ABSTRACTS

1953
CONFERENCE ON

R Geballe

GASEOUS ELECTRONICS

WASHINGTON, D.C.
OCTOBER 22-24, 1953

under the joint sponsorship of the

AMERICAN PHYSICAL SOCIETY
DIVISION OF ELECTRON PHYSICS

and the

OFFICE OF NAVAL RESEARCH

PREFACE

In the five years since its first meeting at Brookhaven, the Conference on Gaseous Electronics has grown and prospered. It has established its reputation as a forum suitably organized for both pleasant and effective exchange of scientific intelligence. This is attributable, in no small measure, to the conscientious and enlightened efforts of successive executive committees. With this, the sixth meeting, we find the Conference still growing in interest and participation. That this interest and participation has been sufficient to justify an annual three-day conference seems a remarkable tribute to the vitality of the subject matter and to the imagination and energy of the scientists who explore it.

Needless to say, the situation outlined above is applauded by the Office of Naval Research which, since its inception, has sought to foster both financially and administratively a sustained research effort in the important fields of gaseous electronics. As early as July 1948, this Office brought seven of its contractors together for an informal meeting which could be considered a precursor of the present Conference. Thus, the Office of Naval Research welcomes the opportunity to co-sponsor this sixth annual Conference on Gaseous Electronics.

Wayne R. Gruner
Office of Naval Research

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AND PROGRAM

Thursday
October 22
8:45 - 9:45 A. M.

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Thursday, October 22

9:45 A. M.

SESSION A

PLASMA PROPERTIES

Chairman: D. J. Rose

Bell Telephone Laboratories

CALCULATED VALUES OF THE PARAMETERS OF NOBLE GAS DISCHARGES

Walter J. Graham and Arthur J. Ruhlig
Naval Research Laboratory
Washington, D. C.

Molar properties of gaseous discharges are determined by the transport cross-section which is expressible in terms of the phase shifts defined in electron-atom scattering theory.

σ_t (v) was calculated for helium, neon and argon using values of phase shifts η_0 to η_6 derived by Westin[1] from existing scattering data. Druyvesteyn distribution functions were calculated for E/p from 0.1 to 1.0. Average values were then calculated for collision frequency, drift velocity, diffusion coefficient, and average energy. Also, collision frequency and elastic energy loss were calculated using Maxwell distributions for kT_e up to 10 ev. These calculations are particularly useful at very low energy, where extrapolation of phase shifts is more reliable than of the experimental data. Values of σ_t are compared with those of Barbiere (taken from direct scattering data); values of drift velocity are somewhat lower than Nielsen's data.

For Argon, at E/p = 1 essentially no electrons have ionizing or exciting energies

[1]K. Norske Vidensk. Selsk. Forh. 1946 Nr. 2.

A-2

RF NOISE FROM LOW-CURRENT, ATMOSPHERIC-PRESSURE ARC DISCHARGES IN AIR

M. I. Skolnik
The Johns Hopkins University, Radiation Laboratory
Baltimore, Maryland

It was found that broadband rf noise can be obtained from low current dc arcs operated in air. Arc currents ranging from 50 to 200 ma and electrode separations from 0.01" to 1/8" were used. The largest amount of noise power was obtained with cold-cathode arcs using aluminum or copper cathodes. Noise power measurements were made over the frequency range from 38 to 4500 Mc. For arc currents of 125 ma, noise factors (ratio of noise power actually obtained to the noise power theoretically available from a resistor at room temperature) exceeding 60 db were found over the entire frequency range with a maximum of 107 db at 100 Mc. The maximum corresponds to an effective noise temperature of approximately 10^{13}°K. From 60 to 400 Mc, the noise level was greater than 100 db. The noise output was reduced after a layer of oxides formed on cathode. With aluminum this occurred after approximately one-half hour and with copper it occurred after a few minutes of operation. When thermionic cathodes, such as tungsten or carbon, were used, little noise was produced. Although the mechanism of the noise production is not completely understood, it seems to be related to the phenomena at the cathode.

CROSS MODULATION*

J. M. Anderson
Electrical Engineering Department
University of Illinois
Urbana, Illinois

Investigation of guided microwave propagation through gaseous discharge plasmas has shown a "cross modulation" effect[1] substantially the same as the "Luxembourg Effect" observed in the ionosphere. The interaction of microwaves (X-band) in the essentially isothermal plasma is explained, to a first approximation, on the basis of a theory proposed by Drs. V. A. Bailey and D. F. Martyn.[2]

A pulse modulated, "disturbing" wave (450 milliwatt peak) was propagated in square wave guide at polarization orthogonal to that of a lower power continuous "wanted" wave through a gaseous discharge tube contained in the waveguide. Measurements were made in the decaying plasmas established in the rare gases at 1 to 20 mm Hg pressure. The envelope of the transmitted wanted wave, to which the pulse modulation has been transferred, yields a value for G (Townsend Energy Loss Factor $\sim 2m/M$). The excess electron gas "temperature" created by the absorbed microwave energy has been calculated to be of the order of a few times kT ($T \sim 300^\circ$ K).

Cross modulation is enhanced when a constant magnetic field at the gyro-resonance intensity is applied to the plasma.

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*Supported by Air Force Cambridge Research Center and Wright Air Development Center.

[1] L. Goldstein, et al, Phys. Rev. (90), 151, April 1953.

[2] V. A. Bailey and D. F. Martyn, Phil. Mag. (18), 369, (1934).

A-4 AFTERGLOW QUENCHING*

L. Goldstein
Electrical Engineering Department
University of Illinois
Urbana, Illinois

Phenomena associated with the gas of free electrons in a decaying gaseous discharge plasma, phenomena which exhibit strong dependence upon the excess temperature of the electron gas, should be affected by the absorption in that plasma of low level electromagnetic energy. One such effect has been observed by us on the afterglow intensity in the rare gases, namely, a quenching of the afterglow,[1] as reported earlier by Dr. Carl Kenty[2] for the case of electron acceleration by a d.c. potential applied to the plasma.

Pulse modulated microwave energy (X-band) was propagated in square waveguide as described in Part I, and afterglow intensity was observed by means of photomultipliers along the discharge tube. From the magnitude of the afterglow quenching and other measurements the following have been found: (a) Law of quenching as a function of the microwave power absorbed in the plasma; (b) Total radiative recombination coefficient[3] of positive ions and electrons, and; (c) Variation of the recombination coefficient as a function of the excess temperature of the electron gas.

Somewhat higher microwave power absorbed at early times in the decay of the plasma excites rather than quenches the afterglow (neon in particular). This is most probably metastable excitation and measurement of which should yield answers to: (a) Initial concentration and decay of metastables; (b) Electron gas temperature decay; (c) Metastable lifetimes, and; (d) Removal of metastables by an impurity gas.

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*Supported by Air Force Cambridge Research Center and Wright Air Development Center.

[1]L. Goldstein, et. al., Phys. Rev. (90), 486, May 53.

[2]C. Kenty, Phys. Rev. (32), 624, 1928.

[3]Strictly a combination of radiative recombination and dielectronic recombination.

MICROWAVE MEASUREMENTS OF THE PROPERTIES OF A DC HYDROGEN DISCHARGE*

Burton J. Udelson and John E. Creedon
National Bureau of Standards
Washington, D. C.

By microwave methods, the variation of electron density was determined along the length of a dc discharge in 3 mm Hg of hydrogen, operating at currents of the order of 0.5 ma. A determination was also made of the variation of electron density and electron collision frequency (νc) as functions of both gas pressure and tube current in the positive column of a dc discharge.

The method employed was the measurement of the change of resonant frequency and the change of voltage standing wave ratio at resonance produced by the introduction of a region of the discharge into the high field gap of a re-entrant S-band cavity. Discharge tubes of approximately 0.2 in. diameter and 0.01 in. wall thickness were employed. From these measurements, relative electron density and νc were calculated.[1] The resultant values of collision frequency ($\nu c = 4.4 \times 10^9 \times$ gas pressure) agreed favorably with the values calculated from the data of collision probability obtained from Brode.[2]

electron density $\sim 5 \times 10^{10}$

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*This work was sponsored by the Bureau of Ships.

[1] D. J. Rose, and S. C. Brown, J. Appl. Phys., 23, 1028 (1952).

[2] R. B. Brode, Rev. Mod. Phys., 5, 257 (1933).

A-6 A MICROWAVE MEASUREMENT OF THE VELOCITY DEPENDENCE OF THE COLLISION CROSS SECTION OF SLOW ELECTRONS IN HELIUM*

Lawrence Gould**
Research Laboratory of Electronics
Massachusetts Institute of Technology
Boston, Massachusetts

A microwave method previously reported[1] for determining the collision probability for momentum transfer of slow electrons has been modified so that a variation in average electron energy from .012 to 3 electron volts may be obtained. Measurements of the ratio of the real to the imaginary part of the complex conductivity, using a null method,[2] are made in the afterglow of a pulsed discharge. The average electron energy is varied by applying a microwave electric field in the afterglow, and, under appropriate assumptions, the average energy is determined theoretically from this field. Measurements from .012 to .052 electron volts are also obtained by varying the gas temperature from 95°K to 400°K. The value of the collision probability in helium is 18.3 ± 2% from 0 to .75 electron volts and increases slowly to a peak value of 19.2 ± 2% at 2.2 electron volts.

*This work has been supported in part by the U. S. Army Signal Corps, the Air Materiel Command, and the Office of Naval Research.

**Now at Microwave Associates, Boston, Mass.

1A. V. Phelps, O. T. Fundingsland, and S. C. Brown, Physical Review 84, 559 (1951).

2L. Gould and S. C. Brown, Journal of Applied Physics, 24, 1053 (1953).

THE EXCITATION OF PLASMA OSCILLATIONS*

Duncan H. Looney** and Sanborn C. Brown
Massachusetts Institute of Technology
Boston, Massachusetts

A beam of high energy electrons, injected into the plasma of a dc discharge from an auxiliary electron gun, excited oscillations in the plasma at the plasma electron oscillation frequency

$$\omega_p{}^2 = \frac{ne^2}{m\epsilon_0} .$$

A movable probe showed the existence of standing-wave patterns of the oscillatory energy in the region of the plasma in and around the electron beam. Nodes of the patterns coincided with the electrodes which limited the region of the plasma traversed by the beam. The standing wave patterns were independent of the frequency of the oscillation. At any particular frequency, the standing-wave pattern was determined by the thickness of the ion sheaths on the bounding electrodes. The mechanism of the energy transfer from the electron beam to the oscillation of the plasma electrons was established as a velocity modulation process by the detailed behavior of the frequency of oscillation and the transitions in the standing-wave patterns as the sheath thickness was varied.

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*This work has been supported in part by the U. S. Army Signal Corps, the Air Material Command, and the Office of Naval Research.
**Now at the Bell Telephone Laboratories, Inc., Murray Hill, N. J.

Thursday, October 22

2:00 P. M.

SESSION B

FORMS OF DISCHARGES

Chairman: D. Alpert

Westinghouse Research Laboratories

ON THE ELECTRON CURRENT SATURATION IN A BALL OF FIRE DIODE

G. Medicus
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

The electron current saturation in a ball of fire discharge, as described in[1], can be understood as follows:

The electrons constituting the anode current diffuse against a retarding field which surrounds the ball of fire, in the non-saturated as well as in the saturated state. In the latter a thin Langmuir sheath along the anode develops which captures all the electrons that reach its edge by diffusion. So, regarding the electrons, the anode in principle behaves like a large plane probe with a good saturation characteristic. The ions in the non-saturated state reach the anode by their mobility in the accelerating field. At electron current saturation, however, no ions can reach the anode because of the retarding field of the Langmuir sheath. In this case, the ions very probably are swept out from the space between anode and cathode onto the glass walls of the tube (and to the cathode housing) by an ion wind.

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[1] G. Medicus, J. Appl. Phys, 24, 233, 1953.

B-2 MAGNETICALLY SELF-FOCUSSING STREAMS

Willard H. Bennett
Nucleonics Division
Naval Research Laboratory
Washington, D. C.

In the original presentation of the theory of magnetically self-focussing streams[1] it was assumed that the charged particles have Maxwellian velocity distributions about the mean velocities of the several kinds of particles in the stream. This restriction is not necessary and is inapplicable in most physically important cases.

Regardless of the kinds of velocity distributions the value can be derived for the minimum stream current which the stream must have to be self-focussing.

From the more general form of the theory it can also be shown that: (a) self-focussing streams pulsate; (b) streams containing both slow and fast particles of like kind tend to eject the slow particles and keep the fast ones; (c) streams of one kind of particle, only, entering an ionized or ionizable region can be self-focussing; (d) axial asymmetries grow in arcs but disappear in low density self-focussing streams.

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[1] Phys. Rev. 45, 890, (1934).

BUILDUP TIMES OF GLOW-DISCHARGES IN AIR* B-3

Alex Mayer and L. H. Fisher
New York University
New York, New York

This constitutes a preliminary report on the buildup time of glow discharges in air. Two chambers of different diameters (three and six inches) were studied. The electrodes were two-inch circular disks of brass in both chambers and the dry air sample was shared from the same manifold. External ultraviolet illumination of the cathodes was provided to avoid statistical lags. At an electrode separation of 2 cm and a pressure of 1 mm of Hg the chambers give essentially identical results, the time lags being of the order of 1000 microseconds near threshold and 2 microseconds at an overvoltage of about 35 percent. For the same electrode separation and 0.1 mm of Hg (below the Paschen minimum) the tubes behave quite differently from each other. The breakdown voltage of the larger tube is considerably lower than that of the smaller tube. The formative time lag of the smaller tube is 0.1 second at an overvoltage of 24 percent and decreases to 9 microseconds at an overvoltage of 550 percent; in contrast, the time lag for the larger tube is 1350 microseconds at 0.5 percent overvoltage and decreases to 4 microseconds at 500 percent overvoltage. Results will be given for longer gaps.

*Supported by the Office of Naval Research and the Research Corporation.

B-4

FORMATIVE TIME LAGS OF UNIFORM FIELD BREAKDOWN IN HYDROGEN*

I. Lessin and L. H. Fisher
New York University
New York, New York

Formative time lag measurements of spark breakdown in uniform fields[1] have been extended to hydrogen. The variation of formative time lags with percent overvoltage was studied for pressures between 200 mm of Hg and atmospheric, and for electrode separations ranging from 0.5 to 2.0 centimeters.

The lags in hydrogen were found to be independent of pressure and to increase with increasing electrode separation. The pressure independence of the lags corresponds to the results in air and nitrogen, but is in marked contrast to the results in argon and oxygen. The time lags in hydrogen are of the same order of magnitude as those found in air and nitrogen but are somewhat longer at the higher overvoltages and somewhat shorter at the lower overvoltages.

These results indicate once again a Townsend buildup before breakdown. Preliminary attempts to interpret the data quantitatively in the manner given by Kachickas and Fisher for air, nitrogen and argon have not succeeded too well. Calculations have been hampered by unavailability of reliable α/p values in the E/p region in which most of the data lie. However, it is concluded that the secondary mechanism is a photoelectric effect at the cathode.

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*Supported by the Office of Naval Research and the Research Corporation.
[1] L. H. Fisher and B. Bederson, Phys. Rev. 81, 109 (1951); G. A. Kachickas and L. H. Fisher, Phys. Rev. 79, 232 (1950); 88, 878 (1952); 91, 775 (1953).

B-5

CURRENT GROWTH IN THE FORMATIVE TIME LAG OF SPARKS*

H. W. Bandel
Department of Physics
University of California
Berkeley, California

Following the work of Fisher and associates[1,2] an oscilloscopic study has been made of the growth of current preceding streamer spark breakdown, during long formative time lags at low over-voltages. Time lags from 10 - 100 microseconds have been observed in dried air at 730 mm Hg. Currents have been observed from microamperes in the early part of the formative time rising to 10^{-2} amp. just before breakdown. With heavy electron triggering a relatively consistent set of curves of current vs. t/τ, where τ is the time lag, is obtained. Investigation with triggering of the order of 10 electrons per microsecond reveals that statistical factors cause great variations in the formative time lag and rate of current build-up.

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*Supported by the Office of Naval Research and National Science Foundation funds, and a Research Corporation of America Fellowship.

[1] L. H. Fisher and B. Bederson, Phys. Rev. 81, 109 (1951).

[2] G. A. Kachickas, Doctor's Thesis, New York University.

B-6

HITHERTO UNRECOGNIZED ASPECTS OF BREAKDOWN STREAMERS*

Leonard B. Loeb
Department of Physics
University of California
Berkeley, California

Oscilloscopic observations of streamers yield v_t the velocity of streamer tip advance, and n the number of positive ions left behind per cm advance which has remarkably constant values over the gap depending on streamer type. The fields X_c down the streamer must be sufficient to maintain conduction against charge loss, to yield a drift velocity v_x and to maintain the integral of X_c along the channel less than the applied potential V. This can only occur for observed values of v_t if $v_x = n/n_x\, v_t$, where n_x is the number of electrons per cm carrying current up the streamer, with a constant $n_x + n$ electrons and ions created per cm advance. The volume density produced by n ions per cm causes radial expansion of the space charge by indrawn avalanches leaving a transient expanding luminosity behind the streamer tip. This expanded ionization slowly decays the current being carried up the narrow channel of n_x electrons/cm which is followed by the return stroke. Further properties of preonset and breakdown streamers, and of stepped lightning leaders are presented.

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*Part of the investigations involved were supported by the Office of Naval Research funds and a grant from the Research Corporation.

FAST TIME ANALYSIS OF BURST PULSE, PREONSET STREAMER AND TRICHEL PULSE POINT-TO-PLANE CORONAS*

M. R. Amin
Department of Physics
University of California
Berkeley, California

Presented by L. B. Loeb

By developing suitable oscillographic techniques using both electrical and photomultiplier cell studies the three common aspects of point-to-plane corona have been studied in detail. Burst pulse corona is initiated by a burst of 2×10^7 ions followed by a sequence of smaller pulses after dead times of 1 - 10 microseconds, with 10^6 ions each. As potentials increase above threshold, the sequences increase in length until interrupted by a gross space charge in the low field regions. This extinguishes the burst and a long clearing time follows. The whole sequence from threshold to steady corona is observed. Preonset streamers are shown to consist of a sharp peak followed by luminosity from radial expansion behind the tip. The tip velocity and ions per cm advance are observed and further details explained. The Trichel pulse corona at atmospheric pressure lasts less than 10^{-8} sec., depends on a photoelectric γ and is quenched by dissociative attachment of electrons to O_2 molecules yielding O^- ions within 0.05 cm of the point. At lower pressures the choking space charge forms further out in the gap; more ions and time are needed to quench. The longer discharge is sustained by a positive ion γ after starting with a photon γ. The variation of repeat rate with potential and current and the nature of conditioning of the point at higher currents are revealed.

*These studies were supported by the Office of Naval Research and later by a grant from the Research Corporation.

B-8

IMPULSE CORONA AND BREAKDOWN OF A POINT-PLANE GAP

T. W. Liao
General Electric Company
Pittsfield, Massachusetts

Impulse corona currents of positive and negative point-plane gaps in air have been measured from corona-start to breakdown with 1.5 x 40 μs voltage waves. The current pulse in the ground circuit represents essentially the electronic current for the positive point, but mostly the ionic current for the negative point. The negative point corona current increases much more uniformly with the applied voltage from corona-start to breakdown than the positive point. The positive point of breakdown is a streamer process progressing from the point to the plane. The negative point corona prior to breakdown produces negative space charge which retards the progression but gradually increases the field at the plane resulting in a "reverse streamer" process. Calculations show that the field at the plane due to the space charge is about 5 to 10 times higher than the applied field for the critical breakdown condition. The time to breakdown increases with the gap spacing, extending as long as 37 μs for a 6" gap.

FURTHER STUDIES OF PHOTON PRODUCTION IN EXTERNALLY SUSTAINED DISCHARGES*

B-9

D. S. Burch, R. C. Irick, and R. Geballe
Department of Physics
University of Washington
Seattle, Washington

A photo cathode has been employed in more extensive studies of the dependence of photon production rates on E/p in several gases. In H_2, earlier measurements made with a Geiger detector[1] have been augmented, yielding results in agreement with published theoretical predictions.[2] In pure O_2 and N_2 the magnitudes of the observed effects are approximately equal and are small compared with H_2. The intensity is approximately constant over the range of E/p from 60 to 90 volts/cm/mm. In air and in a 4% mixture of O_2 and N_2 the effect is an order of magnitude larger than in the pure gases, and rises slowly with E/p in the range from 40 to 120 volts/cm/mm. Possible interpretations of these results will be presented.

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*Partially supported by the Office of Ordnance Research, Department of the Army.

[1] R. Geballe and J. M. Templeman, Conference on Gaseous Electronics, Pittsburgh, 1949.

[2] R. W. Lunt and C. A. Meek, Proc. Roy. Soc., 157A, 146 (1936).

Friday, October 23

9:15 A. M.

SESSION C

ATOMIC COLLISIONS

Chairman: R. N. Varney

Washington University

CHARGE TRANSFER IN THE UPPER ATMOSPHERE C-1

S. N. Ghosh
Geophysics Research Directorate
Air Force Cambridge Research Center
Cambridge, Massachusetts

Some charge transfer reactions appear to have higher reaction rates than that of any other collisional process in the upper atmosphere. For reactions involving Ca^+ emanating from the sun, the energy defects are large and, therefore, for near-adiabatic collisions the maximum probabilities occur long before these ions have lost all their energy by colliding with atmospheric gases. On the other hand, the energy defects are small for reactions involving solar protons which have reached the earth's atmosphere. These reactions have been tested for Wigner's spin conservation rule.

The possible charge transfer reactions between neutral atoms and molecules with the ions present in the ionized layers of the upper atmosphere have also been discussed and tested for Wigner's rule. For the low-energy ions present in these layers, the cross-sections are very low for nearly all reactions.

C-2

CROSS SECTIONS FOR CHARGE TRANSFER COLLISIONS OF LOW ENERGY IONS IN N_2 and O_2

Roy F. Potter
National Bureau of Standards
Washington, D. C.

Measurements have been made of the cross sections for charge transfer collisions between the low energy (9-250 ev) ions, N_2^+, O_2^+, O^+, and N^+, and the molecules N_2 and O_2. Two reactions (N^+, N_2; O^+, N_2) have been reported by other workers and will be compared with present work.

The experimental method utilizes a radiofrequency mass spectrometer as an ion source. The ions are collimated and enter a weak radial electric field of cylindrical symmetry. The secondary ions are separated from the primary beam and the ratio of the two currents is measured as a function of pressure.

Results will be discussed in terms of the adiabatic collision condition and possible internal energy states of the ions.

Fundingsland not sure what ion is present, N_2^+ most likely

MEASUREMENT OF DISSOCIATIVE RECOMBINATION IN NITROGEN

A. C. Faire, O. T. Fundingsland*, and A. L. Aden
Geophysics Research Directorate
Air Force Cambridge Research Center
Cambridge, Massachusetts

Laboratory investigations of two-body recombination of thermal electrons and molecular ions have been conducted in nitrogen using a modified version of a microwave method previously reported.[1] By adding atomic helium to the molecular gas in such proportion as to maintain a total gas pressure high enough to subordinate ambipolar diffusion to the walls of a microwave cavity, measurements of the electron-positive ion recombination coefficient are extended to lower pressures than those previously reported by Biondi and Brown.[2] The electronic energy levels of helium all lie above the first ionization potential of nitrogen. Hence, during the discharge afterglow the helium serves mainly as a passive recoil agent to retard diffusion and to speed up the energy decay of free electrons to thermal equilibrium with the ions.

Recomb between thermal electrons & N_2^+
Bates $\alpha \sim 10^{-7}$ cc/sec

Add He to build up pressure so ambipolar diff will occur.
He not excited by N_2^+

~~If diss recomb~~

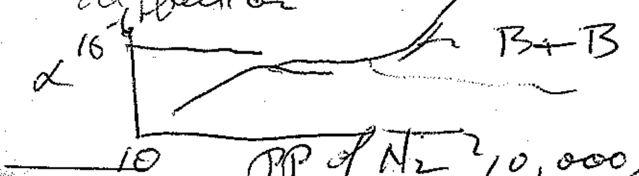
Linde gases to check Biondi & Brown

He 1mm, N_2 200μ

Decay appears to be recomb. for first 1500 μsec, then evidence for diffusion

rather than large modes of diff.

BL finds they may have N_4^+



Believe to be dissoc. recomb; Bates estimate of 10^{-7} seems conservative

*Now with Electronics Defense Laboratories, Mountain View, California.
[1] Manfred A. Biondi, Sanborn C. Brown, Phys. Rev., 75, No. 11, 1700 (1949).
[2] Manfred A. Biondi, Sanborn C. Brown, Phys. Rev. 76, No. 11, 1697 (1949).

The lag due to greater concentration of molecular ions at high p.

because 1/n plots are linear, semi-log are not

C-4 DOPPLER BROADENING OF DISSOCIATIVE RECOMBINATION LINES

Manfred A. Biondi
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

The extremely large electron-ion recombination cross sections observed in microwave afterglow studies have been attributed to the process of dissociative recombination, e.g.,

$$He_2^+ + e \rightarrow He^* + He + \text{kinetic energy.}$$

Previous attempts to verify this hypothesis by examination of the excited states formed in the recombination process gave inconclusive results.[1] The present investigation is based on a characteristic feature of the dissociative recombination reaction: the excited atom formed has kinetic energy in excess of thermal energy. If this fast excited atom undergoes a radiative transition before losing its excess kinetic energy in collisions with gas atoms and before the excitation is transferred to a slow atom, then the line emitted is broader than the thermal Doppler width. At present, a shuttered Fabry-Perot interferometer is being used to determine the profiles of recombination lines emitted from helium afterglows. While the intensity problem is severe, preliminary data indicate that the experiment is feasible.

$\sigma_{rad} = 10^{-18}$ Pressure 3mm

$\sigma_{diss} = 10^{-15}$?

$He_2^+ + e = He^* + He + KE$

look for broadening of the radiation from He* — 5876 Å

He* (3D) → He* 2P

thermal width ~ 0.2 cm^{-1}

For .3ev KE) ~ .3-4 cm^{-1}

Very low intensity — used Interference filter + Fabry Perot 70-90 hrs

Δ(KE) = .3eV

Excited Atom Temp 800°K 1400°K

Cap space Afterglow

[1]M. A. Biondi and T. Holstein, Phys. Rev. 82, 962 (1951); 83, 1078 (1951).

EXCITATION BY PROTON IMPACT

Ernest J. Dieterich and O. Oldenberg
Harvard University
Cambridge, Massachusetts

The light produced when protons having an energy of a few thousand e.v. pass through a low-pressure gas is of interest in connection with the aurora, and also has an intrinsic theoretical interest. In previous attempts to observe this light, either the light has been masked by much stronger light excited by fast neutral atoms, or the nature of the exciting ion has been uncertain. Apparatus has been constructed in which hydrogen ions from a radio-frequency ion source are magnetically separated in high vacuum. Protons, H_2^+, or H_3^+ can be focussed on a small aperture leading into an observation chamber containing hydrogen, or helium with a trace of hydrogen, at a pressure of a few microns. Neutrals produced in the ion source can be eliminated by a baffle in the mass-separator; the few neutrals produced by charge exchange within the observation chamber can be adequately separated by electrostatic deflection. The light is observed through a window by a fast spectrograph. The results presented will mainly illustrate the operation of the apparatus. Approximate relative cross-sections for several observed excitation processes have been obtained, and possible mechanisms will be discussed.

$H^+ + M = H^+ + M'$ — low prob

25 V loss

$H^+ + M = H + M'$
2 fast

$H + M = H^* + M^*$

$H_2^+ + M = H_2^+ + M^*$
$= H^* + H^+ + M^*$

all have higher prob.
$M = H_2$ or He

$H^+ + M = H' + M^+$

$M + R = M + R' + KE$

$H + He = H^* + He' + KE$

	H_2	He
H^+	30	1
H_2^+	60	60

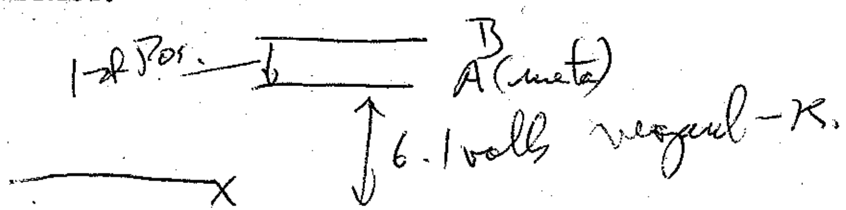
← Target
Rel. prob.

C-6

PROBABILITY OF FORBIDDEN TRANSITION IN THE N_2 MOLECULE

O. Oldenberg and D. G. Bills
Harvard University
Cambridge, Massachusetts

In order to determine the probability in the N_2 molecule of the forbidden transition that is responsible for the Vegard Kaplan bands the absolute intensity of these bands and the population of the metastable level should be measured. If a sufficient population of metastables can be realized it may be possible to measure it by the absorption of the first positive bands. In order to explore the most favorable condition these populations were compared for several sources. The intensity of the Vegard Kaplan bands in emission served as a qualitative criterion. The "ozonizer" discharge operated with one atmosphere of pure nitrogen, first used for the excitation of these bands by Janin, supplied the highest intensity. This result shows that the metastable level is remarkably insensitive to collisions with N_2 molecules, although it is highly sensitive to impurities.



H_2 very poisonous

Ti as getter for residual H_2

[illegible]

TIME RESOLVED SPECTROSCOPY OF NITROGEN AND HYDROGEN

C. F. Hendee and W. B. Brown
Philips Laboratories, Inc.
Irvington-on-Hudson, New York

The long decay time of the First Positive bands of N_2 in a pulsed N_2 discharge[1] has been re-examined by the use of the pulsed photomultiplier technique. The decay times of individual bands were obtained because of the increased sensitivity of this method. The transition probabilities of these bands vary by a factor of ten.[2] However, only a slight variation of decay time was observed, giving substantiation to the process of indirect excitation through the $a'\pi$ level.

The light from a H_2 thryatron has been studied with pulsed photomultipliers. The pulse shapes of the Balmer and band lines were similar for normal square-wave currents. When the current during the pulse oscillated at about 10 mc there was a modulation of the light during the first oscillation in each pulse. A time resolution of .03 μ sec. is inferred from the results. Under these conditions, the pulse shapes of the Balmer and singlet band lines differed from that of the triplet lines and continuum.

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[1] C. F. Hendee, Conference on Gaseous Electronics (1951).
[2] Jarmain and Nicholls, University of Western Ontario, Scientific Report No. 4, Contract No. AF 19(122)-470.

C-8 NEW METHOD FOR EXCITING METALLIC SPECTRA BY ACTIVE NITROGEN: THE EXCITATION OF XE

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

By passing condensed sparks across metallic gaps in 30 cm A plus 1 cm N_2, "flames"[1] have been produced of W, Ta, Mo, Pd, V, Cb, Cr, Co, Fe, Ni, Pt, Au, Ir, Rh, Zr, Ti, Be, Al, Cu, Ag, U, Th, and Re. Strongly colored flames are: V, red; Cb, yellow; Pd, green; W, blue; Cr, blue-violet; and Fe, violet. Photographs show that the spectra are metal arc lines of unusual intensity distribution. The metal atoms are sputtered off by the discharge and excited by some form of active nitrogen (A.N.). The spectra are identical using He, Ne, or A but somewhat modified and weaker with Xe. Kr gives a slight modification. Some yellow afterglow (Y.A.) is produced along with the flames with He, Ne, A and Kr but not with Xe. No kind of discharge, 60 ~, 1 MC or DC, produces Y.A. with Xe though any weak discharge does with the other gases. Xenon (3 cm) added to 30 cm A + 1 cm N_2 with a weak discharge greatly weakens Y.A. but causes after-fluorescence of the Nonex wall, absent with the other rare gases, and indicating Xe resonance radiation excited by A.N.

Results indicate at least two carriers of energy, one, possible N_2 $(a^1\pi_g)$ following Nicholls[2] excites N_2 $(B^3\pi_g)$ i.e., Y.A. and also Xe (and Kr slightly); the other, possibly N metastables (^2P or ^2D) and/or one or more of the other singlet[2] metastables or $A^3\Sigma_u^+$, mainly excites the flames.

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[1] C. Kenty, Phys. Rev. 89, 339 (1953).
[2] R. W. Nicholls, J. Chem. Phys. 20, 1040 (1952), and private communication.

Friday, October 23

2:00 P. M.

SESSION D

ELECTRON EJECTION AND METASTABLE ATOMS

Chairman: L. H. Fisher

New York University

PHOTODETACHMENT OF THE HYDROGEN NEGATIVE ION*

Lewis M. Branscomb
National Bureau of Standards
Washington, D. C.

and

Wade L. Fite
University of Pennsylvania
Philadelphia, Pennsylvania

The photodetachment of one electron from the hydrogen atomic negative ion, H^-, has been demonstrated experimentally and the cross section measured in a crossed beam experiment using an incandescent light source. This process was proposed in 1939 by Wildt[1] to explain the gray-body character of solar radiation in the near infrared, and the proposal received strong support from solar observations. A beam of 200-volt H^- ions is generated in a glow discharge source[2] and, after mass separation in a crossed field velocity selector, is passed through a very intense light beam in a region of high vacuum. The light beam is chopped at 450 cps, producing about 10^{-13} amps of alternating electron current, which is extracted from the ion beam by weak electric and magnetic fields. Using the measured intensity and spectral distribution of the light, the measured velocity of the ions, and the theoretical cross section, the theoretically expected ratio of detached electron current to ion current is calculated and compared with experiment. Preliminary measurements confirm the theoretical result of S. Chandrasekhar[3] and his colleagues, who reported a cross section whose maximum value is 4.52×10^{-17} cm^2 at 8275 A. The use of yellow and red filters also confirms the approximate spectral distribution of the theoretical cross section. The photodetachment of negative ions from an oxygen discharge has also been observed and is being investigated.

Mean 4.9x10^{-7} for prob.
Calc 5.2
Anode side of fractions
10^{-9} – 10^{-6} amp of H^- can be made
Bigger yield when H_2O vapor added

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*This experiment was initiated at Harvard University, and successfully completed at the National Bureau of Standards.

[1] R. Wildt, Astrophys. J. 89, 295 (1939) and 93, 47 (1941).

[2] Wade L. Fite, Phys. Rev. 89, 411 (1953).

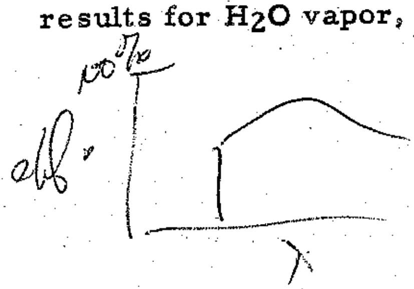
[3] e.g. S. Chandrasekhar, Astrophys. J. 102, 395 (1945).

Bennett thinks pure H_2O would give better yield of H^-

D-2 PHOTOIONIZATION IN ATMOSPHERIC GASES*

N. Wainfan, W. C. Walker, and G. L. Weissler
University of Southern California
Los Angeles, California

Using methods described elsewhere by the authors,[1] the ionization limits, absorption coefficients and the number of ion pairs appearing per 100 absorbed photons were determined for N_2 and O_2 in the wavelength range from 473A to 1100A. The first ionization limit of O_2 was found to be $12.1 \pm .1$ volts and that of N_2 to be $15.6 \pm .1$ volts. These results are in good agreement with those obtained by electron impact methods.[2] The absorption coefficients obtained were substantially the same as those reported previously.[3] In O_2, for wavelengths between 1019A and 700A, a region of strong absorption bands, the fraction of absorbed photons that yielded ion pairs varied rapidly. At wavelenghts shorter than 700A the absorption mechanism was found to be entirely due to photoionization. For N_2 the fraction of absorbed photons producing photoionization rose rapidly from the ionization limit and for wavelenghts shorter than 750A the entire absorption process appeared to be photoionization. Additional results for H_2O vapor, CO_2, and CH_4 will also be presented.



*The aid of the Office of Naval Research is gratefully acknowledged.
[1]N. Wainfan, W. C. Walker and G. L. Weissler. To be published in Journal of Applied Physics.
[2]H. D. Hagstrum. Rev. Mod. Phys. 23, 185 (1951).
[3]G. L. Weissler and Po Lee. J. Opt. Soc. Amer. 42, 200 (1952).
G. L. Weissler, Po Lee and E. I. Mohr. J. Opt. Soc. Amer. 42, 82 (1952).

PHOTOELECTRIC YIELDS OF SOME METALS IN THE VACUUM ULTRAVIOLET* D-3

W. C. Walker, N. Wainfan, and G. L. Weissler
University of Southern California
Los Angeles, California

The absolute quantum yields of the noble metals Ag and Au and the transition metals Mo, Ni, Pd, Pt, Ta and W in the wavelength region from 991A to 473A were measured for both untreated and heat treated surfaces.[1]

The photoyields of all the metals investigated were found to be smaller for heat treated samples than those for untreated ones, but in no instance was the decrease found to be greater than a factor of three. All of the transition metals with the exception of Pd and Pt gave evidence of a spectral maximum in the wavelength region covered. The yields of a heated sample of Ni were the largest of any metal studied with values ranging from 0.09 electrons per photon at 991A to 0.15 at the maximum which occurred at 640A. Platinum and Palladium, which gave similar results, were found to have the smallest photoyields exhibiting a constant value of about 0.035 electrons per photon over the entire wavelength region. More extensive work is now in progress on these and other metals.

Falls above ~ 950Å

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*The aid of the Office of Ordnance Research, Department of the Army, is gratefully acknowledged.

[1]N. Wainfan, W. C. Walker and G. L. Weissler. Journal of Applied Physics (to be published) Oct. 1953.

D-4 IONIZATION PROBABILITY CURVES NEAR THRESHOLD FOR Hg, Cd, and Zn

W. M. Hickam
Westinghouse Research Laboratories
East Pittsburgh, Pennsylvania

Using the retarding potential difference method[1] with the 90° sectored type mass spectrometer, the ionization probability curves for Hg, Cd, and Zn have been obtained over the energy range from threshold to some four electron volts above. The Hg curve is in substantial agreement with that of Nottingham[2] and shows a hump at approximately 0.4 ev above threshold. A linear rise is observed in the Cd curve for some 3 ev at which point the slope increases followed by a hump at approximately 3.5 ev. The zinc curve rises linearly for approximately 1.3 ev and displays a plateau in the neighborhood of 2 ev above threshold.

An attempt is made to correlate the observed structure with autoionization of atomic states identified by Beutler,[3] and other unidentified states. These states arise from excitation of a single inner electron (e.g., $3d^{10}\,4s^2 \rightarrow 3d^9\,4s^2(^2D_{5/2})\,4p$ in the case of Zn). Autoionization from the identified levels seems insufficient to explain the obtained results.

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[1] R. E. Fox, W. M. Hickam, and T. Kjeldaas, Jr., Phys. Rev. 89, 555 (1953).
[2] W. B. Nottingham, Phys. Rev. 55, 203 (1939).
[3] H. Beutler, Zeits. Phys. 86, 710 (1933).

ELECTRON EJECTION BY SLOW POSITIVE IONS INCIDENT ON FLASHED AND GAS-COVERED METALLIC SURFACES

James H. Parker, Jr.
University of California
Berkeley, California

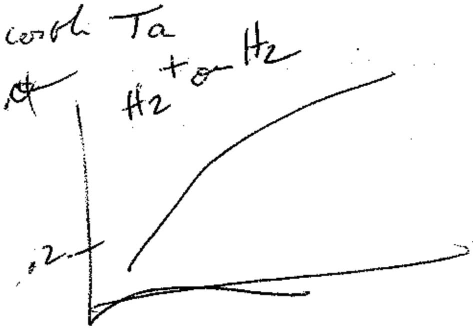
A direct measurement of the ejected electron yield (γ_i) for A^+ incident on flashed and H_2, N_2 and O_2 treated Ta and Pt and for the singly charged Hydrogen, Nitrogen, and Oxygen ions incident on Ta and Pt after treatment with the respective parent gas has been made for the kinetic energy range of 5 to 150 e.v.

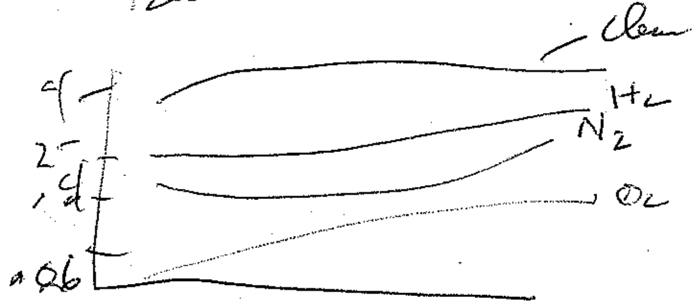
The gas treatment for Pt consisted of an exposure to the molecular gas at a pressure of a few mm. of Hg while the treatment for Ta consisted of an exposure plus a glow discharge in which the Ta surface served as the cathode.

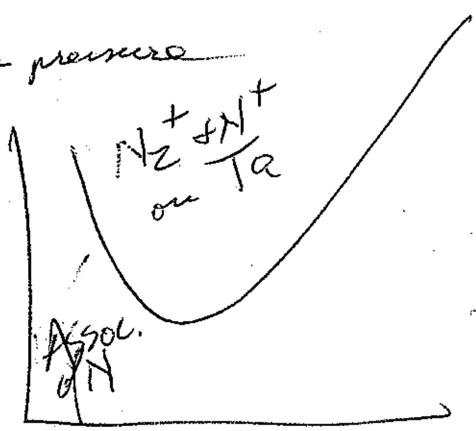
In general, gas treatment of Ta and Pt was found to effect large decreases in γ_i for A^+ ions, with the effect increasing with decreasing ion energy. For both Ta and Pt the O_2 treatment was found to be the most effective in reducing γ_i while the H_2 treatment was found to be the least effective. γ_i for Nitrogen ions on N_2 treated Ta and Pt showed a unique behavior at low ion energy in that it was found to increase with decreasing ion energy. This behavior was not observed for the other ions in this study.

A^+ on Flashed Pt
H_2 covered Pt
O_2 " "
N_2 " "
$N^+ + N_2^+$ on " " "
$O^+ + O_2^+$ " O_2 " "
$H^+ + H_2^+$ " H_2 "
Beam ~10^{-8} amps at 10^{-5} ... pressure

Also with Ta







D-6 REFLECTION OF IONS AS IONS OR AS METASTABLE ATOMS AT A METAL SURFACE

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

In a small fraction of the encounters of a noble gas ion with a metal surface the ion is not completely neutralized but is reflected either as an ion or as a metastable atom. Measurements have been made which yield values of the reflection coefficients for normal incidence of ions to ions, R_{ii}, and of ions to metastable atoms, R_{im}. In the experiment an ion beam of variable kinetic energy is allowed to strike a target at the center of a spherical collector. A retarding field is applied between target and collector sufficient to suppress completely the secondary electron current ejected from the target. One is left with the secondary reflected ions and the tertiary electrons ejected at the collector by the reflected ions and metastable atoms. The secondary ionic component alone is determined by measurement with a magnetic field of ca. 60 gauss applied in the target-collector region. γ_i at the collector surface has been measured for slow ions by reflecting the primary ion beam onto the collector. These measurements are sufficient to determine R_{ii} and R_{im}. R_{ii} for He^+ on W is found to remain approximately constant at 0.015, independent of ion energy, whereas R_{im} rises steadily from zero to near 0.10 in the ion energy range 50 to 1000 ev. R_{ii} for Ne^+ on W is found to rise at ion energies below 100 ev. For an ion-target combination for which resonance neutralization is impossible the present results appear to require the possibility of ions becoming metastable atoms very close to the metal surface. It can then be shown that the constancy of R_{ii} and the rise in R_{im} are consistent. If resonance neutralization is possible detailed analysis of the results becomes very difficult.

AN IMPROVED OPTICAL ABSORPTION TECHNIQUE FOR THE STUDY OF METASTABLE ATOMS

D-7

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

An improved optical absorption technique has been developed for the study of the decay of the density of metastable atoms following a pulsed discharge. Light from a capillary source is passed through the discharge tube and the intensity of one of the lines which is absorbed by the metastables is measured using an interference filter and a gated photomultiplier. The photomultiplier gate occurs at twice the discharge pulse frequency so that alternate pulses of the photomultiplier output are reduced by absorption. Therefore the component of the photomultiplier output at the discharge frequency is proportional to the absorption and can be measured using a narrow-band amplifier and phase sensitive detector. The sensitivity of this system is limited by the fluctuations in the number of photoelectrons leaving the photomultiplier cathode. At present useful measurements can be made down to a few hundredths of a percent absorption with a time resolution of one part in one hundred. This represents an increase in the sensitivity by a factor of at least one hundred over that available with previous techniques. Typical metastable decay curves will be presented.

D-8

TIME CONSTANTS OF SELF-SUSTAINED TOWNSEND DISCHARGES

W. S. Huxford
Northwestern University
Evanston, Illinois

Comparison of measured ionization coefficients of argon in parallel-plate phototubes with parameters of self-sustained discharges in the same tubes confirms the hypothesis of volume ionization of metastables. Calculations based on space charge considerations do not account for the negative potential-current characteristic. Further confirmation of this hypothesis is obtained from rates of growth and decay of small perturbing currents impressed upon the steady discharge. Frequency modulation and also square wave light and electrical pulses are used in argon and helium at pressures from .25 to 3.0 mm Hg. Time constants in argon have values from .001 to .01 second (smaller for He) for the lower currents (1 to 20 μ amps.) for which τ varies inversely with current density. These magnitudes are reasonable for rates of mutual collisions corresponding to metastable atom densities estimated, whereas life-times dependent upon diffusion are much lower ($\sim 10^{-4}$ sec.). Direct evidence of volume metastable ionization is shown by the rates of current decrease occurring when the discharge is irradiated with the 2.058 μ He line from an intense arc. Space charge effects are observed at currents above a critical value, and τ decreases rapidly by a factor of 10 or more.

Saturday, October 24

9:15 A. M.

SESSION E

SPUTTERING AND COUNTERS

Chairman: J. D. Cobine

General Electric Research Laboratory

STATISTICAL MECHANICS OF CATHODE SPUTTERING E-1

Don E. Harrison, Jr.*
Yale University
New Haven, Connecticut

The author has developed a statistical mechanical treatment of the sputtering process. Most of the problems inherent in such an approach have been overcome or bypassed; so that the remaining complications are chiefly mathematical.

The process may be described in terms of four interacting distribution functions which are assumed to satisfy the Boltzmann transport equation. Using mathematical methods developed in the study of neutron diffusion, it is possible to obtain exact solutions of the two fundamental integro-differential equations when the masses of the ions and metallic atoms are equal. The theory is developed assuming that the lattice atoms are at rest and that the particles interact like elastic hard spheres.

Comparison of the theory with the available experimental data indicates that the curves are of the same general form. The sputtering threshold, used as a fitting parameter, has a reasonable value.

Work is in progress to obtain solutions where the masses are unequal. The general form of these results can be predicted by comparison with similar problems studied in neutron diffusion theory.

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*Now at the University of Louisville.

E-2

SPUTTERING OF ALKALI METALS BY INERT GAS IONS OF LOW ENERGY

R. C. Bradley
Department of Physics
University of California
Berkeley, California

Direct measurements of sputtering have been made using sodium and potassium targets bombarded by the ions He^+, Ne^+, A^+, and Xe^+, the sputtered atoms being counted by a surface ionization detector. The energy range covered was 0 - 1800 e.v. Secondary electron coefficients were measured simultaneously.

Over most of the energy range covered the measured sputtering coefficient (number of atoms reaching the detector per ion incident on the target) was linear in $\ln E$ for He^+ and Ne^+ and in $\sqrt{E}$ for A^+ and Xe^+, where E is the ion energy. At energies less than about 150 volts the coefficient appeared to depend only on the amount of kinetic energy which could on the average be transferred to a single surface atom in a direct two body collision. Thus, at low energies Ne^+ produced the most sputtering from a sodium target and A^+ the most from a potassium target. At high energies the sputtering rate was in the same order as (but not proportional to) the mass of the ion. Absolute sputtering coefficients (total number of sputtered atoms per incident ion) could not be measured directly but were estimated from the geometry. The effect of surface contamination was also studied.

SPUTTERING BY ION BOMBARDMENT--A MOMENTUM TRANSFER PROBLEM

E-3

Gottfried K. Wehner
Components Laboratory
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

An important, mostly overlooked parameter in sputtering experiments is the angle of incidence of the striking ions.[1] With simple, conclusive experiments it can be shown, that sputtering under oblique angles starts at lower ion velocities and is much more efficient in knocking out atoms from a surface than with perpendicular impacts.

A characteristic and well defined threshold voltage which is a function of the angle of incidence exists for every gas-metal combination. Threshold voltages V_o for perpendicular impacts of many metals were measured in a high plasma density low pressure mercury discharge. It turns out, that these threshold voltages are linked to the momentum transferred on impact to the lattice, the velocity of sound in the metal and the heat of sublimation.

These investigations are not only of much practical interest for gas tubes but give an explanation why materials like C (V_o = 1200 volts) in Hg give such extremely low, or Ag (V_o = 30 volts) such extremely high sputtering rates.

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[1]H. Fetz Z. f. Phys. 119,590 (1942).

E-4

(Invited Paper)

Laura Colli and Ugo Facchini
C.I.S.E.
Milan, Italy

Persson

X-RAY ABSORPTION PROCESSES IN PROPORTIONAL COUNTER GASES

C. S. Duffendack and C. F. Hendee
Philips Laboratories, Inc.
Irvington-on-Hudson, New York

When a medium X-ray photon is absorbed by a gas atom, a photoelectron is emitted. Subsequently, the absorbing atom emits a characteristic fluorescent X-ray photon or an Auger electron. If the fluorescent photon escapes from the counter gas, only a fraction of the incident energy is utilized in creating ion-pairs. This process gives rise to the "escape" peak in the pulse height distribution of a proportional counter. The "main" peak is formed by complete utilization of the incident energy. The energy gap between "main" and "escape" peak is equal to the emission energy of the absorbing gas atom (characteristic fluorescence). The positions of the K and L "escape" peaks in the pulse height distribution for argon, krypton, and xenon are discussed. The ratio of the number of counts in the "escape" peak to the total number is a measure of the fluorescent yield of the gas atom. The "escape" peak should exhibit a fine structure, due to the fluorescence of the absorbing gas atom in the K or L series lines. Indications are that the "escape" peak, though long neglected, is of greater interest than the "main" peak in many applications of proportional counters.

E-6

PROPORTIONAL COUNTER "ESCAPE" PEAK RESOLUTION AND FINE STRUCTURE

S. Fine
Philips Laboratories, Inc.
Irvington-on-Hudson, New York

An extension of some unpublished work of O. R. Frisch indicates that the half-widths of the peaks in pulse height distributions of proportional counters decrease with decreasing pulse height. This is evident from the results obtained with some counters developed for medium X-ray detection. Pulse height distributions indicate that the energy gaps between "main" and "escape" peaks are an intrinsic characteristic of the absorbing atom and that more precise information concerning the fluorescence yield may be obtained with higher atomic number gases where the escape peaks are more resolved. With the optimum combination of absorbing gas and incident energy, values of the fluorescence yields of the $K\alpha$, $K\beta$ emission have been obtained using the escape peak. Work with radiations simulating the characteristic fluorescence of two contiguous rare earths shows that separation and identification may be accomplished only in the "escape" peak region.

Saturday, October 24

1:30 P. M.

SESSION F

ARCS

Chairman: W. H. Bennett

Naval Research Laboratory

HIGH PRESSURE ARC ANODE PHENOMENA

J. D. Cobine and E. E. Burger
General Electric Research Laboratory
Schenectady, New York

A study has been made of the more important processes occurring at the anode of the high-pressure, high-current arc. In these arcs, the anode current density may be from 10,000 to 50,000 amp/cm^2. The input power density at the anode spot may be in the range 60,000 to 500,000 watts/cm^2. It is shown that under these conditions evaporation is the most important process in the energy balance at the anode spot. Evaporation probably maintains a substantially constant temperature at the spot surface. The heat flow into the metal from the active area appears to be of the order of 10 per cent of the anode energy input in one-half cycle (60 cps). The amount of energy radiated from the spot is quite small. Experimental data on electrode erosion permit a rather good estimate to be made of the anode spot temperature. For example, copper with an erosion rate of 86.5 grams/cm^2/sec has a probable spot temperature of 2650°K. Other probable spot temperatures are approximately 2300°K for Ag, 3300°K for Al, 3650°K for Ni, 3600°K for Fe, and 4750°K for Ti.

F-2 RETROGRADE MOTION OF CATHODE SPOT IN TRANSVERSE MAGNETIC FIELDS

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

Experiments on motion of cathode spot in mercury arcs in transverse magnetic fields have given results consistent with previous observations.[1,2] With constant arc current and no foreign gas the retrograde velocity increases smoothly up to about 11,000 oersteds after which it increases very rapidly to nearly double its previous velocity as observed by Smith.[1] The field strength needed for the rapid increase in velocity is lowered by increasing the arc current.

The spectrum of the cathode spot showed strong atomic lines and a continuum which was not like that from Hg_2 molecules.

At low magnetic field strengths (H L 1000 oersteds) the spectrum of the negative glow showed only Hg I lines but at high magnetic field strengths (about 11000 oersted) both Hg I and Hg II lines appeared. Smith[1] observed also Hg III lines. The potential drop across the arc changed from about 12 to about 15 volts with change in field strength from 1000 to 11000 oersteds. The addition of helium eliminated all of the Hg II lines and made the cathode spot more diffuse.

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[1] C. G. Smith. Phys. Rev. 83, 194 (1951); 84, 1075 (1951).
[2] C. J. Gallagher, The Retrograde Motion of the Arc Cathode Spot. Special publication by General Electric Co.

ORDERLY SUBDIVISION OF A MERCURY ARC CATHODE SPOT

Charles G. Smith
Raytheon Manufacturing Company
Newton, Massachusetts

Arc currents above approximately two amperes split the cathode spot. Division is here studied in rapidly moving "anchored arcs". A polished molybdenum cylinder, 1.2 cm. diameter, axis vertical, projects 1/2 cm. above a mercury pool of an arc tube. Above and larger than the molybdenum stump is a disc-shaped anode having a radial slot above which is an ion collector. A vertical magnetic field of 5000 oersteds races the arc spot 120 meters per second in the retrograde direction around the molybdenum cylinder to which the arc is anchored. Passage of arc under the anode slot shows a signal on the ion collector. The oscillograph pattern shows a steep front followed by a tapering off portion. Below two amperes there is a smooth pattern. Increased current causes a sharp nick in the steep wave front. More current deepens and widens the nick. "Cathode spot" becomes a close double. More current makes more spots. Splitting is a reproducible function of current. It shows that a part of the spot influences a remote part.

F-4

MOTION OF THE ARC CATHODE SPOT IN A MAGNETIC FIELD

C. G. Miller and N. L. Sanders*
University of California
Santa Barbara, California

The motion of the arc spot on liquid metal cathodes subjected to a transverse magnetic field has been investigated using various ambient gases. A number of workers[1,2,3,4] have observed that the arc spot moves in a retrograde direction (opposite to that of the electromagnetic force) in a restricted range of ambient temperatures and pressures when in a magnetic field. The present work indicates that there may be two modes of operation of the arc, and that the arc when travelling in the retrograde direction depends on gas or vapor ionization near the cathode. The two modes of operation may occur simultaneously; the arc spots of each mode when moving may pass through each other without losing their identity. The p.d. across the arc differs for the two modes; when the modes coexist, the larger p.d. governs.

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*Now at University of Southern California, Los Angeles, California.
[1]N. Minorski, J. de Phys. et Rad. 9, 127 (28).
[2]C. G. Smith, Phys. Rev. 62, 48 (42); 69, 96 (46); 73, 543 (48).
[3]C. J. Gallagher, J. Appl. Phys. 21, 768 (50).
[4]G. J. Himler and G. I. Cohn, Elec. Engr. 67, 1148 (48).

AN EQUATION FOR THE V-I CURVE OF THE HIGH CURRENT ARGON ARC

T. B. Jones
The Johns Hopkins University
Baltimore, Maryland

and

J. W. Dzimianski
Allis-Chalmers Mfg. Co.
Milwaukee, Wisconsin

A study was made of the fundamental properties of the high current dc arc in argon at atmospheric pressure as the electrode materials were varied. Rod electrodes of tungsten, tantalum, molybdenum, titanium, iron and copper were used over current ranges of 25 to 100 amperes for precise measurements and 25 to 200 amperes for free burning measurements.

These arc studies made it possible to develop a new empirical equation which depicts the electrical characteristics of the arcs investigated over a wide range of currents including the positive slope region of the V-I curves. With this equation as a basis the distribution of power and voltage in the arc was calculated. The melting rate data seemed to support the conclusion that in arcs of this type over the current range studied the anode drop is zero or extremely small whereas the cathode drop may be affected materially by deposition of anode metal on the cathode surface. For each of the metals tested the appropriate constants were calculated for insertion in the empirical equation. These constants showed that variation of the electrode materials had a significant effect on the electrical characteristics of the arc but this effect was not nearly so great as that caused by different inert gases.

LIST OF CONTRIBUTORS

Def. Res. Lab,
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