Gould - used our α ty in μwave Disch. - CW + pulsed
+ gets good agreement with theory.

8th *Annual*

GASEOUS ELECTRONICS CONFERENCE

PROGRAM

AND

ABSTRACTS OF PAPERS

SCHENECTADY, NEW YORK

OCTOBER 20-22, 1955

under the Joint Sponsorship of the

DIVISION OF ELECTRON PHYSICS, AMERICAN PHYSICAL SOCIETY

and the

GENERAL ELECTRIC RESEARCH LABORATORY

EIGHTH ANNUAL GASEOUS ELECTRONICS CONFERENCE

October 20-22, 1955

Program

Thursday
October 20
9:00 - 9:30 A.M.

Registration in Lobby
General Electric Research Laboratory

A. BREAKDOWN

CHAIRMAN: R. N. Varney, Washington University

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F. POSITIVE COLUMNS AND PLASMAS

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Thursday, October 20

9:30 A. M.

SESSION A

BREAKDOWN

Chairman, R. N. Varney

Washington University

FIRST AND SECOND TOWNSEND COEFFICIENTS IN HYDROGEN AND NITROGEN *

A-1

D. J. De Bitetto and L. H. Fisher
New York University
New York, New York

Ionization currents were measured in uniform fields in hydrogen and nitrogen at pressures from 100 to 400 and 300 mm Hg respectively. Log i vs δ curves yielded accurate values of α/p in the low E/p region reproducible to two percent. Current-voltage measurements taken in the same gas samples to within 0.05 percent of the sparking potential check the consistency of the α/p measurements and provided numerous evaluations of γ. The values of γ are about 10^{-3} in both gases (nickel cathode) and are independent of E/p in the range covered. The values of γ are reproducible to within twenty percent and are not affected by breakdown or by large changes in initial current. At all pressures studied, self-sustained currents of the order of 10^{-7} amp were obtained in both gases and in nitrogen these were associated with an anode glow. The values of α/p obtained in nitrogen are in excellent agreement with those of Dutton, Haydon and Llewellyn Jones [1]; however, the values of γ obtained in nitrogen are about five times larger. The measurements in both gases verify the Townsend criterion for breakdown to within experimental error.

---

* Supported by the Office of Naval Research

1. Dutton, Haydon, and Llewellyn Jones, Proc. Roy. Soc. (London) A213, 203 (1952).

A-2 SEMI-EMPIRICAL CALULATION OF THE TOWNSEND α

Peter L. Auer
General Electric Research Laboratory
Schenectady, New York

Studies concerning the rapid estimation of polyatomic molecules's ionization coefficient reported on at last year's meeting [1] has been extended in the present paper by an application of the molecular formalism given by Kihara. [2]

The Maxwellian model is used to describe elastic scattering, while empirical relations are used to describe inelastic scattering. In the first order approximation it is found that below excitation threshold energies the velocity distribution is of Maxwellian form with an adjusted temperature value. Above excitation threshold the velocity distribution is expressed in terms of confluent hypergeometric functions for a class of inelastic scattering formulas. Application of this formalism to helium gas yields results in agreement with previous calculations. [3]

Some justification is obtained for the empirical formula

$$\alpha = AP \exp(-BP/E),$$

where B may be related explicitly to molecular parameters. The calculation of the factor A and the determination of its dependence on the variable (E/P) is in general a difficult task. For correlative purposes, however, the estimation of B is usually sufficient.

$$a = \left[\tfrac{1}{3} m_1 \mu v^2 + kT\right]^{-1}, \quad b = m_1 a/\mu\lambda$$

$\lambda = \lambda_t/\lambda$ $\quad \lambda_t =$ total mfp

$\lambda =$ diff. mfp.

1. R. W. Crowe and J. C. Devins, Gaseous Electronics Conference, New York, N. Y., October 14-16, 1954.
2. Taro Kihara, Rev. Mod. Phys. 24, 45 (1952).
3. J. Abdelnabi and H. S. W. Massey, Proc. Phys. Soc. A66, 288 (1953).

FORMATIVE TIME LAGS OF POSITIVE POINT-TO-PLANE CORONA IN NITROGEN AND ARGON * A-3

L. A. Bornstein and L. H. Fisher
New York University
New York, New York

Previous positive point-to-plane corona measurements in air[1] showed formative times so short as to preclude a secondary cathode mechanism in corona formation. Nitrogen and argon have been studied from 100 to 700 mm Hg with a variety of points and gaps. In nitrogen, with pulsed voltage resulting in localized corona at the point, lags have been found from 10 μsec to 0.1 sec at overvoltages of a few percent to a few tenths of a percent respectively. At overvoltages of about 0.1 percent, with pulsed ultraviolet irradiation, lags up to 10 minutes have been observed. Reduction of ultraviolet irradiation produces a marked increase in lags. In argon, at low overvoltages leading to a glow corona near the point, no sharp breakdown has been found. Synchroscope studies indicate a gradual development of this discharge in argon. Both nitrogen and argon at about 10 percent overvoltage show filamentary breakdown with lags between 0.1 and 1 μsec, independent of overvoltage. It is concluded that positive localized corona formation in nitrogen and argon is cathode dependent.

---

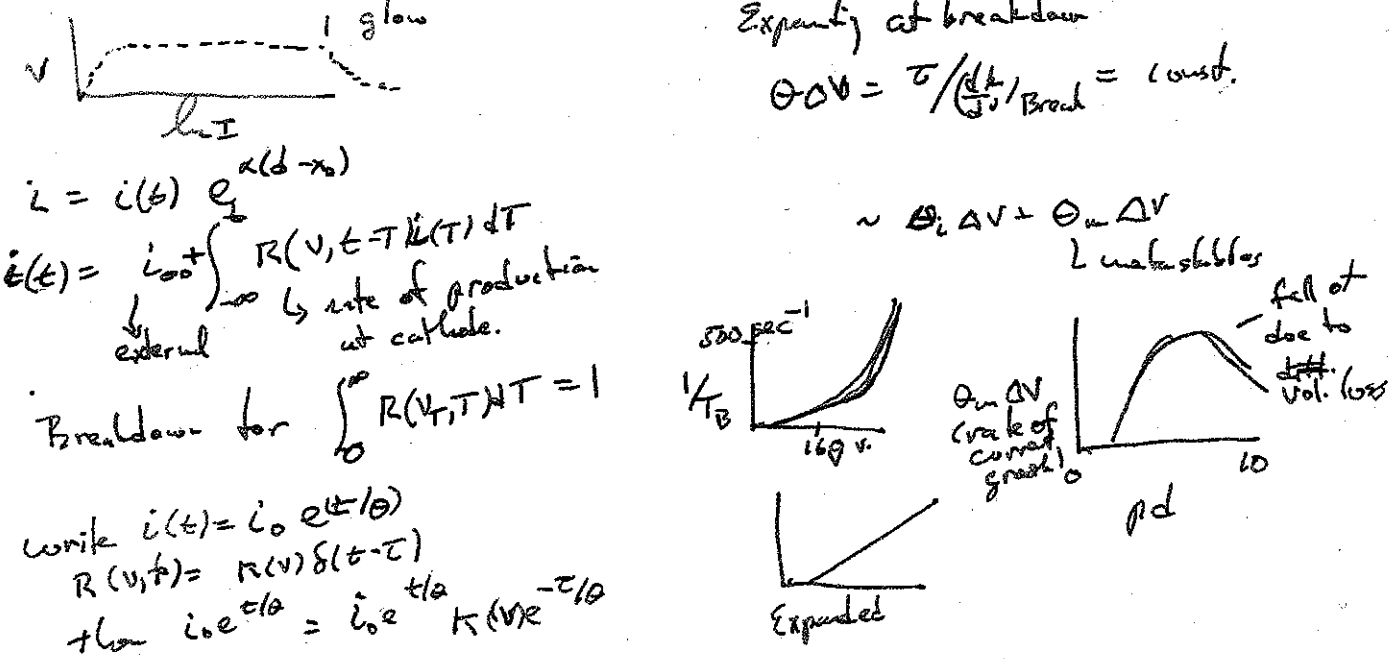
* Supported by the Office of Naval Research.

1. M. Menes and L. H. Fisher, Phys. Rev. 94, 1 (1954).

A-4 FORMATIVE BREAKDOWN DELAYS IN NOBLE GASES AT SMALL OVERVOLTAGES

B. T. McClure
Bell Telephone Laboratories
Murray Hill, New Jersey

During most of the time between the application of a small overvoltage, Δ V, and the attainment of a current recognized as breakdown, the current increases exponentially with a single time constant, θ. For sufficiently small overvoltages, $\theta \Delta V$ is observed to be constant and too large to be explained solely on the basis of ion transit times. Explicit consideration of the effect of metastables returning to the cathode of a plane parallel discharge leads to a theoretical expression for $\theta\Delta V$. The metastables are assumed to be lost by diffusion to the electrodes as well as by destruction in the volume.[1] For neon Rogowski[2] gives the metastable production coefficient as a function of E/p_o. The breakdown delays of a plane parallel discharge in neon have been measured for $1<p_od<11$. The values of $\theta\Delta V$ derived from these data are in excellent quantitative agreement with the theory.



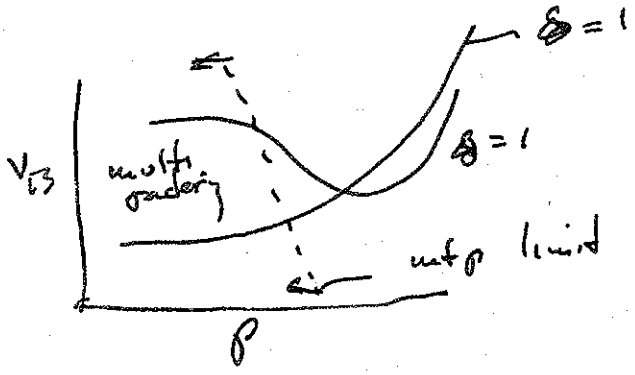
1. A. V. Phelps and J. P. Molnar, Phys. Rev. 89, 1202 (1953).
2. W. Rogowski, Zeits f. Phys. 115, 257 (1940).

STREAMER BREAKDOWN STUDIES IN VARIOUS DC POTENTIAL CORONA GAPS

A-5

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

The study of the development of anode streamers in spark breakdown, in point-to-plane DC corona, has been made by observations with two photomultiplier cells, one viewing the anode tip, the other scanning the gap vertically and laterally at various distances from the cathode. Studies were made largely in room air with gaps having lengths varying from about 1 to 3 cm and higher, diameters ranging from two-tenths of a millimeter to 3.5 cm against a large plane. In all cases, the spark breakdown sequence was initiated by the anode streamer mechanism which shows a fast primary streamer tip followed by a slower, more luminous expanding secondary streamer. When the latter presumably crosses the gap, it leads to the brilliant return stroke. Impact of primary streamers on the cathode where seen give rise to visibly bright point flashes on the cathode. In all these gaps, the streamers followed the field axis of the order of one cm from the point, but then showed much branching as they reached the space charge in low field region leading to the familiar crooked spark in the return stroke for longer gaps.



A-6 HIGH FREQUENCY GAS DISCHARGE BREAKDOWN IN NEON-ARGON MIXTURES

H. J. Oskam
Philips Research Laboratories
N. V. Philips' Gloeilampenfabrieken
Eindhoven-Netherlands

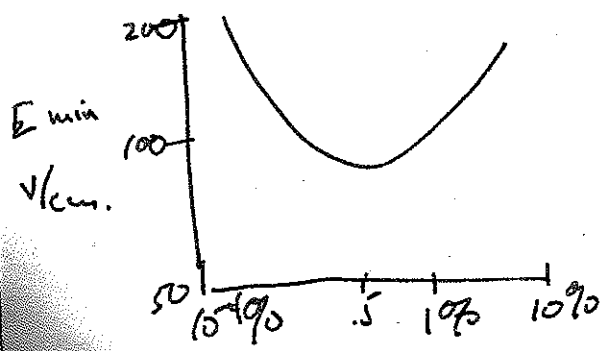
Presented by: W. Elenbaas
Philips Research Laboratories
N. V. Philips' Gloeilampenfabrieken
Eindhoven-Netherlands

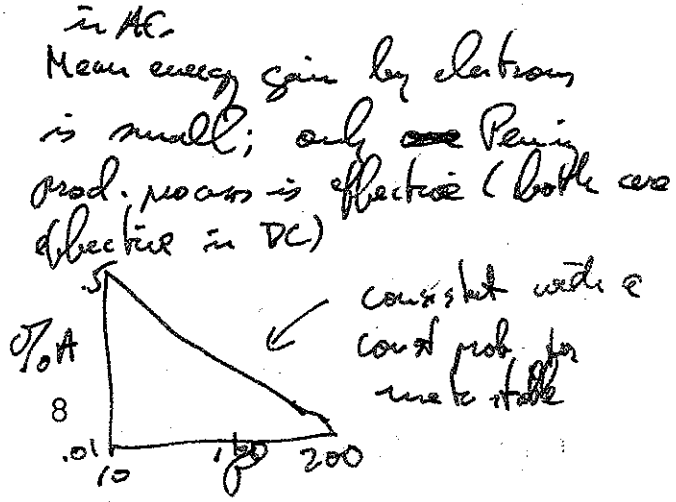
Breakdown electric fields in a waveguide at 9500 Mc/sec are presented for neon-argon mixtures at various pressures. The purity and constancy of the gas mixtures were checked in two ways.

In contrast with measurements of Penning, who found for d. c. discharges two minima in the E_b versus p curves, in the h. f. discharge only one minimum is found. This can be explained by the difference in the energy build up process in the d. c. and h. f. discharge.

Plotting the minima of E_b versus p curves against the argon concentration gives a smooth curve (with a minimum at 5.10^{-2} % A), in contrast with measurements of MacDonald (Phys. Rev., 98, 1070, 1955) carried out at 2800 Mc/sec. The behavior of the curve is due to a dependence on the argon concentration of the number of ionizing collisions of metastable neon with argon and the energy losses of electrons by excitation collisions with argon.

Plotting breakdown fields at fixed pressures against the argon concentration shows that for higher pressures the argon concentration giving the lowest breakdown field decreases. The behavior of the curve giving this dependence can be explained by considering the number of the collisions of metastable neon with argon atoms as a function of the pressure.





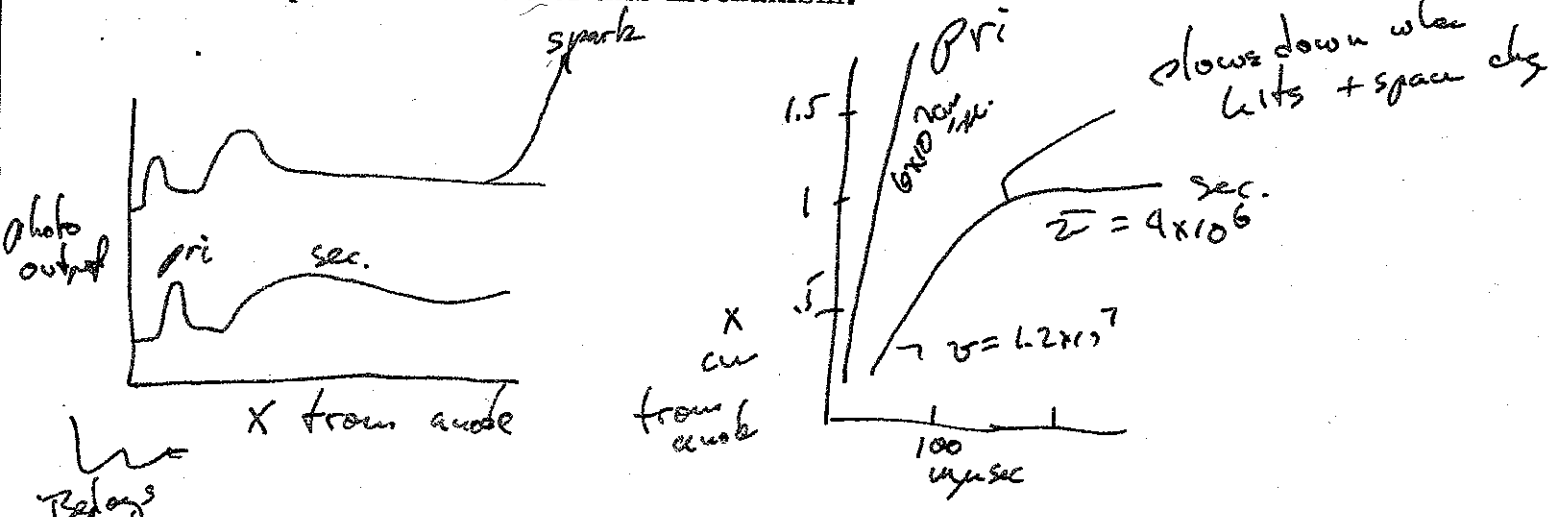
PRESSURE LIMITS OF THE HIGH FREQUENCY SECONDARY ELECTRON RESONANCE BREAKDOWN MECHANISM*

A-7

Albert J. Hatch and H. Bartel Williams
Physical Science Laboratory and Physics Department
New Mexico College of Agriculture and Mechanic Arts
State College, New Mexico

Experimental studies have been made of the transition region between the gas controlled diffusion mechanism and the electrode surface controlled secondary electron resonance mechanism of high frequency breakdown in order to determine the pressure limits of the latter mechanism. Plane parallel internal metal electrodes were used (1) at 53 Mc/sec and 1 to 5 cm separation in air at pressures of 10^{-4} to 1 mm Hg and (2) at 100 to 170 Mc/sec and 1 cm separation in air, hydrogen and helium at pressures of 10^{-6} to 10 mm Hg.

Plots of breakdown field strength as a function of pressure exhibit typical Paschen minima at pressures of the order of 0.1 mm Hg with a steep rise on the low pressure side when only the diffusion mechanism is operative, i.e., below the secondary electron resonance cut-off frequency. At frequencies above cut-off, however, the minima occur at much lower field strengths and the rise on the low pressure side terminates in pressure independent plateaus extending from approximately 10^{-2} to 10^{-6} mm Hg. These plateaus are characteristic of the secondary electron resonance breakdown mechanism and establish the pressure limits of this mechanism.



*Supported by the Navy Bureau of Ordnance.

A-8 SEMI-RANDOM SPARKING IN A SHORT AIR GAP

C. D. Maldonado and R. C. Retherford
University of Wisconsin
Madison, Wisconsin

Erratic post-breakdown currents are sometimes observed with short air gaps. Closer examination shows that the current consists of sharp pulses occurring in semi-random sequence. The phenomenon may be satisfactorily described in terms of relaxation oscillations having a fluctuating time interval between pulses. In this respect it is similar to that reported by Skolnik and Puckett.* However in the present case operation is at a much lower current, well below that of any self-sustained discharge. In a typical case a planar gap 0.003 in. in length was used between brass electrodes 0.187 in. in diameter. The current was limited by a 66 megohm resistance and the stray capacitance shunting the gap was 11 micromicrofarads. Under these conditions the current was 2-4 microamperes. The sparking potential was found to be about 700 volts and the extinction potential about 460 volts. Oscilloscopic observation readily shows that fluctuation of the extinction potential account for most of the variation in the interval between pulses. Fluctuation of the sparking potential is considerably less. Factors influencing the phenomenon will be discussed.

* M. I. Skolnik and H. R. Puckett, Jr., J. Appl. Phys., 26, 74 (1955).

NEGATIVE ION FORMATION IN IODINE BY ELECTRON CAPTURE

A-9

R. E. Fox
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

The techniques for obtaining monoenergetic electrons[1] have been applied to the study of negative ions in iodine vapor. Preliminary studies indicate that the maximum cross section for the dissociative attachment process $I_2 + e \longrightarrow I^- + I + K.E.$ occurs at an electron energy of less than 0.1 ev. This is in disagreement with earlier work by Buchdahl[2] who found a sharp decrease at lower energies from a maximum cross section occurring at about 0.4 ev. However, these results agree with those of Biondi[3] who found a large cross section for electron attachment at thermal energies (0.04 ev) in the afterglow of a microwave discharge. The energy scale for the electrons in the present work was calibrated by observing the appearance potential for SF_6^-.[4] The results were complicated by the formation of HI in the apparatus which also yields a negative ion by the dissociative process $HI + e \longrightarrow I^- + H + K.E.$ This and other experimental difficulties associated with the study of halogen molecules will be discussed briefly.

1. Fox, Hickam, Kjeldaas, Jr., and Grove, Phys. Rev., 84, 859 (1951).
2. R. Buchdahl, J. Chem. Phys., 9, 146 (1941).
3. M. A. Biondi, Phys. Rev., 89, 337(A) (1953).
4. W. M. Hickam and R. E. Fox, Phys. Rev., 98, 557(A) (1955).

Thursday, October 20

2:30 P. M.

SESSION B

ELASTIC COLLISIONS AND MOBILITY

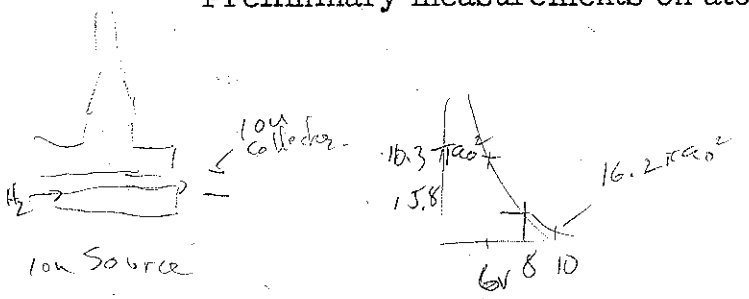
Chairman, E. Gerjuoy

Westinghouse Research Laboratories

LOW ENERGY SCATTERING OF ELECTRONS BY ATOMS* B-1

J. Hammer, H. Malamud and B. Bederson
Department of Physics, New York University
New York, New York

An atomic beam method for obtaining hitherto unavailable data on low energy electron scattering has been devised. Specifically this method allows the determination of the total electron scattering cross section for atoms normally bound in a molecule. Two rectangular beams are made to cross at right angles. One of these beams consists of electrons and the other consists of the atoms or molecules whose scattering cross section is being investigated. The electron beam is produced by an electrostatically focused gun and the atomic beam by a slit in a quartz tube containing the gas under investigation. An electrodeless discharge in the tube produces a beam of high atomic content which reaches the scattering region after suitable collimation. The atomic beam is mechanically modulated at 24 cps and the scattered electrons are collected by a Faraday chamber and measured by a phase sensitive narrow bandwidth amplifier. Data obtained using an H^2 beam are in good agreement with the results of the Ramsauer method and can be used as a calibration to yield absolute values for the cross sections. Preliminary measurements on atomic hydrogen will be discussed.



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

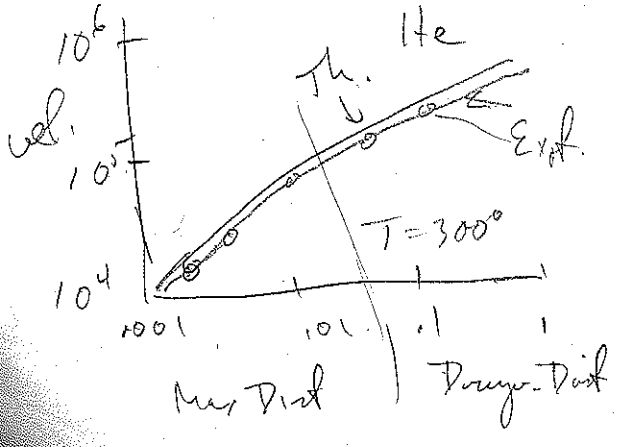
B-2 DRIFT VELOCITY OF ELECTRONS IN HELIUM AND HYDROGEN AT LOW FIELDS

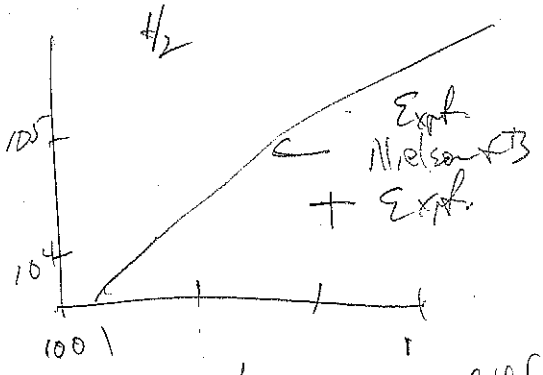
J. L. Pack and A. V. Phelps
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

Measurements of drift velocity of electrons in helium and hydrogen have been made at 300°K for E/p between 0.001 and 0.2. Data obtained with a tube of the Nielson[1] type using modern pulse techniques will be presented. Good agreement is obtained with previous data of Hornbeck[2] and Nielson[3] in helium at an E/p of 0.1 and above. A comparison is made between the experimental drift velocity in helium and the theory of Margenau[4] using a constant collision probability obtained from microwave experiments of Gould and Brown.[5] Good agreement is obtained with previous data of Bradbury and Nielson at an E/p of 0.03 and above in hydrogen.

2 electron shutters
Copper-plated electrodes to reduce contact pot.
d = 7.6 cm. ; pure 100% silica window from Corning for good UV trans.
Used square pulses. Diffusion dist < 0.1 × drift dist.
V.b. reed electrometer, current ≤ 10^{-15}
Rep. freq ~ 20-100 Kc

1. N.E. Bradbury and R.A. Nielson, Phys. Rev. 49, 388 (1936).
2. J.A. Hornbeck, Phys. Rev. 83, 374 (1951).
3. R.A. Nielson, Phys. Rev. 50, 950 (1936).
4. H. Margenau, Phys. Rev. 69, 508 (1946).
5. L. Gould and S.C. Brown, Phys. Rev. 95, 897 (1954).





N. the mirror — check from MFP.

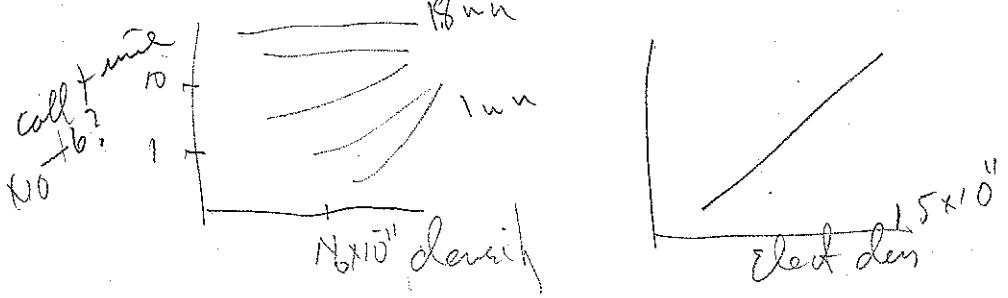
MICROWAVE STUDIES OF SLOW ELECTRON COLLISION PROCESSES IN HELIUM PLASMAS*

B-3

J. M. Anderson and L. Goldstein
Electrical Engineering Research Laboratory
University of Illinois
Urbana, Illinois

The method of interaction of microwaves in plasmas, previously described,[1] has been applied to the determination of the momentum transfer collision cross sections of helium atoms, q_m, and positive ions, q_i, with free electrons. A controlled variation of the mean energy of the electrons permitted the determination of the variation of q_m with electron energy from 4/100 to 4/10 e.v.

For these experiments guided microwaves in the X-band (~9000 Mc/s) have been propagated in plasmas with electron densities of the order of 10^{11} elec./cc. Under these conditions appropriate charge interactions have been considered. The "effective" cross section of the helium atoms for electrons of 4/100 e.v. was found to be 6.6×10^{-16} cm^2. The mean fraction of excess energy loss factor of the electrons upon collision, G, was found to be $\sim 2.7 \times 10^{-4}$, the expected 2m/M value. In the isothermal plasma at 300°K, q_i was found $\sim 2 \times 10^{-10}$ cm^2 for electron densities $\sim 10^{11}$ elec./cc.



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* Work supported by Air Force Cambridge Research Center.

1. L. Goldstein, J. M. Anderson, and G. L. Clark, Phys. Rev. 90, 151 (1953).

Electron coll. rate is varied by disturbing signal, which increases mean energy. Thus the attenuation of signal is increased

B-4

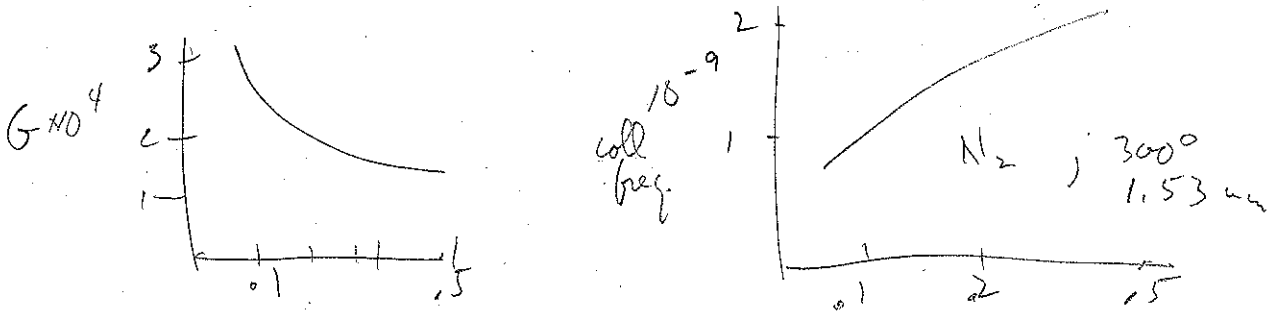
COLLISION CROSS SECTION OF NITROGEN MOLECULES WITH SLOW ELECTRONS*

J. Goldstein and J.M. Anderson
Electrical Engineering Research Laboratory
University of Illinois
Urbana, Illinois

The method of interaction of microwaves in plasmas has been applied to the determination of momentum transfer collision cross section, q_m, of nitrogen molecules with free electrons. The mean energy of the electrons was varied from 4/100 to 46/100 ev. At 4/100 ev q_m was found $\sim 17 \times 10^{-16}$ cm^2 and decreased to $\sim 8 \times 10^{-16}$ cm^2 at 0.5 ev. The mean fractional excess energy loss of the electrons, G, was found to extrapolate to $\sim 4 \times 10^{-4}$ at 4/100 ev and to fall to $\sim 2 \times 10^{-4}$ at 0.5 ev. The mean fractional energy loss of the slow electrons, λ, related to G by

$$\lambda = G\left(1 - \frac{\epsilon_m}{\epsilon_e}\right)$$

where ϵ_m and ϵ_e are the mean energies of the molecules and electrons respectively, is then ~ 5.5 in units of 2m/M. This is in agreement with the theory proposed by Gerjuoy and Stein[1] if the above found q_m is used in an adoption of the theory to compare with experiment.



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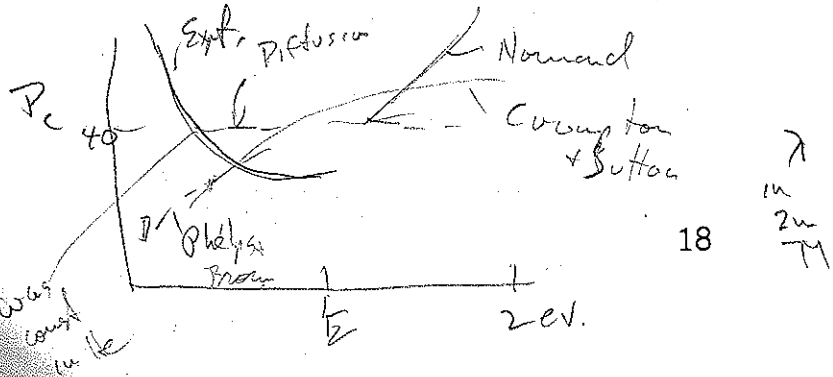
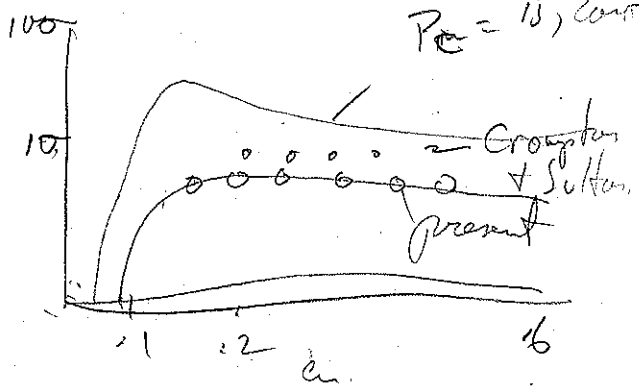
* Work supported by Air Force Cambridge Research Center.

1. E. Gerjuoy and S. Stein, Phys. Rev. 97, 1671 (1955).

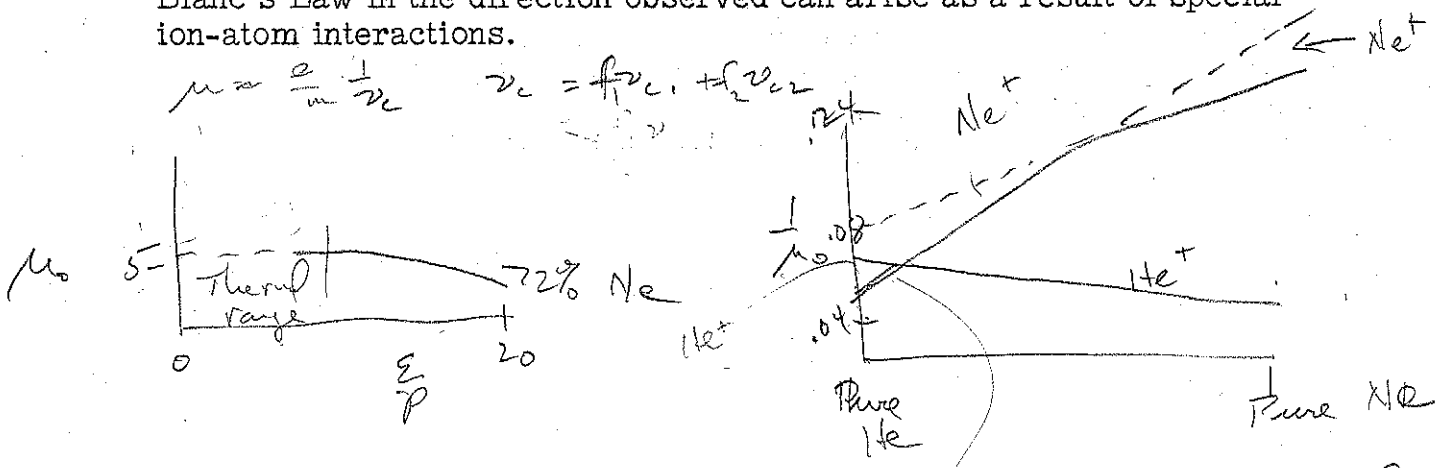




DEVIATIONS FROM BLANC'S LAW OF IONIC MOBILITIES: B-5 NE^+ IN NEON-HELIUM MIXTURES

Manfred A. Biondi and Lorne M. Chanin
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

According to Blanc's Law the reciprocal of the mobility of an ion moving in a gas mixture varies linearly with the fractional concentration of constituent gases. In the present experiment deviations from Blanc's Law have been found for the case of Ne^+ in neon-helium mixtures. It is found that the curve of $1/\mu$ vs. neon concentration exhibits a concave-downward shape and at its midpoint deviates by 6 per cent from the straight line joining the end points of the curve. In general, deviations from Blanc's Law have been ascribed to "clustering" - i.e., the formation of weakly bound complex molecules. In the present case of Ne^+ and helium atoms such clustering appears unlikely in view of the small polarizability of helium. Theoretical calculations[1] indicate that small deviations from Blanc's Law in the direction observed can arise as a result of special ion-atom interactions.



fit with parabola
Mean deviation is 25% less than a single straight line

1. T. Holstein, accompanying paper.

$Ne^+ + He + \begin{Bmatrix} He \\ \text{or} \\ Ne \end{Bmatrix} \rightleftharpoons HeNe^+ + \begin{Bmatrix} He \\ \text{or} \\ Ne \end{Bmatrix}$

Rate must be >> transit time (5×10^{-5})

Rate of $He_2^+ + He \rightarrow He_3^+$, + similar $\tau \sim \frac{1}{100p^2} \sim 40\times10^{-5}$

∴ no intermediate should be found; a mean should be observed.

B-6 MOBILITY OF POSITIVE IONS IN GAS MIXTURES

T. Holstein
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

It has generally been assumed that the mobility of positive ions in a mixture of two gases, A and B, obeys Blanc's Law,

$$\frac{1}{\mu} = \frac{f_A}{\mu_A} + \frac{1 - f_A}{\mu_B}$$

where f_A is the fractional concentration of gas A. In the present work, the validity of this relationship has been investigated by the use of a variational treatment of Boltzmann's transport equation. The result may be expressed in the standard form[1] $\mu = \mu_1 / (1-\epsilon_0)$, where μ_1, the first order Chapman-Enskog mobility formula, obeys Blanc's Law, and ϵ_0 is a positive quantity. It is found that $d^2\ \epsilon_0/df^2 > 0$, from which it follows that ϵ_0 does not exceed the larger of the two extremes, ϵ_{0A} or ϵ_{0B}. This condition generally suffices to limit deviations from Blanc's Law to a few per cent.

$K(v \to v') = f K_A(v \to v') + (1-f) K_B(v \to v')$ Transition Prob.

$\mu = \frac{1}{E} \int v_E f(\vec{v})\, d\vec{v}$, $f(v) = f_0 (1 + \varphi(v))$

$$\frac{eE}{M} \frac{\partial f_0}{\partial v_E} = \int L(v,v') \{\phi(\vec{v}) - \varphi(\vec{v})\}\, dv'$$

$$L = e^{-\frac{1}{2}Mv^2/kT} K(v \to v')$$

$$\frac{1}{\mu^*} = \frac{kT}{2e} \frac{\iint L(v,v') \{\varphi(v) - \varphi(v')\}^2\, dv\, dv'}{\{\int v_E f_0 \varphi(v)\, dv\}^2} \quad ; \quad \frac{1}{\mu^*} \geq \frac{1}{\mu}$$

1. cf., Massey and Burhop, Electronic and Ionic Impact Phenomena, pp. 367, equations 7, 8, and 9.

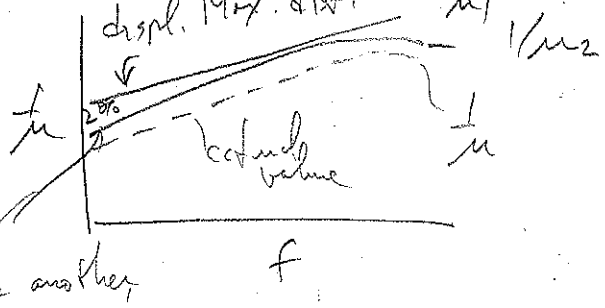
For fixed $\varphi(v)$ (Ind. of Conc.) $\frac{1}{\mu^*} = \frac{f}{\mu_A^*} + \frac{(1-f)}{\mu_B^*}$

Cases: $V(r) \propto 1/r^4$ Hard sphere ($M_i = M_a$) $M_i \gg M_a$

ϵ (Model) 0 .019 $\leq \left(\frac{M_a}{M_a + M_i}\right)^2$

20 determination of ϵ

$\frac{1}{\mu_2} = \frac{1+\epsilon}{\mu_1}$



THE TEMPERATURE DEPENDENCE OF IONIC MOBILITIES: Ne^+ AND Ne_2^+ IN NEON

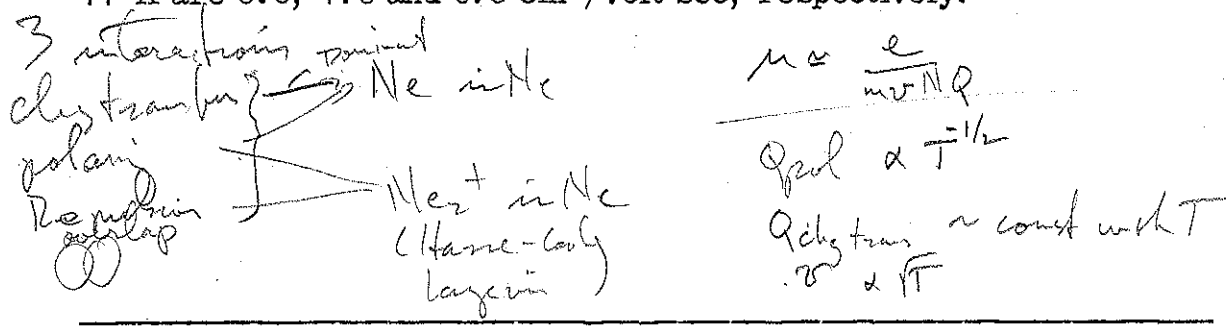
B-7

Lorne M. Chanin and Manfred A. Biondi
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

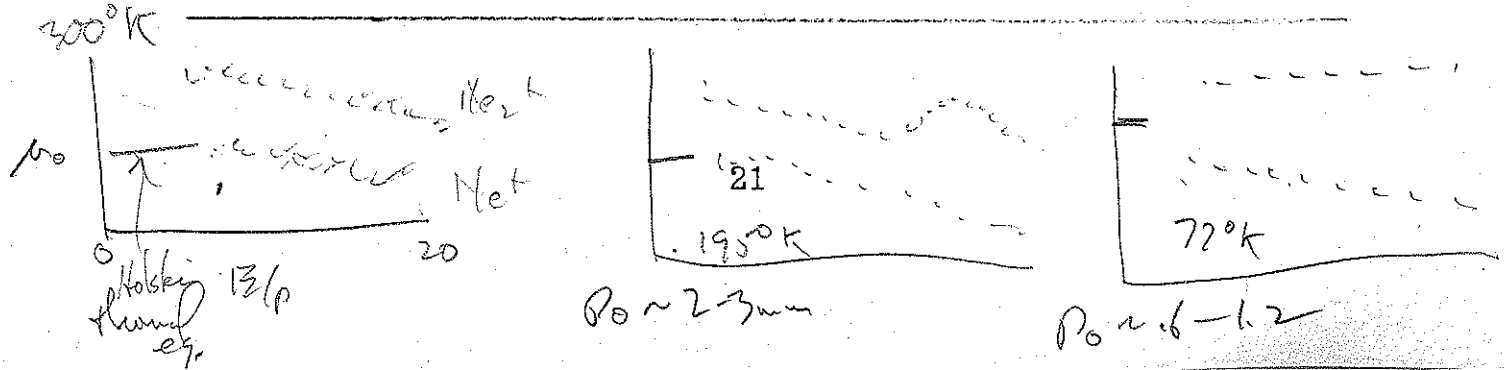
Measurements have been made of the mobilities of Ne^+ and Ne_2^+ ions moving in neon gas at 300°K, 195°K, and 77°K. The mobility tube[1] permits measurements at sufficiently low values of E/p so that the ions are very nearly in thermal equilibrium with the gas. The results for Ne^+ are compared with theoretical calculations based on Holstein's theory[2] in the following table.

T(°K)	300°	195°	77°
μ_o (exp't.) cm^2/volt sec	4.0	4.3	5.3
μ_o (theor.)	4.1	4.7	6.0

As in the case of He^+ in helium[3] the experimental values lie below the theoretical values, the difference being greatest at low temperatures. The experimental values for Ne_2^+ in neon at 300°, 195°, and 77°K are 6.5, 7.3 and 6.8 cm^2/volt sec, respectively.



1. M.A. Biondi and L.M. Chanin, Phys. Rev. 94, 910 (1954).
2. T. Holstein, J. Phys. Chem. 56, 832 (1952).
3. L.M. Chanin and M.A. Biondi, Bull. Am. Phys. Soc. 30, 32 (1955).



Friday, October 21

9:00 A.M.

SESSION C

EXCITATION AND AFTERGLOW

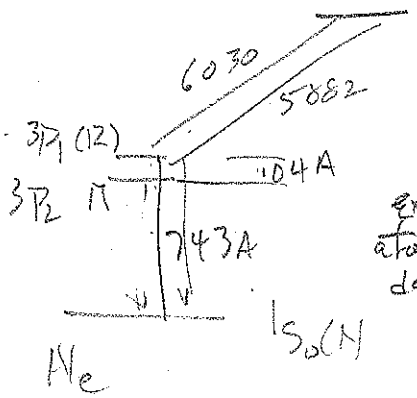
Chairman, W.P. Allis

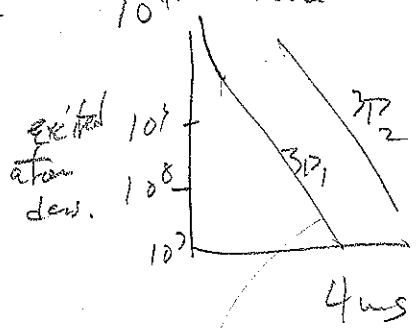
Massachusetts Institute of Technology

LIFETIME OF IMPRISONED RESONANCE RADIATION IN NEON C-1

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

Absorption studies of the lowest metastable and radiating states of neon have shown that the concentration of excited atoms in the resonance state is sufficient to cause an appreciable reduction in the rates of metastable destruction compared with the values which would be present in the absence of imprisonment.[1] We have made use of this fact to determine the effective lifetime of atoms in the resonance state, i.e., the lifetime of the imprisoned resonance radiation. Measurements show that the lifetime is independent of the neutral gas density to within the experimental error and that it varies inversely as the square root of the radius of the absorption cell as predicted by Holstein's theory.[2] The natural lifetime of the $2p^5 3s^3P_1$ state as calculated from these measurements is 1.3×10^{-8} sec compared to a value of $1.6 \pm 0.8 \times 10^{-8}$ sec obtained from measurements by Shütz of the natural line breadth of the $2p^5 3s^1P_1$ state[3] and Shortley's calculation of the relative natural lifetimes for the two resonance states.[4]





Measurements of 6030 + 5882

$$-\frac{dM}{dt} = 2M = \frac{D_N}{N\Lambda^2} M + \gamma N^2 M + AN(M - 7.65R)$$

$$-\frac{dR}{dt} = 2R = \frac{D_R}{\Lambda^2} R - AN(M - 7.65R)$$

$$\nu_R = \frac{7.65 A^2 N^2}{D_N N \Lambda^{-2} + \gamma N^2 + AN - 2}$$

Same time constant (experimental only)

1. A. V. Phelps, Bull. Am. Phys. Soc. 30, 4, 31 (1955).
2. T. Holstein, Phys. Rev. 72, 1212 (1947) and 83, 1159 (1951).
3. W. Shütz, Ann. Physik 18, 705 (1933).
4. G. H. Shortley, Phys. Rev. 47, 295 (1935).

3 Body: $N(^3P_2) + 2Ne \rightarrow Ne_2^* + Ne$

2 " : $Ne(^3P_1) + Ne \rightleftarrows Ne(^3P_1) + Ne$

7.56 = ratio of backward + forward rates

C-2 THE OPTICAL TEMPERATURE OF A PLASMA

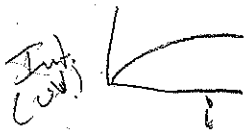
Francis Bitter*
Massachusetts Institute of Technology
Cambridge, Massachusetts

and

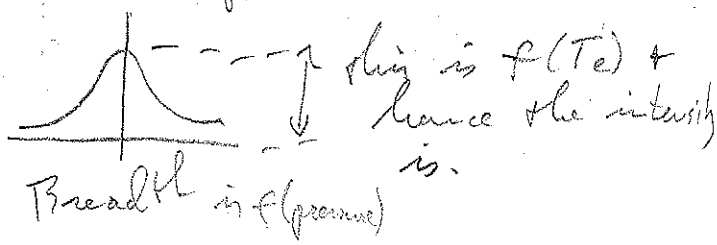
John F. Waymouth
Sylvania Electric Products Inc.
Salem, Massachusetts

We have found the concept of an "optical temperature" helpful in computing certain limits for the resonance radiation emitted from an electrically excited vapor. This is defined as the temperature at which the ratio of concentrations of atoms in the excited and ground states would be in equilibrium. This optical temperature will have its maximum value at the center of a lamp and decrease toward the surface. It will necessarily be less than the electron temperature. If the optical temperature were uniform, the spectral intensity radiated near the center of the resonance line would be that of a black body. The line width radiated by a lamp would be determined by the condition that quanta having frequencies at the edges of the line can escape from the center of the lamp without being absorbed. If the optical temperature is not uniform, the spectral intensity at any particular wavelength will be determined by some average of the optical temperatures of the atoms radiating that wavelength out of the lamp without absorption.

Hg-A discharge (e.g. commercial fluorescent lamp)



why this limit? what is spectral dist.?



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* This work was done at the Sylvania Electric Products Inc. plant in Salem, Massachusetts.

U. V. CONTINUUM OF THE XE HG' MOLECULE C-3

Carl Kenty
Advanced Lamp Development Laboratory
General Electric Company
Nela Park, Cleveland, Ohio

In a study of the excitation of metal vapors by active nitrogen as obtained in a high pressure of rare gas,[1] the case of Hg has proved of interest in several respects. A 3 sec afterglow of a 1 - 10 ma diffuse discharge in a mixture of 100 mm Xe, .3 mm N_2 and Hg at R. T. reveals besides Hg lines an intense continuum from ~ 2537 to beyond 3000 A with a broad maximum at ~ 2700 A. The same continuum occurs in the discharge itself, and in fluorescence under excitation by 2537. Without the N_2 the continuum is somewhat weaker in the discharge and much weaker in fluorescence. The intensity but not the breadth of the continuum increases with Xe pressure. A somewhat similar continuum[2] extending from ~2537 to beyond 2700 A was found with Kr as the main gas, and a still narrower one[2] in the case of A. Continua and bands associated with 2537 of Hg, emitted by Van der Waals molecules in the rare gases, chiefly other than Xe, were studied by Oldenberg[2] and others.[3] The continuum here found in Xe is unique in its large extent and intensity and in having a maximum ~ 200 A removed from 2537.

The discharges studied are unusual in that the voltage is strongly lowered by the addition of N_2 to a Hg-rare gas mixture. In the case of 23 cm of Xe with Hg at 3°C, .3 mm N_2 lowered the voltage from 1400 to 400. The result can be explained in terms of a high concentration of the N_2 metastables[1] a' and w.

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1. C. Kenty, Phys. Rev. 98, 563 (1955)
2. O. Oldenberg, Z. Physik 55, 1 (1929).
3. See W. Finkelnburg "Continuerlich Spektren," Julius Springer, 214+ (1938).

C-4 LIGHT ABSORPTION AND PHOTOIONIZATION IN NO AND N_2O

W. C. Walker and G. L. Weissler
Department of Physics
University of Southern California
Los Angeles 7, California

Total absorption cross sections, photoionization efficiencies and cross sections of NO and N_2O have been measured in the wavelength region between the ionization onset and 680 A using techniques previously described.[1] In NO the ionization onset was found at 1347 ± 5 A or 9.20 ± 0.03 ev in agreement with other work.[2] The cross sections found were independent of pressure. However, because of their rapid variation with wavelength due to the presence of diffuse bands, it was not possible to establish with any degree of certainty the contour of the NO ionization continuum. In N_2O the ionization onset was measured at 695 ± 5 A or 12.83 ± 0.07 ev, in agreement with electron impact results[3] and Duncan's Rydberg series value.[4] The cross sections showed some pressure dependence indicative of resonance bands which were sharp in comparison to the width of the radiation band passed by the exit slit. In spite of this difficulty it was still possible to assign a tentative contour to the N_2O ionization continuum. Preliminary results on the identification of photoionization products will be discussed.

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1. N. Wainfan, W. C. Walker, and G. L. Weissler, Phys. Rev. 99, 542 (1955).
2. K. Watanabe, J. Chem. Phys. 22, 1564 (1954); H. D. Hagstrum, Rev. Mod. Phys. 23, 185 (1951).
3. H. D. Smyth and E. C. G. Stueckelberg, Phys. Rev. 36, 478 (1930).
4. A. B. F. Duncan, J. Chem. Phys. 4, 638 (1936).

THEORY OF IONIZATION PROBABILITY NEAR THRESHOLD* C-5

Sydney Geltman
Applied Physics Laboratory
The Johns Hopkins University
Silver Spring, Maryland

The behavior of the probability or cross section for ionization by electron impact is investigated in the vicinity of threshold. A method is developed which is analogous to the Mott and Massey[1] treatment of inelastic scattering. The scattered electron is subject to the Coulomb field of the ion core and the ejected electron is regarded as being in a continuum state of the atom. The result of this treatment is a limiting probability which varies as the n^{th} power of the incident energy above threshold for n-fold ionization. Absolute values of the S partial cross section are calculated for the single ionization of the H and He atoms and the double ionization of He. The Born approximation is employed and the effect of electron exchange is included. Comparison will be made with the available experimental data.

electron impact E^n exponent
photon " E^{n-1} (fewer electrons coming off)
i.e. for single ionization, σ is constant

---

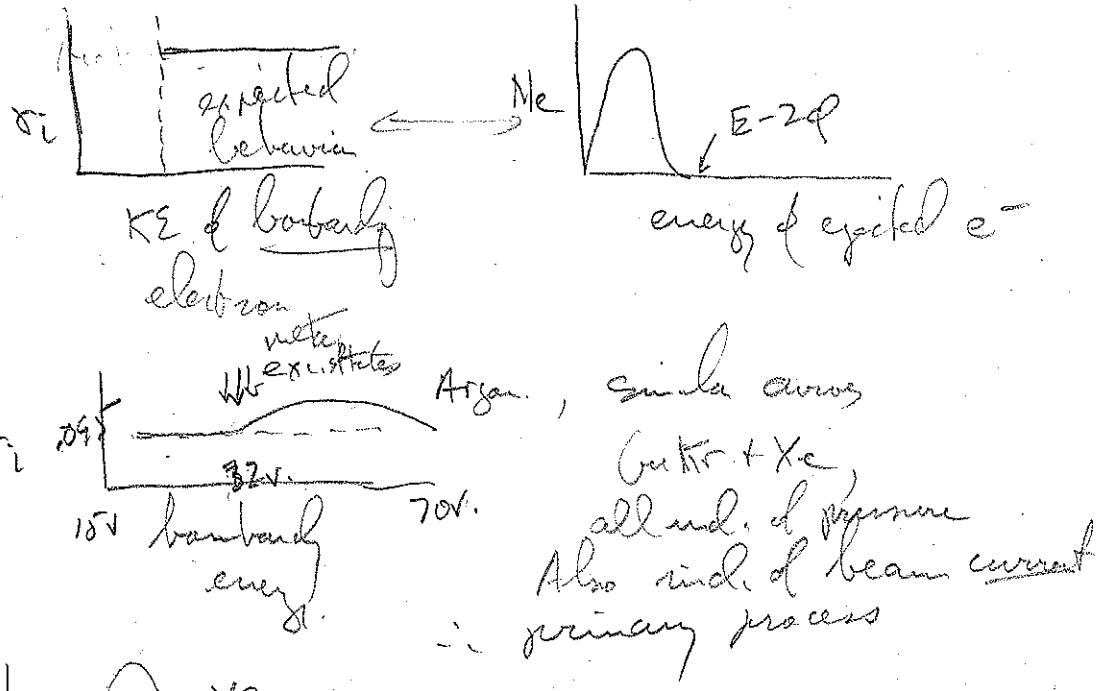
* This work was supported by the Bureau of Ordnance, Department of the Navy, under NOrd 7386.

1. N.F. Mott and H.S.W. Massey, The Theory of Atomic Collisions, Second Edition, Oxford University Press (1949).

C-6 FORMATION OF METASTABLE AR^+, KR^+, AND XE^+ BY ELECTRON IMPACT

Homer D. Hagstrum
Bell Telephone Laboratories
Murray Hill, New Jersey

Metastably excited, singly charged ions of argon, krypton, and xenon formed by single electron impact have been detected by their greater ability, with respect to unexcited ions, to eject electrons from an atomically clean metal surface. The yield (γ_i) of electrons ejected per ion by all singly charged ions has been measured as a function of electron energy. γ_i is found to be constant only up to electron energies near 32.2, 28.9, and 24.0 ev for Ar, Kr, and Xe, respectively, above which energies ions in the lowest lying metastable levels ($4D_{7/2}$) can be formed. At greater energies the increase in γ_i above that for unexcited ions gives directly the form of the cross section for formation of the excited ions. To determine the absolute magnitude of the cross section one must estimate γ_i for the excited ions. Assuming this to be equal to that measured for doubly charged ions (an upper bound), one calculates a lower bound of about 0.02 for the ratio of the cross sections for the formation of metastable ions and unexcited ions at the second ionization energy.



Invited Paper

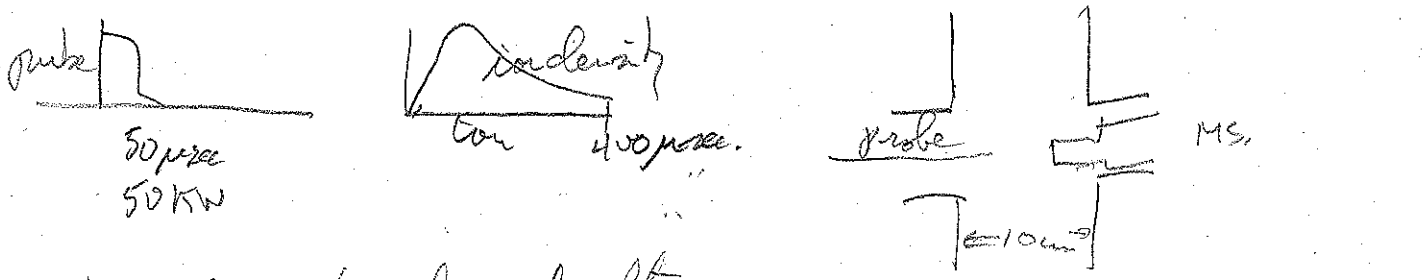
IONIC STUDIES OF AFTERGLOWS

C-7

J. Sayers
University of Birmingham
Birmingham, England

Mass spectograph and electron density studies have been made as a function of time in the afterglows of various gases and gas mixtures following a fairly high power ionizing pulse of radio frequency. The pulse power was 50 K.W.; frequency 200 Mc/sec and duration 20 microseconds.

The mass spectograph was of the Bennett type in miniature form enclosed in a hollow probe and the electron density measurements were made by Langmuir probe methods. Charge exchange and recombination reactions have both been observed at appropriate times in the afterglow period.



take probe data at const volts, then cross plot

$O_2^- + O^-$ decay

$He + O_2$ mixtures

different times

cools faster at more O_2 content

Find recomb at high n_i from decay rate

diff " low

$A + O_2$ O_2^+ formed by exchange with A^+ gives const conc of O_2^+ which then dissociatively recombines at much

$\alpha_T = 1.14 \pm 0.09 \times 10^{-4}$ cm/sec at RT

$.0075 < p < 2.0$ ← Direct recomb.

$300 < T < 2500$ K $O_2^+ + e = O + O$

N_2 $\alpha_T = 3.8 \pm .4 \times 10^{-4}$

$.01 < p < 2.0$

$3100 > T > 300$

$\alpha_i = 2 \times 10^{-6}$ $n_e = \frac{[N_2^+]}{\tau} \sim 10^{-9}$

C-8 TRANSIENT BEHAVIOR FOLLOWING BREAKDOWN AND ITS RELATION TO AFTERGLOW PROCESSES*

Donald E. Kerr and Eldred F. Tubbs
The Johns Hopkins University
Baltimore, Maryland

Following application of a pulse of microwave power to form a helium discharge in a resonant cavity, there is a period of about one millisecond which is characterized by a transient behavior of both emitted light and r-f properties, particularly transmitted power. In general atomic radiation first rises sharply, then undergoes quasi-oscillatory behavior in approaching a stationary value. During the pulse molecular radiation is generally weak, but rises manyfold at the end of the pulse. Detailed measurements of certain transitions show atomic light falling abruptly in the afterglow; but molecular light rises sharply then falls more slowly. The radiation is usually characterized by more than one time constant, the larger one being markedly dependent upon pulse length and pressure. The abrupt rise of molecular radiation at the end of the breakdown pulse is strongly dependent upon pulse length. Consequently the relative predominance of molecular or atomic radiation can be controlled by pulse length. This fact casts doubt on interpretations of afterglow mechanisms which depend upon predominance of either type of spectrum. Other rare gases are under study.

* This work was supported by the Office of Scientific Research, U.S. Air Force.

LOW PRESSURE AFTERGLOW STUDIES IN NITROGEN C-9

A. C. Faire and George W. Griffing
Geophysics Research Directorate
Air Force Cambridge Research Center
Air Research and Development Command
Cambridge, Massachusetts

Quantitative laboratory studies have been conducted on the afterglow following a pulsed microwave[1] discharge in N_2 + He, N_2 + Ne and N_2 + A at partial pressures of nitrogen below 20 microns Hg. These measurements extend the work previously reported for partial pressures of nitrogen in the range of 20 microns to 3 mm Hg.[2, 3] A discussion of the loss mechanism at early times in the afterglow is presented.

1–20 μ Hg
At upper pressures
$N_2^+ + e \rightarrow N^* + N''$
$N_2^+ + e \Rightarrow (N^+)' + N' + e$
$He^* + N_2 \rightarrow He + N_2^+ + e$
$\alpha \sim 10^{-6}$ in these ranges
He Ne + A effective recombination coefficient
Spectroscopic obs. of discharge in O_2-He + N_2-He mixtures, 7 0.2 μ
molecular spectra, lower set He

1. M. A. Biondi and S. C. Brown, Phys. Rev. 76, 1697 (1949).
2. A. C. Faire, O. T. Fundingsland, and A. L. Aden, Gaseous Electronics Conference Paper, October 1953, Washington, D. C.
3. A. C. Faire, O. T. Fundingsland, and A. L. Aden, Conference on Electron Physics, June 1954, University of Birmingham, Birmingham, England.

C-10 SCATTERING OF LOW ENERGY H^- IONS IN HELIUM*

T. L. Bailey and E. E. Muschlitz
College of Engineering
University of Florida
Gainesville, Florida

Measurements have been made by the method of Simons and co-workers[1] on the scattering of H^- ions in helium gas at incident ion energies of 4 ev to 300 ev. Both elastic and total inelastic cross sections have been determined as functions of ion energy. The results are similar to those for the scattering of H^- ions in H_2.[2,3] From the elastic cross-section data below about 50 ev a potential law is calculated which is characteristic of an ion-induced dipole interaction. From 100 ev to 300 ev the apparent elastic cross section increases slightly with ion energy; this increase is attributed to the electronic excitation of He atoms by the incident H^- ions. The inelastic cross section for the electron detachment process $H^- + He = H + He + e^-$ is nearly constant from 300 ev to about 200ev. Below 20 ev the detachment cross section drops sharply but seems to persist to incident ion energies as low as 2 ev.

My wire grids, gold plated

---

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

1. Simons, Muschlitz, and Unger, J. Chem. Phys. 11, 307 (1943).
2. E. E. Muschlitz, Phys. Rev. 95, 635 (a) (1954).
3. E. E. Muschlitz, T. L. Bailey, and J. H. Simons, in process of publication.

Friday, October 21

2:30 P.M.

SESSION D

ARCS

Chairman, H. Margenau

Yale University

PAST AND PRESENT IDEAS ABOUT COLD ARCS

A. von Engel
Oxford University
England

D-2

DISCHARGE MECHANISM OF MERCURY POOL ARCS*

K. G. Hernqvist
Radio Corporation of America
RCA Laboratories
Princeton, New Jersey

A model for the discharge mechanism of mercury pool arcs will be proposed. This model is based on the following two basic assumptions:

1) Electron emission from the cathode occurs directly into a dark plasma adjacent to the cathode surface at approximately the same potential as the Fermi level of the cathode.

2) Mercury pool arcs operate in a discharge mode very similar to the ball of fire mode of externally heated hot cathode discharges. [1]

Conclusions drawn from this model will be shown to be in agreement with experiments. These include measurements of arc drop, potential and current density distributions, studies of arc spot motion, and pulse measurements. Studies of the discharge behaviour after arc extinguishing will be shown to indicate that the ion to electron current ratio of the arc is not larger than about one hundredth. Possible mechanisms of electron emission will be briefly discussed.

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* This research was supported by the United States Air Force through the Office of Scientific Research of the Air Research and Development Command.

1. E. O. Johnson, Paper B-8, 7th Gaseous Electronics Conference, October 14, 1954. (To be published in RCA Review, December 1955.)

SHORT ARCS

D-3

L. H. Germer and W. S. Boyle
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey

Short field emission arcs are of two types, those which vaporize metal predominantly from the anode by electron bombardment, and those in which the metal of the arc is supplied from the cathode by melting points by field emission currents flowing through them. These are appropriately called "anode arcs" and "cathode arcs." An anode arc erodes a pit in the anode, and leaves a roughened area on the cathode. A cathode arc leaves on the cathode a dispersed array of pits which lie largely along scratches; often there is no mark on the anode. These arcs differ in arc voltage, higher for cathode arcs, and in other ways. Both types have been observed for many metals. For clean palladium all arcs are cathode arcs at 400 volts, but at 300 and lower voltages anode arcs occur also, becoming more frequent at lower voltages. For surfaces activated by carbonaceous material only cathode arcs occur at all potentials. In anode arcs metal is transferred in both directions, as measured by radioactive tracers, with net transfer from anode to cathode. Cathode arcs transfer from cathode to anode only, and less metal per unit of arc energy than is transferred in anode arcs.

D-4

SOME PROPERTIES OF ARC CATHODE SPOTS IN MAGNETIC FIELDS

Dino Zei,* Robert St. John, and J. G. Winans
University of Wisconsin
Madison, Wisconsin

The velocity of the cathode spot of a mercury arc in a transverse magnetic field has been measured with the arc spot in a groove above the junction line between the metal cathode and mercury. The approximate doubling of velocity[1] at fields about 11,000 to 15,000 oersteds does not take place under these conditions. However, the velocity is always greater than when the arc spot is at the mercury-electrode junction.

Spectra of the arc showed some Hg II lines enhanced at the arc spot. There was no broadening of the Hg I lines like that observed when the arc spot was at the junction between mercury and metal.

---

* Now at State Teachers College, St. Cloud, Minn.

1. Robert St. John and J. G. Winans, Phys. Rev.

THE HIGH PRESSURE XENON-MERCURY DISCHARGE

D-5

W. Elenbaas
N. V. Philips' Gloeilampenfabrieken
Eindhoven, Netherlands

Measurements have been made on discharges in xenon at a pressure of 10 atm. (at room temperature without a discharge), to which different amounts of mercury (0.2 - 16 per cent) have been added. At a constant input per cm length (25 W/cm), the intensity of a number of Xe- and Hg-lines and the electrical gradient have been measured.

From the intensity decrease of the Xe-lines at increasing mercury content, the temperature decrease can be derived (a). The temperature decrease may also be calculated from the intensity variation of the mercury lines (b) and finally from the energy balance of the pure Xe- and the pure Hg-discharge. Compared with method (a), method (b) results in a steeper temperature decrease, whereas method (c) gives a flatter temperature curve at low mercury contents. Method (a) is considered to give the best results. The deviations found with methods (b) and (c) may be explained by the increase of the absorption of the mercury radiation from zero at very low Hg-contents to normal at higher mercury additions. The absorption may be calculated from the deviation as well from method (b) or from method (c).

On the basis of the temperature decrease derived according to (a) and the ratio of the cross sections of the Xe-atom and of the Hg-atom for electrons, the very large increase of the electrical gradient (65 per cent increase for an addition of 1 per cent Hg) may be explained.

D-6

GLOW-TO-ARC TRANSITIONS IN THE COLUMN OF THE HIGH-PRESSURE GLOW IN HYDROGEN

W. A. Gambling
University of Liverpool
Liverpool, England

By using relatively cool copper or tungsten electrodes in hydrogen it is possible to obtain a transition from glow to arc in the column of a high (1 atm.)-pressure discharge while the cathode regions remain in the glow state. Experiment shows that the column transition is governed by thermal considerations, in accordance with the predictions of King [1] and others. Excitation temperature and other measurements indicate that in the glow column, as at low pressure, the electron temperature is very high and the gas temperature low. With increasing current the electron temperature falls and the gas temperature rises until the transition to an arc column occurs. The current density is now higher, and the voltage gradient lower than in the glow column but the electron temperature is still appreciably higher than that of the gas, and the measured ion density does not agree with that calculated using the Saha equation. As the current or the pressure increases the gas and electron temperature difference falls and the measured ion density approaches more closely that given by the Saha equation.

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1. L. King, Nature 174, 1008 (1954).

ON THE PRONOUNCED DEVIATIONS FROM THE MAXWELLIAN VELOCITY DISTRIBUTION OF THE ELECTRONS IN HOLLOW HOT CATHODE DIODES WITH NE FILLING

D-7

G. K. Medicus
Wright-Patterson Air Force Base
Dayton, Ohio

At about 1 mm Hg an electron velocity distribution is observed which consists of three different groups. Near the cathode the fastest group sets in at about 16 ev with a steep rise. The slowest group has a Maxwellian velocity distribution corresponding to temperatures in the order of 3,000°K. In between there is a middle group with a maximum at about 11 ev, which seems to correspond to that found by Druyvesteyn* under comparable conditions. The inset voltage and steepness of inset slope of the fastest group decreases with increasing distance from the cathode, due to collision losses. The numbers in the two fast groups change with time of operation in favor of the middle group. Tentative explanation: The inset of the fastest group is given by the two metastable levels at 16.6 and 16.7 ev, which provide for step-wise ionization. The middle group arises from small contaminations given off by the oxide cathode. The slowest group contains the secondaries.

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* M. J. Druyvesteyn, Zeits. f. Phys. 64, 781 (1930).

Saturday, October 22

9:00 A.M.

SESSION E

MAGNETIC FIELD EFFECTS AND MISCELLANEOUS

Chairman, H.D. Hagstrum

Bell Telephone Laboratories

ISOTOPIC SEPARATION BY MAGNETO-IONIC EXPANSION

E-1

Joseph Slepian
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

A metallic gas, at a high temperature, 100,000°C or higher, and therefore ionized, is sent down a tube of increasing cross section, and precipitates on insulated slats. It is prevented from precipitating on the side walls by a combination of a strong enough magnetic field set parallel to the walls and perpendicular to the discharge of gas, and an electric potential between the side walls, drawing current from the one wall to the other wall. It is prevented from precipitating on the insulated end walls by the large separation of these walls from the point of inlet of the ionized gas.[1] The potential for uranium, for example, may be a few hundred volts, the magnetic field about 6000 gauss, the tube length a foot or two, the tube egress section some 20 square feet.

The current to the side walls, if the magnetic field and electric potential are high enough, is negligibly small. All the precipitation is among the insulated slats. The isotopes become separated there, the deposit on the insulated slat adjacent to the negative side wall being richer in the lighter isotope, and the deposit on the insulated slat adjacent to the positive side wall being richer in the heavier isotope. The enrichment is proportional approximately to the square of the distance between the two side walls at the insulated slat egress end.

This isotope separator will offer isotopes of metals more cheaply than any other device known to me.

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1. Proceedings of the National Academy of Sciences, July 1955.

E-2

ION DIFFUSION IN A UNIFORM MAGNETIC FIELD*

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Tufts University
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A new method has been used to measure ion diffusion coefficients in the presence of a magnetic field. A high power pulse discharge was produced in a small diameter quartz tube inserted into a long cylindrical microwave cavity. The TM_{010} mode was used to produce the discharge and the TE_{119} mode utilized to measure the electron density in the afterglow. A specially designed coil was used to produce a uniform magnetic field. Considerable care was taken with the vacuum technique to insure the purity of the hydrogen gas used in the measurements.

The values obtained for the ion diffusion coefficient when B/p was small were in agreement with classical theory for diffusion in the presence of a magnetic field. On the other hand, values measured when B/p was large were consistent with the theory of Simon.[1] It seems probable that there is a steady transition from ordinary ambipolar conditions, with small B/p, to Simon's free ion diffusion conditions, with large B/p. The transition may also be a function of p or, at least, of the ratio of mean free path to the tube dimensions.

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* This work was sponsored by the Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command.

1. A. Simon, Phys. Rev, 98, 317 (1955).

RESONANT POWER TRANSFER WITHIN A PLASMA IN A MAGNETIC FIELD*

E-3

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Electronic Defense Laboratory of Sylvania Electric Products Inc., Mountain View, California

This paper presents the results of a study of conditions under which power can be transferred to or from a small oscillating electric field within the body of a plasma in a magnetic field. By Lagrange's method of characteristics, the linearized Boltzmann equation is solved under the assumption that the collision rate between electrons and neutral gas molecules is much less than the cyclotron frequency. From this and Maxwell's equations, a conductivity tensor, $\overleftrightarrow{\sigma}(\omega)$, is derived and a set of resonant frequencies is found for which the power transfer $\vec{E}_{\omega} \cdot \overleftrightarrow{\sigma}(\omega) \cdot \vec{E}_{\omega}$ can become large. When the kinetic energy density of the electrons is much less than the energy density of the static magnetic field, the resonant frequencies for power transfer reduce to integral multiples of the electron cyclotron frequency. Thus, additional physical insight is provided concerning the "gaps" in the electromagnetic propagation at these frequencies obtained by E.P. Gross. For plasmas with relatively large kinetic energy densities, the electromagnetic vector potential, which was dropped by Gross, becomes important and significant deviations from the cyclotron multiples are predicted for the first several resonances. A practical upper limit is found to the spectrum of resonant frequencies for which significant energy transfer occurs.

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* This work was performed under Signal Corps Contract No. DA-36-039-sc-31435.

E-4 CYCLOTRON RESONANCE OF ELECTRONS IN GASEOUS DISCHARGE PLASMAS*

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University of Illinois
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Resonance phenomena in gyromagnetic gaseous discharge plasmas can be particularly useful for investigating certain fundamental processes in plasmas. A study was made of such phenomena at microwave frequencies (10,000 Mc) in noble gases at pressures of the order of 10 mm Hg and plasma electron densities of the order of 10^{11} e/cc. The gases were contained in a discharge tube which passed through a section of waveguide located in a periodically varying magnetic field.

The results indicated that the principal resonance was the cyclotron resonance of free electrons. The widths of these resonances gave values for the probabilities of collision for electrons with molecules at room temperature (300°K) which are in agreement with other published determinations. These values were also found to be consistent with the experimentally determined increases in the electron collision frequency resulting from the enhanced heating of the electron gas during resonance. Also found, were additional "resonance like" effects at the higher electron densities which may be associated with the intrinsic behavior of gyromagnetic plasmas.

3500 gauss max field
no heating above
time-varying H.

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* Work sponsored by Air Force Cambridge Research Center.

HIGH INTENSITY ION SOURCES

E-5

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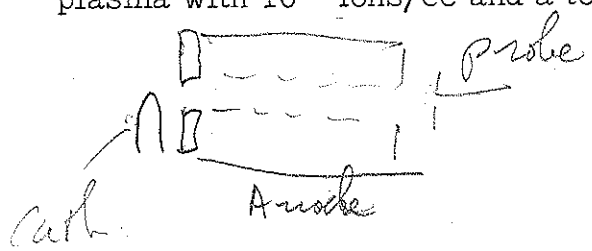
Curtiss-Wright Corporation
Clifton, New Jersey

High intensity ion sources consist of the source plasma, acceleration region, and ion beam. Processes in the plasma of high production ion sources are discussed and a particular ion source developed with the use of these processes is described. The processes are described by D.C. probe measurement in and ion currents from a plasma with 10^{14} ions/cc and a temperature of 40 ev.



150 ma of H^+

~75 " " $H_2^+ + H_3^+$

Spread ~ 10V

E-6

STATISTICAL MECHANICS OF CATHODE SPUTTERING

Don E. Harrison, Jr.
University of Louisville
Louisville, Kentucky

In an earlier paper, the author has discussed a theory of cathode sputtering.[1] The equal mass restriction, made in this earlier work, has now been removed. The results appear as a convergent series of exponential functions of the logarithmic energy. In most cases the first term dominates completely.

The final expression for the sputtering ratio depends upon four parameters, only two of which are even approximately experimentally known, but the theoretical curves are extremely sensitive to the choice of parameters, and the required values are consistent with what we know of the physical system. Agreement with Keywell's experimental data[2] is satisfactory, although much of the fitting is to curves formed from three or four experimental points.

The present theory is not completely satisfactory for systems of small mass ratio, but the cause of breakdown is apparent from the behavior of the curves. Extension of the theory to cover these cases is possible, but hardly warranted at this time.

Lattice collision → cool off beam ion
→ eject lattice atoms, some of which are removed to outside.
Binary collisions not wholly justifiable, but use Boltzmann anyway.

1. Don E. Harrison, Jr., Phys. Rev., 93, 652A (1954).
2. Frank Keywell, Phys. Rev., 87, 160 (1952); Phys. Rev., 97, 1611 (1955).

MINIMUM QUENCHING TIMES OF LOW VOLTAGE, NON-SELFQUENCHING GEIGER COUNTERS

E-7

Roger D. Erickson
Honeywell Research Center
Hopkins, Minnesota

An expression is derived for the minimum quenching time, τ_m, of non-selfquenching Geiger counters. This expression relates τ_m to the gas pressure, counter geometry, initial number of positive ions, secondary electron coefficient, ionization coefficient, positive ion mobility constant and the quenching voltage. Experimental data were obtained using Geiger tubes filled with neon-argon mixtures. The data showed that τ_m is proportional to the gas pressure from 3 mm Hg to 125 mm Hg; it is also independent of the gas mixtures tested - neon with 0.05 per cent to 1.00 per cent argon. A dependence of τ_m on the quenching voltage was observed. The plateau lengths of the Geiger counters are determined by τ_m when a thyratron quenching circuit is used. The secondary electron mechanism is responsible for the relatively long minimum quenching times observed (0.01 to 0.30 sec).

E-8

ELECTRICAL CHARACTERISTICS OF LOW PRESSURE SPARK DISCHARGES

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Alexandria, Virginia

and

R. G. Fowler
University of Oklahoma
Norman, Oklahoma

Precise investigations have been made of the current and voltage characteristics of spark discharges in helium, neon, argon, and xenon at pressures ranging from 1 mm Hg to 100 mm Hg. The derived quantities power and resistance have been calculated, and an analysis has been made of the resistance curves so obtained. It is found that initially the resistance is governed by the need to develop an ion concentration sufficient to carry the current, but that after this is accomplished, the resistance varies inversely as the current until the discharge has waned to a point that recombination exceeds ion production. The course of the resistance curve is wholly interpretable in terms of fundamental gas constants.

Saturday, October 22

1:30 P. M.

SESSION F

POSITIVE COLUMNS AND PLASMAS

Chairman, L. Varnerin
Westinghouse Research Laboratories

INCLUSION OF COULOMB INTERACTIONS IN THE BOLTZMANN EQUATION*

F-1

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Massachusetts Institute of Technology
Cambridge, Massachusetts

The method of Fokker-Plank has been used to extend the Boltzmann Transport equation to include the random Coulomb interactions in an ionized gas. The time rate of change of the particle distribution function due to these interactions is expressed as the divergence of a flow vector in velocity space, and consists of two parts:

1) The flow resulting from the average retarding force, and 2) A diffusion-like flow in velocity space resulting from the fluctuations in the interaction force.

An expansion of the distribution function in spherical harmonics is used to derive the equation satisfied by the spherical part of the electron distribution function, and a criterion is derived for the degree of ionization at which Coulomb interactions first exceed the effects of inelastic collisions and external electric fields. Above this degree of ionization the distribution becomes Maxwellian, but the average electron energy and the rate of ionization are not altered appreciably from their values at low electron density. It is shown that charged particles in a fully ionized gas can be accelerated indefinitely by an external electric field provided their velocities are larger than a critical barrier velocity.

coulomb interaction becomes important, e.g. in H_2 at $\frac{\mathcal{E}}{p} = 56$ when $n_e = 10^{-5} n_{gas}$.

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* This work has been supported in part by the Signal Corps, Air Material Command, and ONR.

** Now at the University of California Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

F-2 PRODUCTION AND LOSS OF EXCITED ATOMS IN THE HELIUM POSITIVE COLUMN

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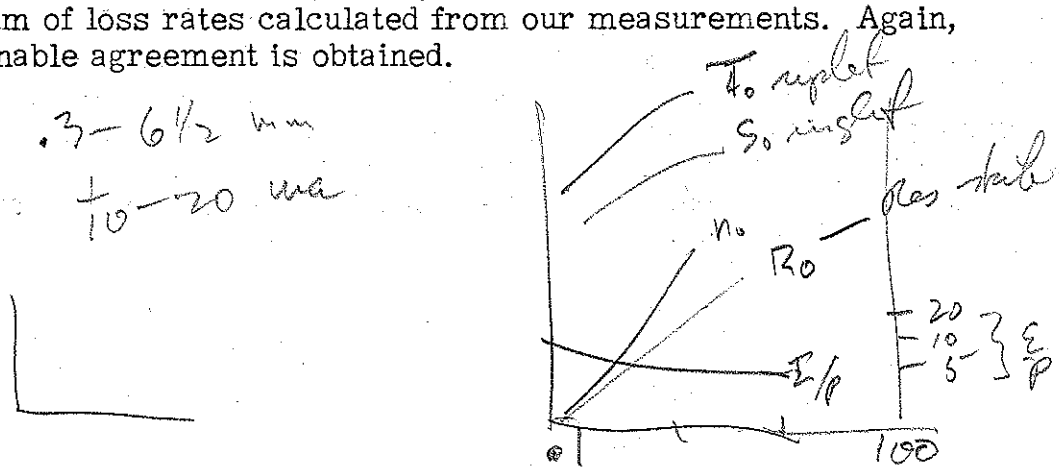
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

Measurements of the important parameters of a helium positive column reported previously[1] have been refined and extended over wider ranges of electron density and pressure. Electron density is measured by microwave techniques; the density of singlet and triplet metastable atoms and of atoms in the resonance state are measured by means of optical absorption; the axial electric field and the average electron energy are measured with fine wire probes. A power balance is presented, comparing the total input power per electron to the sum of power losses associated with diffusing ions, electrons and metastables, with resonance radiation and with elastic recoil. Agreement is obtained within limits defined by experimental accuracy and uncertainties in necessary coefficients. The data at low electron densities indicate somewhat smaller deviations from ambipolar diffusion than predicted by the transition diffusion theory of Allis and Rose.[2] A comparison is made between the combined rate of excitation and ionization given by the theory of Reder and Brown,[3] and the sum of loss rates calculated from our measurements. Again, reasonable agreement is obtained.



1. L. S. Frost and A. V. Phelps, Phys. Rev. 98, 559 (1955).
2. W. P. Allis and D. J. Rose, Phys. Rev. 93, 84 (1954).
3. F. H. Reder and S. C. Brown, Phys. Rev. 95, 885 (1954).

FAILURE OF SCHOTTKY THEORY FOR THE POSITIVE COLUMN OF O_2*

F-3

D. S. Burch, G. H. Dunn, R. Geballe, and V. M. Madsen
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Seattle, Washington

Measurements of the potential gradient in the uniform positive column of the O_2 glow discharge have been made using cold probes. The results are in agreement with those of Guntherschulze[1] and in the range $0.2<pR<2.4$ mm cm lie between 23 and 15 volts/cm mm. The Schottky theory for the uniform positive column has been extended to include electronegative gases. This extension predicts a lower limit to E/p corresponding to a value for which the attachment coefficient and the ionization coefficient are equal. In oxygen, equality occurs for E/p = 35,[2] considerably higher than the above measured values. Oscillographic studies of the current and light emission show rapid time variation,[3] implying that the column does not have the uniformity on which the theory is based. N_2 has been subjected to the same observations. Measured fields in this gas do agree with predictions of Schottky theory. No current and light variation is found in N_2 in the range of current and pR for which the theory is valid.

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1. A. Guntherschulze, Zeit f. Phys. 42, 763 (1927).
2. M. A. Harrison and R. Geballe, Phys. Rev. 91, 1 (1953).
3. E.g.: T. Donahue and G. H. Dieke, Phys. Rev. 81, 248 (1951);
A. B. Stewart, J. Opt. Soc. Am. 45, 651 (1955);
N. L. Oleson, Phys. Rev. 98, 559 (1955).

* This work has been supported in part by the U.S. Office of Ordnance Research.

F-4 THE OSCILLATING GLOW DISCHARGE PLASMA*

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Yellow Springs, Ohio

The plasma potential, electron temperature, and electron concentration have been measured as functions of both time and position in the positive column of an argon glow discharge with moving striations. Plane circular tungsten probes 0.5 mm in diameter that could be saturated in the electron collecting region were used.

The variations of potential, electron temperature, and charge obtained demonstrate that the moving striations in the glow discharge are closely related in their electrical properties to the striations in the argon arc studied by Pupp.[1] In the glow discharge however, in addition to the positive striations, there are weak light flashes that travel with speeds greater than 10^5 m/sec. The plasma potential is observed to drop about 10 volts within 1/8 of a period after the flash. Although space charge concentrations with maxima approximately 5 times the average concentration in the plasma accompany the positive striations, no increase in concentration was observed at the time of the light flash.

The reliability of the probe measurements and the bearing of the results on theories of the moving striations will be discussed.

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* Supported by the National Science Foundation.

1. W. Pupp, Physik, Zeits. 34, 756 (1933).

TRAVELING DENSITY WAVES IN POSITIVE COLUMNS F-5

S. Watanabe
U.S. Naval Postgraduate School
Monterey, California

It was previously shown[1] that there can exist, in the positive column, traveling waves of ion density and electron density whose physical nature is different from the so-called plasma oscillation. Further refinement of the theory, in particular, in regard to the connection between these waves and the sound wave will be presented.

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1. S. Watanabe and N.L. Oleson, to be published in one of the September issues of the Phys. Rev. 1955.

F-6 PROPAGATION OF IONIZING POTENTIAL PULSES IN LONG GLOW DISCHARGE COLUMNS

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University of California
Berkeley 4, California

In glow discharges, 144 cm long between 2 cm diameter aluminum electrodes in air, oxygen, and clean nitrogen, operating at around 2×10^{-2} mm pressure, when the potential is raised well into the abnormal region, or when operating near this level in the abnormal region without oscillations on imposing a small step voltage, breakdown into a transient arc with 1,000 to 10,000 fold increase in current follows. This starts with the formation of a minute bright cathode spot which sends pulses of ionization and luminosity sweeping from cathode to anode and back to the cathode. Triggering the photomultiplier sweep by observing the initiating cathode spot, the progress of the luminous pulse can be studied along the tube by a second photomultiplier. The pulses from cathode to anode have a higher velocity than the return pulses which are the more luminous. The pulses vary in velocity in the different portions of the glow discharge, e.g., Faraday dark space and positive column, presumably depending on ion concentrations. Velocities are greater, the lower the pressure and are higher in the presence of oxygen than in nitrogen. Velocities from 2×10^{9} cm/sec on down have been observed.

DERIVATION FROM BOLTZMANN'S EQUATION OF THE SIMILARITY LAWS FOR IONIZED GASES

E-7

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Sandia Corporation
Albuquerque, New Mexico

Similar discharges are defined as discharges whose distribution functions $f(\underset{\sim}{v}, \underset{\sim}{r}, t)$ are in a constant ratio at all corresponding points and times.* This can be obtained only if like terms in their Boltzmann's equations are also in a constant ratio. By expressing each term in Boltzmann's equation as the product of a combination of parameters times a function which has the same value at corresponding points and times, we can derive the two sets of laws of similarity:

$$1/R \propto 1/T \propto \omega \propto E \propto N \propto \{ n \text{ or } nR \}$$

where R and T are the characteristic length and time, ω is the frequency of the field, E is the applied field strength, N is the molecular density, and n is the electronic or ionic density.

Similarity with the electronic density varying as indicated is possible only when certain processes are negligible. Most important, the term n cannot be valid in the presence of space charge. Space charge is compatible with the term nR but processes quadratic in n (coulombic collisions, recombination) are not.

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* H. Margenau, Phys. Rev. 73, 326-8 (1948).

LIST OF CONTRIBUTORS

GASEOUS ELECTRONICS CONFERENCE
EXECUTIVE COMMITTEE