12th ANNUAL

PROGRAM and ABSTRACTS of PAPERS

GASEOUS ELECTRONICS CONFERENCE

NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C.

Under the joint sponsorship of

The American Physical Society
Division of Electron Physics

And

The National Bureau of
Standards

OCT 14-16, 1959

ANNOUNCEMENT

The Committee decided at the time of the 11th Conference to continue to avoid simultaneous sessions and to adhere to a 3- rather than 4-day meeting. This policy appeared to be the consensus of those present at last year's meeting and was supported by the 11th Conference Committee and by the Nominating Committee for this year.

Eighty-five papers were received on or before the deadline date and four were invited. Even with 3 strenuous days, rejection of none would have allowed only 9.7 minutes for each paper, including discussion. The Committee therefore found it necessary to select 47 of the 85, which was, to say the least, an unenviable task. Several interesting subjects, such as sputtering, were regretfully omitted altogether, in spite of the high quality of the abstracts.

Since the number of abstracts submitted continues to grow monotonically, it appears that this problem will recur next year. The Bussiness Session is set for a 20-minute period Thursday morning; to allow sufficient time for a full discussion of the problem would have required the rejection of several more papers. Therefore, the Committee urges you to make your views known by (1) attending the Business Session and nominating a person who will represent your viewpoint at the Nominating Committee meeting and (2) by indicating below your views and placing the ballot in the appropriate box at the entrance to the Lecture Room.

CONFERENCE COMMITTEE

Lewis M. Branscomb, Secretary

(CREASE AND TEAR)

When many more than 50 abstracts are contributed, I prefer:

1. Drastic cutting down to about 45 papers. /_/
2. Four-day meetings. /_/
3. One or more simultaneous sessions. /_/
4. Other ______________________________

In the event of 3-day meetings, I prefer:

Wednesday - Friday /_/ Thursday - Saturday /_/ No preference /_/

1959

GASEOUS ELECTRONICS CONFERENCE COMMITTEE

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

D. J. Rose, Massachusetts Institute of Technology

D. E. Kerr, Johns Hopkins University

W. B. Kunkel, University of California

L. M. Branscomb, National Bureau of Standards, Secretary

PROGRAM

TWELFTH ANNUAL GASEOUS ELECTRONICS CONFERENCE

October 14-16, 1959

TUESDAY, OCTOBER 13

8:00 p.m. Advance registration, lobby of Sheraton Park Hotel

WEDNESDAY, OCTOBER 14

8:30 a.m. Registration, Fourth Floor, East Building, NBS

9:15 a.m. Session A: SCATTERING THEORY
Chairman: U. Fano, NBS

Welcome: Dr. R. D. Huntoon, Deputy Director, NBS

A-1 ON THE USEFULNESS OF THE ADIABATIC APPROXIMATION IN ATOMIC SCATTERING PROBLEMS
B. A. Lippmann

A-2 DISPERSION RELATIONS IN ATOMIC SCATTERING PROBLEMS
N. A. Krall and E. Gerjuoy

A-3 APPLICATION OF METHOD OF POLARIZED ORBITALS TO SCATTERING OF ELECTRONS FROM HYDROGEN
A. Temkin

A-4 ELECTRON SCATTERING BY NOBLE GASES
B. Kivel

A-5 SOME COLLISION PROCESSES INVOLVING A MU MESIC ATOM
T.-Y. Wu, National Research Council, Ottawa (Invited)

11:30 a.m. Break for lunch

1:30 p.m. Session B: SCATTERING (continued)
Chairman: K. Rubin, New York University

B-1 ELECTRON-HYDROGEN ATOM ELASTIC SCATTERING
S. Geltman

B-2 APPROXIMATE CROSS SECTIONS FOR INELASTIC COLLISIONS OF ELECTRONS WITH ATOMS
S. N. Milford

B-3 CROSS SECTIONS FOR THE EXCITATION OF THE METASTABLE 2S STATE OF ATOMIC HYDROGEN BY ELECTRON COLLISION
W. Lichten and S. Schultz

B-4 SPECTRAL DEPENDENCE OF THE H^- AND O^- PHOTODETACHMENT CROSS SECTIONS
S. J. Smith

B-5 COLLISIONS BETWEEN ATOMIC SYSTEMS
D. R. Bates, Queens University, Belfast (Invited)

3:15 p.m. Intermission

3:45 p.m. Session C: INELASTIC COLLISIONS
Chairman: S. J. Smith, NBS

C-1 LOW PRESSURE HELIUM EXCITATION FUNCTION
R. M. St. John and F. E. Fajen

C-2 MEASUREMENT OF ARGON TRANSITION PROBABILITIES USING THE THERMAL ARC PLASMA AS RADIATION SOURCE
H. N. Olsen

C-3 EXCITATION AND IONIZATION OF N_2 BY CONTROLLED PROTON IMPACT
W. F. Sheridan, N. P. Carleton, and O. Oldenberg

C-4 DIFFERENTIAL CROSS SECTIONS FOR PRODUCTION OF SECONDARY ELECTRONS BY PROTONS IN HYDROGEN GAS
C. E. Kuyatt

C-5 FAST MOLECULAR NITROGEN BEAM
G. H. Miller and N. G. Utterback

C-6 RESONANCE ELECTRON CAPTURE FOR H^+ AND HE^+ IONS IN MODERATELY LARGE ANGLE COLLISIONS WITH ATOMS
E. Everhart, F. P. Ziemba, and G. J. Lockwood

5:30 p.m. End of Session C.

THURSDAY, OCTOBER 15

9:00 a.m. Session D: SWARM EXPERIMENTS
Chairman: J. D. Cobine, General Electric

D-1 IMPROVED MICROWAVE TECHNIQUES FOR MEASURING PLASMA CHARACTERISTICS
R. F. Whitmer and J. Kannelaud

D-2 ELECTRON COLLISION FREQUENCIES IN NEON AND NITROGEN
R. M. Hill, A. J. Penico, and E. F. Tubbs

D-3 THEORY OF SWARM EXPERIMENTS IN HYDROGEN
L. S. Frost and A. V. Phelps

Business Meeting (20 minutes)

D-4 DRIFT VELOCITY OF HYDROGEN AND DEUTERIUM IONS IN THEIR PARENT GASES
D. J. Rose

D-5 CROSSED BEAM MEASUREMENTS OF ION-ATOM COLLISION CROSS SECTIONS
W. L. Fite, General Atomic (Invited)

11:30 a.m. Break for lunch

1:30 p.m. Session E: SWARMS (continued)
Chairman: L. B. Loeb, University of California

E-1 SOME NEW OBSERVATIONS ON COLLISION PROCESSES IN THE UPPER ATMOSPHERE FROM AURORAL SPECTROSCOPY
M. H. Rees

E-2 TRANSPORT CROSS SECTIONS FROM ELECTRON MOBILITY DATA IN THE NOBLE GASES AND IN NITROGEN
J. C. Bowe

E-3 ELECTRON TEMPERATURE DEPENDENCE OF THE ELECTRON-ION RECOMBINATION COEFFICIENT IN HELIUM
C. L. Chen, C. C. Leiby, and L. Goldstein

E-4 VOLUME RECOMBINATION AND DIFFUSION IN AFTERGLOWS
E. P. Gray and D. E. Kerr

E-5 EXPERIMENTAL STUDIES OF COLLISIONS OF LOW ENERGY ELECTRONS WITH ATMOSPHERIC GASES
A. V. Phelps, Westinghouse (Invited)

3:15 p.m. Intermission

3:45 p.m. Session F: OXYGEN REACTIONS
Chairman: G. Bekefi, Massachusetts Institute of Technology

F-1 THERMAL ELECTRON ATTACHMENT IN OXYGEN AND OXYGEN-CONTAINING MIXTURES
V. A. J. Van Lint, E. G. Wikner, and D. L. Trueblood

F-2 ELECTRON CAPTURE IN O_2
G. S. Hurst and T. E. Bortner

F-3 ATTACHMENT-DETACHMENT PROCESSES IN OXYGEN MICROWAVE AFTERGLOWS
M. A. Biondi

F-4 CROSS SECTION FOR O_2^- COLLISIONAL DETACHMENT
D. K. Bailey and L. M. Branscomb

F-5 DISSOCIATION OF OXYGEN IN MICROWAVE DISCHARGES
F. Kaufman and J. R. Kelso

F-6 DISSOCIATION OF MOLECULAR IONS BY ELECTRIC FIELDS
J. R. Hiskes and J. L. Uretsky

5:30 p.m. End of Session F

Evening Cocktails and Banquet, Sheraton Park Hotel
After-Dinner Speaker: H. Margenau, Yale University
"Physics and Operational Definitions"

FRIDAY, OCTOBER 16

9:00 a.m. Session G: RADIATION IN PLASMAS
Chairman: N. L. Oleson, U.S. Naval Postgraduate School

G-1 THE EFFECT OF COLLISIONS ON THE OPTICAL REFRACTIVITY OF A PLASMA
O. Theimer and H. Hoffman

G-2 CYCLOTRON RADIATION FROM A MAGNETIZED ELECTRON GAS IN THERMAL EQUILIBRIUM
H. R. Rosner

G-3 CYCLOTRON RADIATION FROM PLASMAS
J. L. Hirshfield and G. Bekefi

G-4 RADIATION FROM A TEST OSCILLATOR IN A PLASMA
H. Dreicer

G-5 ELECTROMAGNETIC WAVES OF RADIOFREQUENCY IN A GYROPLASMA
K. V. Narasingarao, J. T. Verdeyen, and L. Goldstein

G-6 THE INFLUENCE OF ACOUSTICAL WAVES ON THE INTERACTION BETWEEN AN ELECTROMAGNETIC FIELD AND A BOUNDED PLASMA
K.-B. Persson

G-7 DIFFUSION OF PLASMA ACROSS A MAGNETIC FIELD
T. K. Allen, G. A. Paulikas, and R. V. Pyle

11:30 a.m. Break for lunch

1:30 p.m. Session H: SHOCKS AND PLASMAS
Chairman: S. Buchsbaum, Bell Telephone Laboratories

H-1 SPECTRAL LINE BROADENING FROM STRONGLY INHOMOGENEOUS OR MACROSCOPICALLY NON-UNIFORM PLASMAS
L. Gold

H-2 TIME BEHAVIOR OF SPECTRAL LINE SHAPES BEHIND STRONG SHOCKS
S. P. Cunningham, F. R. Scott, and R. F. Wenzel

H-3 ELECTRON DIFFUSION AHEAD OF STRONG SHOCK WAVES
H. D. Weymann

H-4 MAGNETOHYDRODYNAMIC SHOCK IN A COLLISION FREE PLASMA
A. Kantrowitz, R. M. Patrick, and H. E. Petschek

H-5 VISCOUS EFFECTS IN HIGHLY IONIZED ROTATING PLASMAS
W. R. Baker, A. Bratenahl, A. W. DeSilva, and W. B. Kunkel

H-6 PLASMA CONTAINMENT BY R-F AND D-C FIELD COMBINATIONS
R. C. Knechtli and D. Dow

3:15 p.m. Intermission

3:45 p.m. Session I: BREAKDOWN AND ARCS
Chairman, D. S. Burch, Oregon State College

I-1 PRODUCTION OF RADIATION, IN PARTICULAR OF λ=1850 A IN THE LOW PRESSURE MERCURY-ARGON DISCHARGE
A. A. Kruithof

I-2 BREAKDOWN STREAMERS IN CORONA TO ARC TRANSITION IN CONTAMINATED AND VERY PURE ARGON
R. G. Westberg, H. C. Huang, and L. B. Loeb

I-3 MEASUREMENTS OF NEGATIVE STATIC CHARACTERISTICS IN ARGON
M. J. Reddan and A. L. Ward

I-4 RELAXATION TYPE OSCILLATIONS IN ARGON GLOW DISCHARGES
R. J. Stansfield, J. P. Wise, and N. L. Oleson

I-5 THE MEASUREMENT OF THERMIONIC EMISSION IN HOT CATHODE DISCHARGE TUBES
J. F. Waymouth

I-6 ARC RECOVERY PHENOMENA
J. D. Cobine, G. A. Farrall, and D. E. Hagge

5:30 p.m. End of Session I

SESSION A

WEDNESDAY, OCTOBER 16

9:15 a.m.

SCATTERING THEORY

CHAIRMAN

U. FANO
NATIONAL BUREAU OF STANDARDS

A-1 ON THE USEFULNESS OF THE ADIABATIC APPROXIMATION IN ATOMIC SCATTERING PROBLEMS*

B. A. Lippmann
Lawrence Radiation Laboratory, University of California
Livermore, California

The adiabatic approximation assumes that a slowly moving particle causes a perturbation equivalent to the same particle at rest. That is, in the detailed calculations, (a) the kinetic energy operator of the particle is ignored, and (b) the potential is evaluated by fixing the position of the particle precisely. These requirements are complementary; they cannot simultaneously be satisfied exactly. To determine the extent to which they are compatible, the particle should be replaced by a wave-packet of dimensions $\sim\delta r$, where δr is so large that the kinetic energy is negligible, and so small that the variation of the potential over the wave-packet is inappreciable. Or, if E is the energy of the system, M the mass of the incident particle, and the potential varies as r^{-n}($m=e=\hbar=1$),

$$\frac{r}{n} \gg \delta r \gg (13.6/ME)^{1/2}.$$

Application of this criterion shows that the adiabatic approximation is not appropriate for the scattering of electrons by atoms; it is, however, meaningful when protons or heavier particles are scattered by atoms.

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

A-2 DISPERSION RELATIONS IN ATOMIC SCATTERING PROBLEMS

N. A. Krall and E. Gerjuoy
John Jay Hopkins Laboratory for Pure and Applied Science
General Atomic Division of General Dynamics Corporation
San Diego, California

Dispersion relations connecting scattering amplitudes with total cross-sections have been used by workers in the field of meson and strange particle physics, to help interpret scattering experiments. These quite simple relations can be applied to the scattering of electrons by atoms, and other atomic scattering processes. This approach is not common because in atomic problems the forces are well known; it is still of value in situations where the problem is too complex to allow direct calculation using the known forces. The appropriate relations are applied to the elastic scattering of electrons by free hydrogen atoms. Two experiments presently exist,[1,2] yielding quite different results for the total cross-section, with theoretical attempts[1,3] to justify each experiment. Dispersion relations provide a useful tool for resolving differences of this sort, and in this case support the experiments of Brackmann, Fite, and Neynaber.

[1] R. T. Brackmann, W. L. Fite, and R. H. Neynaber. Phys. Rev. 112, 1157 (1958).

[2] B. Bederson, and M. Malamud. Bull. Am. Phys. Soc. (II), 2, 122 (1957).

[3] K. Omidvar. New York University Report CX-37, January, 1959.

A-3 APPLICATION OF METHOD OF POLARIZED ORBITALS TO SCATTERING OF ELECTRONS FROM HYDROGEN

A. Temkin
National Bureau of Standards, Washington, D.C.

The method of polarized orbitals[1] is being applied to the calculation of the s-, p-, and d-wave phase shifts for the low energy scattering of electrons from atomic hydrogen. The adiabatically perturbed wave function in our original method has been modified in such a way as to automatically cut off the singularity at the origin of the polarization potential in the final scattering equation. This latter integrodifferential equation has been reduced to a set of uncoupled ordinary differential equations by an extension of the transformation used by Omidvar.[2] Some numerical results have already been obtained for the p-wave, and it is hoped that the remaining results will have been obtained at the time of the meeting.

[1] A. Temkin. Phys. Rev. 107, 1004 (1957).

[2] K. Omidvar. New York University Research Report No. CS-37 (1959) (unpublished).

ELECTRON SCATTERING BY NOBLE GASES*

B. Kivel
Avco-Everett Research Laboratory, Everett, Massachusetts

A numerical integration of the partial wave Schrodinger equation has been carried out for the electron scattering by argon at energies below 1 ev. The cross section at zero energy is found to be 7.5×10^{-16} cm^2, which is appreciably above measurements by Whalin and by Phelps, Fundingsland, and Brown, but consistent with recent measurements by Pack and Phelps. The zero energy cross section can be accounted for by considering only the polarization force at distances greater than 8 atomic units, which is effectively outside of the atom. Making the assumption that this is the case for all of the noble gases, we find their zero energy cross sections determined by their polarization tails to be consistent with experimental data on low energy electron scattering. The resulting zero energy cross section is $4\pi a_o^2(p/r_o)^2$, where p is the atomic polarizability and r_o is the atomic size both in atomic units and $4\pi a_o^2 = 3.52 \times 10^{-16}$ cm^2.

* This work was supported by the Ballistic Missile Division, Air Research and Development Command, United States Air Force, under contract AF 04(647)-278.

Invited Paper

A-5 SOME COLLISION PROCESSES INVOLVING A MU MESIC ATOM

T.-Y. Wu
National Research Council, Ottawa, Canada

$(p-\mu-p)^+$ system like H_2^+
$(p-\mu-d)^+$ " HD^+ ← fusion

$(p+\mu)+p \to (p+\mu)+p$ elastic
$(p+\mu)+d \to (p+\mu)+d$
$\to (d+\mu)+p$

$(p+\mu)+H \to (p+\mu+p)^+ + e$

Observation of fusion demonstrate that molecular systems exist.
Born-Opp. approx is not good enough because

SESSION B

WEDNESDAY, OCTOBER 14

1:30 p.m.

SCATTERING (continued)

CHAIRMAN

K. RUBIN
NEW YORK UNIVERSITY

B-1 ELECTRON-HYDROGEN ATOM ELASTIC SCATTERING

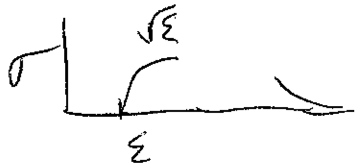
S. Geltman
Atomic Physics Section
National Bureau of Standards, Washington, D.C.

The elastic scattering of electrons by hydrogen atoms has been calculated in many approximations since 1928. The novel features of the present calculation are: (1) inclusion of partial waves up to the d-wave; and (2) use of a non-separable wave function containing a non-linear variational parameter. The Kohn variational method is applied with a trial function that is the sum of an asymptotic term containing the phase parameter and an interior term to describe the region in which the two electrons are strongly interacting. The interior term is a product of functions of each of the electron radial coordinates involving the one non-linear and three linear variational parameters and is made to vanish exponentially as either electron coordinate goes to infinity. Results for the s-wave indicate symmetric (singlet) phase shifts up to .25 radian below previous calculations at energies $\lesssim$13.6 ev, while the antisymmetric (triplet) phase shifts are unchanged.

B-2 APPROXIMATE CROSS SECTIONS FOR INELASTIC COLLISIONS OF ELECTRONS WITH ATOMS

S. N. Milford
St. John's University, New York, New York

The threshold and large energy properties of cross sections are combined with the energy derivative of the cross section at its maximum. The resulting formula relates the maximum cross section to the energy ϵ_1 at this maximum. The multipole expansion then gives a simple formula within 10 o/o of the Born approximation maxima for many allowed transitions of hydrogen induced by electron impact. Choosing ϵ_1, the approximate formula gives the momentum cut-off in the Bethe approximation. The Bethe and threshold shape is then compared to electron plus hydrogen atom Born cross sections for allowed transitions. The simple formula gives (a) the Born maximum within a factor of two, and (b) the Born approximation for all energies within a factor of three. Thus, when the dipole moment is known from experiment or calculation, the approximate cross section can be found at all energies by several minutes' calculation. The method is being extended to atom-atom collisions.



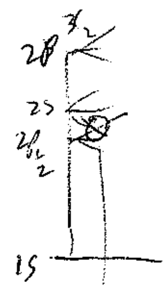
B-3 CROSS-SECTIONS FOR THE EXCITATION OF THE METASTABLE 2S STATE OF ATOMIC HYDROGEN BY ELECTRON COLLISION[+]

W. Lichten[*] and S. Schultz
Columbia University, New York, New York

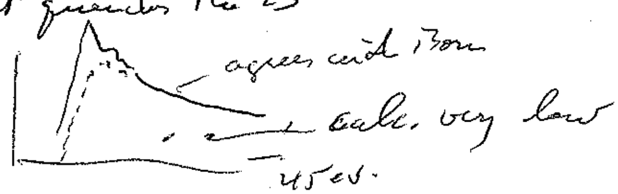
The function for excitation of the 2S state of atomic hydrogen by electron impact has been measured from threshold to 45 ev by an atomic beam method. The absolute value of the total cross-section has been determined by two independent methods which are in agreement. In one method the excitation function was normalized to the Born approximation at the higher energies. The mechanism of cascade from higher P states was found to play a significant role in population of the metastable 2S level. The other method proceeded by determining the metastable detection efficiency in terms of the known efficiency for Lyman α photons. The total cross-section reaches a maximum value of $.35\pm.05\pi a_0^2$ at 11.7 ev. The yield for ejection of electrons from an untreated platinum surface by H(2S) is .065±.025. The exchange cross-section was also measured by the atomic beam method. The incident atoms were polarized in a Stern-Gerlach experiment; the metastable atoms were analyzed by the selective quenching action of a magnetic field of 575 gauss. The ratio of the exchange to total cross-section is .45±.05 near threshold. At higher energies, this ratio approaches zero. The cross-section for production of metastable atoms by direct bombardment of molecular hydrogen is $.03\pi a_0^2$. This value is considered correct to within a factor of two.

[+] Work supported jointly by the U.S. Army, Navy, and Air Force.

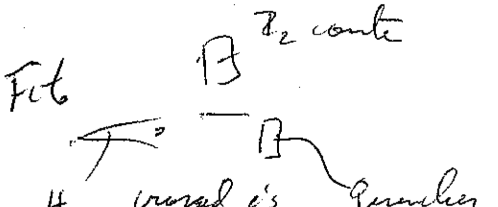
[*] Now at the University of Chicago, Chicago, Illinois.



This experiment quenches the 2S



575 gauss



Fit

Q2S / Q2P like Lichten

Abs. value more like calc.

B-4

SPECTRAL DEPENDENCES OF THE H^- AND O^- PHOTODETACHMENT CROSS SECTIONS*

S. J. Smith
Atomic Physics Section
National Bureau of Standards, Washington, D.C.

Recent careful measurements of the spectral dependences of the photodetachment cross sections of H^- and O^- will be discussed. The measurements are based on the detection of free electrons photodetached in high vacuum at the intersection of a beam of ions and a quasi-monochromatic beam of photons from a carbon arc projection lamp. The problem of eliminating systematic errors in measurements of the spectral dependence of the photon beam intensity was met by monitoring the photon beam with a bolometer which was in turn calibrated by use of a spectrally non-selective calorimeter. Calibrations were reproduced over the period of several weeks during which the O^- and H^- cross sections were carefully measured. Statistical probable errors in the cross section measurements were about 1 or 2 percent. Measurements were made at a number of wavelengths longer than 4000 A. The cross section obtained for O^- in this limited spectral range can be combined with an earlier precise measurement of the O^- threshold by Branscomb et al., and with a Born approximation calibration at high proton energies to give a reasonably consistent estimate of the cross section over an extended spectral range. The H^- cross section will be compared briefly with the results of several calculations.

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

1/4 - 1/2 watt of photons.

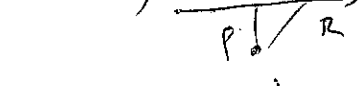
Invited Paper

B-5

COLLISIONS BETWEEN ATOMIC SYSTEMS

D. R. Bates
Queens University, Belfast, Ireland

Hi Energy Region – use 1st Born Approx, but complicated.
$A + B \to A' + B'$, B' in a definite state; A in any of a no. of states
can derive asymptotic formula, summing over states of A, but only at
energies too high for interest. Projectile is bare nucleus.
~~Confus~~ Normally pure wave treatment but in some cases can be
treated classically – motion of projectile is classical, undeviated.



$\Psi = \sum_n a_n(z)\,\phi_n(r)\exp(-i\varepsilon_n t)$ (energy of target system
(target

$a_0(-\infty) = 1$, $a_n(-\infty) = 0$ for $n > 0$

sub. in Schrod. Eq & get relation for a_n

$i\frac{\partial a_p}{\partial z} = \frac{1}{v}\sum_n a_n(z)\,(p|V|n)\exp(-\frac{i}{v}(\varepsilon_n - \varepsilon_p)z)$; $z = vt$

Born approx: use only the initial state on R.H.S.

$i a_p = \frac{1}{v}\int_{-\infty}^{z}(p|V|0)\exp(-\frac{i}{v}(\varepsilon_0 - \varepsilon_p)z)\,dz$

can see when B.A. breaks down; $\sum_{p \neq 0}|a_p(z)|^2 \ll 1$ for validity

i.e. for $H^+ + H(1s) \to H^+ + H(n,\ell)$, $\Sigma < 0.1$ if energy
of ~~relative motion~~ incident H^+ is > 200 keV.

But $\Sigma > 0.5$ if energy of $H^+ < 50$ keV.

There are 2 paths for elaborating on 1st Born:

(a) 2nd Born: sub. $i a_p(z)$ in $i\frac{\partial a_p}{\partial z}$ & integrate again; infinite series;
can be shown valid only if the 2nd approx is small. Even
computer calc. aren't helpful.

(b) Try to allow for defects in 1st Born.
In sum appearing in $i\frac{\partial a_p}{\partial z}$ take also the term $p = n$ which
is time-ind. This is "distortion" approx, due to static field of target.
Since target field ~ 50 eV, one doubts at first that it can be important for
50 keV particles. This shows up also in wave treatment. The change in
wavelength depends only on interaction field, not KE.
$H^+ + H(1s) \to H^+ + H(2s)$ at 50 keV, distortion reduces σ by $\frac{1}{2}$;
at 10 keV by factor of 10.

SESSION C

WEDNESDAY, OCTOBER 14

3:45 p.m.

INELASTIC COLLISIONS

CHAIRMAN

S. J. SMITH
NATIONAL BUREAU OF STANDARDS

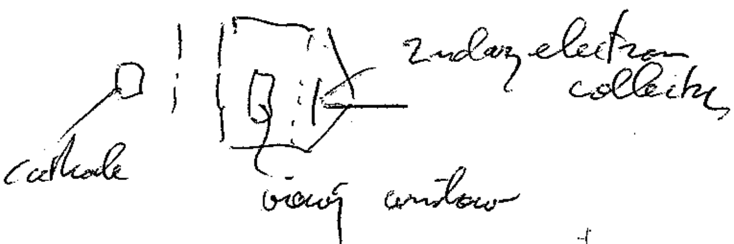
C-1 **LOW PRESSURE HELIUM EXCITATION FUNCTION**

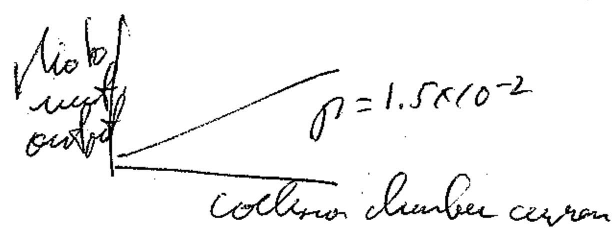
R. M. St. John and F. E. Fajen
Department of Physics, University of Oklahoma, Norman, Oklahoma

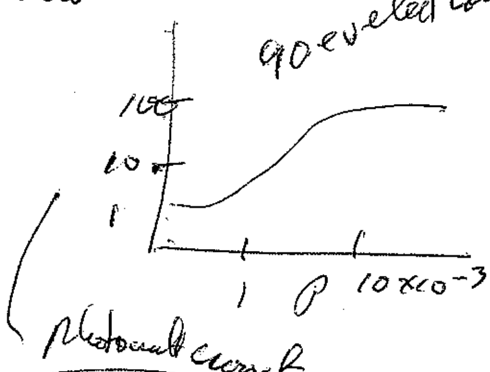
The excitation function for several excited states of helium have been examined for electron energies from 30 to 500 ev. The absolute value of the 3^1P function has been obtained through the use of a tungsten strip standard lamp. A sensitive photomultiplier was used for light detection. Pressures utilized in the excitation measurements were as low as $1x10^{-4}$ mm and absorption of resonance radiation was negligible for pressures below $3x10^{-4}$ mm. Filters were used for wavelength selection. When more than one line was transmitted, spectrographic data gave relative intensities. Levels contributing cascade components to the 3^1P level were studied and their effects eliminated. The 3^1P function of excitation by electron impact only has a peak value of $2.4x10^{-18}$ cm^2 at 100 ev.

Elect Energy spread <1 ev at 30 ev.

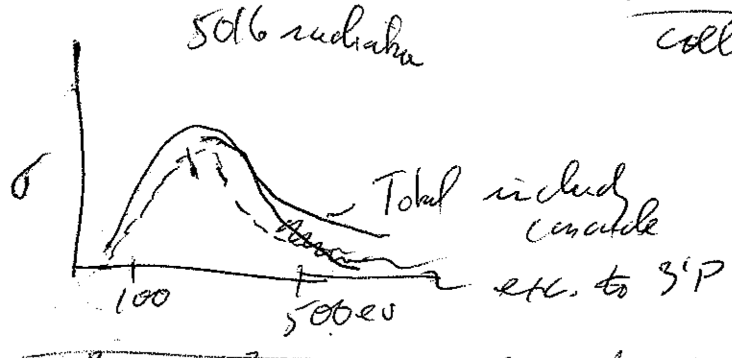
calibrate lite detector against standard lamp (GE calibrated lamp)

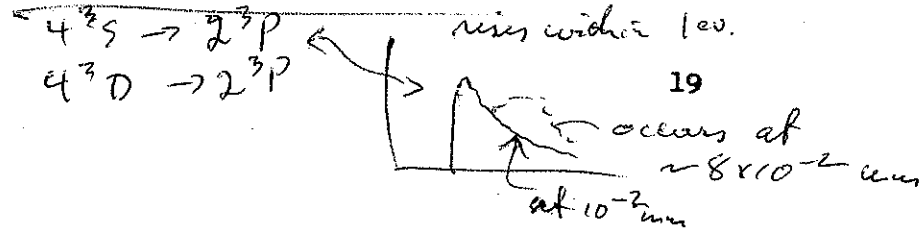






agrees with Hodges up to 10^-2 — above that self-absorption lowers effect.





C-2 MEASUREMENT OF ARGON TRANSITION PROBABILITIES USING THE THERMAL ARC PLASMA AS RADIATION SOURCE

H. N. Olsen
Linde Company, Indianapolis, Indiana

The high current argon arc plasma whose electrical and thermal properties were described in a previous paper[1] has been used as a radiation source of known temperature to measure absolute transition probabilities of atomic and ionic argon spectral lines. Temperatures determined by the Larenz[2] method from radial intensity distributions (corrected for source inhomogeneities) of both atomic and ionic spectral lines and of the electron continuum agree to better than ±5 percent. Intensity measurements were made on an absolute scale using the positive crater of low current carbon arc as a radiation standard. Measured intensities and temperatures have been combined with particle densities calculated according to the Saha equation to give experimental values for the spontaneous transition probabilities of selected atomic and ionic spectral lines. Estimated accuracy of the measured probabilities is ±10 percent.

[1] H. N. Olsen. Paper B-6, 11th Annual Gaseous Electronics Conference (1958).

[2] W. Larenz. Z. Physik, 129, 327 (1951).

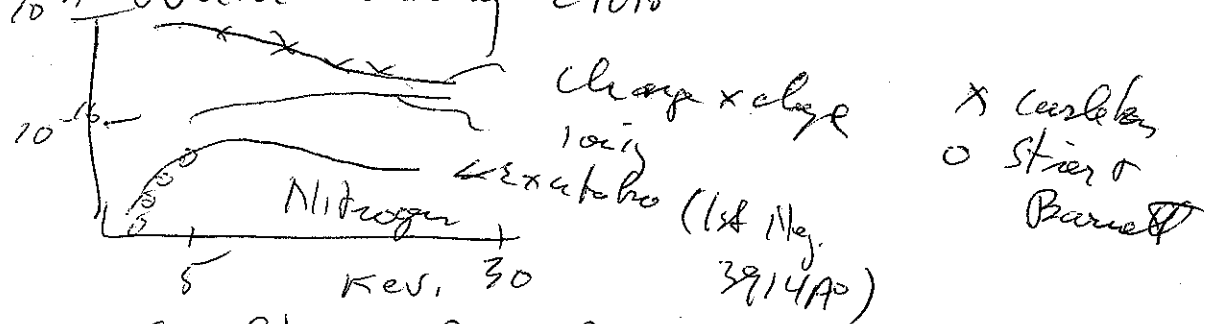
C-3

EXCITATION AND IONIZATION OF N_2 BY CONTROLLED PROTON IMPACT

W. F. Sheridan, N. P. Carleton,* and O. Oldenberg
Geophysics Research Directorate, Air Force Cambridge Research Center, Bedford, Massachusetts, and *Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts

It has been recognized that the auroral glow is partly due to the impact of protons on the atmospheric gases. We are making a laboratory study of the excitation of atmospheric gases subject to controlled proton impact. We have bombarded N_2 at low pressures with 4 kev to 30 kev protons and determined cross sections for excitation of the 1st Negative bands of N_2^+ and for ionization of N_2. Simultaneous measurements of cross sections for charge exchange yield results in good agreement with those of other workers.

Electrodeless discharge source 75 watts, 60 mc
5 kev accel. voltage
Mass + energy analysis — beams 0.5 x 5 mm.
Lens + filter to transmit radiation, photo-mult. — select 75-100 A width.
guard plates allow correction for background.
Only relative light intensity determined.
Greatest source of error is in pressure — ±5%
Overall accuracy ~10%



To obtain abs values, but with Carleton data at 4 Kev.

C-4 DIFFERENTIAL CROSS SECTIONS FOR PRODUCTION OF SECONDARY ELECTRONS BY PROTONS IN HYDROGEN GAS

C. E. Kuyatt
University of Nebraska, Lincoln, Nebraska

Hydrogen gas was bombarded by 50, 75, and 100 kev protons and the differential cross section for production of secondary electrons measured as a function of electron energy at angles of 23°, 45°, 67-1/2°, 90°, 112-1/2°, 135°, and 152° from the proton beam direction. The differential cross sections are largest at 23°, dropping off rapidly at larger angles. As a function of electron energy, at a fixed angle, the differential cross section shows a broad peak at 4 to 9 ev with a monotonic decrease at higher electron energies. Measurements are in progress at higher proton energies, and will be reported on if available.

C-5

FAST MOLECULAR NITROGEN BEAM*

G. H. Miller and N. G. Utterback+
University of Virginia, Charlottesville, Virginia

A 20- to 200-ev molecular nitrogen beam has been produced by the technique of ionization, acceleration and focusing, analyzing, energy selection, and neutralization by charge exchange in nitrogen gas. Intensities of the order of 10^{10} molecules per second are obtained. The neutralization-to-scattering probability ratio is favorable over the energy range studied, and 20 percent neutralization of the ion beam is easily obtained. Data will be presented on the ionization cross-section for nitrogen molecules in nitrogen gas and on the probability of secondary electron emission from a gold surface upon nitrogen molecule impact, as determined using this beam.

* Work supported by the National Aeronautics and Space Administration.

+ Authors now at Denver Research Institute.

chg xch. 24×10^{-16} at 25 ev.
21 at 100
15 at 200

C-6

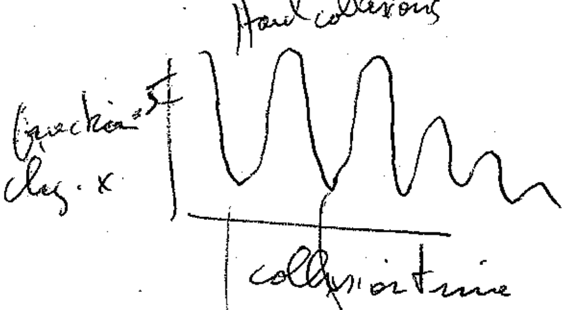
RESONANCE ELECTRON CAPTURE FOR H^+ AND HE^+ IONS IN MODERATELY LARGE-ANGLE COLLISIONS WITH ATOMS*

E. Everhart, F. P. Ziemba, and G. J. Lockwood
University of Connecticut, Storrs, Connecticut

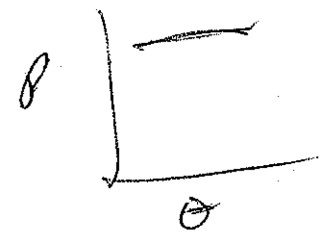
The recent discovery of multiple resonances for electron capture in large-angle He^+ on He collisions[1] has prompted a search for similar resonances in other combinations. Incident ions of H^+ and He^+ in the energy range of 4 to 200 kev were studied in single collisions with H_2, He, N_2, O_2, Ne, A, and Kr targets. The probability of electron capture by an incident particle which scattered through a 5^o angle in a single collision is plotted versus energy. In all cases where protons were the incident particle, two pronounced peaks were found. When He^+ ions were incident, the probability was always fairly high over an extended energy region with several resonance peaks of low amplitude superimposed. Where the target is monatomic, the incident particle passes almost through the center of the target atom in these violent collisions. The electronic wave functions become practically overlapped and concentric at the midpoint of the collision. The location of the electron capture peaks are compared with those predicted by the simple near-adiabatic theory.

* Sponsored by the Office of Ordnance Research, U.S. Army

[1] F. P. Ziemba and E. Everhart. Phys. Rev. Lett., 2, 299 (1959).



He+ on He
5° scatter
equal spacing



80 kev 26 kev, 13.5, 7.2, 4.8, 3.3, 2.2 minima
equal times to hop on & off.
H+ on He, D+ on He also, to get to lower energy
5°   3°
H2+ on He - weaker resonance, spacing as for H+
H+ on H2 3 peaks - same in coll time
22 kev, 4, 1.7   24
D+ on H2

For light elements –
only one impact parameter – zero.
peaks evenly spaced in time – is there
theoretical oscillation to off – on.
Explain highest energy peak first – others are satellites
Adiabatic theory not applicable
Curious energy for
many collisions
Lot of energy transferred

SESSION D

THURSDAY, OCTOBER 15

9:00 a.m.

SWARM EXPERIMENTS

CHAIRMAN

J. D. COBINE
GENERAL ELECTRIC COMPANY

D-1

IMPROVED MICROWAVE TECHNIQUES FOR MEASURING PLASMA CHARACTERISTICS

R. F. Whitmer and J. Kannelaud
Microwave Physics Laboratory
Sylvania Electric Products Inc., Mountain View, California

In the past microwave interferometer techniques have been used to measure the electron density and the electron-neutral particle collision frequency in an ionized gas. This was accomplished by measuring the attenuation and phase shift of an electromagnetic wave traversing the plasma and relating these measured quantities, by means of an elementary theory, to the desired plasma parameters. Many limiting assumptions were made in deriving the relationship between the measured quantities and the desired quantities. These include the assumptions of plane wave propagation in an infinite medium of uniform electron density, and in most cases these assumptions were not satisfied in the experimental arrangement. As a result, such measurements must be considered somewhat unreliable. An improved experimental arrangement has been designed which closely approximates the model used in the theory. Comparisons have been made between measurements performed with the new technique and measurements performed with the usual arrangement. The results indicate that unless proper precautions are taken, a considerable error in the measured quantity may result. For example, the measured value of the electron-neutral particle collision frequency may be in error by as much as a factor of 5 if the improved technique is not employed. In addition, the new arrangement greatly increases the reproducibility of the results.

D-2 ELECTRON COLLISION FREQUENCIES IN NEON AND NITROGEN*

R. M. Hill, A. J. Penico, and E. F. Tubbs
Microwave Physics Laboratory
Sylvania Electric Products Inc., Mountain View, California

Electron collision frequencies at thermal energies in neon and nitrogen have been determined from measurements of electron-cyclotron-resonance line width. In reducing the data the assumption is made that $\nu_c = B_h v^h$ where v is the electron velocity and h is an interger. Under this assumption the measurements yield $P_c = 2.7\ cm^{-1}\ mm\ Hg^{-1}$ for neon at 300^oK and $P_c = 18.6\ cm^{-1}\ mm\ Hg^{-1}$ for nitrogen for a temperature range from 300 to 600^oK. The data indicate a slight negative slope for the variation of P_c with temperature. These results will be compared with the results of other workers.

* This work was performed under Air Force Contract No. AF 30(602)-1886.

D-3 THEORY OF SWARM EXPERIMENTS IN HYDROGEN*

L. S. Frost and A. V. Phelps
Westinghouse Research Laboratories, Pittsburgh, Pennsylvania

The energy distribution function of electrons in hydrogen at 77°K has been computed at values of the applied field to pressure ratio such that rotational excitation is the dominant energy loss process. The numerical calculations were carried out by machine and included energy gain and loss terms due to elastic and inelastic collisions. Deduced values of drift velocity and characteristic energy, D/μ, are compared with the available experimental values. The results are consistent with a rotational excitation cross section in hydrogen which is about 2.5 times the value calculated by Gerjuoy and Stein[1] and a momentum transfer cross section which is in good agreement with the results of Bekefi and Brown.[2]

* These studies were supported in part by ARPA 5-58 Task 1, Contract Nonr-2584(00) with the Office of Naval Research, and by Contract AF 29(601)-1254, project 5776, with the Air Force Special Weapons Center.

1 E. Gerjuoy and S. Stein. Phys. Rev. 98, 1848 (1955).

2 G. Bekefi and S. C. Brown. Phys. Rev. 112, 159 (1958).

D-4

DRIFT VELOCITY OF HYDROGEN AND DEUTERIUM IONS IN THEIR PARENT GASES

D. J. Rose*
Bell Telephone Laboratories, Murray Hill, New Jersey

Drift velocity of ions in H_2 and D_2 have been measured, using a pulsed Townsend technique similar to that developed by Hornbeck.[1] Expressed in terms of mobility μ_o(cm^2/volt x sec) as a function of E/p_o(volts/cm x mm Hg) (μ_o; E/p_o) it was found for hydrogen: (11.8; 26.0); (15.3; 48); (11.6; 150). For deuterium: (9.0; 23.0); (11.5; 47); (7.5; 180). For each ion, first and last values represent the limits on E/p_o, and the intermediate value represents the maximum mobility. The experiment was performed with uranium-purified gas in an ultra-high vacuum system. Ions were not identified as atomic, diatomic, or triatomic, and may change their nature, depending on the value of E/p_o. These mobility values appear at variance with some other published data.

* Now at Massachusetts Institute of Technology, Cambridge, Massachusetts.

1 J. A. Hornbeck. Phys. Rev. 83, 374 (1951); 84, 615 (1951).

Not √2

Invited Paper

D-5

CROSSED BEAM MEASUREMENTS OF ION-ATOM COLLISION CROSS SECTIONS

W. L. Fite
General Atomic, San Diego, California

Ultimate noise is that on ion beam

SESSION E

THURSDAY, OCTOBER 15

1:30 p.m.

SWARMS (continued)

CHAIRMAN

L. B. LOEB
UNIVERSITY OF CALIFORNIA

E-1 SOME NEW OBSERVATIONS ON COLLISION PROCESSES IN THE UPPER ATMOSPHERE FROM AURORAL SPECTROSCOPY

M. H. Rees
Geophysical Institute, University of Alaska, College, Alaska

Results from recent photometric and spectroscopic measurements of the aurora are reported. The observational data on the absolute intensity of the green and red lines of oxygen and a band of the ionized nitrogen molecule are discussed in terms of the relative importance of specific excitation processes. A spectroscopic study of an intense red aurora has indicated the importance of charge transfer processes in producing at least some of the auroral excitation. These quantitative data together with preliminary results from one year's high time resolution spectra are intérpreted in terms of the respective role of protons and electrons in auroral excitation.

E-2 TRANSPORT CROSS-SECTIONS FROM ELECTRON MOBILITY DATA IN THE NOBLE GASES AND IN NITROGEN*

J. C. Bowe
Argonne National Laboratory, Lemont, Illinois

Transport collision cross-sections were obtained for slow electrons (ϵ <10 ev) in the noble gases from experimental drift-velocity data. Analysis and interpretation of these data yielded the following values (σ_t in cm^{-1} and ϵ in ev): $\sigma_t=(28\pm1)$, $0.13\leq\epsilon\leq4$, for He; σ_t increases from 5.6 to 9.1 in the interval ϵ =0.37 to 5.4, for Ne; $\sigma_t=(6.3\pm0.6)\epsilon$, $1.6\leq\epsilon\leq11$, for A; $\sigma_t=14\epsilon$, $1.6\leq\epsilon\leq3$, for Kr; $\sigma_t=26\epsilon$, $1\leq\epsilon\leq2.4$ for Xe. These results are compared with values computed from the Ramsauer-Kollath scattering data and, where possible, with values reported from microwave experiments. Comparison is also made with values computed from the partial-wave phase-shifts of Westin, Morse, and Allis, and Holtsmark. The mobility data for nitrogen, when combined with the cross-sections of Phelps, et al, yielded a value of 20(2m/M) for the average fractional energy-loss per collision for electrons in the energy range 0.07 ev to 0.15 ev. This is in good agreement with the average value of 25(2m/M) obtained from the theoretical curve of Gerjuoy and Stein.

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

E-3 ELECTRON TEMPERATURE DEPENDENCE OF THE ELECTRON-ION RECOMBINATION COEFFICIENT IN HELIUM*

C. L. Chen, C. C. Leiby, Jr., and L. Goldstein
University of Illinois, Urbana, Illinois

The phenomenon of "afterglow quenching" is employed in determining the electron temperature dependence of the electron-ion recombination coefficient in pure helium. The variation of the two characteristic spectral lines of helium, 5876A(3^3D-2^3P) and 3888A(3^3P-2^3S), as well as the total visible light intensity as a function of electron temperature, have been studied. It is found experimentally that the recombination coefficient varies inversely as the three-halves power of the electron temperature in the range of 300°K to 1500°K and at electron density of $\sim 10^{11}$(cm^{-3}) and gas pressure of 10 − 30.3 mm Hg. At room temperature ($\sim$300°K), the recombination coefficient is found to be $(8.7\pm0.3)\times10^{-9}$ cm^2/cm^3.

* This research was sponsored by the Air Force Cambridge Research Center under Contract AF19(604)-2152.

Believe impurities less than 10^{-9}

$He^+ + 2He \rightleftharpoons He_2^+ + He$, $\nu_{convert} = 65\,p^2(He)\,sec^{-1}$

$He_2^+ + e = He + He'$

excitation of He by e's negligible

$I \propto \frac{dn_e}{dt}$

Agrees with Bates' theory

can predict accurately the luminosity at beginning & end of transient.

Biondi says Kerr found only bands, no lines; Biondi found ~~one~~ line under special condition

Kerr says predominantly molecular spectrum, $\alpha < 2\times10^{-9}$
" looks over many millisec, Leiby for but a μ sec.
" says atomic line time dependence quite different than molec.

Biondi says at very low p, find α between 10^{-8} & 10^{-9}

E-4 VOLUME RECOMBINATION AND DIFFUSION IN AFTERGLOWS

E. P. Gray*
Applied Physics Laboratory
Johns Hopkins University, Silver Spring, Maryland
and D. E. Kerr+
Physics Department
Johns Hopkins University, Baltimore, Maryland

We have investigated the limits of applicability and reliability of the microwave method for determining the volume recombination coefficient α from the slope of a $1/n$ versus t plot of the decaying electron concentration, n, in an afterglow. Numerical solutions have been obtained for infinitely long cylindrical and for spherical plasmas, over a wide range of the parameter[1] $\beta = \alpha n_o \Lambda^2 / D_a$ of the diffusion equation with a quadratic recombination loss term, which governs electron loss when only one species of positive ion is present. The usual boundary condition, $n_{wall} = 0$, was imposed. Both the lowest "diffusion mode" distribution and a uniform distribution were used as initial conditions. The quantity directly measured in the microwave method, $\bar{n}$, the average electron density weighted by the square of the electric field, was calculated, using the unperturbed TM_{010} mode, and various ratios of plasma to cavity diameters. Approximate solutions, with the Laplacian replaced by $-n/\Lambda^2$, were also evaluated and the corresponding averages compared with the correct $\bar{n}$. The following conclusions can be drawn: (1) A linear $1/\bar{n}$ versus t plot does not by itself constitute proof of recombination control unless $\bar{n}$ changes by a factor of 5 (or even more in some cases) over the linear portion; (2) The microwave method is valid (i.e., the slope of the $1/\bar{n}$ versus t plot is close to α) only for very large β. Application of these results to measurements of the recombination coefficients in argon, neon, and helium will be discussed.

* Supported by the Bureau of Ordnance, Department of the Navy, under NOrd 7386.

+ Supported by the Air Force Office of Scientific Research.

[1] n_o = initial axial electron concentration, Λ = diffusion length in lowest "diffusion mode," D_a = ambipolar diffusion coefficient.

Can get a large α = 1×10⁻⁸ even with no recomb, boundary the slight curvature in a straight line within ~2%.

In He, Biondi & Brown have f ~ 1.8 — ... believe recomb control. Ne + A, >15 no results ~10%

$$\beta = \frac{\alpha\, n(0,0)}{D_a/\Lambda^2}$$

$$\frac{dN}{dt} = \frac{1}{\rho}\frac{\partial}{\partial\rho}\left(\rho\frac{\partial N}{\partial\rho}\right) - \beta N^2$$

Integrated for initial uniform dist & ideal J_0. $\lambda_1 = 2.404$

$$\bar{N} = \int_0^{\lambda_1} N E^2(\rho)\rho\, d\rho \Big/ \int_0^{\lambda_1} E^2(\rho)\rho\, d\rho$$

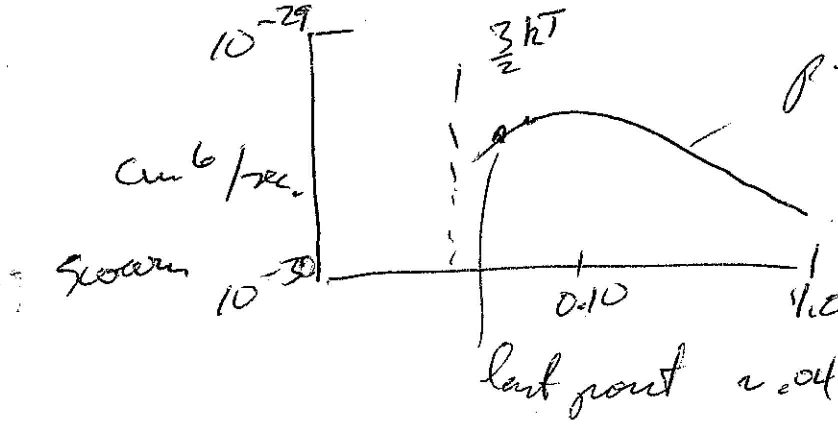
$\gamma = R(\text{plasma})/R\,\text{cavity}$

$f = N_{max}/N_{min}$ — should be > 3 to determine α within a factor of 5

Invited Paper

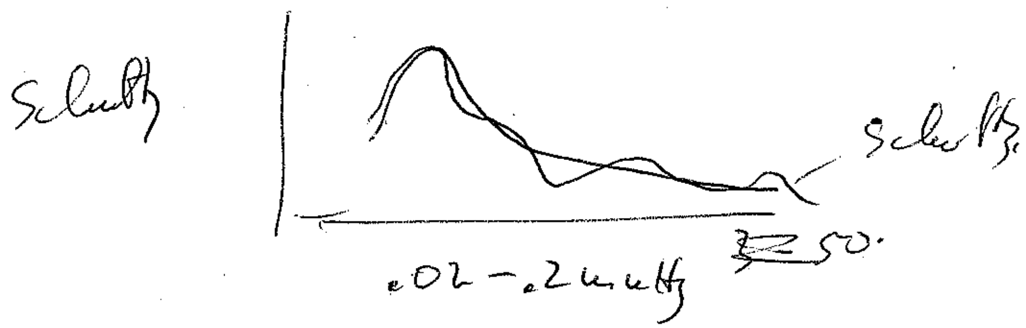
E-5 EXPERIMENTAL STUDIES OF COLLISIONS OF LOW ENERGY ELECTRONS WITH ATMOSPHERIC GASES

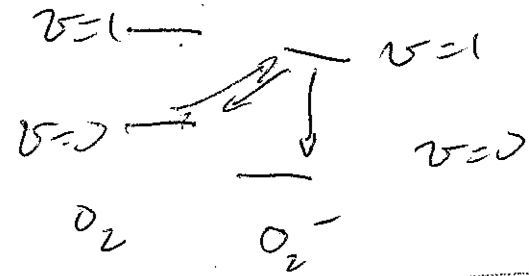
A. V. Phelps
Westinghouse Research Laboratories, Pittsburgh, Pennsylvania



pure O, O + He similar curves — can't tell apart.

3–50 mults.



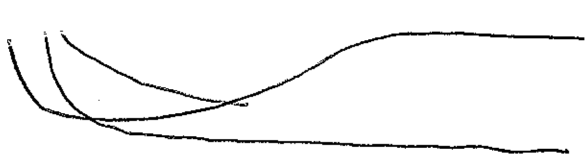


B-B process $e + O_2(v=0) \rightarrow O_2^-(v=1)$

$O_2^-(v=1) + O_2(v=0) \rightarrow$

$O_2^-(v=0) + O_2(v=1)$

Diss. Attach. of O_4



σ incredible 10^{-13}

Schulz's data are consistent generally with B-B— structure may refer to higher vib. state. Diss Attach O_4 also possible

SESSION F

THURSDAY, OCTOBER 15

3:45 p.m.

OXYGEN REACTIONS

CHAIRMAN

G. BEKEFI
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

F-1

THERMAL ELECTRON ATTACHMENT IN OXYGEN AND OXYGEN-CONTAINING MIXTURES*

V. A. J. Van Lint, E. G. Wikner, and D. L. Trueblood
John Jay Hopkins Laboratory for Pure and Applied Science
General Atomic Division of General Dynamics Corporation
San Diego, California

The attachment of electrons in oxygen has been measured by a radiation afterglow experiment. The gas sample was ionized by a short pulse of radiation from the General Atomic electron linear accelerator. The ionized electron density was measured as a function of time after this pulse by observing the phase shift and attenuation of a low power microwave traversing the gas sample. At 300°K the data can be interpreted as a three-body attachment process: 0.1 μsec pulse

$$-\frac{dn}{dt} = KnN^2$$

where n and N are the electron and molecule densities, respectively, and $K=2.1\times10^{-30}$ cm^6 sec^{-1} with a probable error of 10 percent. Within this error there was no deviation from the three-body pressure dependence in the pressure range 1 to 150 mm Hg. The temperature dependence of the attachment process has been observed indicating a minimum value at 170°K. At 300°K nitrogen molecules can act as the third body in the attachment reaction, but they were observed to be only 5.3 percent as effective as another oxygen molecule. However, as the temperature was decreased below 200°K, the relative effectiveness of nitrogen was observed to increase. Addition of helium to oxygen, as well as the low temperature data, indicate that electron thermalization is complete before attachment. The data on helium-oxygen mixtures can be interpreted by assigning a helium atom an effectiveness as a third body of 3.6 percent compared to an oxygen molecule.

* Sponsored by U. S. Air Force Special Weapons Command, AF29(601)-1225

Take data at different ionizing levels - eliminate effect of recomb.

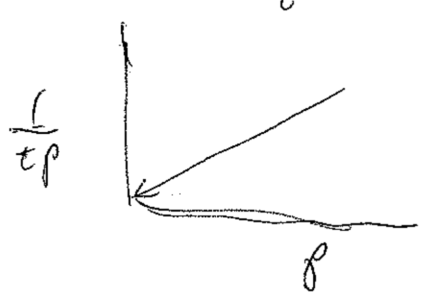
$\frac{1}{\tau} = \frac{-1}{n}\frac{dn}{dt}$, $\frac{1}{\tau p} = \alpha + \alpha_3 p + \beta_2 f + \beta_3 f p + \frac{\gamma}{p^2}$

f = fraction ionized

β = recomb. coeffs.

α = 2 body attach

α_3 = 3 " "



ELECTRON CAPTURE IN O_2

G. S. Hurst and T. E. Bortner
Health Physics Division, Oak Ridge National Laboratory*
Oak Ridge, Tennessee

The cross section for electron capture to form O_2^- (by the impact of low energy electrons on O_2) is a complex phenomenon, depending on the pressure of O_2 and the pressure and type of other kinds of molecules present. Following this observation, several experiments have been performed[1] with mixtures of various gases with O_2. For the case of O_2-N_2 mixtures the attachment coefficient, α, (probability of capture per mm O_2 pressure and per cm travel in the field direction) may be written as

$$\alpha = Af_1P + Bf_2P + Cf_1Pf_2P$$

where f_1P is the O_2 pressure, f_2P is the nitrogen pressure, and A, B, and C depend on E/P (the field per unit pressure in volts per cm per mm Hg). For O_2-C_2H_4 the results are

$$\alpha = \alpha_o + B'f_2P$$

where f_2P is the ethylene pressure, and α_o and B' are constants depending on E/P. All these results, as well as those for O_2-CH_4, appear to be interpretable in terms of an extension of the Bloch-Bradbury[2] theory, although as pointed out by Bates and Massey,[3] the earlier pressure independent results are not consistent with the theory.

* Operated by Union Carbide Corporation for the U.S. Atomic Energy Commission.

1 T. E. Bortner and G. S. Hurst. Health Physics 1, 39 (1958); G. S. Hurst and T. E. Bortner, Rad. Res., Suppl. 1, 547 (1959); Phys. Rev. 114, 116 (1959).

2 F. Bloch and N. Bradbury, Phys. Rev. 48, 689 (1935).

3 D. R. Bates and H. S. W. Massey, Phil. Trans. Roy. Soc. A239, 269 (1943).

F-3

ATTACHMENT-DETACHMENT PROCESSES IN OXYGEN MICROWAVE AFTERGLOWS*

M. A. Biondi
Westinghouse Research Laboratories, Pittsburgh, Pennsylvania

Microwave studies of the decay of electron density in oxygen afterglows[1] at pressures $\sim$10 mm Hg have led to the inference of a two-body attachment process with a cross section of $\sim 10^{-22}$ cm^2. However, recent drift tube measurements[2] have shown that, at thermal energies, the attachment occurs via a three-body reaction and at a rate which is more than 100 times the microwave values. It will be shown that it is possible to account quantitatively for the observed time dependence and pressure dependence of the afterglow electron decay by a quasi-equilibrium between attachment and detachment of the type

$$2(O_2)+e \rightleftharpoons (O_2^-)^*+(O_2) \rightleftharpoons (O_2^-)+(O_2)^*.$$

If it is assumed that an excess population of O_2 in a vibrationally excited state, $(O_2)^*$, is created by electron impact during the discharge, the final decay of electron density can then be shown to follow the decay of this excess population during the afterglow.

* These studies have been supported in part by the Air Force Special Weapons Center under contract AF 29(601)-1254, project 5776.

1 M. A. Biondi. Phys. Rev. 84, 1072A (1951); E. Holt, Bull. Am. Phys. Soc. II 4, 112 (1959); M. C. Sexton, private communication.

2 Chanin, Phelps, and Biondi. Phys. Rev. Lett. 2, 344 (1959).

@ 10 mm Hg, $\nu_a \sim 3\times 10^5$ sec^{-1}

Detachment would explain microwave: $O_2(v=2 \text{ at least}) + O_2^- \rightarrow O_2(v=0) + O_2 + e$

this together with 3 body attach., gives in late afterglow, a decay at the rate of de-excitation of the v=2.

Massey + B give ~10^{-5} coll. for de-exc., or 10^3 sec^{-1}

but M+B made error - used air rather than pure O_2

actually for pure O_2 ~10^{-7}

Transfer of vib. would explain microwave: $O_2(v=2) + (O_2)^*_{v=0} \overset{45}{\rightleftharpoons} O_2(v=1) + O_2(v=1)$

Zener gave 10^{-5}, actually > 10^{-2}

F-4 CROSS SECTION FOR O_2^- COLLISIONAL DETACHMENT

D. K. Bailey* and L. M. Branscomb+
*Page Communications Engineers, Inc., Washington, D.C.
+National Bureau of Standards, Washington, D.C.

See paper in Proc IRE

Following certain strong solar flares the earth's atmosphere is bombarded in the polar regions with a strong approximately isotropic flux of low energy cosmic rays of solar origin, consisting primarily of protons in the energy range from about 20 to a few hundred MEV. These protons penetrate into and through the D region of the ionosphere with a flux which decays with a time constant of the order of two days, steadily decreasing through day and night alike. The ionization produced by these protons is responsible for absorption of cosmic noise which is very strong compared with normal D region effects. Quantitative measurement of the absorption at 32 Mc/s shows a large diurnal effect. Electrons are released from O_2^- mainly by photodetachment during the day and by collisional detachment during the night. The ratio of day to night absorption is seen to depend primarily on the cross sections for attachment and detachment of electrons from O_2, both radiative and collisional. Since all of these cross sections, except the collisional detachment cross section, have now been measured in the laboratory, a careful analysis (including the non-equilibrium effect of primary ionization and recombination) yields a value for the collisional detachment coefficient of about 2×10^{-17} cm^3/sec at an average temperature of 230^oK (0.03 ev). The accuracy of the result and its relationship to laboratory measurements of the reverse process by Chanin, et al., will be discussed.

Ioniz ~60Km prod. by about 1 hr after flares
3+ or greater & continue for days.
$K = 2 \times 10^{-17}$ cm3/sec for detach.

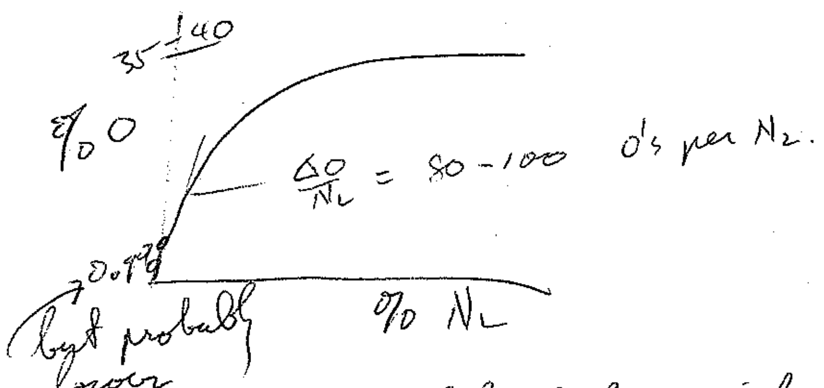
F-5 DISSOCIATION OF OXYGEN IN MICROWAVE DISCHARGES*

F. Kaufman and J. R. Kelso
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

It has long been known that small amounts of added species have a large effect on the extent of dissociation of diatomic molecules in electrical discharges. This has often been ascribed to wall effects; i.e., the poisoning of the wall to recombination reactions. We are studying this systematically, starting with O_2 dissociation with added N_2 or NO using a magnetron (2450 Mc, 0-800 W, c.w.). We measure oxygen atoms by a gas titration with NO_2 and also determine the air afterglow intensity downstream of the discharge, the emission spectrum of the discharge, and the amount of NO produced as a function of the added gas, pressure, and power. Our results show that the dissociation is indeed a most sensitive function of added N_2. Very pure O_2 produces less than 1 percent of atomic oxygen. For very small additions (0.01 percent) of N_2 this value rises at the rate of about 80 oxygen atoms produced for every N_2 molecule added. The effect has nothing to do with the condition of the wall downstream of the discharge. The concentration of free electrons is approximately unchanged upon N_2 addition. The effect appears to be truly chemical and catalytic and throws serious doubt on the importance of the accepted mechanisms for dissociation.

i.e. $O_2 + e = O_2^{*} + e$ (repulsive) → O + O

* Supported by the Advanced Research Projects Agency.



NO formed by discharge with 90% efficiency

He, A, H_2
1, 1, 2
.2 .2 200 = $\frac{\Delta O}{X}$ X = 1k, for He

elect. conc. unchanged when enough N_2 added to give 4x the O conc.

conjecture $NO^+ + e = N + O$ need $\alpha \sim 10^{-5}$
$N + O_2^+ = NO + O^+$ to make chain
$N + O_2 \to NO$ ruled out - too slow

F-6 DISSOCIATION OF MOLECULAR IONS BY ELECTRIC FIELDS

J. R. Hiskes and J. L. Uretsky
Lawrence Radiation Laboratory
University of California, Berkeley, California

The dissociation of molecular ions by the Lorentz force, $e\vec{v} \times \vec{B}$, may provide a means for trapping energetic particles inside fusion devices. Here we consider the dissociation in the presence of an electrostatic field, with the hope that it will exhibit the essential features of magnetic dissociation. The dissociation of the H_2^+ ion can be treated exactly by using available wave functions;[1] the primary mode of dissociation proceeds according to $H_2^+ \rightarrow H + H^+$. The fields required for dissociation are a sensitive function of the initial vibrational state of the ion. We now find the threshold for dissociation of the uppermost vibrational state to be appreciably lower than had been previously estimated.[2] For dissociation in 10^{-8} sec, the fields required for dissociating the upper states are 1, 3, 10, 30, and 50×10^5 v/cm respectively, ranging upward to 2×10^8 v/cm for the ground state. The rates of induced dipole transitions to lower vibrational states are negligibly small compared with the dissociation rates. Some discussion of the method of calculation will be given.

[1] S. Cohen, J. R. Hiskes, and R. J. Riddell, Jr. UCRL-8871, Oct. 1959.

[2] J. R. Hiskes and J. L. Uretsky. UCRL-8255, April 1958.

SESSION G

FRIDAY, OCTOBER 16

9:00 a.m.

RADIATION IN PLASMAS

CHAIRMAN

N. L. OLESON
U. S. NAVAL POSTGRADUATE SCHOOL

G-1

THE EFFECT OF COLLISIONS ON THE OPTICAL REFRACTIVITY OF A PLASMA*

O. Theimer and H. Hoffman

Department of Physics, University of Oklahoma, Norman, Oklahoma

The vibrational amplitude A of free electrons in a plasma exposed to an electromagnetic field with frequency ω_o is proportional to ω_o^{-2}. For low frequency radio waves A is larger than the average distance of neighboring ions and the cross section q_c for "randomizing collisions", as used in the dispersion theory, is very nearly identical with the collision cross section in static fields. Contariwise, the amplitude A induced by infrared or visible radiation is infinitesimally small and q_c is found proportional to $\omega_o^{-2/3}$ and very nearly independent of the temperature. Accordingly, q_c is unexpectedly large for infrared radiation, but this result cannot be extended into the microwave region where approximations, valid for optical frequencies, break down.

* Work supported by the Office of Ordnance Research, U.S. Army.

G-2 CYCLOTRON RADIATION FROM A MAGNETIZED ELECTRON GAS IN THERMAL EQUILIBRIUM*

H. R. Rosner
Republic Aviation Corporation, Mineola, Long Island, New York

The radiation intensity per unit volume of a nonrelativistic electron gas in thermal equilibrium is investigated in the presence of a uniform external magnetic field. The derivation is carried out by means of two conceptually distinct processes. Expressions are obtained for the rate of radiation loss per unit volume. The spectral properties of the nonrelativistic radiation are then investigated, with the result that only the first spectral component is significant. In conclusion, the radiative contributions of mixed-in relativistic electrons of a given mean energy are examined, as concerns both total and spectral intensities. The radiation of these relativistic electrons is shown to be principally in directions transverse to the magnetic field.

* Written under Air Force Special Weapons Center contract, in continuation of a Plasma Studies program begun in 1958.

G-3 CYCLOTRON RADIATION FROM PLASMAS*

J. L. Hirshfield and G. Bekefi
Department of Physics and Research Laboratory of Electronics
Massachusetts Institute of Technology, Cambridge, Massachusetts

The incoherent microwave noise from the positive column of a dc discharge subjected to an external magnetic field was measured at frequencies in the neighborhood of the electron cyclotron frequency. The radiation was observed along, and perpendicular to, the magnetic field for various electron densities and gas pressures. Kirchhoff's radiation law for anisotropic media, which relates the emission to the absorption, was used to interpret the measurements. The absorption was obtained from the tensor rf conductivity of a cold plasma of low degree of ionization. When the plasma is transparent, the emission reduces to that obtained by summing the radiation from individual electrons orbiting in the magnetic field. This result is used in finding the electron temperature by integrating the radiation intensity under the resonance line. As the plasma becomes more opaque, changes in the line shape are observed. These are compared with computations.

* This work was supported in part by the U.S. Army (Signal Corps), the U.S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U.S. Navy (Office of Naval Research).

G-4 RADIATION FROM A TEST OSCILLATOR IN A PLASMA

H. Dreicer
University of California
Los Alamos Scientific Laboratory,* Los Alamos, New Mexico
and Boeing Scientific Research Laboratories
Seattle, Washington

This paper discusses the spontaneous emission of electromagnetic radiation from an oscillating test charge which is moving through a hot collisionless plasma of infinite extent. Simultaneous solution of the kinetic and field equations shows that the radiation field decays exponentially with radial distance from the oscillator for those harmonics whose frequency falls below the plasma frequency. Harmonics whose frequency exceeds the plasma frequency contribute to net emission. The mechanism involved is discussed in terms of the charge and current clouds with which the plasma shields the test oscillator. The extension of the theory to plasmas of finite extent and a large number of oscillators will be discussed with special reference to the case of cyclotron emission in magnetic fields.

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

G-5 ELECTROMAGNETIC WAVES OF RADIOFREQUENCY IN A GYROPLASMA

K. V. Narasingarao, J. T. Verdeyen, and L. Goldstein
College of Engineering
University of Illinois, Urbana, Illinois

The subject of this paper is the investigation of the interaction of high radiofrequency electromagnetic waves with gyromagnetic low temperature gaseous plasmas. The technique used in this study involves the interaction of two microwave signals which are simultaneously propagated in the gyroplasma. Experiments performed with neon gas in the pressure range of 0.5-10 mm Hg, with microwaves in the frequency range of 4.0 to 7.0 Kmc, will be discussed. The experimental results obtained in the microwave interaction studies are correlated with the measurement of visible light intensities radiated from the plasma. The microwave interaction in the gyroplasma leads to a simple method of electron collision frequency measurement. This method was used to determine the electron collision frequency (and cross section) in helium and nitrogen.

G-6 THE INFLUENCE OF ACOUSTICAL WAVES ON THE INTERACTION BETWEEN AN ELECTROMAGNETIC FIELD AND A BOUNDED PLASMA

K. Persson
General Electric Research Laboratory, Schenectady, New York

A short review of acoustical waves or collective plasma oscillations is given. The simple wave equation for electrons is used to explain the anomalous resonance absorption which was observed by Romell and Dattner in the microwave range. A discussion is presented of the relative importance of electron and ion sound waves and electromagnetic waves with or without a static magnetic field. It is concluded that the sound wave mechanisms are much more important for the bounded plasmas than has generally been considered. It is shown that the sound wave mechanism is of considerable importance in the interpretation of electron density measurements made by the microwave cavity method. The limits for an accurate interpretation of the microwave measurements has to be adjusted considerably if the acoustical waves are taken into account. Some of the debated interpretations of the microwave measurements are explained as being effects of the non-linear interaction between the plasma, the acoustical waves, and the electromagnetic field.

G-7 DIFFUSION OF PLASMA ACROSS A MAGNETIC FIELD*

T. K. Allen,+ G. A. Paulikas, and R. V. Pyle
Lawrence Radiation Laboratory
University of California, Berkeley, California

The experiments of Lehnert,[1] which have been interpreted as indicating enhanced diffusion across magnetic fields for fields above a critical value, have been repeated and extended. Glow discharges in tubes 250 cm long and 19 mm and 55 mm inside diameter are studied under conditions in which the positive column is partially immersed in a steady longitudinal magnetic field which is uniform over a distance of 155 cm. Measurements of electric field strength, electrical noise, and light-intensity fluctuation have been made in discharges in hydrogen and several inert gases over a wide range of conditions. The results include and agree with Lehnert's observations, and some additional information on the loss mechanism may be obtained from the striation behavior in the discharge.

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

+ Visiting Lawrence Radiation Laboratory from AERE, Harwell.

1 B. Lehnert. Proc. 2nd Internat'l Conf. on Peaceful Uses of Atomic Energy, A/Conf. 15/P146, Geneva, 1958 (United Nations, N.Y., 1958), V. 32, p. 349.

SESSION H

FRIDAY, OCTOBER 16

1:30 p.m.

SHOCKS AND PLASMAS

CHAIRMAN

S. BUCHSBAUM
BELL TELEPHONE LABORATORIES

H-1 SPECTRAL LINE BROADENING FROM STRONGLY INHOMOGENEOUS OR MACROSCOPICALLY NON-UNIFORM PLASMAS

L. Gold*

Radiation, Inc., Research Division, Orlando, Florida

The latest review by Margenau on the theory of line broadening, and particularly the most current efforts to further refine the Holtsmark theory to account for the appearance of spectral emission from shocks,[1] make it in order to direct attention to an aspect that has been overlooked. When dealing with plasmas in a high perturbed state, the conventional microscopic or intrinsic sources of line broadening (appropriate for quiescent plasmas) may become submerged by macroscopic inhomogeneities. A special category of such line broadening, the "gradient-Doppler," has been presented,[1] rendering intelligible what seemingly were a number of isolated observations. It indeed predicts line contours resembling the remarkable asymmetric and double peaks observed by Goldberg _et al_. for the Lyman alpha emission during a solar limb flare. Also, the observation of double peaks by Turner in the Balmer series from shock spectra and the failure of Griem to detect such a line profile for H_δ in arcs may be accounted for in that the latter plasma was essentially homogeneous. Experimental affirmation of line broadening likely to be encountered in the spectra emanating from grossly inhomogeneous discharges relates to the anisotropy of the intensity contour as the direction of viewing is altered. This is already born out by Goldberg _et al_., but even more convincing should be the variegated profiles recorded for the 21 cm line radiation of hydrogen in radio astronomy. The recommendation is made that shock excited spectra, notably in the laboratory, be examined in this manner.

* Present Address: Princeton University, c/o Project Matterhorn, Princeton, New Jersey.

1 Address given at the IV International Conference on Ionization Phenomena in Gases, Uppsala, August 17-21, 1959.

Bailey ~~disagrees~~ cautions that self-abs. may be much more important than these effects

H-2

TIME BEHAVIOR OF SPECTRAL LINE SHAPES BEHIND STRONG SHOCKS*

S. P. Cunningham, F. R. Scott, and R. F. Wenzel
John Jay Hopkins Laboratory for Pure and Applied Science
General Atomic Division of General Dynamics Corporation
San Diego, California

Using a scanning device which images a spectral profile onto a battery of seven 1P21 photomultipliers we have observed the behavior of prominent emission lines in an electromagnetically driven shock. Gases used were helium, deuterium, and mixtures of helium and deuterium. In particular, the He 5875 A line exhibits a Lorentz shape and a shift to the violet which is proportional to the line width. Both diminish with time after the passage of the shock front. The observed width of 2.5 A and shift of 0.5 A are compared with the theoretical values of M. Baranger[1] and B. Kivel[2] on electron impact broadening of this line. We use the the electron density and temperature given by equilibrium shock theory. Provided the temperature can be assumed constant for some distance behind the shock front, the width of the line is proportional to the electron density. The electron density thus derived follows the two-body recombination law. The experiment yields a value of 5×10^{-12} cm^3 sec^{-1} for the radiative recombination coefficient of helium. This result is preliminary. The lines He 3888 A, He 4471 A, He^+ 4685 A, and D_β have also been mapped.

* This work was done under a contract between General Atomic and the Texas Atomic Energy Research Foundation.

1 Private communication.

2 B. Kivel. Phys. Rev. 98, 1055 (1955).

H-3 ELECTRON DIFFUSION AHEAD OF STRONG SHOCK WAVES

H. D. Weymann
University of Maryland, College Park, Maryland

The diffusion of electrons ahead of shock waves of M_s=8 to M_s=12 into argon of 3 to 10 mm Hg pressure was investigated with electrostatic probes[1] and a newly developed induction probe. The latter is sensitive to changes of the electron current density in the shock tube. The electrostatic signals showed rather sharp fronts with front velocities of up to three times the shock velocity. Experiments with the induction probe confirmed that the electrostatic signals are due to electrons. The electron densities behind the fronts were found to be of the order of 10^8 cm^{-3}. The question whether the observed electrons have diffused from the plasma behind the shock front or are created by photoionization ahead of the shock front will be discussed.

[1] H. D. Weymann: On the Mechanism of Thermal Ionization behind Strong Shock Waves. Institute for Fluid Dynamics and Applied Mathematics, University of Maryland, College Park, Tech. Note BN-144, July, 1958.

H-4

MAGNETOHYDRODYNAMIC SHOCK WAVES IN A COLLISION FREE PLASMA

A. Kantrowitz, R. M. Patrick, and H. E. Petschek
Avco-Everett Research Laboratory, Everett, Massachusetts

Ordinary collisional dissipation becomes very small in a high temperature plasma. However, in some cases such as a shock wave some form of rapid dissipative process is required. It is probable that the dissipative mechanisms which occur are associated with random fluctuations in the flow properties on a scale large enough to include many particles, but small enough compared to the apparatus size to be considered as microscopic (i.e., what has loosely been called "magnetohydrodynamic turbulence"). This fluctuating field can be described in terms of the MHD waves which can exist in a uniform collision free plasma. By the interaction of these waves with the macroscopic gradient in the flow field and their non-linear interaction with each other an integro-differential equation is derived for the wave amplitudes as a function of their position and wave length. This equation is analogous to the Boltzmann equation in ordinary kinetic theory. The non-linear interactions represent the collision term, and the interaction with the gradients represent the flow in phase space. The amplification mechanism of the waves is included in this equation in a manner analogous to the way in which the ordinary Boltzmann equation allows for temperature rises in the gas. From this "Boltzmann equation" a rough estimate has been made of the effective viscosity and heat conduction coefficients due to the waves. From these coefficients the thickness of a shock propagating perpendicular to the magnetic field into a cold plasma has been estimated as being several ion Larmor radii. Shock waves with a sufficient temperature to reproduce the required conditions have been obtained in a magnetically driven shock tube (MAST).[1] The shock thickness has been measured from the time required for the bremsstrahlung intensity to reach a steady value behind the shock front. Comparison of the experimental results with the preliminary theoretical estimate indicate rough agreement.

[1] R. M. Patrick: The Production and Study of High Speed Shock Waves in a Magnetic Annular Shock Tube. AVCO-Everett Research Laboratory, Research Report No. 59, July, 1959.

H-5 VISCOUS EFFECTS IN HIGHLY IONIZED ROTATING PLASMAS

W. R. Baker, A. Bratenahl, A. W. DeSilva, and W. B. Kunkel
Lawrence Radiation Laboratory
University of California, Berkeley, California

Rotating highly ionized plasmas may be generated in systems of cylindrical symmetry by passing a large radial current through a low-density gas in an axial magnetic field. The rotation is hindered by contact with the stationary walls of the vacuum chamber. Under the simplifying assumptions of steady-state laminar fluid flow and uniform viscosity, two extreme cases may be treated analytically. In the first, the flat-disc approximation, the flow is considered to be controlled by axial shear alone. If zero slip is assumed to exist at the insulating surfaces which confine the plasma axially, the current is shown to flow in a thin boundary layer, the thickness of which is of the order $\delta = 1/B(\mu/\sigma)^{1/2}$. Consequently, the electrical resistance of the plasma appears many times that in the absence of the magnetic field. It also follows that the speed of rotation of the plasma in this case should be inversely proportional to the distance from the axis. These conclusions are partially supported by experimental evidence. In the second case treated analytically, the long-cylinder approximation, only radial shear is considered important. In this case the current density is independent of the axial position. Here the apparent resistance is even higher because now all the current has to pass through regions of rapidly spinning plasma in whose frame of reference the electric field is very low. It is therefore practically impossible to construct a simple rotating-plasma machine whose volume resistance is lower than the resistance along the end plates. In one obvious scheme to prevent the current from flowing near the insulators an attempt is made to keep the entire plasma from making contact with the insulator surfaces. The first of such models is briefly introduced and the main results are summarized.

H-6 PLASMA CONTAINMENT BY R-F AND D-C FIELD COMBINATIONS

R. C. Knechtli and D. Dow
Hughes Research Laboratories, Culver City, California

The purpose of the investigations reported here is to utilize the desirable properties of r-f fields to contain hot dense plasmas such as those needed for controlled fusion. Because high losses due to skin effect are associated to r-f fields, they will be used at the lowest possible frequency, and only where they constitute a useful supplement to the cheaper d-c fields. Such r-f fields are to be useful for reducing the plasma leakage present in most d-c confinement systems, and to prevent some of the instabilities inherent to d-c systems. One particular combination of d-c and r-f fields has been analyzed in detail. It consists of a homogeneous axial d-c magnetic field (or a d-c mirror field) containing a plasma column against radial diffusion; the ends of the column are "sealed" by means of r-f fields. By using the proper polarization of the r-f fields, it is shown that appreciable plasma pressures can be contained, using r-f fields of frequencies as low as a few Mc. By using r-f powers of the order of a few kilowatts, it is expected to be feasible to contain plasmas of a density exceeding 10^{14} charges/cm^3 at temperatures exceeding 10 ev over sizeable volumes.

SESSION I

FRIDAY, OCTOBER 16

3:45 p.m.

BREAKDOWN AND ARCS

CHAIRMAN

D. S. BURCH
OREGON STATE COLLEGE

I-1 PRODUCTION OF RADIATION, IN PARTICULAR OF λ=1850 A IN THE LOW PRESSURE MERCURY-ARGON DISCHARGE

A. A. Kruithof
Physical Laboratory, Lightgroup
N.V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands

The general theory of gas discharges may be applied in particular to every specific discharge one wishes to investigate. Simplifications can then be used, since certain processes will be relatively unimportant. It is, however, always important to trace the paths along which the energy supplied to the discharge is converted into radiation and heat. Further important processes are the production of the positively and negatively charged particles which carry the electric current. These considerations are applied to the low pressure mercury-argon discharge. A diagram for the production of radiation in this discharge has been drawn up by Kenty. This diagram, however, does not give data on the mercury resonance line λ=1850 A. The ratio of the excitation of several phosphor coatings in 40 W fluorescent lamps by the lines λ=1850 A and λ=2537 A is determined with the aid of tubular filters transmitting both lines in widely different proportions. One of the phosphors was sodium salicylate. If use is made of the property of this phosphor that its quantum efficiency according to several investigators does not depend on the wavelength of the exciting radiation, the ratio of the energies of λ=1850 A and λ=2537 A can be found. These measurements generally give lower values for the part played by λ=1850 A than those of Fabrikant and Butaeva. Quantum efficiencies for both mercury lines have been calculated from the luminous output of quartz-walled lamps, in which the unabsorbed portion of the U.V. radiation can readily be measured. Although the values for λ=1850 A generally exceed those for λ=2537 A, no values definitely exceeding 1 have been found.

I-2 BREAKDOWN STREAMERS IN CORONA TO ARC TRANSITION IN CONTAMINATED AND VERY PURE ARGON

R. G. Westberg, H. C. Huang, and L. B. Loeb
Department of Physics, University of California, Berkeley, California

The fast oscillographic time analysis as applied by G. G. Hudson to the study of breakdown streamers in the spark breakdown of a point-to-plane corona to a transient arc in air at atmospheric pressure has been extended to argon gas of varying degrees of purity from 400 mm in pressure down. In argon with a percent of air, even at 100 mm, the primary and secondary cathode directed anode streamers were observed as in Hudson's air studies. Linde's "spectroscopically pure argon" yields no primary-secondary sequence. Despite feeble luminosity the transition is preceded at high amplification by a very irregular pulse starting from the anode and crossing to the cathode before the rise of the main stroke. Exceptionally pure argon cleansed of most impurities of lower ionizing potential by gas cataphoresis at 300 mm pressure yields a rather fainter diffuse spark channel with maximum luminosity at the cathode. No streamers from the anode have been observed in this case. Apparently the preceding corona does not create enough metastables to create a two-component photo-ionizable gas and streamers do not form.

I-3 MEASUREMENTS OF NEGATIVE STATIC CHARACTERISTICS IN ARGON*

M. J. Reddan and A. L. Ward
Diamond Ordnance Fuze Laboratories, Washington 25, D.C.

Measurements have been made of the negative slope portion of voltage-current characteristics for plane parallel electrodes in comercial, spectroscopically pure argon. The pressure range extended from 0.5 mm Hg to 200 mm Hg, and the gap spacing from 0.1 to 1.5 cm. The gap spacing was precisely adjustable over a continuous range. (A nickel cathode was employed.) Measurements were made quasi-statically (i.e., a very gradual change in applied voltage) and proved to be continuous and reversible over extensive portions of the negative slope region. Comparison of experimental data with calculations[1] is made difficult by a tendancy for the discharge area to contract in this region. Photographs of the discharge were used to obtain improved estimates of the discharge area. Generally, the discharge first becomes visible as an anode glow, then builds up toward the cathode as the current increases. Except for very low pd values, a discontinuous voltage drop accompanied the formation of a cathode spot. When the estimated area of the discharge was used to obtain experimental current density static characteristics, agreement with calculations is quite good.

* Supported by the Office of Ordnance Research.

[1] A. L. Ward, Phys. Rev., 112, 1852 (1958).

I-4 RELAXATION TYPE OSCILLATIONS IN ARGON GLOW DISCHARGES*

R. J. Stansfield,+ J. P. Wise,+ and N. L. Oleson
U.S. Naval Postgraduate School
Monterey, California

In the course of investigating the effects of external parameters on moving striations in the positive column of an argon glow discharge between 4 to 20 millimeters pressure, it was found that sufficiently high values of external resistance caused the striations to be replaced by relaxation type oscillations in which the whole column appeared to be pulsating, or if moving striations were present, they would have velocities in excess of 25,000 meters per second. The accompanying voltage oscillation increased from the order of 40 volts to approximately 500 volts and current pulses of several amperes amplitude and about 10 microseconds duration were observed. The light intensity in the afterglow increased to a maximum of about 100 microseconds after the excitation was removed and then decayed following processes formulated by other investigators in this field. A secondary light peak occurred during the latter stages of this decay. Evidence will be present to indicate that this secondary peak might be attributed to metastable recombination near the walls.

* Supported by the Office of Naval Research.

+ Lieutenant Commander, United States Navy.

I-5

THE MEASUREMENT OF THERMIONIC EMISSION IN HOT-CATHODE DISCHARGE TUBES

J. F. Waymouth
Sylvania Lighting Products, Salem, Massachusetts

A method has been discovered for measuring the zero-field thermionic emission current from hot cathodes in gas discharge tubes of the fluorescent lamp type. It depends on detecting the vanishing of the space-charge potential minimum in front of the cathode when the current ceases to be space-charge limited. When this potential minimum is present, mercury ions can get trapped in it, and oscillate, producing rf noise in the frequency range 100-200 kc. The thermionic emission from an externally heated cathode is measured by increasing the discharge current from a low to a higher value and observing the current at which the rf noise stops. This marks the disappearance of the space-charge potential minimum, and hence marks the maximum zero-field thermionic emission. The method appears to be generally applicable to hot-cathode discharges in various gases.

I-6

ARC RECOVERY PHENOMENA

J. D. Cobine, G. A. Farrall, and D. E. Hagge
General Electric Research Laboratory
Schenectady, New York

A study of the recovery phenomena of short arcs in nitrogen and in argon has been made for $500<pd<5000$ (mm Hg mm) using a range of pressure from 10 to 760 mm Hg, and three gap lengths for a current of 50 amp. The electrodes were of pure carbon with a cone of thoria in the cathode. For times less than 100 μs the recovery voltage is of the order of the glow voltage and most arc reignitions probably start as a glow established in the residual plasma. For times as long as 1000 μs the recovery strength is independent of pd. This appears to be due partly to a very weak residual plasma, and partly to non-uniform cooling of the gas column which experiences local heating by hot spots on the electrodes. At delay times in excess of 4 milliseconds the recovery strength is an increasing function of pd. However, at the current under study, a true pd relation does not exist until the delay times are greater than 10 milliseconds. For times longer than this the recovery strength is that of an essentially un-ionized but low density column that is slowly cooling.

LIST OF CONTRIBUTORS

GPO 881590