. Judge, A. L. Morse, and G. L. Weissler, Proc. of the Sixth Int'l. Conf. on Ionization Phenomena, Paris; to be published.

B-4

INVERSIONS OF SLOWLY RADIATING STATES IN DISCHARGES

P. J. Walsh and G. E. Courville
Fairleigh Dickinson U. and S. F. D. Labs.

The density of a radiating state populated by a Maxwellian electron energy distribution is held below its Boltzmann equilibrium value in the ratio of radiation lifetime to electron collision lifetime. Long-lived states then easily attain inversion over stronger radiating states. The radiation lifetime, τ, depends on λ^3 where λ is the wavelength. States which can only radiate in the infrared are thus quasi-metastable and can build up high inversions, ΔN. Since stimulated gain depends upon $\Delta N\,\lambda^3/\tau \propto \Delta N$, extremely high gain lasers result.[1] Attainable inversions with true metastable states may even make possible stimulated emission of forbidden radiation in discharges.[2] Inversions for discharges controlled by wall losses are shown to depend on tube radius, R, approximately as R^{-2n}, where n is the ratio of excitation to ionization potentials. This agrees qualitatively with experiments. For monoenergetic electrons, the ratio of excited to ground state populations due to collisions is given by the ratio of excitation to de-excitation cross sections. At large energies, this ratio exceeds unity only for forbidden transitions. Inversion of triplet levels over the ground state thus appears possible using a monoenergetic beam of electrons in the alkaline earth vapors.

1. R. A. Paananen and D. L. Bobroff, App. Phys. Letters 2, 99 (1963).
2. P. J. Walsh and G. E. Courville, J. Opt. Soc., 53, 1043 (1963).

B-5

BROADENING OF BALMER LINES FOR HIGH QUANTUM NUMBER

B. H. Armstrong
Lockheed Missiles and Space Company

Recently, extensive and impressive measurements of line shapes were reported for the Balmer series of H up to n = 16.[1] Satisfactory agreement was obtained between experiment and the recent theory of Baranger, Kolb, and Griem in which quasi-static ion broadening due to Stark effect has been combined with electron-impact broadening. Griem has inferred and recent evidence[2] indicates that electron-impact broadening alone dominates at sufficiently large n. The approximate formula $w_n = (8\pi^2 e^2 \alpha a_o^2/Z^2) \times (mc^2/2\pi kT)^{1/2} \rho n^4$ has been used to obtain the half width w_n due to this broadening for the Balmer series under the experimental conditions cited.[1] The values obtained are, as expected, too small for the lower series members, but at n = 16, $w_n/2 = 0.728$ Å, and agreement is obtained with experiment and with the quasi-static theory results for ions plus electrons. In addition, we show that a Lorentz shape with this width fits the H_{16} profile as appropriate for pure impact broadening. The ability of the Lorentz shape to reproduce the profiles deteriorates as n decreases. The surprising numerical agreement between the two theoretical approaches at high n is discussed.

1. E. Ferguson and H. Schlüter, Ann. Phys. 22, 351 (1963).
2. B. H. Armstrong, Bull. Am. Phys. Soc. 8, 476 (1963). (to be published, JQSRT).

B-6

IMPRISONMENT OF RESONANCE RADIATION IN GASES III

H. Zwibel and T. Holstein
University of Pittsburgh

A wave-optical treatment of the transport of resonance photons in gases has been carried out. Its principal result is a transport equation for the photon distribution in position and wave-vector space. The equation has been applied to a study of the decay of resonance excitation in a gas-filled enclosure under conditions such that (a) the line is predominantly Doppler-broadened, but (b) the enclosure is so large that, at the absorption-edge of the line (the frequency at which the opacity of the enclosure is ~ 1), the line shape is dominated by natural broadening. A formula, $T = (3/2\pi)^{1/2} \tau k_o L$, for the decay time T, (in terms of the atomic life time, τ, and the opacity, $k_o L$, at the center of the absorption line) is obtained. The spectral distributions of photon density and emergent flux have also been determined.

B-7

EFFECT OF RESONANCE CHARGE TRANSFER ON EXCITATION FOR PROTON HYDROGEN COLLISIONS*

M. B. McElroy** and S. E. Lovell
University of Wisconsin

Using the impact parameter formulation, calculations have been made of charge transfer and excitation cross sections for collisions between protons and hydrogen atoms. A truncated, two center expansion in atomic eigenfunctions[1] was used. At low energies the coupling effect of resonance transfer led to unexpectedly large cross sections for the non-resonance processes. These results, and their comparison with the conventional two state solutions also obtained, are presented and discussed.

* Work supported by the National Aeronautics and Space Administration.
** Present address: Kitt Peak National Observatory.
1. D. R. Bates, Proc. Roy. Soc. A 247, 294 (1958).

B-8

EMISSION CROSS SECTIONS FOR N_2^+ FIRST NEGATIVE SYSTEM EXCITED BY 1 TO 10 keV N_2^+ ON N_2

John P. Doering
Los Alamos Scientific Laboratory

Cross sections for excitation of the (0, 0) and (0, 1) N_2^+ first negative bands have been measured in the excitation of N_2 by 1 to 10 keV N_2^+. Light produced along a 15 cm path was integrated and analyzed with a monochromator. The light output per unit incident particle was measured as a function of N_2 gas pressure from 0.1 to 20 microns at each energy. From these data it was possible to distinguish between light produced by primary N_2^+ impact and that produced by fast neutral N_2 excitation. A 180 eV electron beam was used for calibration purposes with the aid of Stewart's data[1] on (0, 0) N_2^+ first negative band excitation by electrons. The cross sections for (0, 0) and (0, 1) excitation by N_2^+ reach a broad maximum around 7 keV. The maximum value of the (0, 0) excitation cross section is near 1.2×10^{-17} cm^2.

1. D. T. Stewart, Proc. Phys. Soc. 69, 437 (1956).

B-9

OPTICAL EXCITATION OF GASES BY ALKALI ION BOMBARDMENT

R. P. Lowe and H. I. S. Ferguson
University of Western Ontario

Spectra have been obtained of the luminescence resulting from the bombardment of N_2, CO, and argon with potassium and sodium ions at incident energies up to 8 keV. While the most intense lines are due to charge capture into excited states of the bombarding particles, many features resulting from the dissociation and excitation of the target gas are observed. Relative cross sections have been measured photoelectrically for many of the excitation processes.

SESSION C

THURSDAY, OCTOBER 17
9:00 A. M.

RECOMBINATION; AFTERGLOWS

CHAIRMAN

A. V. PHELPS
WESTINGHOUSE RESEARCH LABORATORIES

C-1

ELECTRON-ION RECOMBINATION IN CESIUM-SEEDED ATMOSPHERIC-PRESSURE PLASMAS

Lawson P. Harris
General Electric Research Laboratory

Measurements of ionization relaxation following low-power perturbing electrical pulses are being made in gaseous mixtures formed by adding 0.1 to 10 torr cesium vapor to atmospheric-pressure argon. The apparatus consists mainly of two heated zones, a low-temperature seeding oven where a very slow argon flow picks up the cesium vapor, and a small electrically-heated furnace containing a diode test section where the mixture is held near thermal equilibrium at temperatures in the 1500 - 2000°K range. The principal measurements taken are the seeding-oven temperature, furnace temperature, and the currents and voltages in the diode. These measurements plus the assumption of thermal equilibrium for the unperturbed plasma permit calculation of recombination coefficients for cesium plasmas, in the presence of an atmosphere of argon, over an electron density range of approximately 5×10^{11} - 5×10^{13} cm^{-3}. The results show good agreement with a theoretical prediction[1] for the two-electron three body recombination process when the electron density exceeds 5×10^{12} cm^{-3}; at lower densities, however, the recombination coefficient appears higher than expected for either this process or radiative recombination.

1. E. Hinnov and J. G. Hirschberg, Phys. Rev. 125, 795 (1962).

C-2

ION BEAM MEASUREMENTS OF RECOMBINATION CROSS SECTIONS*

J. M. Hammer, J. J. Thomas and B. B. Aubrey
RCA Laboratories, Princeton

An ion beam method of measuring recombination cross sections has been developed. Initial measurements have provided an upper bound of 5×10^{-19} cm^2 for the recombination of atomic cesium ions and of 3×10^{-14} cm^2 for the recombination of molecular cesium ions (probably dissociative recombination). The technique consists of passing an ion beam through a partially-neutralized electron cloud and observing the change in the emergent atom current as the electron density is turned on and off. The constituents of the ion beam are determined by mass analysis. A lower bound on the electron density is found using a capacitive technique. The atom beam is detected by an electron multiplier. The experiment will be described in detail and the initial results will be discussed.

* Work supported in part by the U. S. Army Transportation Corps.

C-3

LINE BROADENING STUDIES OF DISSOCIATIVE RECOMBINATION IN NEON*

T. Robert Connor and Manfred A. Biondi
Department of Physics, University of Pittsburgh

An attempt has been made to determine whether the large electron capture by positive ions observed in microwave afterglow studies is the result of dissociative recombination. If so, it should be possible to detect the kinetic energy of dissociation of the excited atom formed during the recombination process. Earlier studies of helium afterglows[1] gave some indication of excess kinetic energy in the excited atoms. In the present studies, 3 cm microwaves and a photoelectric recording Fabry-Perot interferometer were used to study recombination in neon afterglows. The microwave electron density measurements, carried out at an order of magnitude larger electron density than in earlier studies, yield a two-body recombination coefficient ($\alpha \simeq 2 \times 10^{-7}$ cm^3/sec) in agreement with the earlier work. Line shape studies of the neon λ 5852 line indicate essentially a thermal doppler width during the discharge, followed by a rather abrupt increase to a constant, markedly larger width during the afterglow. The inferred kinetic energy of the dissociating atoms produced by the recombination is approximately 1 eV. Line narrowing with increasing neon gas pressure, resulting either from excitation transfer or from slowing of the fast excited atoms before they can radiate, has been observed.

* This research has been supported, in part, by the Office of Naval Research.

1. W. A. Rogers and M. A. Biondi, Bull. Am. Phys. Soc. [2] 2, 87 (1957).

C-4

ELECTRON-ION RECOMBINATION IN NITROGEN*

W. H. Kasner and Manfred A. Biondi**
Westinghouse Research Laboratories

Combined microwave, mass spectrometric and optical techniques have been used to study the afterglow decay of electrons, ions and excited atoms from microwave discharges in N_2 - Ne gas mixtures under conditions where N_2^+ is the only significant afterglow ion, i.e., at nitrogen pressures less than 10^{-2} mm Hg. Optical absorption studies show that neon metastable atoms, an undesirable ionization source, are present in the early afterglow, the concentration being inversely related to the discharge pulse length. Under conditions of no detectable metastable concentration and for neon pressures in the range 12 to 40 mm Hg, the afterglow decay is controlled by the recombination of N_2^+ ions and electrons, yielding a recombination coefficient of $(2.8 \pm 0.5) \times 10^{-7}$ cm^3/sec. Temporal mass analysis shows similar decay rates for N_2^+ ions and for electrons over the major portion of the afterglow. The observed recombination coefficient shows no dependence on nitrogen or neon pressures in the ranges indicated. The variation of the metastable decay rate with nitrogen pressure gives a cross section of $(5.4 \pm 1.0) \times 10^{-16}$ cm^2 for the destruction of the $^3P_2$ neon metastable state by nitrogen.

* This research has been supported in part by the Army Research Office (Durham).

** Physics Department, University of Pittsburgh.

C-5

AMBIPOLAR DIFFUSION AND ELECTRON RECOMBINATION IN AN OXYGEN AFTERGLOW AT ELEVATED TEMPERATURES

Michael H. Mentzoni
Applied Research Laboratory, Sylvania Electronics Systems

Ambipolar diffusion, $D_a p_o$, and electron recombination, α_r, have been measured using microwave techniques. The measurements were taken at pressures ranging from 100 microns to 4 mmHg at the gas temperatures 300, 569, 734 and 894°K. For low values of the ratio discharge-current/pressure the values of $D_a p_o$ and α_r at 300°K are in fair agreement with those previously reported for O_2^+. At higher temperatures the data indicate that the mobility of these ions goes through a maximum of about 5.0 $cm^2 sec^{-1} volt^{-1}$ at 569°K reduced to 760 mmHg declining slightly thereafter. α_r drops from $3.7 \times 10^{-7} cm^3 sec^{-1}$ to $1.9 \times 10^{-7} cm^3 sec^{-1}$ over the entire temperature interval, the most rapid change taking place between 300 and 569°K. In the afterglow of the strong-current-discharge one finds at room temperature $D_a p = 216 \pm 20$ $cm^2 sec^{-1}$ and α_r reduced by a factor of about three as compared with the low-current-discharge. Radiation temperature measurements indicate that the plasma is nearly isothermal at post discharge times varying from 30 to 40 microseconds, which is almost ten times faster than in neon mixed with 5 per cent oxygen. At pressures above 1 mmHg attachment, υ_a, becomes increasingly important, however, the limited pressure range available prevented υ_a to be determined unambiguously.

C-6

A SHORT-DURATION VISIBLE AFTERGLOW IN HELIUM

Arthur L. Schmeltekopf
Central Radio Propagation Laboratory
National Bureau of Standards, Boulder

A bright, reproducible afterglow which consists of helium atomic and molecular emission which has been observed in the flow products of an electrical discharge in a nozzle will be discussed. This afterglow has been observed at pressures from 0.4 to 20 mm Hg and with flows from 10 to 1000 cm^3/sec NTP. Increasing pressure increases the brightness of the afterglow and increasing flow increases its length. Metastable He atom concentrations decrease after the discharge and then increase in the region of afterglow emission. The afterglow is very sensitive to impurity concentrations greater than a few parts in 10^5. Emission intensity and metastable atom concentrations in the afterglow are diminished by the presence of an rf field, presumably because electron heating retards recombination.

$$2e + He^+ \longrightarrow He^* + e$$

$$2e + He_2^+ \longrightarrow He_2^* + e.$$

Calc. T^{-4} dependence (Hinnov & Hirschfelder)

Expt (some one else) $T^{-1.5}$

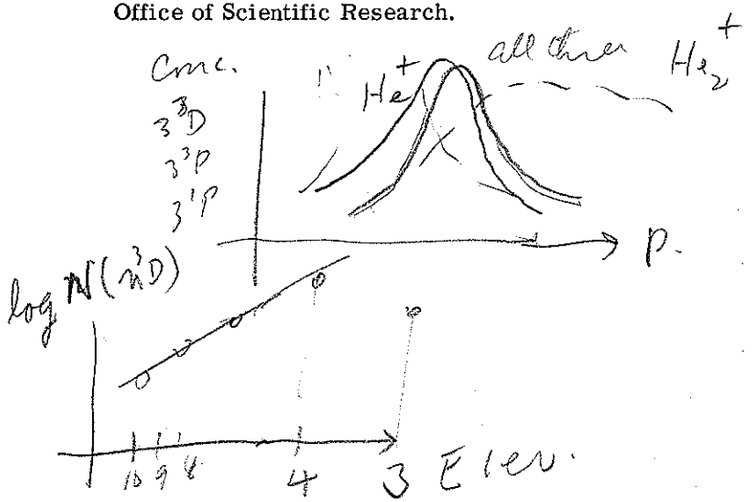
C-7

ATOMIC EMISSION IN THE HELIUM AFTERGLOW*

C. B. Collins and W. W. Robertson
The University of Texas

A bright helium afterglow emitting both the atomic lines and molecular bands was observed in a flowing system at pressures ranging from 5 to 45 mm Hg. The populations of He^+ and He_2^+ could be detected independently by titration with a second gas. By examining these populations together with the intensity of atomic helium emission as functions of both the pressure and the coordinate in the direction of the flow, it could be established that the molecular ion He_2^+ was not involved in the population of the excited atomic states. Plotting the logarithm of the population of the ^3D states as a function of ionization potential for that state revealed the presence of local equilibria between the atomic ions, the electrons and the atomic levels with $n \geq 4$. This suggests that the excited atomic states are populated by the collisional-radiative recombination of He^+.

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



C-8

MEASUREMENT OF IONIC RECOMBINATION IN O_2*

V. A. J. van Lint and M. E. Wyatt
General Dynamics Corporation, San Diego

The two-body ionic recombination coefficient in oxygen has been measured in an ionization afterglow by observing the frequency shift of a 300-Mc resonant cavity during the recombination process after the electrons have been attached. Preliminary analysis of the data yields a value of $\alpha_i = 4 \times 10^{-9}$ cm^3/sec, although some normalization factors, which may change this value somewhat, are being calculated.

* Sponsored by Air Force Special Weapons Center under Contract AF29(601)-2779 and Defense Atomic Support Agency under Contract DA-49-146-XZ-041.

SESSION D

THURSDAY, OCTOBER 17
2:00 P. M.

AFTERGLOWS; ELECTRON SCATTERING

CHAIRMAN

K. B. PERSSON
NATIONAL BUREAU OF STANDARDS, BOULDER

D-1

AFTERGLOW STUDIES IN HYDROGEN*

H. J. Oskam and V. R. Mittelstadt**
University of Minnesota

The electron density was measured during the decay period of plasmas produced in hydrogen by means of the microwave cavity method. At gas pressures smaller than 5 Torr the time dependence of the electron density was exponential during the late part of the afterglow period. The value of the effective mobility calculated from the effective ambipolar diffusion coefficient depended on the value of the plasma excitation pulse length and varied from 13 to 16.3 cm^2/volt sec. The lowest mobility value was constant between 0.5 and 5 Torr and is believed to refer to H_3^+ ions. This value is in good agreement with $\mu_o(H_3^+)$ = 12.3 cm^2/volt sec as measured by Chanin[1] using the time of flight technique. The highest mobility value most probably refers to H^+ ions. The mobility data are in disagreement with those reported by Persson and Brown.[2] The validity of these conclusions as well as the reliability of the measurements will be discussed.

* Work supported by the National Science Foundation.
** Present address: Autonetics, Anaheim, California.
1. L. M. Chanin, Phys. Rev. 123, 526 (1961).
2. K. B. Persson and S. C. Brown, Phys. Rev. 100, 729 (1955).

D-2

AFTERGLOW STUDIES ON THE DEACTIVATION OF THE METASTABLE $A^3\Sigma_u^+$ STATE OF NITROGEN*

Edward C. Zipf, Jr.+
The Johns Hopkins University

A value for the diffusion coefficient, radiative lifetime and cross section for collisional deactivation of nitrogen molecules in the metastable $A^3\Sigma_u^+$ (v' = 0) state was obtained by measuring the intensity of the (0, 6) Vegard-Kaplan band ($A^3\Sigma_u^+ \rightarrow X^1\Sigma_g^+$) as a function of time and pressure in the afterglow of a microwave discharge in nitrogen. These measurements were made under a wide variety of excitation conditions in several discharge cells with different fundamental diffusion lengths. No collisional depopulation of the $A^3\Sigma_u^+$ (v' = 0) state was observed in pure nitrogen. However, in contaminated nitrogen the $A^3\Sigma_u^+$ state was rapidly depopulated in two-body collisions with impurity molecules. The cross section for deactivation of the $A^3\Sigma_u^+$ (v' = 0) state by ground-state nitrogen molecules was less than 2.7×10^{-23} cm^2. An earlier value[1] of 0.202 cm^2 sec^{-1} at 760 mm Hg and 300°K for the diffusion coefficient and 1 sec for the radiative lifetime of the $A^3\Sigma_u^+$ (v' = 0) state was also confirmed by these studies.

* Work supported by the National Aeronautics and Space Administration.
+ Present address: Joint Institute for Laboratory Astrophysics, Boulder, Colorado.
1. E. C. Zipf, Jr., J. Chem. Phys. 38, 2034 (1963).

D-3

DE-ACTIVATION OF NEON METASTABLES BY HYDROGEN GAS*

Thomas C. Marshall
Columbia University

Optical analysis of faint afterglows in the mixture Ne 99.7% + H_2 0.3% has shown that the resonance reaction

$$Ne^*(^3P_{2,1,0}) + H_2(1s,1s) \rightarrow Ne\ (^1S_0) + H(1s) + H\ (3s,p,d) + .05\,eV$$

completely accounts for losses of neon metastables by collisions with H_2. Several neon resonance radiations and Hα, Hβ were used to establish that the cross section for de-activation of the $^3P_2$ is 0.7×10^{-15} cm^2 at 300°K, but increases to 2.5×10^{-15}cm^2 at 650°K. De-activation of the $^3P_{1,0}$ states is roughly as probable as $^3P_2$ at 300°K, but the latter cross section increases when D_2 replaces H_2. Fabry-Perot analysis of the Hα line, from a cw discharge in this mixture, showed no increase of Doppler broadening when this reaction was the dominant Hα source. Measurements of metastable and electron concentration, and electron temperature are presented for glow discharges in this mixture. A comparison of the intensities of the Hα, β, γ spectral output of glow discharges in He - H_2 and Ne - H_2 has been made to illustrate the dissociative energy transfer effect.

* This work supported by Air Force Office of Scientific Research under grant AF AFOSR-48-63.

D-4

ELECTRON ENERGY DECAY IN HELIUM AFTERGLOW PLASMAS AT CRYOGENIC TEMPERATURES*

P. D. Goldan, J. H. Cahn and L. Goldstein
University of Illinois

Studies of decaying afterglow plasmas in helium have been made in which the neutral "parent" gas in maintained near 4°K by immersion in a liquid helium bath. By means of a maser radiometer system, the electron temperature has been followed below 200°K. Guided microwave propagation and wave interaction techniques permit determination of electron number density and collision frequencies for momentum transfer. Electron temperature decay rates of the order of 150μ Sec/p (mmHg @ 4.2°K) have been found. Since thermal relaxation by elastic collisions should be some two orders of magnitude faster than this, the electrons appear to be in quasi-equilibrium with a slowly decaying internal heating source. Correlation of the decay rates of singlet metastable helium atoms with the electron temperature decay gives good agreement with the present experiment.

* This work was supported by the Office of Aerospace Research Air Force Cambridge Research Laboratories.

D-5

MICROWAVE NOISE MEASUREMENT OF ELECTRON TEMPERATURES IN AFTERGLOW PLASMAS

C. C. Leiby and W. D. McBee
Sperry Rand Research Center

Transient electron temperatures in afterglow plasmas have been determined for He(5 and 10 Torr), Ne and Ne+5% Ar (2.4 and 24 Torr) by combining measurements of plasma microwave noise power, and plasma reflectivity and absorptivity. Use of a low-noise parametric preamplifier permitted continuous detection during the afterglow of noise power at 5.5 Gc in a 1 mc bandwidth. Electron temperature decays were a function of pressure and gas, but were slower than predicted by electron energy loss mechanisms. The addition of argon altered the electron density decay in the neon afterglow, but the electron temperature decay was not appreciably changed. Resonances in detected noise power vs time in the afterglow were observed for two of the three plasma waveguide geometries studied. These resonances correlate with observed resonances in absorptivity and occur over the same range of electron densities for a given geometry independent of gas type and pressure.

D-6

ANALYSIS OF HELIUM-PLASMA RATE PROCESSES BY MEANS OF SIMULTANEOUS DIFFERENTIAL RATE EQUATIONS*

A. R. Tynes+ and J. J. Brady
Oregon State University

A set of seven simultaneous differential rate equations which describe both the temporal and spectral characteristics of a pulsed microwave discharge in pure helium is derived. The rate equations describe the plasma characteristics, as well as the light emission, both during and after the application of the microwave power pulse to the discharge tube which is situated in a travelling wave structure rather than a cavity. A computer is used to solve the rate equations and the solutions are compared with experimental results. The role of the processes $He^+ + 2He \rightarrow He_2^+ + He$, $He^m + He^m \rightarrow He_2^+ + e + KE$, and $He^m + He^m \rightarrow He^+ + He + e + KE$ in producing the afterglow is examined and estimates of the conversion frequencies of the latter two are obtained.

* Work supported in part by Air Force Cambridge Research Center.

+ Present address: Bell Telephone Laboratories, Holmdel, New Jersey.

D-7

THE MONOPOLE AND DIPOLE FIELDS INDUCED IN A CESIUM ATOM BY AN INCIDENT ELECTRON

J. C. Crown
Pratt and Whitney Aircraft

A. Russek
Physics Department, University of Connecticut

The potential energy between an incident electron and a neutral atom has been calculated using first order perturbation theory in the adiabatic approximation. The results are shown to be expressible in terms of a multipole expansion suitably generalized to allow for the fact that the wave function of the target atom is of infinite extent. The monopole and dipole contributions have been calculated in detail for cesium using simple analytic wave functions developed by one of the authors. For small separations the induced monopole potential is small compared to the induced dipole potential but becomes increasingly significant at smaller separations. The polarization potential obtained is compared with those used by other authors. For infinite separation the calculations can be interpreted to yield the atomic polarizability. The result for cesium (52.2 Å^3) is in good agreement with experimental results.

D-8

COMPARISON OF BREMSSTRAHLUNG AND ELASTIC SCATTERING OF ELECTRONS FROM AIR AND NITROGEN*

Raymond L. Taylor and Bennett Kivel
Avco-Everett Research Laboratory

The absolute intensity of infrared radiation from air and nitrogen, shock heated to an equilibrium temperature of 6000 - 9000°K, has been measured at nearly atmospheric density over the wavelength range of 2 - 8μ. This continuum radiation is interpreted as due to free-free scattering of electrons from neutral atoms and molecules-Bremsstrahlung. The temperature dependence of this Bremsstrahlung has been determined at 2.35 and 3.88μ for air and 3.07μ for nitrogen. An analysis of the temperature dependent data using the classical Kramers-Unsold relation has resulted in establishing the effective coulombic charges, Z^2, for N_2, N and O which indicate that in air the bulk of the free-free radiation is due to scattering from nitrogen atoms and molecules; oxygen gives a negligible contribution. The trend of the Z^2's from the Bremsstrahlung is shown to be consistent with the trend of the low energy elastic scattering cross sections for electrons scattered from N, N_2, and O as determined from conductivity measurements in shock tubes and beam experiments. This comparison suggests that the Bremsstrahlung intensity is proportional to the electron scattering for heavy elements such as nitrogen and oxygen.

* Jointly supported by U. S. Air Force and Advanced Research Projects Agency.

D-9

INTERPRETATION OF CYCLOTRON RESONANCE LINE SHAPES IN SLIGHTLY IONIZED GASES

L. R. Megill, F. C. Fehsenfeld and L. K. Droppleman
National Bureau of Standards, Boulder

Detailed calculations of the conductivity in a slightly ionized gas as a function of magnetic field show that, in the vicinity of cyclotron resonance, the shape of the resonance curve can be interpreted in terms of the average collision frequency only if the energy dependence of the collision frequency is known. We have derived the appropriate line shape parameters for argon, nitrogen, oxygen, and helium from experimentally determined cross sections. We find that the simple power law expressions previously assumed are inadequate. We have also found that when the energy dependence of the collision frequency is strong, contaminants may cause serious errors, especially if the derivative line shape is used in the analysis. The effects of these errors on interpretation of experimental data will be discussed.

D-10

EFFECT OF INELASTIC COLLISIONS ON THE DRIFT VELOCITY OF ELECTRONS IN NOBLE GASES*

Joseph C. Bowe
Argonne National Laboratory

The experimental curves for drift velocity v_d are linear functions of E/p when inelastic collisions occur. These data can be understood on the basis of a formula derived in the Allis-Brown[1] approximation; $v_d = (1/6)(e/m)\left[\upsilon_m(v_o)\right]^{-1}\left[S_j(w_o)/S_{j+1}(w_o)\right]$ where $w_o(E/p, u_o)$ is a dimensionless variable, u_o is the cutoff energy which is greater than the excitation energy u_1, $\upsilon_m(v_o)$ is the collision frequency for momentum transfer, and (S_j/S_{j+1}) is a ratio of infinite series where j denotes the power law of the elastic cross section, i. e., $Q_m(v) \propto v^{j-1}$. Evaluation of the infinite series furthermore shows that departure from linearity should set in at $E/p \sim 5$ or 6 for Ar, and 2 or 3 for Ne. An expression is also derived for the overshoot from which the cross section for inelastic collisions $Q_1(u) = h(u - u_1)^{\gamma}$ can be deduced i. e.,

$$(u_o - u_1) = \left\{\Gamma(1/\gamma + 2)/\Gamma\left[\gamma + 1/\gamma + 2\right]\right\}\left\{3(\gamma+2)\, N_o^2\, Q_m(u_1)\, h\,(eE/p)^{-2}\right\}^{\frac{-1}{\gamma+2}}$$

Note that the correct overshoot of 0 and ∞ is obtained in the limiting cases where Q_1(i. e. h) is ∞ and 0 respectively.

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

1. W. P. Allis and S. C. Brown, Phys. Rev. 87, 419 (1952).

SESSION E

FRIDAY, OCTOBER 18
9:00 A. M.

EXCITATION AND IONIZATION BY ELECTRONS

CHAIRMAN

R. W. CROMPTON
AUSTRALIAN NATIONAL UNIVERSITY

E-1

THE ROTATIONAL EXCITATION OF N_2 AND H_2 BY ELECTRONS

R. C. Mjolsness and D. H. Sampson
General Electric Company, Valley Forge, Pennsylvania

The cross section for slow electron excitation of molecular rotational states is calculated from induced dipole plus quadrupole interactions using the method of distorted waves. The central part of the potential, suitably cut off, is used to calculate distortion. The calculation is supplemented by analytic results obtained by fitting the interaction to an exponential potential. These approximations are discussed in detail. It appears that only distortion of the $\ell = 0$ partial wave is significant up to several tenths eV electron energy. The induced dipole interaction makes a significant contribution to the total cross section, especially for nitrogen. The calculations indicate that when the change in electron energy is ignored the effect of distortion of the zeroth order partial wave is to reduce the Born approximation cross section by an amount varying from zero at low energy to ~ 9 per cent and 15 per cent for H_2 and N_2 respectively, at 1 eV. This result is supported by a general calculation showing that, to the same approximation, the limiting effect of distortion on the total cross section at low energy is zero. The results are being extended to properly account for the change in electron energy.

E-2

DETERMINATION OF MOMENTUM TRANSFER AND INELASTIC COLLISION CROSS SECTIONS FOR ELECTRONS IN NITROGEN USING TRANSPORT COEFFICIENTS*

A. G. Engelhardt, A. V. Phelps, and C. G. Risk
Westinghouse Research Laboratories

Momentum transfer and inelastic cross sections for electrons in N_2 have been obtained from a comparison[1] of experimental and calculated transport coefficients for values of the characteristic energy between 0.007 to 4.0 eV. The momentum transfer cross section derived is essentially the same as that of Frost and Phelps.[1] For rotational excitation it is found that a positive quadrupole moment of .94 in atomic units and the inclusion of a polarization correction[2] yield the best agreement. Our results for vibrational excitation are consistent with those of Schulz[3] if the sum total vibrational cross section is normalized to 5.5×10^{-16} cm^2 at 2.3 eV. The electronic excitation cross sections are also consistent with the work of Schulz.[3] The data of Tate and Smith[4] served as the basis for the ionization cross sections used.

* Work supported in part by the U. S. Air Force Special Weapons Center.

1. L. S. Frost and A. V. Phelps, Phys. Rev. 127, 1621 (1962); A. G. Engelhardt and A. V. Phelps, Phys. Rev. 131, (Sept. 1, 1963).
2. A. Dalgarno and R. J. Moffett, Indian Academy of Sciences Symposium on Collision Processes, 1962 (unpublished).
3. G. J. Schulz, Phys. Rev. 116, 1141 (1959); ibid 125, 229 (1962); and private communication.
4. J. T. Tate and P. T. Smith, Phys. Rev. 39, 270 (1932).

E-3

EXCITATION RESULTING FROM LOCAL ELECTRIC FIELDS IN THE IONOSPHERE

N. P. Carleton
Smithsonian Astrophysical Observatory and Harvard University

L. R. Megill
National Bureau of Standards, Boulder

We have developed a method for accurate calculation of the distribution of electron energies in the ionosphere under the influence of an electric field.[1,2] From this calculation we can predict rates of excitation of radiating states of N_2, O_2, and O as a function of the strength of a hypothetical applied field. We have earlier concluded[3] that the airglow emissions around 100 km altitude cannot be excited by electric fields. On the other hand, further work enables us to show that certain auroral forms (especially the so-called mid-latitude red arcs), in which the red lines λ6300-6364 of atomic oxygen dominate the spectrum, are almost certainly caused by local electric fields, perpendicular to the magnetic field, and of the order of 1 mv/cm in strength. This hypothesis, as well as explaining quantitatively the preferential excitation of low-lying electronic levels, is consistent with the observed height profiles of the red emission, and with the increased drift velocity and decreased density of electrons which are observed to accompany mid-latitude red arcs. A field of the magnitude required could be caused by separation of charge in the magnetosphere due to the solar wind. Because the conductivity parallel to the geomagnetic field is very much greater than that perpendicular to the field, at all altitudes above 120 km or so, the electric field would exist everywhere in the ionosphere and magnetosphere above this altitude. This mechanism of generation would be consistent with the observed correlation of the occurrence of red arcs with other geomagnetic phenomena.

1. N. P. Carleton and L. R. Megill, Phys. Rev. 126, 2089 (1962).
2. L. R. Megill and J. H. Cahn, to be published.
3. N. P. Carleton and L. R. Megill, Bull. Am. Phys. Soc. 7, 633 (1962).

E-4

MEASUREMENTS OF ABSOLUTE ELECTRON EXCITATION CROSS SECTIONS OF HELIUM AND COMPARISON WITH THEORETICAL VALUES*

F. L. Miller, R. M. St. John and C. C. Lin
University of Oklahoma

The apparent electron excitation functions of helium have been measured for the 4^1S, 5^1S, 6^1S, 3^1P, 4^1P, 4^1D, 5^1D, 6^1D, 4^3S, 5^3S, 3^3P, 3^3D, 4^3D, 5^3D and the 6^3D states at pressures sufficiently low so that the effects of radiation imprisonment and collisional excitation transfer can be neglected. Corrections due to polarization of the radiation and the cascading from the upper excited states have been applied to the experimental data to obtain the true excitation functions. The experimental cross sections agree satisfactorily with the theoretical ones (calculated by the Born Approximations) for the ^1S and ^1P states at high electron energies, but are about three or four times larger than the theoretical values for ^1D. In the case of the triplet series the experimental cross sections exceed the calculated values by factors of ten or more. Reasons for this discrepancy are analyzed and discussed.

* Supported by the Air Force Office of Scientific Research.

E-5

CROSS SECTIONS FOR INELASTIC COLLISIONS BETWEEN ELECTRONS AND He, Ne, AND Ar ATOMS*

B. T. McClure
Honeywell Research Center

We observe the total ionization produced when primary electrons having various reasonably well-defined energies are stopped in a gas. If the energy of the primary electrons is between the ionization energy and twice the lowest excitation energy of the gas under study, the total cross section, Q_x, for inelastic, nonionizing collisions is a simple function of the known cross section for ionization and the average total ionization. We are thus able to determine Q_x as a function of electron energy over a significant range. We find that the cross sections in He, Ne, and Ar are 1.5×10^{-17} cm^2, 2.1×10^{-17} cm^2, and 1.4×10^{-16} cm^2 respectively. We find little variation of Q_x over the energy range defined above. The lower part of our useful energy range overlaps that of Maier-Leibnitz.[1] The ratio of the cross sections listed above to those obtained by Maier-Leibnitz are 1.7, 2.0 and 2.6 for He, Ne, and Ar respectively. We suggest that part of this discrepancy may be resolved by a reconsideration of the statistics of diffusion experiments.[2]

* Work sponsored in part by the U. S. Army Research Office (durham).

1. H. Maier-Leibnitz, Z. Physik 95, 499 (1935).
2. B. T. McClure, Phys. Rev. 130, 1295 (1963).

E-6

CALCULATION OF EXCITATION CROSS SECTIONS FOR HELIUM FROM SPECTRAL MEASUREMENTS ON A RECOMBINING PLASMA*

Frank Robben
University of California

The cross section for increasing the excitation of a helium atom by an inelastic collision with an electron has been deduced from an analysis of the intensity of the spectral lines emitted from the recombining plasma of an arc jet.[1] A collisional-radiative model of recombination[2] is shown to be valid, and the collisional rate constants deduced appear to be independent of electron temperature, indicating that the cross sections are proportional to the square root of the excess energy. It is found that $Q_{2,3} = 9.3\,(E)^{1/2}$, $Q_{3,4} = 73\,(E)^{1/2}$, and $Q_{4,5} = 380\,(E)^{1/2}$ where $Q_{n,\,n+1}$ is the averaged excitation cross section from the levels with principal quantum number n to the levels with principal quantum number n + 1 in units 10^{-15} cm^2, and E is the excess energy in eV. If the square root dependence is valid, these cross sections have an estimated error of about 30 per cent for electron energies up to about 0.3 eV.

* Work supported by the U. S. Air Force

1. F. Robben, Univ. of Calif. Eng. Proj. Report HE-150-211 (1963).
2. Bates, Kingston and McWhirter, Proc. Roy. Soc. 267A, 297 (1962).

Gryzinsky
Classical results

E-7

CROSS SECTIONS FOR THE 3s-3p TRANSITIONS IN Na PRODUCED BY ELECTRON IMPACT*

Neal F. Lane and Chun C. Lin
University of Oklahoma

The cross sections for the 3s → 3p transitions of Na produced by electron impact have been calculated by a method devised for inelastic collisions under near-resonance conditions. The partial cross sections are obtained by first solving the limiting exact-resonance problem as the zeroth order approximation and then using this solution to find the first order solution by means of an iteration procedure. The calculated cross sections are 61.7, 62.9, 57.7, 51.6 and 43.5 (in units of πa_o^2) at electron energies of 7.36, 10.5, 16.8, 23.1 and 33.7 eV respectively as compared to the corresponding experimental values of 54.0, 55.0, 48.5, 43.8 and 38.5. The results of this work show considerable improvement over those of the Born Approximation and of Seaton's B'II method. Detailed comparison of the partial cross sections of this calculation with those obtained from other methods will be presented.

* Supported by the Air Force Office of Scientific Research.

E-8

ENERGY DEPENDENCE OF ELECTRON IMPACT IONIZATION

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

Retarded Potential Difference

A study of ionization cross sections for nitrogen and argon has been made using the R. P. D. technique to simulate mono-energetic electrons; giving results agreeing with those of earlier workers (where available). Linear segments have been observed in many ionization efficiency curves and their existence is confirmed by these measurements. Discontinuities are attributed to the onset of production of excited states of the ion but difficulties are encountered when the linear segments are considered with respect to vibrational excitation of the ion. The energy dependence of the excitation probability for a given vibrational state of an ion produced by electron impact on a molecule has been experimentally determined. The observed ionization to a given electronic band of the ion should consist of the sum of a set of such curves, producing increasing slope of the energy dependence curve for the particular electronic band. The linear threshold behavior for atomic ionization by electrons is well established experimentally and theoretically. Many workers have observed linear segments in ionization of molecules uncomplicated by vibrational contributions although emission studies indicate such effects should be present. Explanations for this behavior seem artificial and require either improbable threshold vibrational relationships or electron impact ionization mechanisms involving compound states.

E-9

INELASTIC SCATTERING OF ELECTRONS BY THE HYDROGEN MOLECULE ION*

James M. Peek
Sandia Laboratory

The problem of inelastic scattering of electrons by H_2^+ is formulated within the framework of the first Born approximation. The exact H_2^+ wave functions[1] are used in evaluating the required integral, and transitions from the gound state to any discrete excited state are considered. It is found that numerical quadrature over one variable is required to obtain a differential cross section. In addition, the orientation of the H_2^+ with respect to the incident electrons must be explicity included in this integral and the resulting differential cross section must be averaged over all possible orientations. Numerical examples are explored for the transitions $1s\sigma_g - 2p\pi_u$ ($R - 2.0\ a_o$), $1s\sigma_g - 2s\sigma_g$ ($R = 2.0\ a_o$), $1s\sigma_g - 2p\sigma_u$ ($R = 1.4,\ 2.0,\ 3.2\ a_o$), in the notation of 1, and the corresponding total cross sections are also obtained for incident energies up to 400 eV. The total cross section was found to have a strong dependence on internuclear distance in the $1s\sigma_g - 2p\sigma_u$ case.

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

1. D. R. Bates, Kathleen Ledsham, and A. L. Stewart, Phil. Trans. Roy. Soc. A246, 215 (1953).

SESSION F

FRIDAY, OCTOBER 18
1:45 P. M.

ION MOBILITIES; HEAVY PARTICLE COLLISIONS

CHAIRMAN

E. W. McDANIEL
GEORGIA INSTITUTE OF TECHNOLOGY

F-1

THE MOBILITY OF NO^+*

R. A. Young, C. R. Gatz, R. L. Sharpless and C. M. Ablow
Stanford Research Institute

NO ions are produced between parallel electrodes by photoionization using the Kr resonance line at 1236 Å. Rectangular voltage pulses, separated by a variable time interval, are applied to the electrodes. The transient current, as charges are swept out of the collection region, is displayed on an oscilloscope and recorded photographically; from this curve the mobility of the charge carriers may be deduced. Experimental values for the mobility of NO^+ in He, Ar, N_2, and H_2 at 20°C and 760 mm Hg are: 19.1 ± 2.4, $3.7 \pm .2$, $3.3 \pm .2$, and 16.3 ± 1.2 cm^2 sec^{-1} $volt^{-1}$, respectively. The mobility of NO^+ in He - N_2 mixtures obeys Blanc's law indicating negligible complexing of NO^+ with N_2 or He. The integrated transient current is related to the total charge in the collection region at the initiation of collection; the rate of growth of ion density as the time interval between pulses is increased indicates the predominant ion loss process and its rate. In these experiments, the integrated current is consistent with ion loss by diffusion, with $D = K\,kT/e$, where K is the experimental ion mobility. The transient current shape and the role of space charge, diffusion, and initial charge distribution have been treated theoretically.

* Work supported by Advanced Research Projects Agency, Project Defender, and Defense Atomic Support Agency.

F-2

ION MOBILITIES IN ARGON

K. B. McAfee, Jr., D. Edelson and D. Sipler
Bell Telephone Laboratories, Murray Hill, New Jersey

Previous measurements of ion mobilities in argon using the technique of the pulsed Townsend discharge, and drift apparatus using the Tyndall tube method have yielded in total three distinct mobility values. Identification of the three ions was deduced by comparison with mobility theory and by appearance potential arguments. These identifications have been mutually conflicting in several cases. Using a new ion drift spectrometer comprising a Townsend source, a drift space and a mass analyzer, the ion drift spectrum of argon has been re-examined. In the pressure range of 1 to 2 Torr and E/p from 17 to 80 mobilities of the three ions Ar^{++}, Ar^+, Ar_2^+ have been determined. The ion with the lowest mobility is Ar^+ - agreeing with the conclusions of Hornbeck, Biondi, and Beaty. The two larger mobilities are Ar_2^+ and Ar^{++} in that order. The latter ion mobility curves obtained with the drift spectrometer are compared with new measurements using a conventional drift tube and with several previous determinations.

F-3

LOW ENERGY CESIUM ION-ATOM COLLISION CROSS SECTIONS*

R. H. Bullis
Research Laboratories, United Aircraft Corp.

The total cesium ion-atom collision cross section has been measured over the energy range of 0.1 to 10 eV. A modified Ramsauer collision chamber in which contact potential differences have been eliminated was employed in the measurements. For energies less than 1 eV, small stray electric fields of the order of millivolts per centimeter can drastically effect ion trajectories in magnetic fields giving rise to spurious experimental results. Therefore, the basic concept employed in these measurements was to produce a completely field free region in which the energy of the ion beam can be uniquely determined and in which the collisional event can take place. Cesium ions were produced by contact ionization of cesium atoms on a hot tungsten surface. Ion beam currents focused through the collision chamber for energies of 1 to 10 eV followed a $V^{3/2}$ dependence. For energies below 0.8 eV the ion current attenuated faster than would be predicted from the $V^{3/2}$ or Child's law dependence. Ion beam current at a beam energy of 0.1 eV was approximately 6×10^{-18} amperes. The cesium ion-atom total collision cross section measured at an ion energy of 0.12 eV was 25,570 P_c (number of collisions per centimeter of path at one millimeter gas pressure). At an ion energy of 9.7 eV the measured cross section was 5,685 P_c. These results will be compared with results of other investigators and also with the predicted theoretical high energy limit.

* Portions of this work were supported by the National Aeronautics and Space Administration.

F-4

HYDROGEN ION CROSS SECTION DETERMINATION BY ION CYCLOTRON RESONANCE

Darold C. Wobschall and John R. Graham, Jr.
Cornell Aeronautical Laboratory

The collision cross sections of H_2^+ and H_3^+ in H_2 were determined from measurements of ion cyclotron resonance line widths. At low E/P, the $H_2^+ - H_2$ cross section was found to be 90 $\mathring{A}^2$, in agreement with theoretical estimates. The $H_3^+ - H_2$ cross section is also 90 $\mathring{A}^2$, in agreement with dc mobility determinations. High E/P measurements were also made. From the ratio of line intensities, the cross section for the formation of H_3^+ from H_2^+ in H_2 was estimated to be of the order of 10 $\mathring{A}^2$. These results confirm the generally held belief that H_2^+ cannot be observed with dc mobility experiments.

F-5

A CONVERGENT SERIES FOR REARRANGEMENT COLLISIONS*

A. Chen, S. Tani and S. Borowitz
New York University

The usual Born approximation is likely not to be valid for rearrangement collisions since the Born series is believed to be divergent for all incident energies.[1] We have examined a model one dimensional three particle problem with a separable interaction, originally proposed by Schwebel.[2] In this model, the Born series for rearrangements diverges. A series constructed by extending Tani's method of orthogonality conditions[3] to rearrangement collisions is found to converge. The first term of the series is different from the usual Born approximation. The relationship of this method to Weinberg's[4] will be discussed.

* Research jointly supported by ARPA through ONR, ARO and NSF.

1. Aaron Amado and Lee, Phys. Rev. 121, 319 (1961).
2. S. Schwebel, Phys. Rev. 103, 814 (1956).
3. S. Tani, Phys. Rev. 117, 252 (1960).
4. S. Weinberg, Phys. Rev. 131, 440 (1963).

F-6

ISOTOPIC EFFECTS IN ION-TRANSFER REACTIONS*

Clayton F. Giese
University of Chicago

Cross sections have been measured, as functions of ion kinetic energy, for the reactions $HD^+ + HD \rightarrow H_2D^+ + D$, $HD^+ + HD \rightarrow HD_2^+ + H$, $HD^+ + X \rightarrow XH^+ + D$, and $HD^+ + X \rightarrow XD^+ + H$, where X is He, Ne, Ar, Kr, or Xe. The apparatus has been described.[1] Ion kinetic energy ranges from 10 eV down to less than 0.5 eV in certain cases. The ratio $R_1 = \sigma(H_2D^+)/\sigma(HD_2^+)$ increases from about 1.1 at 0.5 eV to 3.0 at 7 eV. For extremely low ion kinetic energies obtainable only by producing the primary ions directly in the reaction chamber by electron impact and using very low extraction fields, R_1 goes to about 0.8, but becomes >1 for larger extraction fields. For all X, $R_2 = \sigma(XH^+)/\sigma(XD^+)$ appears to approach about 1.3 for low ion kinetic energy. As ion kinetic energy increases R_2 increases for Ar and Kr, but decreases for He and Ne. The case of Xe is not clear yet. These ratios, as well as the total cross sections, will be discussed more fully.

* This research has been supported by a grant from the National Science Foundation.

1. C. F. Giese and W. B. Maier II, J. Chem. Phys. 39, 739 (1963).

F-7

CHARGE CHANGING COLLISIONS OF FAST H ATOMS AND H_2 MOLECULES INCIDENT ON H_2 GAS*

G. W. McClure
Sandia Laboratory

Measurements of the cross sections for electron capture and loss by H atoms of 2 to 120 keV kinetic energy incident on a thin H_2 gas target have been conducted. The two cross sections, σ_{01} and $\sigma_{0\bar{1}}$, agree within 20 per cent with the earlier results of Stier and Barnett[1] in the entire common energy range 4 to 120 keV. Cross section σ_{01} appears to possess a relative maximum at about 3 keV in addition to the well-established maximum at 45 keV. Below 20 keV our results are drastically at variance with the data of Curran and Donahue.[2] The cross sections for the conversion of fast H_2 molecules to fast H_2^+ and H^+ ions were measured for H_2 primaries of 6 - 120 keV energy. The H_2^+ production cross section increases monotonically with energy from 0.5 to 2.0 A^2 in the measured range, while the cross section for H^+ production varies from 0.25 to 0.43 A^2 in the range 10 to 40 keV and decreases rapidly above 50 keV.

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

1. P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956).
2. R. Curran and T. M. Donahue, Phys. Rev. 118, 1233 (1960).

INDEX TO AUTHORS

INDEX TO AUTHORS
(Continued)