TABLE I. Fractional transition probabilities, $f(v', v'')$.

v' \ v''	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	0.385	0.338	0.158	0.077	0.031	0.007											
1	0.479	—	0.125	0.139	0.106	0.095	0.048	0.004									
2	0.228	0.265	0.091	0.037	0.075	0.074	0.108	0.098	0.021								
3	0.037	0.416	0.046	0.160	—	0.033	0.043	0.083	0.136	0.039	0.004						
4	—	0.149	0.383	—	0.151	0.015	0.007	0.012	0.057	0.141	0.071	0.008					
5	—	0.006	0.268	0.285	0.023	0.098	0.021	0.001	0.002	0.027	0.104	0.131	0.029				
6	—	—	0.023	0.376	0.190	0.066	0.031	0.023	0.001	0.001	0.005	0.093	0.139	0.041	0.006		
7	—	0.001	0.003	0.047	0.411	0.084	0.076	0.012	0.068	—	0.013	0.004	0.060	0.152	0.053	0.009	
8	—	—	—	0.012	0.111	0.435	0.022	0.092	0.007	0.024	0.002	0.012	0.018	0.031	0.123	0.076	0.017

primary parabola lying at higher v'' values will include unreported bands in the near infrared which are at the moment being investigated experimentally. The fuller significance of such three-dimensional $f(v', v'')$ surfaces is also being sought.

Although the question as to whether bands of the first positive system may be identified in the spectrum of the upper atmosphere is by no means settled,[4] the results presented above may be useful in discussing this topic.

The results are also of importance in considerations of mechanisms of population of $A^3\Sigma$ as a prelude to the emission of the Vegard-Kaplan system. The sensitivity of the first positive systems to the presence of contaminants, particularly oxygen, has been discussed elsewhere.[5]

A careful experimental determination of the relative intensity of bands of the first positive system is at present in progress, and it was in connection with this work and an associated problem relating to the excitation of the Vegard-Kaplan system that these calculations were originally initiated.

We should like to thank the National Research Council and the Defence Research Board of Canada for interest in and support of this work.

[1] R. W. Nicholls, Phys. Rev. **77**, 421 (1950). R. G. Turner and R. W. Nicholls, Phys. Rev. **82**, 290 (1951).
[2] R. W. B. Pearse and A. G. Gaydon, Proc. Roy. Soc. (London) **A173**, 37 (1939). M. E. Pillow, Proc. Phys. Soc. (London) **62**, 237 (1949); **63A**, 940 (1950).
[3] R. W. B. Pearse and A. G. Gaydon, *The Identification of Molecular Spectra*, 2nd Ed. (John Wiley & Sons, Inc., New York, 1950), p. 168.
[4] G. P. Kuiper, *The Atmospheres of the Earth and Planets* (University of Chicago Press, Chicago, 1949), p. 198 (paper by P. Swings). D. R. Bates, Proc. Roy. Soc. (London) **A196**, 217 (1949).
[5] R. W. Nicholls, J. Chem. Phys. **19**, 250 (1951).

PHYSICAL REVIEW VOLUME 82, NUMBER 4 MAY 15, 1951

Proceedings of the American Physical Society

MEETING OF THE CONFERENCE ON GASEOUS ELECTRONICS, SPONSORED BY THE DIVISION OF ELECTRON PHYSICS OF THE AMERICAN PHYSICAL SOCIETY, AT NEW YORK ON OCTOBER 19–21, 1950

THE third annual Conference on Gaseous Electronics, sponsored on this occasion by our Division of Electron Physics, was held on October 19, 20, and 21, 1950, in the Barbizon-Plaza Hotel, New York City. Following are the abstracts of some of the papers presented at this meeting. The Secretary of the American Physical Society expresses great regret that these abstracts appear so belatedly. Apparently the original copies of this material, duly forwarded in December, 1950, to the office of the American Physical Society, were mislaid and have never since been traced. Mr. J. A. Hornbeck has thus been obliged to prepare a second copy, which is printed hereunder.

A1. Electron Removal Processes in Hydrogen, Argon, and Krypton.* R. B. HOLT, JOHN M. RICHARDSON, AND A. REDFIELD, *Harvard University*.—Previously described techniques[1] for the measurement of electron densities in and light emission from pulsed discharge afterglows have been applied to hydrogen, argon, and krypton. Electron densities were measured by observing the shift in resonant frequency of a microwave cavity containing the discharge. The spectrum of the light emitted was observed *vs* time by means of pulsed photomultipliers and by a spectrograph and high speed mechanical shutter. In argon, recombination-type electron removal was observed in the moderate pressure range (1–30 mm) with a coefficient which depends on pressure and also on the degree of excitation of the ions produced initially. The total light emitted indicated that the electron removal process was partially radiative and partially nonradiative. In hydrogen at moderate pressures, nonradiative (in the optical region, at least) recombination accounts for the removal of most of the electrons. The recombination coefficient was a function of pressure. Recombination-type electron removal was also observed in krypton, with the amount of light emitted strongly dependent on minute amounts of impurities (particularly xenon).

* This work was assisted by the ONR.
[1] Holt, Richardson, Howland, and McClure, Phys. Rev. **77**, 239 (1950).

A3. Ionization by Metastable Atoms in Pure Helium and in Neon. MANFRED A. BIONDI, *Westinghouse Research Laboratories*.—Microwave techniques have been used to study the electron density variation in He and Ne afterglows. An initial *increase* in density is observed lasting for approximately one millisecond after the maintaining field is removed from the discharge. This delayed ionization evidently results from the collision of pairs of metastable atoms. Analysis of the initial rise permits an evaluation of the diffusion and volume loss of the metastable atoms. The results are given in the following table:

Gas	$D_m p$ (cm²/sec)(mm Hg)	Volume destruction cross section, σ_v cm²×10²¹
Airco reagent He	530±30	5.8±0.5
Purified He	565±30	2.9±0.6
Airco reagent Ne	200±20	30±3

The volume loss of Ne metastables can be explained by collisions with normal Ne atoms which raise the metastable to a radiating stage. This explanation fails for He where the nearest radiating level is 0.7 volt above the metastable level. To assure that impurities were not the cause of this volume loss, reagent He was liquefied and re-evaporated into special flasks. From the table it is seen that the volume loss is reduced but not eliminated.

A4. Studies of the Lifetimes of Metastable Atoms in the Afterglow of Rare Gas Discharges.* ARTHUR V. PHELPS, *Bell Telephone Laboratories.*—The lifetimes of the lower metastable states of Ne, He, and A in the afterglow of a pulsed discharge have been measured as a function of pressure, p, at 300°K and 77°K. The lifetimes were determined by passing light of an appropriate wavelength through the gas and measuring the time constant of decay of the absorption at low percentage absorption. In neon at 300°K and high p the probabilities of decay of the lower metastable state and the nearby radiating state are equal and directly proportional to p. Thus, the metastable destruction process appears to be one of excitation to the radiating state by collision with normal atoms. At 77°K the volume destruction is much lower and is proportional to p^2. In helium at high p the destruction is proportional to p^2 and about 60 times as probable at 300°K as at 77°K. In argon the volume loss approaches a p^2 law at 300°K and 77°K and is roughly independent of temperature. The variation in the metastable diffusion coefficients is between $T^{\frac{1}{2}}$ and T at constant gas density.

* The method and apparatus were developed by Dr. J. P. Molnar of the Bell Telephone Laboratories and used by the author at the Laboratories during the summer of 1950 while on leave from the Research Laboratory of Electronics, Massachusetts Institute of Technology.

B2. Mass Spectrometric Studies of Molecular Ions in the Rare Gases. J. P. MOLNAR AND JOHN A. HORNBECK, *Bell Telephone Laboratories.*—Molecular ions of the rare gases (He_2^+, Ne_2^+, A_2^+, Kr_2^+, and Xe_2^+) produced by electron impact at gas pressures from 10^{-4} to 10^{-2} mm Hg were detected with a small mass spectrometer. The ion intensity increased linearly with electron current and with the square of the gas pressure. The form of the ionization *vs* electron energy curves resembles closely curves of excitation probability. The onset (appearance) voltages for the molecular ions were less than those for the atomic ions by 1.4 (+0.7, −0.2) volts for He, 0.7 (+0.7, −0.3) volt for Ne, 0.7 (+0.7, −0.2) volt for A, 0.7 (+0.7, −0.3) volt for Kr. These results can be interpreted, we believe, only by assuming that the method of formation of the molecular ions observed in this experiment is, using helium as an example, first by electron impact $He+e+K.E.\rightarrow He^*+e$ followed by the collision process $He^*+He\rightarrow He_2^++e$, where He^* stands for a helium atom raised to a high-lying excited state. Arnot and M'Ewen[1] proposed a similar interpretation of their mass spectrometric studies of helium, except that they reported onset voltages low enough to permit metastable atoms to form molecular ions.

[1] F. L. Arnot and M. B. M'Ewen, Proc. Roy. Soc. (London) **A171**, 106 (1939).

B3. Mobilities of Rare Gas Atomic and Molecular Ions. JOHN A. HORNBECK, *Bell Telephone Laboratories.* [See Phys. Rev. **80**, 297 (1950).]

B4. Mobilities of Positive Ions in Gases. T. HOLSTEIN, *Westinghouse Research Laboratories.*—The mobilities of Ne^+ and A^+ in their parent gases have been calculated by a procedure similar to that employed by Massey and Mohr[1] for He^+ and He. The results are 4.2 and 1.64 cm/sec per volt/cm, respectively, under conditions of standard gas density (2.69×10^{19}/cc), and $T=293$°K. A crucial step in the procedure is the computation of the "resonance" or charge-exchange component of the total ion-atom interaction. In the present paper, this step is achieved by a new method whose sole requirement is a knowledge of the Hartree-Fock wave function of the outermost atomic shell. The resonance interaction curves so obtained differ somewhat from those given by Massey and Mohr's perturbation treatment. The mobility theory in its present form is strictly valid only for ions whose electronic angular momentum is zero. However, preliminary estimates show that the error incurred in its application to Ne^+ and A^+ (whose ground states are either $^2P_{1/2}$ or $^2P_{3/2}$) is <10 percent.

[1] H. S. W. Massey and C. B. O. Mohr, Proc. Roy. Soc. (London) **A144**, 188 (1934).

B5. Diffusion of Ions in a Strong Electric Field. GREGORY H. WANNIER, *Bell Telephone Laboratories.*—When gaseous ions move with appreciable drift velocity in a strong electric field, the diffusion concept can be salvaged: there exists a diffusion tensor in the frame of reference moving with the ion drift velocity. The tensor has two components D_{zz} and D_{xx}, which are, respectively, diffusion coefficients longitudinal and transverse to the field. They depend on the field strength E; for high field, $D\sim E^{\frac{1}{2}}$ for constant mean free path and $D\sim E^2$ for constant mean free time. In the latter case explicit expressions for the coefficients can be derived:

$$D_{xx}=(M+m)\tau\langle c_x^2\rangle_{Av}[M\langle 1-\cos\chi\rangle_{Av}]^{-1};$$
$$D_{zz}=(M+m)\tau[\langle c_z^2\rangle_{Av}-\langle c_z\rangle_{Av}^2][M\langle 1-\cos\chi\rangle_{Av}]^{-1};$$

where M and m are the masses of the gas molecules and ions, respectively, χ the angle of scattering, and $\langle c_x^2\rangle_{Av}$, $\langle c_z^2\rangle_{Av}$, $\langle c_z\rangle_{Av}$ are velocity averages communicated earlier.[1] Einstein's relation can be generalized to read $eD_{nn}=2$ (ion mobility) (random energy in the direction n). Since this relation contains no model parameters and holds dimensionally in the high field range, it may apply more generally than just to the mean-free-time case for which it was derived.

[1] M.I.T. Conference Report on Physical Electronics, March 30, 1950, p. 65.

B6. Further Studies in Mercury Band Fluorescence. A. O. MCCOUBREY, D. ALPERT, AND T. HOLSTEIN, *Westinghouse Research Laboratories.*—Previous researches on the persistence of band fluorescence in mercury vapor[1,2] have been continued. Shot fluctuations, which limited the accuracy of earlier measurements, have been greatly reduced by time sampling techniques involving the use of a gated photomultiplier tube. Improved measurements of the time decay of band fluorescence as a function of temperature and vapor density have been carried out down to densities as low as 6×10^{15}/cc. At this limit, and with a fluorescence tube of radius 0.65 cm, diffusion of the metastable entities to the walls is found to be the predominant removal mechanism. With a second tube of radius 2.3 cm, in which the diffusion was cut down by a factor of 12.5, and at $T=200$°C, a decay time of seven milliseconds is observed. This time constant is essentially independent of density over the range 0.9×10^{16}/cc to 2×10^{16}/cc. The density independence indicates that the decay process is radiative and hence suggests that the metastable entity is molecular. At higher densities (4×10^{16}/cc), a composite decay curve, indicative of the presence of a second metastable "reservoir," is observed.

[1] Holstein, Alpert, and McCoubrey, Phys. Rev. **76**, 1259 (1949).
[2] McCoubrey, Alpert, and Holstein, Report on Conference on Gaseous Electronics, November 3, 4, and 5, 1949, Paper D1.

B7. Isotope Effect in the Imprisonment of Resonance Radiation. D. ALPERT, A. O. MCCOUBREY, AND T. HOLSTEIN, *Westinghouse Research Laboratories.*—On theoretical grounds[1] it is expected that the decay time of imprisoned resonance radiation in the vapor of a single even isotope of mercury should be from five to six times larger than that observed with the natural samples of mixed isotopic constitution. To investigate this effect experimentally, decay measurements[2] were carried out with a sample of Hg_{198} (3.1 percent contamination of Hg_{199}) kindly loaned to us by the Bureau of Standards. For vapor densities below 3×10^{15} atoms/cc, the predicted effect was verified; e.g., at $N=2\times10^{15}$/cc, the decay time T_{198} is equal to sixteen microseconds, whereas T_{mixed} is three microseconds. For N greater than 3×10^{15}/cc, the ratio T_{198}/T_{mixed} diminishes; this secondary effect can be interpreted in terms of a transfer of excitation from Hg_{198} to Hg_{199} by collisions of the second kind. A rough estimate of the cross section for this process gives a value of 5×10^{-14} cm^2, ten times the gas kinetic cross section and in order-of-magnitude agreement with theoretical expectations.

[1] T. Holstein, Phys. Rev. **72**, 1212 (1947); and subsequent unpublished calculations.
[2] Alpert, McCoubrey, and Holstein, Phys. Rev. **76** 1257 (1949).

C2. Breakdown in Hydrogen at 100-mc Frequency.* SANBORN C. BROWN, *Massachusetts Institute of Technology.*—Previous studies of microwave breakdown in hydrogen have led to a very successful theoretical explanation for the behavior of the phenomenon of ac breakdown. The theory was applied not only to the microwave region but also to longer wavelength measurements. The 100-mc experiment was designed to extend the range of experimental observations beyond the range of the previous theory in the direction of higher pressure. A new theory has been developed for the radiofrequency breakdown in hydrogen which is applicable to higher pressure phenomena. At higher pressures the energy per mean free path which the electrons gain in the field is low, and the electrons make very few ionizing collisions compared to elastic and exciting collisions. A much simpler theory has been developed for this case which is applicable also to high pressure breakdown at lower frequencies calculated by the previous theory, so that the two theories can be shown to overlap. The experimental methods of observation will be outlined, and good agreement will be shown between theory and experiment.

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

C3. Maintaining Electric Fields in a Steady-State Microwave Discharge.* DAVID J. ROSE, *Massachusetts Institute of Technology.*—The microwave field required to maintain a discharge at various electron densities in hydrogen has been measured. The experimental methods are summarized. The electron velocity distribution in the hydrogen plasma is derived from the Boltzmann transport equation, taking account of the dc space charge field. From this distribution, the ionization rate per electron, the diffusion coefficient, and the mobility are calculated by standard formulas. In the steady state, a relation exists between these three quantities and the space charge field. The resulting equation is solved to yield the rate of electron flow out of the discharge and the average electron energy, in terms of the applied microwave field, its frequency, the cavity size, and gas pressure. The spatial distributions of ions and electrons in the plasma also yield an equation for the rate of flow in terms of the diffusion and mobility coefficients of the charged particles and the electron density. The electric field required to maintain the discharge is calculated as a function of electron density, cavity size, and frequency, using the fundamental properties of the gas. Theory and experiment are compared.

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

C4. Electron Recombination and Cross-Section Measurements in Decaying Hydrogen Plasma.* LAWRENCE J. VARNERIN, JR., *Sylvania Electric Products, Inc., Boston, Massachusetts.*—A method is described by which the impedance of a decaying plasma in a section of wave guide may be determined as a function of time by use of transient standing wave detection equipment. From the impedance, both real and imaginary components of the complex dielectric constant of the plasma may be obtained. The density can then be determined and, as a result, the mode of decay of electron density established. In addition, the resistive component is related to the collision cross section of electrons. This measurement affords a means of determining the energy dependence of the mean free path of electrons. Data for hydrogen are presented.

* This work was made possible by S. C. Proj. No. 27-3238-2.

C5. A Microwave Method for Measuring P_c at Thermal Energies.* O. T. FUNDINGSLAND, *A F Cambridge Research Laboratories.*—The ratio σ_r/σ_i of the real to the imaginary part of the complex conductivity of an ionized gas in a microwave resonant cavity can be measured during the post-discharge plasma decay by transient standing wave techniques. The solutions for constant collision frequency ($P_c\propto v^{-1}$) and for constant P_c differ in that σ_r/σ_i is inversely proportional to the pressure p in the first case, but not strictly so in the latter. This distinction is small, but it implies that an experimental plot of $1/p(\sigma_r/\sigma_i)$ *versus* either p or σ_r/σ_i should give some indication of the velocity dependence of P_c. Further evidence concerning $P_c(v)$ can be obtained by noting how the measurements are affected when the average electron energy is raised slightly by increasing the intensity of the probing signal. Measurements at room temperature will be reported for helium, hydrogen, and neon. The values calculated by assuming constant P_c agree satisfactorily with extrapolations of Brode's collision probability curves.

* Performed at M.I.T., R.L.E., supported in part by the Signal Corps, the Air Materiel Command, and ONR.

C6. Dielectric Coefficient of Ionized Gases. DONALD E. KERR, *The Johns Hopkins University.*—The formula for the conductivity or dielectric constant of an ionized gas has been a subject of some controversy, chiefly because of the possible existence of a Lorentz polarization term. Using the single-electron approach in a manner due essentially to Darwin, it is found that Lorentz polarization and positive ion collision forces just cancel in an electrically neutral plasma, but local differences in electron and positive ion densities introduce a correction and also modify the local plasma-resonance frequency. The effects of mixed ac and dc fields and of diffusion are best expressed through the electron energy distribution function and the Boltzmann transport equation. The spherically symmetrical part of the distribution function, F_0, is customarily considered to be independent of time. This is not true, however, when both ac and dc electric fields are present, and the electron current depends upon both the steady and alternating components of F_0 as well as those of the electric field. This fact, coupled with the effects of diffusion in a bounded discharge, renders quantitative measurements difficult. A discussion will be given of the theoretical and experimental problems that are encountered.

C8. The High Frequency Discharge in Helium-Argon Mixtures. C. S. CLAY AND J. G. WINANS, *University of Wisconsin.*—High frequency breakdown and extinction field strengths were measured for argon, helium, and helium-argon mixtures. The excitation frequency was 527 mc. The discharge chamber was a cylinder, 13 mm diameter and 110 mm long. With increase in pressure the breakdown and extinction field strengths passed through a minimum. The pressure for minimum breakdown field strength was less for argon and argon-helium mixtures than for pure helium. The pressure at which the extinction field strength was minimum was less than the pressure at which breakdown field strength was minimum. In mixtures of argon and helium, the spectra of argon was more strongly excited, relative to helium, by high frequency than by low frequency excitation. Under high frequency excitation the source was brightest when the gas pressure was that for minimum extinction field strength. The spectrum of mercury was photographed under pulsed and continuous wave excitation at a carrier frequency of 527 mc. Pulsed excitation gave spectral lines of Hg I, Hg II, as well as Hg_2^+, bands. Continuous wave excitation gave Hg I lines only. The theory of Brown, Herlin, and MacDonald described all observations.[1]

[1] Brown, Herlin, and MacDonald, Phys. Rev. **75**, 411 (1948).

D1. Formative Time Lags of Spark Breakdown in Nitrogen and Argon.* G. A. Kachickas and L. H. Fisher, *New York University.*—Formative time lag measurements of spark breakdown in air[1] and oxygen[2] have been extended to nitrogen and argon. The results in nitrogen and air are almost identical, the time lags in both gases being independent of pressure and increasing with increasing gap separation. In argon, the formative time lags at overvoltages above a few percent are many orders of magnitude longer than the corresponding times in nitrogen and air. The time lag *vs* percent overvoltage (o.v.) curve varies much more slowly in argon than in nitrogen. For example, at a tmospheric pressure and a gap separation of 1 cm, the time lags are 100 μsec at 10 percent o.v. and decrease to 1 μsec at 100 percent o.v. In argon, the time lag *vs* percent o.v. curve is not independent of pressure, the curves for low pressures lying below those for high pressures. The time lags for argon increase with increasing gap separation. Interpretation of the results will be given.

* Supported by the ONR and the Research Corporation.
[1] L. H. Fisher and B. Bederson, Phys. Rev. **78**, 331 (1950).
[2] G. A. Kachickas and L. H. Fisher, Phys. Rev. **79**, 232 (1950).

D2. Ion Pulses in the Positive Ion Space Charge Detector.* Nathan Wainfan and G. L. Weissler, *University of Southern California.*—Using a Kingdon cage space charge detector,[1] pulses were observed due to individual positive ions generated in the residual gas by emission electrons. The pulse shape was essentially independent of the number of pulses; they disappeared when operating the detector in the saturation region. The average pulse duration was of the same order as ion lifetimes found by Kingdon.[1] The pulse number decreased with decreasing pressure, with no pulses in a very high vacuum. However, dry, pure He does not increase the pulse number until the anode voltage is raised to the He ionization potential. Using a Kunsman ion source external to the detector, no induced pulses were observed, in agreement with calculations on electron shot noise and ion pulse heights. An internal ion source produced pulses with very low efficiencies. Differential counting rates will be presented for various instrument parameters and pulse heights. These results were in agreement with expectations. Under certain conditions of electrode potentials and geometry sustained sinusoidal ion oscillations were observed. It will be shown that they are analogous to electron Barkhausen oscillations. The ion oscillation periods are in good agreement with calculated ion transit times.

* Sponsored by the ONR.
[1] K. H. Kingdon, Phys. Rev. **21**, 408 (1923).

D3. Further Results on Absorption Coefficients of N_2 in the Vacuum Ultraviolet.* Po Lee and G. L. Weissler, *University of Southern California.*—Quantitative results of N_2 absorption coefficients have been obtained with a line spectrum source, and the absorption law $I_x = I_0 \exp(-k_\lambda x)$ has been verified for 26 lines. In contrast to our Lyman source work, general scattering or fluorescence in the absorbing gas did not obscure the results. Values of the coefficients between 1300A and 1050A are generally small, 10 cm^{-1} or less. In the N_2 band region from 1050A to 800A, the coefficients oscillate rapidly attaining maximum values of about 350 cm^{-1}, in approximate agreement with Schneider[1] and Clark.[2] They must be regarded with caution due to blending of source lines and absorption bands. From 800A to 500A, k_λ is nearly constant at about 600 cm^{-1}, indicating a decrease toward shorter wavelengths. At 303A, $k_\lambda = 120$ cm^{-1}. Very strong absorption was observed on several plates at 775.9A with a k_λ of at least 2200 cm^{-1} ($N_2^+ = 795.8$A). Agreement between the results presented and Wulf's predictions from N_2 dispersion[3] is fair.

* Supported by the ONR.
[1] E. G. Schneider, J. Opt. Soc. Am. **30**, 128 (1940).
[2] K. C. Clark, Phys. Rev. **73**, 1250A (1948); private communication.
[3] O. R. Wulf and L. S. Deming, Terr. Magn. Atmos. Elect. **43**, 283 (1938).

D5. Time Studies in Positive Point-to-Plane Corona.* M. Menes, *New York University.*—Since the positive point-to-plane corona was of fundamental importance in establishing the streamer theory of sparking, it seemed desirable to study the formative time lags of the various types of discharges encountered with positive points. Tungsten points ranging from about 0.1 to 0.5 mm in radius were used with gaps of the order of 1 cm. Continuous ultraviolet illumination of the cathode provided initiating electrons. An approach voltage well below onset was used and an additional voltage step applied. The time lags were measured from the application of this step by means of an amplifier and synchroscope. The gases studied were air, oxygen, and nitrogen at pressures from atmospheric down to a few mm of Hg. At higher pressures, formative time lags were found to be well defined only for nitrogen. In air and especially in oxygen, a large scatter in the times exists. This scatter (which decreases with increasing illumination) has been tentatively ascribed to electron attachment by oxygen molecules. At higher pressures, the formative time lags for prebreakdown pulses in nitrogen have been found to be of the order of a microsecond or less very near threshold (overvoltages of the order of 0.1 percent).

* Supported by the ONR and the Research Corporation.

D7. Experiments upon the Initiation of an Electric Arc. L. H. Germer, *Bell Telephone Laboratories.*—When a condenser charged to a potential of the order of 50 volts is discharged by bringing two electrodes together, field emission current flows before contact is made. Whether or not an arc is initiated by this current depends upon the nature of the electrode surfaces and upon the circuit voltage and inductance. For clean noble metal electrodes, an arc occurs only if the quotient of the voltage and inductance exceeds about 10^7 amperes per second. For carbon surfaces an arc is struck if this quotient is greater than about 5×10^4. Noble metal surfaces contaminated by very thin carbonaceous films or grease, or by very thin insulating films, or by insulating particles such as magnesia powder, behave much as do carbon surfaces. When an arc occurs the potential across it is characteristic of the electrode material and independent of the nature of the film, if any, by which the arc was initiated, and independent also of the current except during the first 2×10^{-8} second of the arc's duration. The characteristic voltages for silver, copper, gold, palladium, platinum, and carbon are, respectively, 11, 12, 12, 14, 15, and 20–30. The arc voltage is much higher during the first 2×10^{-8} second.

D8. On the Production of Extreme Temperatures by Electrical Discharges. Louis Gold, *Watertown, Massachusetts.*—Recently, stellar temperatures have been identified with nuclear explosions.[1] In the face of literature which attests both mechanical and electrical means for producing such high temperatures, it has been improperly adduced that the above represents our only known approach.[2] Indeed, Anderson[3] resorted to the exploding wire in simulating the excitation presumed to originate by meteors plunging into the sun. Appropriate analysis of the temperatures in such sparks must take cognizance of two facets: (1) collision and radiative processes involving particle-wave interactions, and (2) the circuitry question. Item (1) concerns the opacity in a variable star and is so grossly complicated that it is expedient to deal initially with the circuitry aspect, assuming negligible radiative losses during the energy build-up stage, an assumption for which there is reasonable experimental justification.[4] The circuitry influence is contained in an energy-time function which permits suitable evaluation of the salient features of energy build-up in discharges and on which basis one can show that temperatures of millions of degrees are attainable.

[1] P. Caldirola, J. Chem. Phys. **18**, 846 (1948).
[2] R. F. Bacher, Sci. American **182**, 11 (1950).
[3] J. A. Anderson, Astrophys. J. **51**, 37 (1920).
[4] J. D. Craggs and W. Hopwood, Proc. Phys. Soc. (London) **59**, 771 (1946).

E1. Motion of an "Anchored" Arc Impelled by a Magnetic Field. C. G. Smith, *Raytheon Manufacturing Company.*—A cylinder 2 cm in diameter of polished molybdenum or such, with axis vertical, projects well above a surface of mercury in an evacuated tube. The anode is above and radially larger than the cylinder. An arc anchors along the circle where the mercury wets the molybdenum. A magnetic field of 1000 to 10,000 oersteds applied vertically is parallel to the arc stream except for a few thousandths of a cm where the arc current is radial to the molybdenum. The cathode spot races around on the cylinder in the retrograde direction. Observations were made through a rotating toothed wheel, and with photocell and oscillograph, and with radial probe and oscillograph. The velocity does not change from retrograde to proper for any field strength but usually approaches asymptotically to approximately 120 meters per sec. Current density is greatest at the leading edge of the spot. Spot may be single or a unified flock of two or more equal segments separated by darker regions. A mode of one, two, or more, once established is stable.

E4. Exceptionally Low Voltage Drops in Hot Cathode Gas Diodes. Gustav Medicus and Gottfried Wehner, *Wright Field, Dayton, Ohio.*—The potential, plasma density and electron temperature distribution in Xe low voltage arcs without oscillations and with voltage drops lower than the lowest excitation potential of Xe (8.3 v) were measured. Minimum arc drops of about 1.5 v in the amp range were obtained without an indication of this being a lower limit. The findings of Compton and Eckart[1] and of Druyvesteyn,[2] namely, potential and plasma density maxima near the hot cathode and decreasing electron temperature with increasing distance from the anode, were confirmed, provided the discharge—which normally confines itself to regions of preference, especially of lowest work function of the anode—was prevented from shunning the region of the movable probe. Otherwise, under cylindrically or spherically uniform geometrical conditions no maxima were found, in spite of their doubtless existence in regions not covered by the probe. By artificially increasing the plasma density near its "natural" maximum by means of an auxiliary discharge with fast electrons being extracted from a saturated cathode, the arc drop could be considerably decreased.

[1] K. T. Compton and C. Eckart, Phys. Rev. **25**, 139 (1925).
[2] M. J. Druyvesteyn, Z. Physik **64**, 782 (1930).

E5. Experimental Techniques for the Measurement of Thyratron Breakdown. Hanns J. Wetzstein, *Cambridge, Massachusetts.*—Throughout all tests the anode of the thyratron is connected to the vertical deflection plates of a cathode-ray oscilloscope. A sinusoidal voltage of normal operating frequency is applied to it through a series load impedance of any desired value. (1) A dc voltage varied about once a second over the control range desired is applied to the grid and the horizontal deflection plates simultaneously. The upper edge of the pattern resulting on the screen is the grid control characteristic. (2) A fixed value of dc voltage is applied to the grid (through the usual RC network), and the horizontal deflection plates are connected directly to the grid. The complex pattern gives the grid-anode voltage relationship at all times, including breakdown. (3) The grid is made to fire using dc and some synchronizing voltage. A sinusoidal voltage of anode supply frequency in series with a suitable rf voltage is applied to the horizontal deflection plates. A Lissajous figure is obtained with a straight vertical line (breakdown) on which there is superimposed the rf sine wave, thus allowing accurate measurement of breakdown times. The relative ease and simplicity of the techniques allows close investigation of the influence of all parameters under operating conditions.

E8. Improved Potential-Probe Measurements in Carbon Arcs. Wolfgang Finkelnburg, *Fort Belvoir, Virginia.*—The potential distribution along the arc-stream axis, in the potential drop regions close to the electrodes, and in certain boundary layers of carbon arcs has been studied, despite arc temperatures up to 12,000°K, by means of fast moving potential probes. Tungsten wires covered by insulating glass or quartz, except for a small tip, were whipped through the arc stream, or pneumatically shot against and retracted from the electrodes, while the probe potential with reference to one of the electrodes, the total arc voltage, the arc current, and the position of the probe's tip with respect to the electrode surface were simultaneously recorded by a Hathaway oscillograph. Tungsten probes plated with different metals were used for checking a possible influence of oxide formation, differences of work function, etc. However, the results proved to be independent of the probe material and, in a fairly wide range, of the probe speed. Results concerning potential distribution and potential drops in different regions of carbon arcs at low and high current density will be discussed, together with possible sources of error and their elimination.

E9. Oscillations in Direct Current Arcs.* T. B. Jones and B. H. List, *The Johns Hopkins University.*—Two types of oscillations have been discovered in dc carbon arcs in air. One type, consisting of low audiofrequency oscillations of 100 to 400 cycles/sec, occurs in a narrow current range just below the hissing point. Simultaneous oscillations of voltage, current, light, and sound have been observed. High speed motion pictures show that these so-called "quiet" oscillations are the result of the rotation of the anode spot around the anode crater circumference. The voltage oscillations are a result of the varying arc length as the spot rotates. Their frequency was found to be dependent on the material, size, and separation of the electrodes and the arc current. The second type of oscillations begins when the arc enters the hissing stage. They occur in the rf spectrum in definite bands up to at least ninety megacycles. Their frequency appears to be independent of electrode material, arc length, or current but dependent on the atmosphere. Both types of oscillations are independent of any external inductance or capacitance in the arc circuit. Oscillations are present in materials other than carbon, e.g., W, Al, and Cu. However, the "quiet" oscillations in these materials are very unstable due to melting of electrodes.

* This work was supported by the ONR.

E10. Characteristics of the Helium-Tungsten Arc with High Currents.* T. B. JONES AND MERRILL SKOLNIK, *The Johns Hopkins University.*—Properties of the electric arc are investigated for tungsten rod electrodes in He at a pressure slightly above one atmosphere and for currents ranging from 15 to 80 amperes. The arc properties studied include voltage-current and voltage-arc length characteristics, physical appearance, and starting phenomena. The helium-tungsten arc may exist as the cold-cathode arc, or the thermionic arc. The cold-cathode arc always appears on starting and may last a few seconds before extinguishing. If the current exceeds 70 amperes (approximately), the cold-cathode arc will change quickly to the stable thermionic arc. The voltage-current curves are similar in appearance to the usual *V-I* characteristics for the arc except that in most cases two different curves, displaced by several volts, may be obtained for the same arc length. The arc voltage usually follows the upper of these two curves for low currents and transfers to the lower curve for high currents. This transition is accompanied by a change in arc appearance and is believed to be caused by vaporization of the cathode material. For short electrode separations and higher values of current, the arc voltage approaches 20 volts, which is near the first resonance potential of helium.

* This work was supported by the ONR.

F1. Probe Technique for the Measurement of Electron Temperature. M. A. EASLEY, *General Electric Company, Nela Park.*—A study has been made of the characteristics of the positive column of the low pressure mercury arc in the presence of one to 3.5 mm pure argon or krypton gas. Under some conditions, nonlinear probe characteristics were found, similar to those reported by others for discharges in pure mercury. This discontinuity in the slope of the $\log i_p - V_p$ plots for wire probes was eliminated in many cases by heating the probe by electron bombardment before each reading. With this technique, linear probe characteristics over the measurable range of electron current (i.e., over a 10,000-fold range in probe current) were obtained for discharges in 0.5 to 46μ-mercury vapor mixed with one to 3.5 mm pure krypton or argon gas, provided the discharge was free of oscillations. Nonlinear plots were obtained for discharges with striations and for gas contaminated by a fraction of a micron of CO or CO_2. The linear probe characteristics lead to the conclusion that in the discharges with no oscillations, the electron velocity distribution followed the maxwell distribution law, at least to 10 or 11 volts from space potential. The report will include typical probe plots and electron temperature measurements illustrating the results described.

F2. Gas Temperatures and Elastic Losses in Low Pressure Mercury Argon Discharges. C. KENTY, M. A. EASLEY, AND B. T. BARNES, *General Electric Company, Nela Park.*—The increase ΔT in average gas temperature for ac and dc has

t_{Hg}	Amp	p_A mm	ΔT	T_e	$N_e \times 10^{-12}$	P_m	P_c
17°	0.42	3.5	42.7	15,000	2.5	0.16W	0.19W
60	0.42	3.5	15.8	9,800	2.65	0.061	0.064
42	0.20	3.5	13.1	11,900	1.15	0.047	0.047
42	0.60	3.5	27.1	10,800	3.3	0.107	0.104
42	0.42	1.7	10.0			0.037	
42	0.42	5.1	30.3			0.12	

been determined from measurements of the increase in pressure. A small McLeod gauge was used. Wall temperature was regulated. Corrections for end effects were made by comparing results for long and short tubes of 3.6 cm diameter. Assuming the radial variation of heat input to be parabolic, the temperature distribution was calculated using published values of heat conductivity K. From the results the heat input P_m per centimeter length was calculated. This value was compared with the elastic loss P_e computed from electron temperature T_e and number of electrons N_e per centimeter column, taking into account the variation of mean free path with electron velocity. The table indicates the good agreement obtained.

F3. Characteristics of Moving Striations in a Mercury-Krypton Mixture. H. L. STEELE, JR., *Westinghouse Electric Corporation.*—This paper supplements that presented before the 1949 Conference on Gaseous Electronics. The discharge is photographed with a shutterless camera which moves the film at right angles to the discharge. At low currents and pressures, bright regions (striations) move from anode toward cathode at thousands of centimeters per second with a frequency of hundreds per second. The characteristic mercury color is maintained with or without striations. As the mercury pressure is increased the voltage per striation decreases to about 4 volts, and the distance between striations decreases to 5 centimeters before the positive column becomes homogeneous. The bright regions first disappear from the cathode end of the positive column. The striation spacing changes discontinuously so that an integral number of bright regions exist. This is explained by a synchronization of these striations with an oscillatory phenomenon at the anode, and near the cathode with high speed striations associated with the anode oscillations. When the discharge is pulsed the bright regions are created near the cathode, later ones at constant spacings toward the anode. If a second pulse is applied within 8 milliseconds, striations also carry-over from those in the first pulse. This is evidence of slow diffusion of ions.

F4. Moving Striations in H_2 and D_2 Glow Discharges.* T. M. DONAHUE, *The Johns Hopkins University.*—A study of glows in hydrogen by means of photomultiplier tubes connected to an oscillograph[1] has revealed that such "dc" discharges can exist in both oscillatory and non-oscillatory states. The oscillations found generally have a frequency of a few times 10^4 sec^{-1}. Two regimes for these discharges will be discussed. (1) Low pressure, low current (below 0.2 mm and 1.0 ma): The positive column appears homogeneous, but there exist in it moving striations. The most prominent of these travel toward the cathode at a speed higher than 5×10^7 cm/sec. The frequency of oscillation increases linearly with current and decreases with pressure. (2) Higher pressure and current: Stationary striations begin to appear in the column. Oscillations do not usually exist, but they may appear. Generally this occurs when there are a few standing striations at the head of a homogeneous column. In the homogeneous column, then, moving striations are found, all of which *move toward the anode.* The light intensity in the stationary striations also oscillates. When deuterium glows were studied under identical conditions, no essential differences were noted. Thus, the prominent oscillation parameters are independent of the positive ion mass.

* Work supported through an ONR contract under the direction of G. H. Dieke.
[1] T. Donahue and G. H. Dieke, Phys. Rev. **81**, 248 (1951).

F5. Electrode Reactions in the Glow Discharge. F. E. HAWORTH, *Bell Telephone Laboratories.*—The reactions which occur at silver electrodes in a *normal* glow discharge in air have been determined. These are: (1) formation of $AgNO_2$ and some Ag_2O at the anode at the rate of 3.4 μg/coulomb; (2) loss of metal from the cathode by chemical action at the rate of 3.5 μg/coulomb (probably the same reaction as (1) with subsequent loss of the reaction products by the greater heating of the cathode, but this hypothesis has not been established); and (3) normal sputtering loss at the cathode at the rate of 0.4 μg/coulomb. These processes result in building a conducting layer on the anode. If the electrode separation is so small that the anode extends into the region of the cathode fall, then the high electric field pulls the newly formed and not very coherent growth upon the anode across into a bridge between the electrodes.

F6. Dynamic Characteristics of Glow Discharges in the Rare Gases at Ultrasonic Frequencies.* W. D. PARKINSON, *The Johns Hopkins University.*—A systematic study has been made of the dynamic characteristics of rare gas glow discharges in the frequency range 10 to 300 kc. This region is approximately free from the influence of voltage and current fluctuations associated with moving striations, which play a dominant part at lower frequencies. The peak voltage is always well below the sparking voltage except at the lowest pressures. To a first approximation the glow discharge, especially in He, behaves as a linear resistance at these frequencies. In the heavier gases there is a tendency for the discharge to have a lower conductance while the voltage and current are increasing. During this phase of the cycle there is a brief period in which the current is higher than would be expected. This effect is slight in Ne and much more marked in A and Kr. This is interpreted as due to the low cross section for elastic collision of low energy electrons with rare gas atoms. This is supported by the fact that phototube observations of the positive column during this period show practically no light output in the case of A and Kr, indicating a lack of excitation in spite of the high current.

* This work was supported through an ONR contract under the direction of G. H. Dieke.

F7. Decimeter Oscillations in Mercury Plasmas, Experiments and Considerations.* L. BRENNAN, J. SALOOM, AND R. WELLINGER, *University of Illinois.*—A three-electrode oscillator, as described by G. Wehner,[1] has been investigated extensively. It is shown that this structure displays the same behavior as some gas diode oscillators enclosed in glass, thus establishing a close relation between the diode-type oscillators and the particular Wehner structure. A systematic set of data shows the variation of wavelength with each of the parameters involved in the oscillation. These experimental results disagree with the majority of the formulas published to date. The system oscillates in different modes, and as the cathode current is increased continuously, the frequency remains constant except for discrete jumps. Further, the transit time of the beam electrons between two electrodes is always an integer plus one-quarter times the period of oscillation. A theory similar to Wehner's, based on the model of the double gap klystron oscillator, should describe the oscillations satisfactorily. However, this model implies the questionable assumption that within each dark space there exists a layer with marked resonant properties.

* This work was supported by the Air Materiel Command, Dayton, Ohio.
[1] G. Wehner, J. Appl. Phys. 21, 62 (1950).

F9. Momentary Intensification of the Electron Beam Obtained from a High Voltage Cold-Cathode Discharge. JOHN H. PARK, *National Bureau of Standards.*—A method for obtaining a 10- to 50-fold momentary increase in the intensity of the electron beam obtained from a high voltage cold-cathode discharge tube has been developed. Its application for increasing the recording speed of a high voltage cathode-ray oscillograph is described. Oscillograms have been obtained in which the trace speed is about three-fourths the velocity of light. The intensification is caused by superposing a steeply rising voltage pulse on the normal steady voltage across the electrodes of the discharge tube serving as the electron beam source. The voltage pulse momentarily disrupts equilibrium conditions in the discharge and produces an intense discharge that lasts for about 2 microseconds. Measurements of the magnitude and duration of the superposed pulse and of the changes in discharge current have been made. A tentative explanation of the mechanism of intensification based on these measurements is given.

Author Index to Papers