PHYSICAL REVIEW VOLUME 69, NUMBERS 11 AND 12 JUNE 1 AND 15, 1946

Proceedings of the American Physical Society

Minutes of the Meeting of the New York State Section at Hamilton, New York, April 13, 1946

THE Spring Meeting of the New York State Section of the American Physical Society was held at McGregory Hall, Colgate University, on Saturday, April 13, 1946. This meeting was sponsored jointly by the section and the New York State Science Teachers Association. One hundred and twenty-five members and visitors registered at the meeting. The following program of invited papers was presented:

Morning Session

Address of Welcome. Sidney J. French, *Dean of Faculty, Colgate University*

Recent Developments in Color Photography. John A. Tiedeman, *Ansco Corporation*

Nuclear Physics in the Atomic Bomb Development. Robert F. Bacher, *Cornell University*

The Atomic Bomb and International Relations. Charles R. Wilson, *Colgate University*

Afternoon Session

The Physics of Radar. Joseph B. Platt, *University of Rochester*

General Electric Fellowships for Science Teachers

The 1945 Summer Session

1. **Administrative Viewpoint.** V. Rojansky, *Union College*
2. **Teachers' Viewpoint.** Anna M. Pearsall, *Ithaca High School*
3. **Discussion**

Recent Developments in Procuring War Surplus Equipment. C. W. Gartlein, *Cornell University*

In addition to the above program a radar unit was demonstrated through the courtesy of the Signal Corps.

W. R. Fredrickson
Secretary

Proceedings of the American Physical Society

Minutes of the Spring Meeting at Cambridge, April 25–27, 1946

THE 1946 Spring Meeting of the American Physical Society, the 271st of our meetings, was held in the buildings of Harvard University and of the Massachusetts Institute of Technology on Thursday, Friday, and Saturday, April 25–27, 1946. With eleven hundred registrants, this proved to be the greatest meeting we had ever held by ourselves, and second only to the joint convention four months earlier of our Society and the Association of Physics Teachers. Instructed by our advance underestimate of the previous December, we were not taken unawares; and the Local Committee—headed by J. C. Slater and J. H. Van Vleck—had at least a warning of the burden it might be expected to assume. This burden it carried admirably, and its arrangements were adequate in every detail. The Secretary has thanked many a Local Committee in the past, but some of his adjectives ought to have been reserved for the administrators of these postwar meetings, so much more demanding of labor than any that have gone before.

The circumstances of the time conspired to make this the outstanding "radar and microwave meeting" of the Society. Clearance, or declassification as the term is, had recently been granted to much of the work done in the fields so denoted during the war. What was even more important, the clearance had in many cases come so early that it was feasible for an informal committee of physicists familiar with the wartime work to organize a representative programme of invited papers, to solicit suitable contributed papers, and to sift the material apt for our meeting from the even greater amount more appropriate to other societies. Among those who thus helped to build the programme were J. B. Fisk, A. G. Hill, J. B. Kellogg, J. B. Knipp, J. C. Slater, and J. H. Van Vleck.

Three unified groups of invited papers were arranged by the informal committee, their topics being: Microwave Generation and Transmission, Random Processes and Noise, and Circuits for Precision Measurements. What was planned at first as another such group, devoted to Atmospheric Absorption of Microwaves, was modified into a train of contributed papers led by J. H. Van Vleck's survey "The Atmospheric Absorption of Microwaves." L. A. DuBridge commemorated the M. I. T. Radiation Laboratory in an after-dinner speech under the title "Microwave Radar." A sequence of eleven contributed papers pertained to the subject of Gas-Discharge Transmit-Receive switching tubes, and perhaps a score of the other ten-minute papers (there were of these no fewer than 136 altogether) owed their origin recognizably to radar and microwave investigations.

Other fields of physics were well and abundantly represented. Lise Meitner spoke on many qualities of the fission-process. Nuclear physics, cosmic rays, crystal rectifiers, and shock-waves were the topics of so many ten-minute papers that an almost-complete or a quite-complete half-day session could be devoted to each of these fields; optics and the qualities of the solid state figured prominently. On the Saturday morning the members and guests were refreshed by a most interesting and relatively non-technical programme comprising addresses by J. B. Conant, G. F. Hull, Sr., and K. T. Compton. It is the Secretary's guess that these three and the Meitner address, all four of them held in the Sanders Theatre, were the most numerously attended of all the lectures ever given before the American Physical Society.

The dinner was held on the Thursday evening in the Continental Hotel, and also set a record by being unquestionably the most largely attended of any in our history: 650 members and guests were there. President Condon presided; Vice President DuBridge gave the address which has already been mentioned. The Secretary announced that the Amendments to the Constitution of the Society lately submitted to the Fellows had all been passed. (The tellers of this ballotting, Melba Phillips and M. W. Zemansky, deserve the gratitude of the Society.) The gist of these amendments is that Members are admitted to the franchise on the same terms as Fellows; that in the elections, the name of any Fellow who is nominated to an office by not fewer than one percent of the total number of Members and Fellows together appearing in the latest printed membership list (currently 3751) shall appear on the ballot; and that the functions of the Council in respect to making nominations are transferred to a Nominating Committee composed of seven or nine members, appointed by the Council so that various fields of physics shall be represented.

The Council met on the Friday afternoon and evening, and elected to Fellowship and to Membership the candidates whose names follow hereunder. The Council ratified, on behalf of the Society, the amendments to the Constitution of the American Institute of Physics proposed by its Governing Board.

The Society has lost through death, according to reports reaching the Secretary, the following members: R. E. Hickman (New Zealand), S. J. Simmons (M. I. T.), and W. R. Westhafer (Wooster).

Elected to Membership:

John W. Abrams, John H. Affleck, Leroy R. Alldredge, James R. Ambrose, Raymond K. Appleyard, Erik Backun, Fred L. Bartman, Morris E. Battat, Jane Lucille Berggren, Carl V. Bertsch, Everitt P. Blizard, Harriet May Bredder, Leeroy A. Britton, Vinton A. Brown, Patrick Edward Cavanagh, Harold R. Coish, Henry Milton Crosswhite, Raymond Davis, Jr., John C. Decius, Virginia L. Deno, J. E. Eaton, Herbert P. Eckstein, N. E. Edlefsen, Julian Eisenstein, Milton Q. Ellenby, Joe Oliver Elliot, Raymond J. Emrich, Morris Ettenberg, Jane Faggen, F. J. M. Farley, Francis J. Fennessy, Wilfred J. Ferguson, Jerome L. Flanagan, Paul C. Foote, Richard Foy, Elisabeth J. Fraenkel, Stanley Phillips Frankel, Glenn R. Fryling, Ch'eng-Yi Fu, Raymond L. Garman, Martin A. Garstens, George Abraham Ginsberg, Harold C. Glahe, Lawrence E. Goodman, C. C. Gotlieb, Robert H. Gould, John W. E. Griemsmann, James H. G. Griffiths, Nelson T. Grisamore, Gerard R. Gunther-Mohr, Charles Andrew Hansen, Jr., Gerald Harrison, Hayward W. Henderson, Gerald J. Hine, Claude Wendell Horton, Robert E. Houle, Charlotte R. Houtermans, John Nelson Howard, Clinton D. Janney, Philip Sheldon Jastram, Joseph Kaplan, Leon Katz, Bruria Kaufman, Spurgeon Milton Keeny, Jr., Joseph W. Kennedy, Bernard D. Kern, Donald D. King, Wallace C. Koehler, Richard T. Kropf, Kaiser S. Kunz, Robert Leighton, Edwin S. Lennox, Louis Leprince-Ringuet, Henry Levinstein, Miles A. Libbey, Charles W. Malich, Carl R. Malmstrom, Kenneth C. Mann, Moshinsky B. Marcos, Arleigh H. Markham, Edward G. Martin, Philip K. McGall, Berthus B. McInteer, Jr., Wilkison W. Meeks, Dwight P. Merrill, Siegfried S. Meyers, Ernst Miescher, Frank L. Moore, Jr., Francis Paul Mooring, George W. Morton, Joseph R. Mottl, Max M. Munk, Henry S. Myers, Per Ohlin, Aadne Ore, Heinz R. Paneth, Thomas D. Phillips, W. M. Pierce, Bruno Pontecorvo, Henry H. Porter, Daniel Q. Posin, Marilyn A. Poth, Robert Byron Quinn, Ora L. Railsback, L. G. Raub, Severin Raynor, Leonard Reiffel, Roland Reisley, Charles N. Rice, Theodore A. Rich, Edmund S. Rittner, D. Roaf, Donald Glenn Rose, Isadore Rudnick, Robert E. Ruskin, Frederick Henry Sanders, John H. Sanders, Norman B. Saunders, John E. Scott, Jr., Leo Seren, David M. Sherwood, Hugh H. Spencer, Lawrence Spruch, John Ellsworth Stecklein, Paul Robert Stein, Ellen Swomley Stewart, John Fredrick Streib, Jr., Paul M. Strickler, Arthur Henry Sully, Mary Anne Summerfield, M. Surdin, Clayton Albert Swenson, Guy C. Tavernier, Gordon K. Teal, Lee Morton Thompson, G. C. Tibbetts, John R. Tolmie, George Vaux, Adolf F. Voigt, Sten Von Friesen, Hugh Gordon Voorhies, Jr., John D. Wallace, Albert Wattenberg, John W. Weigl, David K. Weimer, Benjamin Welber, Aaron Wexler, Locke White, Jr., Hollie C. Williams, John Winckler, Irving Wolff, Barbara A. Wright, Joseph P. Wronski, Kazuo Alan Yamakawa, and Ralph Zirkind.

Elected to Fellowship:

E. Scott Barr, W. H. Bostick, W. M. Cady, Glen D. Camp, B. Chance, Ralph J. Christensen, L. J. Chu, A. M. Clogston, E. A. Coomes, S. M. Dancoff, R. H. Dicke, D. H. Ewing, M. Eastham, J. Halpern, D. R. Hamilton, E. L. Hudspeth, W. H. Jordan, Gilbert W. King, L. B. Linford, A. Longacre, E. M. Lyman, P. H. Miller, Jr., J. Millman, M. D. O'Day, W. M. Preston, F. F. Rieke, E. G. Schneider, Rubby Sherr, C. W. Sherwin, W. H. Souder, G. F. Tape, F. E. Terman, H. C. Torrey, G. E. Valley, Jr., and C. A. Whitmer.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York, New York

Invited Papers

Microwave Generation and Transmission

Magnetron Generators. J. B. FISK, *Bell Telephone Laboratories.*
The Klystron. DONALD R. HAMILTON, *Radiation Laboratory, M. I. T.*
The Resnatron. J. J. LIVINGOOD, *Collins Radio Corporation.*
Microwave Circuits. A. G. HILL, *Radiation Laboratory, M. I. T.*

Random Processes and Noise

Theory of Random Processes. G. E. UHLENBECK, *University of Michigan.*
Threshold Signals in the Presence of Noise. J. L. LAWSON, *General Electric Company.*
Response of Non-Linear Devices to Signal and Noise. D. O. NORTH, *RCA Laboratories.*
Fourier Series in Random Processes. S. O. RICE, *Bell Telephone Laboratories.*

Circuits for Precision Measurements

Pulse Amplifiers. HENRY WALLMAN, *M. I. T.*
The Amplification of Low Frequency Signals. G. E. VALLEY, *M. I. T.*
Precision Methods for Pulse Time Measurement. BRITTON CHANCE, *M. I. T.*
Techniques of Cathode-Ray Tube Display Circuits. L. J. HAWORTH, *University of Illinois.*

The Atmospheric Absorption of Microwaves. J. H. VAN VLECK, *Harvard University.*
Microwave Radar. L. A. DUBRIDGE, *University of Rochester.*
Attempt to Single Out Some Fission Processes of Uranium by Using the Differences in their Energy Release. LISE MEITNER, *Forskningsinstitutet for Fysik, Stockholm.*
The Interaction of Science and Society. J. B. CONANT, *Harvard University.*
Fifty Years of Physics, a Study in Contrasts. G. F. HULL, SR., *Dartmouth College.*
Scientific Mission to Japan. K. T. COMPTON, *Massachusetts Institute of Technology.*

ABSTRACTS OF CONTRIBUTED PAPERS

A1. Reflection of Sound Signals in the Troposphere. G. W. Gilman and F. H. Willis, *Bell Telephone Laboratories*.—It is known that many familiar weather phenomena and also the behavior of microwave radio signals depend upon the distribution of temperature, humidity, and momentum in the troposphere. We have attempted to detect the presence of acoustic non-homogeneities in the lower troposphere by using a low-power acoustic "radar." The device has been named the "Sodar." Trains of audio-frequency sound waves were launched vertically upward from the ground, and the echoes were displayed on an oscilloscope and photographed. Periods characterized by strong temperature inversions tended to be accompanied by strong sodar displays, with amplitudes several times as great as those obtained from a standard atmosphere. These periods tended to be coincident with periods of disturbed transmission on a microwave radio path on which the sodar was located. In addition, relatively strong echoes were received when the atmosphere was in a state of considerable turbulence. There was a well-defined fine-weather diurnal characteristic. Limitations in the apparatus as used would prevent the deduction of the vertical distribution of acoustic impedance, even in principle, from the oscilloscope patterns. The experimental evidence leads us to conjecture that the picture of a smooth, quiet, stratiform troposphere, even under conditions of a strong temperature inversion and apparent stability, represents an over simplification of its refractive properties for certain problems in sound and radio wave propagation.

A2. Interaction of Shock Waves. R. J. Seeger, J. von Neumann, H. Polachek, *Bureau of Ordnance, Navy Department. Washington, D. C.*—The interaction of plane shock waves moving with constant velocity has been investigated theoretically for gases and for water-like substances. In the case of one-dimensional interaction for water-like substances there is no peculiar dependence upon the value of the adiabatic exponent γ, as occurs for ideal gases. In the case of oblique collision of two similar shock waves two distinct phenomena are possible: the resulting shock configurations are designated regular and Mach, respectively. A regular, oblique collision may involve pressures higher than those for head-on incidence. A comparison is made between experimental data for stationary configurations and both the simple theory and the simple theory with Prandtl-Meyer modifications. The simple theory appears to be adequate. Mach oblique collision involves three-shock configurations.

A3. Three-Shock Configurations. H. Polachek and R. J. Seeger, *Bureau of Ordnance, Navy Department, Washington, D. C.*—A common occurrence resulting from shock-wave interactions is a configuration consisting of three confluent shocks, which are invariably accompanied by a plane of density discontinuity. All four planes intersect in a line, and form what is known as a three-shock or Mach configuration. This phenomenon is observable in supersonic wind tunnels, in supersonic jets, in the vicinity of high speed projectiles, etc. In order to obtain a reliable estimate of the physical conditions existing in the neighborhood of the intersecting line, an extensive survey has been made of all theoretically possible intersections of this type. Comparison of the theoretical solutions with experimental results shows good agreement in the case of strong incident shocks. However, in the case of weak shocks a systematic deviation is found to exist between theoretical and observed results. Several modifications of the flow pattern in the neighborhood of the intersecting line are given to illustrate the effects on the disposition of the shock waves.

A4. Normal Reflection of a Shock Wave. R. J. Finkelstein, *Bureau of Ordnance, Navy Department, Washington, D. C.*—Determination of the initial pressure produced by the reflection of a shock wave has been studied as far as this is possible by algebraic means. Knowledge of the complete process of reflection can be obtained, on the other hand, only by solving the non-linear differential equations describing the flow. This has been done for normal reflection by Chandrasekhar, who treated the case of reflection from a rigid surface in air by a numerical method. We also have considered normal reflection from a rigid surface, but we have replaced the numerical method by an analytical one, and have extended the work to reflection in other fluids, including water. It is found that gases and water behave differently. In gases the blow is prolonged and the impulse delivered to the reflector exceeds the value predicted by acoustic theory. In water, on the other hand, the blow is shorter and the impulse is less than one would expect from the acoustic approximation.

A5. Shadowgraph Method of Determining the Strength of a Shock Wave. P. C. Keenan, *Bureau of Ordnance, Navy Department, Washington, D. C.* (Introduced by R. J. Seeger).—Since the density in the shock wave from an explosion falls off almost linearly in the region immediately behind the shock front, shadowgraphs taken at two screen distances permit determination of the shock parameters: (1) peak density and (2) density gradient. On the basis of International Business Machine computations involving numerical integrations of the equation of the light path and a series approximation developed by Polachek, tables have been prepared to make possible the practical use of this method in the laboratory. The tables apply to shock waves of strengths normally encountered in air or in water. The relative peak density values of (P/P_0) for the air shocks extend from 1.3 to 4.6 and the range of screen distances is from 3 to 50 times the radius of the shock wave. For the underwater shocks the table covers density ratios from 1.04 to 1.35, corresponding to peak pressures ranging from 1000 to 26,000 atmospheres. Copies of the tables will be available in a NavOrd Report of the Bureau of Ordnance.

A6. Numerical Aspects of Quantitative Interferometry. F. Joachim Weyl, *Bureau of Ordnance, Navy Department, Washington, D. C.* (Introduced by R. J. Seeger).—The modern high precision version of the Mach-Zehnder Interferometer exhibits a qualitative sensitivity of such magnitude as to raise the hope that by its use quantitative experimental results in the study of gas dynamics can be obtained which allow a direct check on current theories. A knowledge of the accuracy with which the numerical reduction of an interferogram can be accomplished is therefore of vital interest. The discussion is restricted here to the analysis of axially symmetric flow where the problem presents itself in terms of an integral equation of well-known type whose solution can readily be written down analytically. The currently employed methods of reduction are briefly sketched, especially the one used by the Bureau of Ordnance, which has so far not been published. The error sources are exhibited, and the resulting uncertainties in the final answers are given in terms of the uncertainties in the basic measurements.

A7. Shock Waves in a Tube. WALKER BLEAKNEY, *Palmer Physical Laboratory, Princeton University.*—A tube of uniform cross section is divided into a compression chamber and an expansion chamber by a thin diaphragm. The pressure ratio between the two chambers is adjusted to a pre-assigned value and the diaphragm is burst by puncturing it at the center. If the dimensions are suitably chosen a plane shock having constant pressures on both sides of the discontinuity is propagated along the length of the expansion chamber. This is the simplest possible shock wave and is ideal for studying the properties of such phenomena. The strength of the shock is determined by the initial pressure ratio across the diaphragm and the velocity of propagation is a function of this strength. The measurement of the velocity which can be done with precision allows the shock strength to be computed with considerable accuracy. The shock tube is used to study the behavior of various gauges and in particular to calibrate such devices. By means of optical methods such as shadow and Schlieren photographs, the behavior of shocks on reflection at a boundary have been studied.

A8. Photographic Investigation of the Reflection of Plane Shocks in Air. L. G. SMITH, *Palmer Physical Laboratory, Princeton University.*—Studies by shadow and Schlieren photography of the reflection at a plane rigid wall of plane shocks produced in a tube show that regular reflection occurs for all angles α between incident shock and wall up to an angle slightly greater than the extreme angle α_e beyond which the two-shock theory shows that regular reflection is impossible and that for larger angles α Mach reflection occurs. The angle α at which Mach reflection sets in has been located between the limits α_c where signals from the corner of the wall first affect the entire reflected shock and $\alpha_{x=0}$ an empirically determined value from 1 to 4 degrees larger than α_c. (α_e is larger than α_c by 0.5 degree or less for all shock strengths.) The Mach reflection configuration may be described at any time t after the incident shock struck the corner in terms of two variables x/t and y/t instead of three such as x, y, and t. Thus the triple point moves along a straight line through the corner away from the wall and angles between shocks at the triple point remain unchanged as the configuration grows. Measured values of the angle α' between the reflected shock and the wall in regular reflection agree well with those predicted by the two-shock theory for all but the strongest shocks where slight unexplained discrepancies are observed. In Mach reflection, measured values of the angles agree with those predicted by the three-shock theory only for strong shocks. For weak shocks the measured values show conclusively that the simple three-shock theory is inadequate.

A9. Theory of Reflection of Shock Waves. A. H. TAUB AND L. G. SMITH, *Palmer Physical Laboratory, Princeton University.*—The Schlieren photographs obtained by Smith indicate that the regions bounded by the shocks are not uniform but have variations in density which are to be interpreted as due to variations in pressure. These do not seem to be "angular" in character, that is, they are not independent of the distance from the triple point and a function only of the angle a radial line makes with the incident shock. Because of the fact that the whole phenomenon is a function of x/t and y/t one must expect that pressure variations would be angular around the triple point. The only known pressure variations of this type are the Prandtl-Meyer waves, but such waves are inadequate to account for Smith's results. The experiments of Smith reported in the previous paper conflict with the predictions of the three-shock theory. There are no solutions to the equations describing this system for certain angles of incidence of the flow and certain (weak) shock strengths. However Smith has shown that the Mach configuration exists for just these angles and shock strengths.

A10. Interaction of Shock Waves and Boundary Layers in Supersonic Gas Flow.* JOHN WINCKLER, *Palmer Physical Laboratory, Princeton University* (Introduced by R. Ladenburg).—Recently** it was shown how quantitative values of density, pressure, temperature, velocity, and Mach number in supersonic gas streams could be obtained optically by the use of an interferometer. The Mach number M may be obtained independently by making shadow photographs of the head wave of a narrow probe placed in the stream. Probe and interferometer Mach number values were in good agreement in a homogeneous stream from a Laval nozzle, but in complete disagreement in an inhomogeneous expanding air jet in the region where standing shock waves occur. This discrepancy has been traced to the influence of the standing shocks on the air flowing at low velocity in the boundary layer along the probe. The shock pressure may cause a separation of the stream from the probe, and a configuration of normal and oblique shocks arises as a result at the region of separation. Further experiments made in a strictly one-dimensional stream show an analogous separation of flow when a normal standing shock wave intercepts the boundary layer. The theory of separation is discussed in the light of some earlier work of Prandtl and Stodola.

* This research sponsored by the Navy Department, Bureau of Ordnance.

** R. Ladenburg, C. C. Van Voorhis, and J. Winckler, "Interferometric study of gas flow around various objects in a free supersonic homogenous air-jet"; J. Winckler, C. C. Van Voorhis, and R. Ladenburg, "Optical analysis of the structure of supersonic inhomogeneous air-jets," Bull. Am. Phys. Soc. 21, No. 1 (Jan. 24, 1946).

A11. Influence of Atmospheric Pressure on Water Entry Phenomena. DAVID GILBARG, *Naval Ordnance Laboratory, Washington, D. C.* (Introduced by George H. Shortley).—Systematic high-speed photographic studies are made of the dependence of air-water entry cavities on the relevant physical parameters; in particular on the atmospheric pressure over the water surface. Experiments on the vertical entry of spheres and cylinders $\frac{1}{4}''$ to $1''$ in diameter, with entrance velocities between 15 ft./sec. and 100 ft./sec., and air pressures between 1/60 atmosphere and three atmospheres, show that surface sealing of the cavity is a major factor in controlling cavity formation, and is most responsible for non-scaling of cavity phenomena. Surface sealing is a function chiefly of the atmospheric density and projectile velocity, but for small projectiles, surface tension also has an important effect. The measured drag of the projectiles is independent of cavity size and shape. Jets are found to occur regularly and with great strength at both deep and surface closures of the cavity. The observed presence of jets in finite cavities is predicted by an extension of the Kirchhoff, Helmholtz, Levi-Civita theory of the infinite (two-dimensional) cavity to the case of finite cavities with finite cavitation numbers. This extended theory requires the existence of jets in finite cavities.

A12. Ultrasonic Absorption and Velocity Measurements in Liquids by Means of Pulse Techniques.* JOHN R. PELLAM AND JOHN K. GALT, *Radiation Laboratory, Massachusetts Institute of Technology.*—Radiation Laboratory equipment has been modified for measurements of sound velocity and absorption in liquids at 10–30 mc. Pulses of one micro-second duration are generated by a transducer, which also picks up the resultant echoes returning from a plane reflector. Velocity measurements are made by determining the distance the transducer must be moved to delay the received echoes by a specified increment. Absorption measurements are made by determining the attenuation necessary to keep the receiver signal constant as the transducer is moved. Preliminary results indicate that the attenuation factor can be measured to an accuracy of 5 percent and sound velocity to about 0.05 percent. Measurements of absorption in homologous series of organic liquids will be reported.

* This paper is based on work done for the Office of Scientific Research and Development under Contract OEMar-262.

B1. A High Intensity Velocity Selector for Neutral Atoms. H. LEVINSTEIN AND H. R. CRANE, *University of Michigan.*—A high intensity velocity selector has been constructed and operated in order to investigate the way in which the character of evaporated metal films depends upon the velocity of the atoms during deposition. The selector consists of a duralumin cylinder in which are milled a large number of helical channels. As the cylinder rotates about its axis, atoms having a velocity equal to the pitch of the helices times the angular velocity of rotation will move along the channels without hitting the sides. There are no "overtones," as there are in selectors employing slotted disks, and, for those atoms having the right velocity, the source "sees" the receiver 75 percent of the time. The rotor is enclosed in a vacuum chamber and is driven at 10,000 r.p.m. by means of magnetic pulses from a coil outside the vacuum. The "commutator" for the motor is a photoelectric cell, also outside the vacuum chamber, which sees a black spot on the rotor. Such a motor is self-starting and its speed is limited only by friction in the bearings. A synchronizing signal can be introduced to maintain constant speed. Preliminary results on the metal films deposited will be given.

B2. Control and Recording Circuits for A Magnetic Beta-Ray Spectrograph. W. C. PEACOCK AND R. K. OSBORNE, *Massachusetts Institute of Technology.*—Circuits have been built for the automatic operation of a thin lens magnetic beta-ray spectrograph. Electrons are detected in a Geiger-Muller counter, and the counting rate must be determined for each value of magnetic field strength. Counting rates are determined by recording the time necessary to detect a predetermined number of counts, e.g., 3200. This time interval is stamped on a paper tape. Thereafter the magnetic field is automatically adjusted to a new predetermined value, and the counting rate measurement is repeated. Control of the magnetic field is accomplished by controlling the current in the lens coil. This current is supplied by a d.c. generator (amplidyne) whose field excitation is controlled by means of vacuum tubes. The coil current is monitored by the voltage drop across a small resistor in series with the coil. This voltage is compared with that across a potentiometer and a circuit arranged to control the generator field current to always reduce the voltage difference to zero. This circuit allows control of two important parameters, the probable error of the counting rate measurement, and the size of the momentum interval between successive points.

B3. Beta- and Gamma-Ray Spectra of La^{140}. R. K. OSBORNE AND W. C. PEACOCK, *Massachusetts Institute of Technology.*—The radiations from La^{140} (40 hr.), produced by deuteron bombardment of lanthanum, have been analyzed in a magnetic spectrometer and by the use of $\beta-\gamma$ and $\gamma-\gamma$ coincidence counters. A Fermi plot of the beta-rays from a source 5 mg/cm^2 thick shows that there are at least three beta-rays of energies 0.90 ± 0.03, 1.40 ± 0.03, and 2.12 ± 0.08 Mev, and intensities 20 percent, 70 percent, and 10 percent, respectively. Some evidence exists for a fourth weak beta-ray of energy 0.40 ± 0.10 Mev. Gamma-rays were studied by observing secondary electrons from a thin gold radiator. Photoelectron lines were observed for gamma-rays of energies 0.333, 0.505, 0.832, 1.61, and 2.52 Mev. These energy values are accurate to about 3 percent. The 1.61 Mev gamma-ray is more intense than the others by roughly a factor of five, and the 0.333 Mev gamma-ray is partially converted. Beta-gamma coincidence measurements with a calibrated gamma-ray counter gave a $\beta-\gamma$ coincidence rate of $(2.88\pm0.12)\times10^{-3}$ per beta-ray. This agrees with the rate expected if the 0.333 and 1.61 Mev gamma-rays are in cascade. Gamma-gamma coincidence measurements gave a $\gamma-\gamma$ coincidence rate of 1.65×10^{-3} per gamma-ray. A tentative disintegration scheme will be given.

B4. Positron Emission, Electron Capture Competition in Zn^{65}. WILFRED M. GOOD AND WENDELL C. PEACOCK, *Massachusetts Institute of Technology.*—Zn^{65}(245 *d*) has been reported to have a 1.14 Mev[1] gamma-ray and positrons of maximum energy 0.4 Mev.[2] Using a calibrated gamma-ray counter, $x-\gamma$ coincidences, and $e^{+}-\gamma$ coincidences we have found that 54 percent of the electrons are captured in the ground state of Cu^{65} while 46 percent go to the 1.14 Mev excited state. By angular correlation techniques it was found that 2.2 percent of the disintegrations go by positron emission directly to the ground state of Cu^{65}. Comparison will be made with previously studied ${}_{11}Na^{22}$, ${}_{23}V^{48}$, ${}_{25}Mn^{52}$, ${}_{27}Co^{58}$ (3) and with theory.

1 Deutsch, Roberts, and Elliott, Phys. Rev. **61**, 389 (1942).
2 L. A. DuBridge, private communication to Seaborg.
3 Good, Deutsch, and Peaslee, in publication.

B5. Nuclear Excitation Functions: 14-Mev Deuteron Reactions on Cu, Mg, and Al. E. T. CLARKE AND JOHN W IRVINE, JR., *Massachusetts Institute of Technology.*—Employing previously reported techniques,[1] excitation functions have been obtained for the production of several radioactive isotopes. Bombardment of a stack of 24 copper foils produces curves for the reactions $Cu^{63}(d, p)Cu^{64}$(12.8 hr.), $Cu^{63}(d, 2n)Zn^{63}$(38 min.), $Cu^{65}(d, 2n)Zn^{65}$(250 d.), and $Cu^{65}(d, \alpha)Ni^{63}$(2.5 hr.). The (d, p) reaction cross section begins at about 2 Mev, shows a maximum $\sigma = 0.25 \times 10^{-24}$ cm² at 8.0 Mev, and decreases with further increase in energy. The (d, α) reaction begins at 9.5 Mev and increases with energy. Both $(d, 2n)$ reaction cross sections rise with increase in energy: Zn^{63} exhibits a threshold at 7.0 Mev and reaches a cross section of 0.30×10^{-24} cm² at 14.0 Mev, while Zn^{65} shows a threshold at about 5.5 Mev and rises to $\sigma = 0.51\times 10^{-24}$ cm² at 14.0 Mev. The two (d, α) reactions in magnesium foils produce similarly shaped excitation functions, both starting at about 2 Mev; Na^{24}(14.8 hr.) reaches a maximum $\sigma = 0.095\times 10^{-24}$ cm² at 8.7 Mev, while Na^{22}(3.0 y.) reaches a maximum $\sigma = 0.15 \times 10^{-24}$ cm² at 9.5 Mev. Both curves decrease steadily beyond their maxima. Bombardment of aluminum foils produces Na^{24} by an unknown reaction, possibly $(d; p, \alpha)$, beginning at about 10 Mev and reaching a cross section of 0.017×10^{-24} cm² at 14.0 Mev.

1 E. T. Clarke and John W. Irvine, Jr., Phys. Rev. **66**, 231 (1944).

B6. Nuclear Induction. F. BLOCH, W. W. HANSEN, AND MARTIN PACKARD, *Stanford University, California.*—The nuclear magnetic moments of a substance in a strong magnetic field H_z would be expected to give rise to a small magnetic polarization, provided thermal equilibrium be established, or at least approached. A superimposed oscillating field H_x in the x direction will produce a change in orientation of the polarization with a component perpendicular to the strong field. The latitude of the polarization can be shown to decrease upon adiabatic approach to magnetic resonance, the rotating component having an appreciable value only if the Larmor frequency in the strong field lies very close to the frequency of the oscillating field. The maximum value of its y component is of interest as to its location in frequency, its phase relative to the oscillating field, and its magnitude. The former two yield directly the value and sign of the nuclear gyromagnetic ratio while the latter is related to the quantized spin value j through Langevin's formula for the nuclear magnetic susceptibility. Observation of the voltage induced by the y polarization can therefore be used to obtain these three data and it will also furnish interesting information about relaxation times and the establishment of spin equilibrium.

B7. Nuclear Induction. MARTIN PACKARD, W. W. HANSEN, AND FELIX BLOCH, *Stanford University, California.*—In observing the above effect the horizontal field H_z was varied periodically at 60 c.p.s., the value being $H_0+\Delta H \cos 377t$ with $1650 < H_0 < 2200$ and $\Delta H \sim 50$ gauss. The oscillating field H_x of magnitude ~ 5 gauss and $7.7 < \nu < 10.7$ mc was produced by a coil with axis horizontal. A second coil, inside the first, and with vertical axis, had voltage induced in it by the rotating moments, and also by the (adjustable) leakage flux from the other coil. The water, which supplied the proton moments used, was contained inside the inner coil in a glass sphere of volume $\sim$.5 cc. The resulting voltage was rectified and amplified, the d.c. due to leakage being removed by the amplifier. The output, whose variations are a measure of the variation of the rotating moment, was applied to the vertical plates of a c-r oscillograph, the horizontal plates being supplied with a voltage proportional to the variations in H_z. Thus the complete magnetic resonance curve is traced cyclically on the oscillograph screen. The curves so plotted showed resonance peaks with the expected aspects and at a constant ratio of the H_z and driving frequency.

B8. Theory of Magnetic Resonance Absorption by Nuclear Moments in Solids. H. C. TORREY, *Radiation Laboratory, Massachusetts Institute of Technology,* AND E. M. PURCELL AND R. V. POUND, *Harvard University.*—If a "diamagnetic" solid containing nuclei of spin I and magnetic moment μ, is placed in a steady magnetic field H, there will be $2I+1$ Zeeman levels separated in energy by $\Delta w = \mu H/I$. Application of a radio-frequency magnetic field perpendicular to H induces transitions between adjacent levels when the frequency is near the resonant value, $\nu = \Delta w/h$. If the population of adjacent levels is unequal, as in thermal equilibrium, there will be a net absorption of energy. At thermal equilibrium the imaginary part of the permeability at resonance is of order $\Delta w/kT$. Although this quantity is small, the effect is easily observable (see the following abstract). Precision measurements of gyromagnetic ratio, (μ/I), are possible for most moderately abundant nuclei. Nuclear spin can be determined[1] by measurement of integrated absorption which is proportional to $I(I+1)$ for constant μ/I. The population of the levels tends to become equalized by transitions induced by the r-f field. This is opposed by transitions induced by spin-lattice coupling tending to restore thermal equilibrium. By balancing these effects through adjustment of the r-f field intensity, the spin-lattice relaxation time may be measured.

1 We are indebted to Dr. W. W. Hansen for calling our attention to this fact.

B9. Measurement of Magnetic Resonance Absorption by Nuclear Moments in a Solid. R. V. POUND AND E. M. PURCELL, *Harvard University*, AND H. C. TORREY, *Radiation Laboratory, Massachusetts Institute of Technology.*—We have observed resonance absorption at 29.8 mc/sec. by magnetic moments of protons in solid paraffin at room temperature. A capacitatively loaded coaxial line resonator, filled with paraffin, was placed in a large magnet with the steady magnetic field perpendicular to the r-f magnetic field. The resonator formed one arm of an r-f bridge. The unbalance-signal produced by a small change in resonator transmission was amplified, detected and indicated on a meter. Resonance absorption occurred at a field of 7100 gauss, in agreement, within the probable error of our calibrations, with the known gyromagnetic ratio of the proton. The width of the absorption line, at half value, was 10 gauss, perhaps due in part to field inhomogeneities, and the maximum diminution in cavity transmission was 0.4 percent. The integrated line strength is in agreement with the theoretical prediction. The relaxation time was less than one minute, contrary to previous predictions of several hours. A more uniform and controllable field, more flexible circuit and detection of an a.c. component in the resonator output, coherent with modulation of the steady field would allow the method to be applied for a wide range of gyromagnetic ratios and nuclear concentrations.

B10. Spontaneous Emission Probabilities at Radio Frequencies. E. M. PURCELL, *Harvard University.*—For nuclear magnetic moment transitions at radio frequencies the probability of spontaneous emission, computed from

$$A_\nu=(8\pi\nu^2/c^3)h\nu(8\pi^3\mu^2/3h^2)\ \text{sec.}^{-1},$$

is so small that this process is not effective in bringing a spin system into thermal equilibrium with its surroundings. At 300°K, for $\nu=10^7$ sec.$^{-1}$, $\mu=1$ nuclear magneton, the corresponding relaxation time would be 5×10^{21} seconds! However, for a system coupled to a resonant electrical circuit, the factor $8\pi\nu^2/c^3$ no longer gives correctly the number of radiation oscillators per unit volume, in unit frequency range, there being now *one* oscillator in the frequency range ν/Q associated with the circuit. The spontaneous emission probability is thereby increased, and the relaxation time reduced, by a factor $f=3Q\lambda^3/4\pi^2V$, where V is the volume of the resonator. If a is a dimension characteristic of the circuit so that $V\sim a^3$, and if δ is the skin-depth at frequency ν, $f\sim\lambda^3/a^2\delta$. For a non-resonant circuit $f\sim\lambda^3/a^3$, and for $a<\delta$ it can be shown that $f\sim\lambda^3/a\delta^2$. If small metallic particles, of diameter 10^{-3} cm are mixed with a nuclear-magnetic medium at room temperature, spontaneous emission should establish thermal equilibrium in a time of the order of minutes, for $\nu=10^7$ sec.$^{-1}$.

B11. Fast Neutron Collision Cross Sections of C and H. WILLIAM SLEATOR, JR., *University of Michigan.*—Collision cross sections of C and H for D-Li neutrons have been measured at several neutron energies. The intensity of the neutron beam in each energy interval was determined with a detector consisting of a thin layer of paraffin, placed in the beam, and a coincidence ionization chamber[1] arranged to count recoil protons from the paraffin. Protons due to neutrons with energies outside the desired interval were eliminated with absorbers or included in the background count. The scatterers, blocks of graphite, and paraffin 15-cm square, were placed at the hole in the water wall, 274 cm from the cyclotron target and 154 cm from the detector (sensitive area 8 cm in diameter). The observed

TABLE I.

Energy (Mev) Center of interval	Limits of interval	$\sigma\times10^{24}$ (cm^2) $n-C$	$n-p$
15	13.4–16.5	1.23	0.61
16.6	15.3–17.8	1.29	0.66
18	16.8–19.1	1.13	0.55
19.5	18.3–20.6	1.32	0.52
21	19.7–22.3	1.17	0.41

cross sections σ for five energies are given in Table I. In each run the uncertainty in σ due to statistical fluctuations was below 10 percent. Runs on different days and with scatterers of different thickness agreed within this range.

[1] Howard Tatel, Phys. Rev. 61, 450 (1942).

B12. Polarization of Neutrons by Resonance Scattering in Helium. JULIAN SCHWINGER, *Harvard University.*—Neutron scattering in helium exhibits an anomaly for neutron energies in the vicinity of 1 Mev, which has been attributed to a P resonance associated with the formation of the unstable He^5 nucleus. The energy dependence of the cross section for back-scattering is accounted for qualitatively on the assumption of a splitting of the two P levels associated with $J=1/2$ and $3/2$, with an energy separation comparable with the width of each level, $|E_{1/2}-E_{3/2}|\sim\Gamma\sim0.4$ Mev. In consequence of the large energy difference between the levels, a neutron scattered by He in the resonance region is effectively subjected to a strong spin-orbit interation, which manifests itself in a polarization of neutrons scattered through a definite angle. The polarization effects are quite large; neutrons scattered through 90° in the center of mass system are practically completely polarized at energies corresponding roughly to the positions of the two levels, the direction of polarization being reversed at the two resonances. The polarization effect can be exhibited by a second scattering process, the resultant intensity being asymmetrical relative to the direction of the first scattered neutron. For neutrons scattered twice through 90° in the center of gravity system, the intensity ratio can be as great as ten. An essential factor contributing to this large ratio is that the energy loss on the first collision is comparable with the doublet separation, whence large polarization effects can occur at both collisions. The polarization effect offers the possibility of producing strongly polarized beams of thermal neutrons by slowing down polarized neutrons in a non-depolarizing medium. The investigation of depolarization in various substances is also of interest.

C1. Noise in Radar Crystal Detectors.[1] L. I. SCHIFF, *University of Pennsylvania.*—The minimum noise produced by a radar crystal detector has been calculated with the assumption that the thickness of the blocking layer is small compared to the electron mean free path. For d.c. bias voltage V, current I, and dynamic resistance $R = dV/dI$, the ratio of noise temperature to actual temperature is $(eIR/2kT)$ coth $(eV/2kT)$. This is equal to unity for $V=0$, as it must be, but can be less than unity for finite V. The mechanism considered is the shot effect of electrons crossing the blocking layer; this gives a frequency-independent noise spectrum. Superposed on this, there is often a large amount of "excess noise" which increases at low frequencies;[2] this is not understood at present.

[1] This work was done in whole under Contract No. OEMsr-388 with The Trustees of the University of Pennsylvania under the auspices of the Office of Scientific Research and Development, which assumes no responsibility for the accuracy of the statements contained herein. Original report issued March 10, 1943.
[2] P. H. Miller, Jr., "Noise Spectrum of Crystal Mixers," 1946 IRE Winter Technical Meeting.

C2. High Frequency Rectification Efficiency of Radar Crystal Detectors.[1] A. W. LAWSON, B. GOODMAN, AND L. I. SCHIFF, *University of Pennsylvania.*—The rectification efficiency of a radar crystal detector is expected to decrease with increasing frequency because of the shunting effect of the capacity of the blocking layer. The observed decrease is not as great as that predicted by a theory which assumes that the capacity is constant. If however a finite time is required to ionize the semi-conductor donator levels in the blocking layer, the capacity of the contact will depend on the frequency. For oscillation periods of the order of or smaller than the ionization time, the charging current and hence the capacity will be smaller than their low frequency values. This ionization time has been calculated by considering the interaction between the electrons and the Debye waves of the crystal lattice. The transition probability of an electron from a bound donator state to the continuum is found to be 10^9 to 10^{10} sec.$^{-1}$ for a typical silicon rectifier. This is of the right order of magnitude to explain the frequency dependence of the rectification efficiency in the microwave region.

[1] This work was done in whole under Contract No. OEMsr-388 with The Trustees of the University of Pennsylvania under the auspices of the Office of Scientific Research and Development, which assumes no responsibility for the accuracy of the statements contained herein. Original report issued July 7, 1943.

C3. Rectification Series. WALTER H. BRATTAIN, *Bell Telephone Laboratories, Inc.*—It is known that point contacts between metals and certain crystals rectify. Considering only the sign of rectification, one classifies all such crystals into two types, P and N. For the P type the direction of easy flow occurs when the crystal is positive, and for the N type when the crystal is negative. Taking one of these crystals and making a point out of it, one finds that the contacts between it and the other crystals rectify and that using this crystal point as a reference a new division depending on sign of rectification will be obtained. If this process is continued on a given group of crystals it has been found that the group can be arranged in a rectification series such that any crystal in the series will rectify one way with those above it and the other way with those below it. Crystals of silicon, SiC, ZnO, and PbS, one or more of each, have been arranged in such a series. Different crystals of any given element or compound will, in general, be found in different places in the series, sometimes far apart.

C4. D.C. Characteristics of Ge and Si Crystal Rectifiers.* H. J. YEARIAN, *Purdue University.*—Current theories of crystal rectification predict currents in the low resistance (forward) direction which rise exponentially with the voltage across the contact for $V \gg e/kT$, and which approach a saturation current in the high resistance direction. In i *vs.* V plots for the forward direction should have a slope $\alpha = e/kT = 40$ volt^{-1} at 300°K. Characteristics of Ge and Si rectifiers usually have an exponential behavior, but α is always less than e/kT, frequently between $\frac{1}{3}$ and $\frac{1}{2}$ of this value. The current in the back direction has a saturation component but also an ohmic component, and a rapidly increasing "tail" at higher voltages. More elaborate theories which include the effects of image forces in lowering the barrier, and of penetration of the barrier, give logarithmic slopes less than e/kT and a "tail" in the back direction. However, such corrections cannot explain the values of α most frequently found without eliminating at the same time the conditions necessary for rectification.

* This work was part of a research program carried out under Contract No. OEMsr-362 between Purdue University Research Foundation and the Office of Scientific Research and Development. Based on NDRC reports, December 3, 1942 and August 14, 1943.

C5. Theory of Crystal Rectifiers.* R. G. SACHS, *Purdue University.***—The observed d.c. current-voltage characteristics for point contacts between metal and semiconductor, Ge and Si, cannot be explained by the diffusion of electrons through a blocking layer at the contact. The ordinary diode theory predicts a characteristic with too steep a slope in the forward direction. Consideration of tunnel effect and the effect of positive space charge does not produce agreement. The multi-contact theory, introduced to explain the observed characteristics, assumes that: (1) The contact potential ϕ varies continuously over the surface of contact. (2) The total current is the sum of the partial currents flowing through regions of varying ϕ. (3) The area of a region with a contact potential ϕ may be a function of ϕ. (4) The number of spots having contact potential between ϕ and $\phi + d\phi$ is a function of ϕ. A Gaussian distribution of ϕ values is assumed. Correction is made for the effect of the image force. Characteristics calculated under these assumptions approximately agree with the observed characteristics.

* This work was part of a research program carried out under Contract No. OEMsr-362 between Purdue University Research Foundation and the Office of Scientific Research and Development. Based on NDRC report on June 15, 1943.
** At present, Metallurgical Laboratory, University of Chicago.

C6. Semi-Quantitative Explanation of D.C. Characteristics of Crystal Rectifiers.* V. A. JOHNSON, R. N. SMITH, AND H. J. YEARIAN, *Purdue University.*—The multi-contact theory is employed to explain the observed d.c. current-voltage characteristics for contacts between metal and semi-conductor (Ge and Si). The area of each spot having contact potential ϕ and the number of spots having contact potential between ϕ and $\phi+d\phi$, are assumed to be exponential functions of ϕ. The parameters of these functions may be determined from measured values of the limiting current in the back direction, the back resistance, and the intercept at zero applied voltage of the forward current. Current limitation is introduced so that the current density does not exceed the maximum current density carried by N electrons per cm^3 (known from Hall effect) moving with thermal velocity. The proper slopes are obtained for the forward current. The variation of characteristic with temperature change can be explained by assuming a corresponding change in distribution of ϕ values. A graphical method of applying the multi-contact theory has been developed such that any characteristic may be rapidly synthesized.

* This work was part of a research program carried out under Contract No. OEMsr-362 between Purdue University Research Foundation and the Office of Scientific Research and Development. Based on NDRC report August 14, 1943.

C7. Small Deviations from Diode Behavior in Crystal Rectification.* K. F. HERZFELD, *Catholic University of America*.—The blocking layer in a crystal rectifier, may be treated according to diode theory if the mean free paths of the electrons is very large compared to the dimensions of the blocking layer so that no collisions occur. The diffusion theory assumes a mean free path very small compared to the thickness of the blocking layer. To get a better insight into the behavior of the electrons it has been assumed that the mean free path is large, but not infinitely large compared with the thickness of the blocking layer, so that some collisions occur, but multiple scattering can be neglected. It is assumed that "collision" means absorption and reevaporation. Simple formulae derived from these assumptions give less dependence of the current on voltage then in pure diode theory, but the effect is very small.

* This work was part of a research program carried out under Contract No. OEMsr-362 between Purdue University Research Foundation and the Office of Scientific Research and Development. Based on NDRC report, May 5, 1944.

C8. Contact Capacity of Crystal Rectifiers.* R. N. SMITH, *Purdue University*.—The capacity across the rectifying point contact formed at a metal semi-conductor interface, has been measured by an indirect method for germanium and silicon mixer crystals. The decrease in efficiency of rectification as the frequency is increased to very high (microwave) frequencies is used to calcu ate the capacity. Two assumptions are made. (1) Crystal rectifiers may be represented by a non-linear contact resistance in parallel with the contact capacity, both in series with a fixed "spreading" resistance. (2) The resistance elements of the rectifier model are independent of frequency. The contact capacity was measured as a function of d.c. bias voltage between + and − one volt bias. For silicon units, the capacity increased slowly at first, as the bias was increased in the forward (low resistance) direction, increasing more rapidly as the voltage across the contact approached the contact potential of the metal-semi-conductor. This behavior is in qualitative agreement with that predicted for a rectifying contact of the "natural barrier" type. For germanium units, however, the increase in capacity with forward bias voltage, was much greater. The discrepancy is great enough to necessitate modification of the simple model and/or the theory of rectification for germanium.

* This work was part of a research program carried out under Contract No. OEMsr-362 between Purdue University Research Foundation and the Office of Scientific Research and Development. Based on report given at NDRC Crystal Meeting, on October 1, 1945.

C9. High Voltage and Photo-Sensitive Characteristics in Germanium.* S. BENZER, *Purdue University*.—Some germanium crystal rectifiers are able to withstand high inverse voltages (as high as several hundred volts) without damage, while large currents are passed in the low resistance direction. The back direction characteristic is double-valued; a voltage peak occurs followed by a negative resistance region. The effects upon the characteristic of temperature, frequency, composition of the germanium sample and the metal electrode at the point contact, treatment of the surface and the contact, and illumination will be described. Other unusual characteristics with pronounced sensitivity to illumination and temperature have also been observed in germanium crystals: (1) a saturated $i-V$ characteristic where the saturation current varies with illumination and temperature and (2) a triple-valued characteristic exhibiting a voltage peak followed by a negative resistance region which becomes positive again at higher currents. In the latter type, illumination or increased temperature eradicates (reversibly) the voltage peak and negative resistance, leaving a single-valued curve. These photo-effects are observable with light in the visible and near infra-red, the maximum sensitivity occurring at about 1.3μ.

* This work was part of a research program carried out under Contract No. OEMsr-362 between Purdue University Research Foundation and the Office of Scientific Research and Development. Based on NDRC Reports: November 1, 1944; December 26, 1944; and October 31, 1945.

C10. Effect of Various Atmospheres on Germanium Crystal Rectifiers.* R. M. WHALEY AND K. LARK-HOROVITZ, *Purdue University*.—Quantitative measurements of voltage-current characteristics have been made for point contacts on various germanium samples prepared in a high vacuum ($\sim 3\times 10^{-6}$ mm Hg), tested in a vacuum, and after admission of gases at various pressures. Samples fall into three classes. (a) Relatively high purity germanium which provided poor rectification in a vacuum and was unchanged by admission of gas. (b) One sample which showed reversible changes upon admission of air. (c) Samples of relatively high conductivity, due to impurity content, which provided good rectification in vacuo and showed irreversible increases in back resistance by factors of 10 to 1000 upon admitting air. Similar changes, usually to lesser extent, followed admission of nitrogen. Observed changes can be accounted for using the multi-contact theory by assuming the removal of very small areas of low positive contact potentials, either by covering them with insulating layers or by converting them to regions of higher positive contact potential. On highly conducting samples, irreversible increases in back resistance were most pronounced at low voltages, but increases did extend to the voltage peak. The peak voltage sometimes was increased by admission of air, usually by factors less than two.

* This work was part of a research program carried out under Contract No. OEMsr-362 between Purdue University Research Foundation and the Office of Scientific Research and Development. Based on paper given on November 19, 1943, at OSRD Crystal Group meeting in New York City.

C11. Image Force and Tunnel Effect in Crystal Rectifiers.* E. D. COURANT, *Cornell University.*—According to elementary theory, the current i through a rectifying junction between a metal and a semi-conductor should vary with the applied voltage U according to

$$i=i_0\left[\exp\left(-\frac{V_c-U}{kT}\right)-\exp\left(-\frac{V_c}{kT}\right)\right], \qquad (1)$$

where V_c is the contact potential, and V_c-U the height of the potential barrier. Experimentally it is found that i increases with U less rapidly than indicated by (1), for positive U, and $|i|$ increases with increasing negative U instead of tending to a constant value, as indicated by (1). Both these effects may be explained by assuming that the height of the potential barrier is reduced by the image force and that some electrons tunnel through the barrier near its top. As a result of these two effects the potential barrier is in effect reduced to $\theta(V_c-U)$, where $\theta<1$, and (1) must be multiplied by

$$\exp\left[-(1-\theta)\frac{V_c-U}{kT}\right].$$

Graphs of θ as a function of U are shown and compared with experimental measurements.

* Work done in 1943 under Contract OEMsr-429 between Cornell University and OSRD, which assumes no responsibility for statements contained herein.

C12. Some Thoughts about Gravitation of Celestial Bodies and Photophoretic Forces. FELIX EHRENHAFT, *New York.*—The law of conservation of momentum in electrodynamics, is in contradiction with the experimental facts. The ponderomotive forces exerted by radiation on matter cause helical paths in longitudinal and transversal photophoresis.* A connecting link between celestial bodies is radiation including magnetic current. The movements in the atom cannot directly be observed, however the atom model was originally taken from observable movements in the solar system. It will be attempted to correlate the directly observable photophoretic paths of testbodies moving with six degrees of freedom in the field of solar radiation** with the paths of celestial bodies, for instance, the planets in the sun's radiational field. If these movements around the sun are regarded as transversal photophoresis, Newton's attractive force as negative longitudinal photophoresis, the excess of the earth's electric charge could be calculated being negative, the earth moving clockwise when looking from the magnetic north (geographic south) to south in accord with Ampère's rule. Because of the ponderomotive actions of solar radiation the usual thermally measured solar constant seemingly represents only part of the energy as indicated by the behavior of test bodies in solar radiation. The author does not claim to explain herewith all gravitational actions but any unified field theory should reckon with these phenomena.

* F. Ehrenhaft, Ann. d. Physik **56**, 81 (1918); Comptes rendus **190**, 263 (1930); Ann. de physique **13**, 151 (1940); J. Frank. Inst. **230**, 381 (1940); **233**, 235 (1942); Science **101**, 676 (1945).
** F. Ehrenhaft, Bull. Am. Phys. Soc., Metropolitan Meeting **19** (Nov. 9, 1945); St. Louis Meeting, E 7 (Dec. 1, 1945); New York Meeting, A 10 and T 1 (Jan. 24, 1946).

C13. World Peace Established on Natural Law and Order Instead of Legislation. H. G. WEHE, *Summit, New Jersey.*—The proposition is offered that world peace depends upon law and order; that the alternative to law and order is chaos; that with chaos there can be neither security nor peace. There are two kinds of law and order. There is the natural law and order built into the universe by the Creator and revealed by careful observation, analysis, and synthesis of ideas and controlled reproducible experiment both objective and subjective. This law and order has five classifications: (a) the Creator's relationship with man, (b) man's relationship with his fellow men, (c) man's relationship with other forms of life in all parts of the universe, (d) man's relationship to energy including matter, and (e) matter and energy interrelationships. Because of ignorance of natural law and order—man's scientific knowledge of the universe is very recent historically—man has permitted lawyer-politicians to set up various forms of government which attempt by edicts and legislation to establish a man-made law and order often in direct violation of natural law and order. Would not peace—harmony with natural law and order—be better attained if lawyer-politicians in government were replaced with scientists skilled in discovering and administering natural law and order?

F1. Diffraction Pattern of a Circular Aperture at Short Distances. C. L. ANDREWS, *General Electric Research Laboratory.*—The diffraction pattern of a circular aperture was studied at distances from zero to five wave-lengths from a circular aperture. Microwaves of 12.8 cm wave-length were employed. The aperture was an iris diaphragm that could be varied between one and six wave-lengths in diameter. The beam was incident normally upon the plane of the aperture from a 4-ft. parabolic reflector 24 ft. away. The sharpest diffraction patterns were in the plane of the aperture. Measurements were made of the intensity of radiation in the electric and magnetic planes through the axis. The individual plots were made of intensities along the diameter and along lines parallel to the diameter at steps of quarter-wave-lengths from the diameter. Measurements were also made of the intensities at fixed points along the axis as the diameter of the iris was varied from one to six wave-lengths. It was seen that Fresnel zone theory could be employed as a rule of thumb even in the illogical case of predicting the intensity at the center of the aperture. Checks were made against Kirchhoff's theorem.

F2. An Interferometric Method for the Determination of the Resolving Power of Spectroscopes. K. W. MEISSNER, *Physics Department, Purdue University.*—If a Perot-Fabry interferometer is crossed with a stigmatic spectroscope in the usual manner and continuous light is employed, a "channeled spectrum" is obtained, provided that the slit of the spectroscope is very narrow. The channeled spectrum consists of parabolic fringes which are convex towards longer wave-lengths. The distance between consecutive fringes decreases with incereasing separation of the interferometer plates and when a certain separation has been reached the fringes cannot be resolved anymore. By determining this critical separation of the interferometer plates, one is able to find the resolving power of the spectroscope. If the resolving power of the interferometer is much greater than that of the spectroscope, a condition which is always fulfilled, the resolving power of the spectroscope is given by $R=2t_c/\lambda$, where t_c is the critical separation and λ the wave-length of the observed region. The method can also be employed for astigmatic spectroscopes if only the central part of the slit is used.

F3. The Light of the Night Sky in the Ultraviolet Range. GEORGES DEJARDIN AND JEAN DUFAY, *Université de Lyon.*—From study of the data obtained by other observers (Elvey, Swings, and Linke; Barbier) and by ourselves, we have set up a wave-length table of emission-maxima in the ultraviolet part of the spectrum of the night sky, comprising only such maxima as we consider to be certainly present. Also we have made a critical study of the identifications hitherto proposed for these maxima, testing the identifications by comparing the number of coincidences (between observed and conjectured maxima) with the number to be expected at random. The Vegard-Kaplan bands are certainly present, but are few and weak in the ultraviolet. Apart from these, our study indicates that the most probable systems are: (a) the Herzberg bands (v' uncertain) and the Schumann-Runge bands ($v'=0$ and $v'=1$) of O_2 and (b) the Lyman bands ($v'=0$ and $v'=1$) of N_2. The Herzberg band system, little known as yet, seems to account for some of the strongest and most characteristic features. Bands of OH and CH are doubtful but possible, and there may also be bands not yet observed in the laboratory. In the ultraviolet as elsewhere, the spectrum of the night sky appears as a "weak-excitation" spectrum: the transitions to the normal state (of O_2 and N_2) are the most reliably identified of all.

F4. The Normal Coordinates of a Mono-Substituted Benzene Molecule. N. GINSBURG AND J. L. GAMMEL, *The University of Texas, Austin, Texas.*—By means of group theoretical methods the kinetic energy of the molecule is written down in terms of symmetry coordinates. The potential energy is expanded in terms of nine potential constants of the type used by Wilson[1] for benzene. Since the frequencies appearing most strongly in the observed spectra of molecules of this type are the eleven totally symmetric frequencies, the secular determinant for these is expanded in order to obtain the mass dependency of the frequencies.

[1] E. B. Wilson, Phys. Rev. 45, 706 (1934).

F5. Ultraviolet Lamps and Ozone. ARTHUR W. EWELL, *Worcester Polytechnic Institute.*[1]—Bactericidal radiation (2537A) from a bactericidal lamp must often be supplemented, at completely shaded surfaces and stagnant air pockets, by a few tenths of one part per million of ozone, produced from the oxygen of the air by a few percent of 1850A radiation, also emitted by the lamp. The important factor is the ozone concentration—determined by the rates of ozone production and decomposition. The former is roughly proportional to the surrounding volume of air (up to a few cubic feet), and the amount of 1850 radiation, which depends upon the transmission of the glass of the lamp, is independent of the temperature (20° to 60°C) and is somewhat reduced by high humidity. The decomposition increases with rise in temperature and/or humidity, the presence of oxydizable or catalytic surfaces, and intense 2537 radiation. Approximately the same bactericidal effect upon surface infection is achieved by equal quantities of energy whether in absorption of 2537 radiation or in formation heat of required equivalent ozone. With air borne infection the bactericidal killing by ozone is nil at low humidity and very great at high humidity.

[1] Consultant, Westinghouse Electric Corporation.

F6. The Photoelectric Mechanism of the Thallous Sulfide Photo-Conductive Cell. A. VON HIPPEL, F. G. CHESLEY, H. S. DENMARK, P. B. ULIN AND E. S. RITTNER, *Laboratory for Insulation Research, Massachusetts Institute of Technology.*—This research was undertaken because the importance of the thallous sulfide cell for war communication systems required a better understanding of the properties and limitations of this photo-element. A quantitative study of the oxidation reaction, correlated step by step with x-ray and electron-diffraction photographs, established that the photo-sensitization is produced by oxygen, entering the structure in solid solution. Thermoelectric measurements showed that pure Tl_2S is an "excess" semi-conductor changing to a "defect" conductor on oxidation. Determination of the cell characteristics as a function of voltage, temperature, light intensity, wavelength, modulating frequency, and composition as well as an examination of the photo-response to light flashes of very short duration led to the formulation of a theory in quantitative agreement with all facts observed. The underlying physical picture is that light is absorbed in the Tl_2S proper and in the presence of oxygen, positive "holes" and negative oxygen ions are formed. The "holes" and ions recombine at a rate proportional to the product of their concentrations. During their lifetime, the negative ions act as space charge compensators for the defect conduction and allow correspondingly higher currents to flow. This space charge compensating action, which is similar to the role played by positive ions in gas discharges, seems to be one essential mechanism of producing secondary photo-effects.

F7. Some Properties of Infra-Red Sensitive Phosphors. R. T. ELLICKSON, *Polytechnic Institute of Brooklyn.*—There have been developed recently* by Urbach, Ward, Fonda and others, a group of phosphors that show a large increase in phosphorescence when irradiated by infra-red. Some properties of alkaline earth sulfide and selenide phosphors activated with two rare earths will be described. They show the effect to a marked degree. The shape of the brightness *vs.* time curves under constant infra-red stimulation indicates that the process is bi-molecular. Measurements of the amount of light stored in the phosphor indicate that under optimum conditions the number of quanta emitted by a fully excited phosphor is about 6×10^{17} per cubic cm. For these samples, the concentration of activators was 2×10^{17} Sm. and 16×10^{17} Ce ions per cubic cm.

* See the group of papers at the March, 1946 meeting of the Optical Society of America.

F8. The Velocity of Propagation of the Transmitted Photo-Effect in Silicon Crystals. F. C. BROWN, *Radiation Laboratory, Massachusetts Institute of Technology.*—The photo-conductivity effect, previously reported as transmitted in selenium crystals, is likewise transmitted in crystals of silicon. The relative magnitude of the transmitted effect is measured over a distance of 2 cm and is a function of the velocity, the coefficient of recapture (α), and the distance travelled. It is expressed by the equation,

$$1/N-1/N_0=\alpha(e^x-1)/V.$$

The velocity is measured directly for a distance of travel from 0.4 cm to 1 cm. This was carried out with a special oscilloscope and a light beam interrupted by a rotating disk. Within the above range the velocity is 400 meters/sec., with a probable error of about 5 percent. Thus far it has not seemed possible to check the velocity for a longer distance in order to satisfy the equation above. The set up made possible the use of an electronic method for determining the effective distance of travel.

F9. A New Bridge Photo-Cell Employing a Photo-Conductive Effect in Silicon. Some Properties of High Purity Silicon. G. K. TEAL, J. R. FISHER, AND A. W. TREPTOW, *Bell Telephone Laboratories, Inc.*—A pure photo-conductive effect was found in pyrolytically deposited and vaporized silicon films. An apparatus is described for making bridge type photo-cells by reaction of silicon tetrachloride and hydrogen gases at ceramic or quartz surfaces at high temperatures. The maximum photo-sensitivity occurs at 8400–8600A with considerable response in the visible region of the spectrum. The sensitivity of the cell appears about equivalent to that of the selenium bridge and its stability and speed of response are far better. For pyrolytic films on porcelain there are three distinct regions in the conductivity as a function of temperature. At low temperatures the electronic conductivity is given by the expression $\sigma=Af(T)\ \exp\ -(E/2kT)$. At temperatures between 227°C and a higher temperature of 400–500°C, $\sigma=A\ \exp\ -(E/2kT)$, where E lies between 0.3 and 0.8 ev; and at high temperatures, $\sigma=A\ \exp\ -(E/2kT)$, where $E=1.12$ ev. The value 1.12 ev represents the separation of the conducting and non-conducting bands in silicon. The long wave limit of the optical absorption of silicon was found to lie at approximately 10,500A (1.18 ev). The data lead to the conclusion that the same electron bands are concerned in the photoelectric, optical, and thermal processes and that the low values of specific conductances found (1.8×10^{-5} ohm^{-1} cm^{-1}) are caused by the high purity of the silicon rather than by its polycrystalline structure.

F10. Corpuscular vs. Undulatory Excitation of Phosphors. H. W. LEVERENZ, *RCA Laboratories, Princeton, New Jersey.*—Phosphors may be broadly classified, according to phosphorescence, as: (1) initially-exponential-decay (ϵ^{-t}), exhibited when oxygen or fluorine are dominant in the crystal anions and (2) power-law-decay (t^{-n}), exhibited when sulphur or selenium are dominant. Excitation of a phosphor to a given peak luminescence by ultraviolet affords a slower latter-stage decay than is obtained after cathode-ray (CR) excitation. This differential effect on phosphorescence is much greater for t^{-n}-decay phosphors. Normal CR excitation of efficient phosphors results in an expenditure of about 40 ev of CR energy per emitted quantum (≈ 2 ev), whereas ultraviolet excitation quanta are about 5 ev with quantum efficiency near unity. The tenfold lower energy efficiency during CR excitation heats the phosphor more, thereby accelerating at least the latter stages of decay. Phosphorescence may be augmented at the expense of fluorescence by cascading suitable cathodo-luminescent and photo-luminescent materials. The much larger differential effect on phosphorescence of t^{-n}-decay phosphors is attributed to the greater thermal sensitivity of their presumably interstitially-located activator centers as contrasted with the less perturbable activator centers in normal lattice sites of ϵ^{-t}-decay phosphors. The differential effect is related to the approximately 100-fold greater activator content and the toleration of 100-fold greater impurity content in ϵ^{-t}-decay phosphors.

F11. A Small Scale Hydrogen Liquefier. HENRY A. FAIRBANK, *Yale University.*—A simple inexpensive Hampson-type hydrogen liquefier, which combines many of the advantages of other small scale liquefiers,[1] has been built at Yale. The apparatus can be constructed from inexpensive and readily obtainable materials in any moderately equipped machine shop and occupies only a few feet of wall space in a laboratory room. No equipment which is unavailable in the majority of laboratories is required. Commercial compressed cylinder hydrogen is used, obviating the necessity of expensive compressors and bulky gasometers and considerably simplifying the purification system. A single charcoal trap immersed in liquid air or nitrogen removes the impurities from the hydrogen gas. The liquefier proper consists of a heat interchanger, a precooler using liquid air or nitrogen under reduced pressure as a refrigerant, a regenerative heat interchanger, a needle-type Joule-Thomson valve, and finally a can to contain the portion of the gas liquefied after expansion through the Joule-Thomson valve. The unliquefied gas passes back through the interchangers and is allowed to escape out the window. The liquid can be syphoned out to any external specimen flask through a double-walled Dewar-type metal syphon. Other details of design, operation, and efficiency are discussed.

[1] C. Starr, Rev. Sci. Inst. 12, 193 (1941).

G1. The Dependence of the Diffusion Coefficient on Concentration. B. SERIN, *University of Pennsylvania.*—It is assumed that the activation energy for the diffusion of foreign atoms in a solid lattice depends on the surrounding number of nearest neighbor foreign atoms. For equal *a priori* probabilities for the formation of different foreign atom configurations in the lattice, the diffusion coefficient D is

$$D=\delta^2\sum_{a_i=0}^{a} q_{a_i}\left\{\frac{a!(a_i+1)}{(a-a_i)!a_i!}\left[1-\frac{(a+1)}{(a_i+1)}f\right]f^{a_i}(1-f)^{a-a_i-1}\right\}.$$

q_{a_i} is the probability that a foreign atom with a_i other foreign atoms as nearest neighbors will make a jump in the lattice, a is the total number of nearest neighbors, δ is the interatomic spacing and f is the fractional atomic concentration of foreign atoms. The statistical terms in the bracket in the above expression change very rapidly with f. While the detailed dependence of D on concentration is determined by the relative magnitudes of the q_{a_i}, it would seem that this dependence is conditioned in large part by the statistical terms.

G2. The Effect of Grain Structure on the Electrical Conductivity of Semiconductors. B. GOODMAN, *University of Pennsylvania.*—Only the effect due to the discontinuities introduced into the periodic lattice potential is considered, although there are probably other phenomena occurring at the grain boundaries which also hinder the flow of electrons. The boundary layers can be considered as local regions at very high "temperatures" with the atoms displaced up to half the interatomic distance. A simplified calculation shows that the mean free path relating to the grain size is approximately equal to the linear dimension of the grain, as might be expected. The added resistivity may sometimes be comparable with that part of the room temperature resistance of silicon and germanium semiconductors due to lattice vibrations. However, it is probably always small compared to the total resistivity which is caused mostly by the scattering from charged impurity ions. These ions result from the excitation of electrons to the otherwise empty conduction band or from the capture of electrons by acceptor impurities in the lattice.

G3. The Plastic Deformation of Zinc as a Function of Strain Rate. SOLOMON LASOF,* *University of Pennsylvania.*—The influence of strain rate on the plastic behavior of single crystals of high purity zinc deformed by compression at constant strain rates of relative magnitude $1.08\times10^7:81:9:1$ has been investigated. The highest strain rate studied corresponds to an impact velocity of 690 cm sec.$^{-1}$. Room temperature stress-strain, or load-compression, curves were obtained for single crystal specimens of various orientations and for polycrystal specimens having a grain size of about 2 mm. All specimens were right circular cylinders 9.5 mm long and 4.75 mm in diameter. The direction of compression was along the cylinder axes. For favorably oriented single crystals, varying the speed of deformation was found to have little or no effect for the three relatively low strain rates studied. Definite evidence for a speed effect was found for the high strain rate. Polycrystals and unfavorably oriented single crystals showed no speed effect for relatively small deformations; but a marked speed effect was observed for larger deformations throughout the range of strain rates studied.

* Now at RCA Laboratories, Princeton, New Jersey.

G4. Recrystallization of Quartz as a Result of Flexure. D. D'EUSTACHIO, *Bliley Manufacturing Corporation, Erie, Pennsylvania.*—The manner in which quartz wafers change from single crystals to "poly-crystalline" material when they are thinner than 25 microns, has been described.[1] Further studies show that the material thus formed is composed of a number of comparatively poor crystals. The area of these crystals varies from a few tenths of a square millimeter to several square millimeters. The photograph of such a crystal, obtained with a Bragg spectrograph using filtered copper radiation, is a network of broad, curved lines. The character of a radiograph of the same areas taken after the quartz is "cold-worked" by flexing the thin plate a few times is entirely different. It is now composed of several short, sharp, straight lines. As the crystal is rotated through several degrees the pattern changes continuously, though retaining the same character. The evidence appears to point to recrystallization of quartz on mild cold-working.

[1] D. D'Eustachio and S. B. Brody, Paper presented at the New York meeting of the American Physical Society, January, 1946.

G5. Oscillographic Study of the Dielectric Properties of Barium Titanate. A. DE BRETTEVILLE, JR.,* *Laboratory for Insulation Research, Massachusetts Institute of Technology.*—Dielectric measurements on barium titanate and solid solutions of barium and strontium titanates indicated that these materials were a new class of ferroelectric compounds exhibiting saturation of the dielectric flux density with increase of field strength.[1] The dielectric properties of such non-linear circuit elements can best be studied throughout the changing and discharging cycle by the oscillograph method of Sawyer and Tower.[2] Barium titanate was investigated by this method over a temperature range from $-175°C$ to $+135°C$ at field strength of 59, 134, 234, 580, and 4800 volts per cm. Peaks in the dielectric constant were observed near $-70°C$, $+10°C$, and 120°C. As the field strength was increased, the two lower peaks increased in magnitude and all peaks shifted to slightly lower temperatures. The loop area which is proportional to the loss per cycle also exhibits irregularities at these three temperatures.

* Present address: Squier Signal Laboratory, Fort Monmouth, New Jersey.
[1] "High dielectric constant ceramics," Laboratory for Insulation Research, Report VII (August 1944), N.D.R.C. 14–300.
[2] C. B. Sawyer and C. H. Tower, Phys. Rev. 35, 269 (1930).

G6. Temperature Coefficients of Interfacial Polarization in Dielectrics. R. F. FIELD, *General Radio Company.*—Gross and Denard[1] have shown by means of current-time curves that a permanent charge may be stored in a capacitor made of carnauba wax by charging it at an elevated temperature and then cooling to a lower temperature. On discharge only that charge is recovered which could be stored at the lower temperature. The remainder is "frozen" in. Graphical analysis of the discharge current curves by the method of Cole and Cole[2] shows that temperature coefficients of all three polarization parameters, change in dielectric constant, relaxation time and storage coefficient are positive. This is in distinction to corresponding negative values for most dipole polarizations. Similar experiments with capacitors made of oil-filled paper, glass steatite, and mica show a positive temperature coefficient of change in dielectric constant and a "frozen" charge when the capacitor is cooled. It seems reasonable to expect similar behavior for other materials.

[1] B. Gross and L. F. Denard, Phys. Rev. **67**, 253 (1945).
[2] K. S. Cole and R. H. Cole, J. Chem. Phys. **10**, 98 (1942).

G7. Thermodynamics of Relaxation Processes. G. E. KIMBALL, *Columbia University.*—Relaxation processes can be divided into two classes: simple and complex. A simple relaxation process is defined as one which can be described in terms of a single variable in addition to the temperature and the external stresses on the relaxing material. For a simple relaxation process a thermodynamic variable X can be introduced which has the property that an infinitely rapid reversible process can be characterized by the condition $dX=0$. For any process in which there is equilibrium between the material and its environment, the energy change can be expressed in the form

$$dE=TdS-\Sigma\sigma d\epsilon+YdX,$$

where σ and ϵ represent the external stresses and the corresponding displacements, and Y is the thermodynamic variable conjugate to X. For slow reversible processes $Y=0$. From this fundamental equation many thermodynamic relationships for slow and rapid processes can be derived.

G8. On the Statistical Mechanics of Systems Involving Molecular Flow. GEORGE JAFFÉ, *Louisiana State University, Baton Rouge, Louisiana.*—If the method of statistical mechanics is to be extended so as to include phenomena like heat conduction or viscosity, the distribution function must be made anisotropic. This can be done, in analogy to Boltzmann's gas kinetic treatment, by multiplying the distribution function for the canonical ensemble by a series progressing by powers of all moments. The distribution function so obtained must be subjected to Gibbs' principle of "conservation of density-in-phase" which thereby takes the place of Boltzmann's integro-differential equation. Thus a system of differential equations for the coefficients of the distribution function is obtained. The treatment of the stationary case leads to satisfactory results under isothermal conditions but fails to determine the heat current in case of a temperature gradient. It, therefore, becomes necessary to solve the time-dependent equations. This can be done, for a linear time-dependent external potential, by a method of successive approximations, and leads to the determination of the heat current and the temperature gradient. Their ratio still depends, in a significant way, on the time rate of change but yields, under suitable restrictions, the time-independent coefficient of heat conduction.

G9. The Stationary Solution of the Fokker-Planck Equation for a Reflecting Boundary. T. H. BERLIN, *University of Michigan.*—The Fokker-Planck Eq. (1) in one dimension describes the diffusion, in x, of heavy particles, subject to an external force $F(x)$, in a medium of temperature T and friction coefficient η.

$$\frac{\partial}{\partial v}\left\{\frac{\eta kT}{m^2}\frac{\partial f}{\partial v}+\frac{\eta}{m}vf\right\}=\frac{\partial f}{\partial t}+v\frac{\partial f}{\partial x}+\frac{F(x)}{m}\frac{\partial f}{\partial v}. \tag{1}$$

Wang and Uhlenbeck[1] conjectured that if a reflecting boundary is required, at $x=0$, the appropriate boundary condition at $x=0$ is $f(0, v, t)=f(0, -v, t)$. It will be shown that in the stationary case the Maxwell-Boltzmann solution is *uniquely* determined by the suggested boundary condition. The proof covers an arbitrary force $F(x)$ and requires weak conditions, in a physical sense, on the distribution function $f(x, v)$. The essence of the proof lies in showing that the diffusion current in velocity space due to collisions between heavy particles and particles of the medium is zero. Similarly, it can be shown that the boundary condition $f(0, v)=0$ for $v>0$ (conjectured for an absorbing wall) leads to a stationary solution identically zero.

[1] M. C. Wang and G. E. Uhlenbeck, Rev. Mod. Phys. **17**, 323 (1945).

G10. Preliminary Studies on the Design of a Microwave Linear Accelerator.* J. HALPERN, E. EVERHART, R. A. RAPUANO, AND J. C. SLATER, *Radiation Laboratory, Massachusetts Institute of Technology.*—We have began the study of several problems connected with the application of microwaves to the acceleration of electrons, namely, the problem of feeding energy from a pulsed magnetron into a high Q cavity; the locking of several magnetrons in phase; and the coupling of many cavities together so that they are excited in a single desired mode. The output of a tunable magnetron operating at 2800 megacycles, with a peak power output of approximately one megawatt and pulsed at two microseconds, was divided between a cavity and resistive load such that 70 percent of the power was fed into the cavity. The magnetron locked to the frequency of the cavity, and from measurements of power into the cavity and its shunt resistance, the peak voltage (across 5 cm of gap) was estimated to be in the neighborhood of two million volts. Preliminary results will be given on phasing of magnetrons and methods of coupling cavities.

* This paper is based on work done for the Office of Scientific Research and Development under contract OEMsr-262.

G11. Phase Stability of Synchrotron Orbits. N. H. FRANK, *Massachusetts Institute of Technology.*—Calculations have been made investigating the phase stability of synchrotron orbits, extending the analysis of Veksler[1] to the case of variation of magnetic field with radius. The first-order theory, using number of revolutions as independent variable, indicates phase stability for small oscillations about the stable phase. Studies are continuing for large amplitudes of oscillation and the bunching process in the betatron-synchrotron transition.

[1] Vaksler, J. Phys. U.S.S.R. **9**, 153 (1945).

H1. System for High Speed Counting of Nuclear Particles. H. L. SCHULTZ, *Yale University.*—The system, designed for high resolution counting of charged particles, is composed of the four following units. (1) Ionization chamber with high collecting field. (2) Pre-amplifier (attached to the ionization chamber) making use of a stable negative capacitance created by positive feedback in a wide band, low phase shift amplifier. This makes possible an input circuit of wide band width for moderately high input resistance. The output connects to a terminated 75-ohm transmission line. (3) Main wide band amplifier with calibrated attenuator for pulse height measurements. (4) Frequency meter with a biased diode circuit to establish an accurately known counting level. This instrument indicates frequency directly from 0 to greater than several hundred kc/sec. and can be used for either random or uniform spaced pulses. Measurements have shown that electrical pulses, corresponding to alpha-rays in the chamber, of the order of 10^{-6} sec. duration are realized with no special sharpening devices used. The system has been used to record fast protons and deuterons at rates exceeding 10^{6} per minute with small error. This type of system has also been designed with time of flight experiments in mind.

H2. Use of a Proportional Counter for Meson Detection. E. C. POLLARD, *Yale University.*—Experiments using a small proportional counter operating at about 20 cm pressure of argon show that oscilloscope deflections proportional to ionization are readily obtainable. The operation of the counter is simplified and made faster by using an input circuit as devised by H. L. Schultz. Estimates of the ionization produced by RaE beta-particles by comparison with Po alpha-particles can be made within a factor of two with certainty and probably much better with adequate collimation. The counter operates satisfactorily in a magnetic field of several thousand gauss. It is proposed to combine such a counter with two Geiger counters arranged in a definite circular arc to operate in triple coincidence. By correct setting of the detection level of the proportional counter and a magnetic field applied across the counter the coincidences can be made to be operative for protons, electrons, or mesons.

H3. Improved Decade Counting Circuit.* VICTOR H. REGENER, *University of New Mexico.*—Ten triodes are used for triggering a ring-of-ten consisting of ten pentodes type 6AK6 through ten states of electrical equilibrium. If twin-triodes type 6J6 are used as triggering tubes, two pairs of input terminals can be provided for clockwise and counter-clockwise feeding (adding and subtracting), respectively. This is applicable to differential counting-rate measurements on two sources. While this circuit uses twenty tubes per ring-of-ten it has a high degree of stability and there are only ten resistors and no condensers. As was the case with previously described circuits, several of these rings can be connected in cascade. With the addition of five resistors to a ring, the number of counted events can be indicated on the screen of a small cathode-ray tube. The resolving time of this circuit (the smallest time interval between two events to be counted separately) is two microseconds.

* Work was done at the University of Chicago.

H4. Organic Vapors for Self-Quenched G-M Counters. E. DERMATEOSIAN AND H. FRIEDMAN, *Naval Research Laboratory.*—A study was made of the characteristics of self-quenched G-M counters filled with mixtures of argon and 28 different organic vapors comprised mainly of aliphatic halides and alcohols. Threshold voltage, length and slope of plateau, sparking voltage, and sensitive volume were observed for each vapor. Methylene bromide, propylene bromide, propylene chloride, nitromethane, and nitroethane produced counters with good characteristics. Marked differences in behavior from that normally observed with alcohol quenched tubes were obtained with methylene bromide vapor. Useful "plateaux" extended over 2000 volts with slopes of 3 percent per 100 volts. Life tests of 10^{9} counts produced little change in tube characteristics. No effects of the cathode composition or treatment on the performance of the methylene bromide-argon counters could be detected. The photo-sensitivity of a copper cathode tube was greatly suppressed for wavelengths as low as the ultraviolet transmission limit of fused quartz. These properties may be explained by the experimental observation that the sensitivity of the counter decreased very rapidly with distance from the wire, limiting the sensitive volume of the counter to a small region around the wire.

H5. Influence of Multiple Scattering on Curvature Measurements. H. A. BETHE, *Cornell University and Consultant at General Electric Research Laboratory.*—It has often been attempted to determine the mass of a particle from the measurement, in a cloud chamber, of its curvature in a magnetic field and its residual range. Great caution is necessary in evaluating such experiments because of the multiple scattering of the particles by the gas atoms in the chamber. Evaluation shows that the curvature measurement is only significant if the velocity of the particle is greater than a certain critical value, i.e., that only tracks of relatively *small* curvature are significant. In the measurements made recently on the GE betatron, argon was used as the cloud-chamber gas and the magnetic field was 1000 gauss. In this case the critical velocity is about 0.1 the velocity of light. Curvature measurements on tracks ending in the chamber are therefore in general not significant. To reduce the multiple scattering a gas of small atomic number should be used, either hydrogen or helium.

Higher magnetic fields are also desirable. The most promising method is to use a thin plate across the cloud chamber and to measure the curvature on both sides of the plate. With hydrogen, this permits the determination of the meson mass to about 10 percent.

H6. Fluctuations in Measurements of Ionization per Centimeter of Path in Proportional Counters. W. F. G. SWANN, *Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania.*—In experiments of Swann and Weisz cited in this programme, it became desirable to compare the ionization produced by an individual mesotron in traveling equal path lengths in two similar proportional counters. Wide differences were found in such pairs of observations, the path length being about 20 cm at a pressure of 40 cm (Hg) in argon. A proposed explanation is as follows: The mesotron ejects secondaries along its path, and these in turn emit tertiaries, and so on. The fraction of the secondaries emitted with energies between Q and $Q+dQ$ is, on the average, AdQ/Q^2, where A is a constant, and the lower and upper limits are customarily taken as 10 volts and 10^8 volts, respectively. From this it results, for example, that half of the total ionization is produced by secondaries of energy greater than 30,000 volts. In a tube of normal dimensions, the situation is modified by the limited active range of the secondaries; nevertheless, these events of high energy are so rare in a mesotron path length of about 20 cm that fluctuations are enough to account for large differences between the total ionization recorded for a single mesotron ray in passing successively through equal lengths in two similar proportional counters.

H7. The Ionization Spectrum of Cosmic-Ray Electrons and Mesotrons. PAUL B. WEISZ AND W. F. G. SWANN, *Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania.*—With a proportional counter arrangement a spectrum of specific ionization values was obtained for about 800 cosmic-ray particles with and without lead shield. Without lead two major peaks were obtained. With 11.5 cm lead the second (higher ionization) peak virtually disappeared. Assigning the first peak to mesotrons, the second to electrons, and averaging the ionization values for each peak, one finds that the average ionization of mesotrons is only about 68 percent of that of the electron component. Both peaks show some "spread" in ionization values, the mesotron peak being particularly broad. Taking the energy distribution from cloud-chamber data, and calculating the resulting ionization spectrum from the normal Bethe-Bloch ionization formula one finds a much smaller difference in average ionization between mesotrons and electrons, and a spread in values not sufficient to account for the experimental spread. However, specific ionization formulae yield average energy-losses, while these experiments have to be analyzed in the light of the statistical distribution of energy-losses as applied to a finite sample of "trials" (primary ionization events), each measurement representing a sample in this sense. Comparing mesotron-electron ionizations, mesotron spin and magnetic moment may not be negligible should there be mesotrons of small rest masses.

H8. Production of Mesons by Electrons. HERMAN FESHBACH, *Physics Department, Massachusetts Institute of Technology.*—The production of "pseudoscalar" mesons originating in the meson field associated with the nucleus has been calculated using the Weizsäcker-Williams method of impact parameters. In the Lorentz system in which the electron is at rest, the nucleus may be replaced by mesons according to a formula given by Heitler and Peng. These mesons are then scattered by the electron. The results for this collision have been calculated by Corben and Schwinger. Using the criterion that the electron, in the system in which the nucleus is at rest, must at least lose an energy equal to the meson mass, it is possible to compute the cross section for the process. Calculation of the production of other meson types by this method is in progress.

H9. Non-Electrical Scattering of Charged Mesotrons. GERHART GROETZINGER AND LLOYD SMITH, *Ohio State University.*—Counter experiments were performed to obtain further data on the "wide angle" scattering of mesotrons. A vertical telescope with 13 cm of lead between its two counters was placed above a 4.5-cm lead block and a second telescope with 15 cm of lead between the counters was pointed at the lead block from below at an angle of 25°. In addition, the lowest counter was surrounded by at least 12 cm of lead to reduce the effect of showers. To determine the number of mesotrons scattered by the 4.5-cm block into the lower telescope, fourfold coincidences were recorded with and without the scattering block in position and the difference compared with the number of mesotrons traversing the upper telescope. Out of 190,000 incident mesotrons, 30 ± 14 were scattered into the lower telescope. Calculations of single and multiple Coulomb scattering in the various lead blocks show that a negligible portion of the 30 counts may be attributed to electrical scattering. It follows that the differential cross section for the non-electrical scattering of mesotrons of energies greater than 6×10^8 ev is of the order of 1×10^{-28} cm^2 per unit solid angle for the angular range 15°–35°.

H10. Determination of the Average β-Ray Energy in Artificial Radioactivity and Its Use in Radiation Dosimetry. L. D. MARINELLI, R. F. BRINCKERHOFF, *Memorial Hospital, New York,* AND E. H. QUIMBY, *College of Physicians and Surgeons, Columbia University.*—In many biological and medical studies where radioactive isotopes are used it is important to estimate rather closely the radiation dose delivered to living tissues by β-radiation. It has been shown[1] for β-ray isotopes that the dose is proportional to the average kinetic energy $\bar{E}$ of the β spectrum. $\bar{E}$, however, is infrequently stated in the literature. Values of $\bar{E}$ obtained from several β-ray spectra by direct graphical computation will be given. In addition it will be shown that once the energy limit, $E_{\max}$, of a spectrum is known (and in the case of complex spectra the relative proportions are given), $\bar{E}$ can be calculated satisfactorily (±6 percent) from the Fermi β-ray distribution function.

[1] L. D. Marinelli, Am. J. Roentgen. Rad. Therapy 47, 210 (1942).

H11. A Convenient Dosage Unit for Radioactive Isotopes Internally Administered. G. FAILLA, *College of Physicians and Surgeons, New York.*—When irradiation equilibrium exists at a point in a mass of tissue, the rate of energy absorption is $3.7\times10^{10}qV$ ev/sec./gram, q being the concentration of isotope in the tissue in curies per gram and V the average energy per disintegration in ev. By incorporating the isotope in the "walls" of an ionization chamber, suitably constructed, it is possible to determine this quantity without knowing q and V. Since this quantity forms the basis of all biological dosage, it is convenient to express it in *roentgen-curies*. One roentgen-curie then represents the amount of any radioactive isotope that emits energy at the rate of 5.35×10^{13} ev/sec. (this being the amount of energy released by one roentgen in one gram of air). Since q and V (especially V) are difficult to measure accurately, the practical advantages of the scheme are obvious. For a given isotope, measurements of this type need be made only once. Thereafter ordinary methods suffice.

H12. A Radium Source Ion Gauge. G. L. MELLEN, *National Research Corporation* (Introduced by R. L. McCreary).—An ion gauge using a radioactive source is described. Constructional details are given and a brief coverage is made of the d.c. amplifier circuits associated with the gauge. Designed to measure pressures between one micron and ten millimeters, the gauge is not harmed by exposure to any pressure. Ionization is produced by the alpha-particles from a small "source" plaque containing approximately 200 micrograms of radium. The active deposit is a gold-radium alloy bonded to a silver backing and is only a few microns in thickness so that it is a highly efficient alpha-emitter. Since ionization is the mode of pressure measurement, the gauge response is a linear function of pressure throughout its operating range. Extension of the range allows for calibration at any higher pressures. By suitable choice of gauge constants, a measuring device may be made for any pressure interval. Of rugged mechanical construction, this gauge has found immediate use in the high vacuum field.

J1. A Pulsed Mass Spectrometer with Time Dispersion. W. E. STEPHENS, *University of Pennsylvania.*—Advances in electronics seem to make practical a type of mass spectrometer in which microsecond pulses of ions are selected every millisecond from an ordinary low voltage ion source. In travelling down the vacuum tube, ions of different M/e have different velocities and consequently separate into groups spread out in space. If the ions are collected in a fixed Faraday cage and the current amplified, then pulses of current corresponding to different ion M/e will be dispersed in time. If the amplified current pulses are put on the vertical plates of an oscillograph whose sweep is synchronized with the pulses, then an M/e spectrum of the ions will be exhibited. This type of mass spectrometer should offer many advantages over present types. The response time should be limited only by the repetition rate (milliseconds). The indication would be continuous and visual and easily photographed. Magnets and stabilization equipment would be eliminated. Resolution would not be limited by smallness of slits or alignment. Such a mass spectrometer should be well suited for gas composition control, rapid analysis, and portable use. A mass spectrometer of this type is being constructed.

J2. The Ionization Potential of CH_2. A. LANGER AND J. A. HIPPLE, *Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania.*—The free radical, CH_2, was produced in the ionization region of a mass spectrometer by the thermal decomposition of diazomethane. The arrangement was similar to that used previously[1] in the measurements of the ionization potentials of CH_3 and C_2H_5 from the decomposition of $Pb(CH_3)_4$ and $Pb(C_2H_5)_4$. Only preliminary measurements of the ionization potential of CH_2 are available since events have intervened which temporarily prevent the completion of the experiment. This preliminary value is $I(CH_2)=11.9\pm0.2$ volts. From the process in methane

$$CH_4+e\rightarrow CH_2^{+}+H_2+2e$$

it is predicted that $I(CH_2)\lesssim 12.0$ volts.[2] The agreement of this value with that measured directly indicates the formation of CH_2^{+} in methane occurs with little excitation or kinetic energy of the fragments.

[1] J. A. Hipple and D. P. Stevenson, Phys. Rev. **63**, 121 (1943).
[2] L. G. Smith, Phys. Rev. **51**, 263 (1937).

J3. Scattering and Absorption of High Voltage X-Rays in Steel. HERMAN FESHBACH AND JOHN A. HORNBECK,* *Physics Department, Massachusetts Institute of Technology.*—The passage of a parallel x-ray beam through steel has been investigated theoretically and experimentally. The x-rays were produced by electrons striking a thick gold target. The electron energy varied from one to two Mev. Using steel thicknesses up to twelve inches, intensity measurements were made of the total radiation immediately below the steel and of the "direct radiation" coming directly from the x-ray source. The difference between these is scattered radiation. The absorption coefficient of the total radiation approached a value independent of steel thickness. This, it can be shown, equals the absorption coefficient of the maximum energy x-ray present in the beam. The Klein-Nishina formula was verified. It was found that the ratio of scattered to direct radiation was proportional to steel thickness. The theory begins by resolving the incident beam into "equilibrium" energy distributions; distributions whose absorption coefficients are independent of steel thickness. An integral equation for these distributions was derived and solved approximately. Using the experimental data for the total radiation it was possible to compute the scattered radiation. The agreement with measured values was good. The effects of filtration and the angular distribution of the scattered radiation could then be calculated.

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J4. Measurement of Betatron Radiation with G-M Counter. C. O. MUEHLHAUSE AND H. FRIEDMAN, *U. S. Naval Research Laboratory.*—The pulses of x-rays from a betatron are of shorter duration than the deadtime of self-quenched Geiger-Mueller counters. As the intensity increases from zero to a maximum the counting rate varies from zero to the pulse frequency of 180 per second. The counting rate is given by:

$$N=M(1-\exp[-N_0\bar{E}])^{\alpha},$$

where M is the betatron pulse rate, N_0 the number of quanta irradiating the counter, $\bar{E}$ the efficiency, and α the number of counters in coincidence arrangement. In monitoring radiographic exposures at the film position the efficiency of the counter should be reduced by a factor of 100 from the optimum obtainable for the betatron wavelengths. Further reduction in response can be accomplished by coincidence counting.

J5. The Insulation of High Voltages in Vacuum. JOHN G. TRUMP, *Massachusetts Institute of Technology.*—Studies from 50 to 700 kv constant potential further demonstrate the inadequacy of the field emission theory to account generally for high voltage breakdown in vacuum. Experiments are described which investigate the 'total voltage' mechanisms proposed by Van de Graaff, including positive ion emission by electron impact (A), electron emission by positive ion impact (B), and photoelectric emission. In the d.c. case these processes contribute to a steady interchange of charged particles between cathode and anode which increases with voltage until breakdown ensues. At the higher breakdown voltages the cathode gradient has diminished far below the value for field emission. Photoelectric emission may be an important contributing mechanism as the product of the particle coefficients (A) and (B) is still well below unity at voltage values close to breakdown. Measurements of electron emission by electrons with energies up to 300 kv for tungsten, steel, aluminum, and graphite are also reported. The properties of vacuum insulation for high constant potentials are discussed, as well as some preliminary results on the insulation in vacuum of high microwave voltages.

J6. A Compact High Voltage Electrostatic Generator Using Sulphur Hexafluoride Insulation. W. W. BUECHNER, R. J. VAN DE GRAAFF, A. SPERDUTO, E. A. BURRILL, L. R. MCINTOSH, AND R. C. URQUHART, *Massachusetts Institute of Technology.*—An electrostatic generator enclosed in a pressure tank 3.5 feet in diameter and 13 feet long will be described. When operated with sulphur hexafluoride[1–3] at a pressure of 200 pounds per square inch as the insulating medium, a potential of 5.6 million volts was produced. An account will be given of observations of the insulating properties at high voltages of air, nitrogen, sulphur hexafluoride, freon, and certain mixtures. Some problems associated with the charging belt, the resistors for controlling the potential distribution along the column, and other aspects of the generator will be discussed.

[1] We are greatly indebted to Professor W. C. Schumb, Director of the M.I.T. Research Laboratory of Inorganic Chemistry, for his recent research on sulphur hexafluoride and for the development of the method for producing the large amounts of the gas supplied for our use.

[2] W. C. Schumb and E. L. Gamble, J. Am. Chem. Soc. **52**, 4302 (1930).

[3] E. E. Charlton and F. S. Cooper, Gen. Elec. Rev. **40**, 438 (1937).

J7. Preparation and Physical Properties of Sulfur Hexafluoride. WALTER C. SCHUMB, *Massachusetts Institute of Technology.*—For the preparation of sulfur hexafluoride, referred to in the preceding abstract, sulfur was burned in fluorine at atmospheric pressure and the mixture of gases thus obtained, containing, besides a preponderance of the hexafluoride, other lower fluorides of sulfur, as well as some air and hydrogen fluoride, was purified by a process carried out largely in metal apparatus. This process included thermal decomposition of an unstable lower fluoride, thorough washing with water and with sodium hydroxide solution, drying with solid absorbents, and condensation as solid in Pyrex traps, from which the purified hexafluoride was transferred to steel storage cylinders by vaporization and recondensation as liquid under a total pressure at room temperature of about 350 pounds per square inch. Sulfur hexafluoride is remarkably stable and inert chemically, comparable even to nitrogen in these respects. Some of the physical properties to be discussed include melting point, sublimation temperature, critical temperature, density (as gas, solid, or liquid), vapor pressure (as solid or liquid), and heat of fusion.

J8. A Method of Determining Focal Spot Size in High Voltage Radiography. ANTHONY SPERDUTO, *Massachusetts Institute of Technology.*—The accurate determination of focal spot size in high voltage radiography presents certain difficulties not encountered at lower voltages. The more penetrating nature of the radiation prevents the use, particularly in the range of very small spots, of the conventional pinhole camera technique used at low voltage. The apparatus developed to meet this need includes two lead blocks bolted together in such a way as to from between them an accurately defined vertical slit .002 inch wide. This assembly is placed under the target and made to move back and forth along a line perpendicular to the plane of the vertical slit. A stationary film is placed horizontally beneath the moving blocks. The width of the darkened line on the film will then afford an approximate measure of the spot size in one dimension. By turning the apparatus 90° about a vertical axis, the width and position of the spot in the other dimension can be observed. A method will be described for determining the necessary correction to obtain the exact spot size. With 2 Mev x-rays, focal spots as small as .006 inch in diameter were measured, and their location on the target accurately determined.

J9. Dissociation Energies of Surface Films of Various Oxides as Determined by Emission Measurements of Oxide Coated Cathodes. HAROLD JACOBS, *Sylvania Electric Products Inc., Kew Gardens, New York.*—A mechanism of falling emission in vacuum tubes is discussed. It is demonstrated that when an electron achieves a critical kinetic energy in moving from the cathode to the anode, and if the anode is an oxide, the electrons will cause a dissociation of the oxide. The liberated oxygen will return to the cathode and falling emission will result. The critical energy of the electron starting the dissociation is found to be equivalent to the heats of formation of the oxides bombarded in the case of five different oxides. Using this equivalence principle, the heats of formulation of two compounds are found which have not been recorded in the literature, Ta_2O_4 and ZrO. In addition, the contact potential between barium oxide cathodes and seven various oxides are determined and the work function of the seven oxides computed.

J10. The Poisoning of Oxide Cathodes by Gold. JEROME ROTHSTEIN, *Evans Signal Laboratory, Belmar, New Jersey.*—A cylindrical indirectly heated (BaSrCa) oxide cathode, central third coated, was divided into equal halves by 5-mil slots extending over most of the length of the Ni base metal. A concentric Ta anode, split, permitted measurement of current from each half of the cathode. One half of the cathode, after exposure to Au evaporated from a Pd-Au wire (80 percent Au), turned gray when cold, the other half remaining white. Emission decreased with time first for the exposed and then for both halves, after which both were uniformly very light gray. Reactivation would occur suddenly whenever the plates ran bright yellow for about a second, after which the emission decayed, decay rate increasing with increasing cathode temperature. Conclusions are that Au readily migrates (diffuses) over (BaSrCa)O and Ni, that Au inhibits emission, and that suitable thermal gradients can alter Au concentration and restore emission. It seems likely that Au exerts its maximum inhibiting effect when present at the outer surface of the oxide.

J11. Secondary Emission of Thermionic Oxide Cathodes. J. B. JOHNSON, *Bell Telephone Laboratories, Inc.*—Secondary emission from thermionic oxide layers has been studied by the use of short pulses of primary electron bombardment, in the micro-second range. The number of secondaries emitted per primary, δ, resembles in general that of insulators rather than that of metals. It reaches unity at about 30 ev primary energy, and a maximum of 4 to 10 in the region of 1200–1500 volts. The cold oxide has the higher δ, but acts as an insulator and quickly acquires a surface charge that limits the escape of secondaries. As the temperature is raised δ decreases from about 8 and remains nearly constant in the neighborhood of 5 between 500° and 850°C. The high temperature value is fairly reproducible but that for the lower temperature is more variable, being apparently sensitive to matter evaporated from the source of primary electrons. The exponential rise of δ with temperature which has been reported[1] is found not to be caused by a true secondary emission but by a temporary increase in thermionic activity resulting from the bombardment.[2]

[1] Morgulis and Nagorsky, J. Tech. Phys. U.S.S.R. **5**, 848 (1938).
[2] J. B. Johnson, Phys. Rev. **66**, 352 (1944).

J12. Velocity of the Anode Spark produced in $CuSO_4$ Solutions by Application of an Impulsive Potential. HUGH F. HENRY, *University of Georgia.*—If a high potential is applied impulsively across two electrodes immersed in a conducting solution, a spark will appear at one, or both, of the electrodes and proceed across the interelectrode space.[1,2] A 0.5-mf condenser was charged to 20 kv potential which was applied to pointed copper electrodes in the solution. The anode spark velocity was determined from measurements of the lengths of the streamers produced when the potential was applied for a predetermined time interval. Gap spaces of 10 to 50 mm and $CuSO_4$ solution concentrations of 1 to 5 g/liter were investigated. In no case was a spark shorter than about 5 mm observed when time interval differences of 0.5 microsecond were used. Beyond that distance, the spark velocity was independent of the interelectrode space for concentrations less than 2.5 g/liter, but at higher concentrations, a velocity dependence was found for gaps longer than 30 mm. For a concentration of 2.5 g/liter, the velocity was 450 m/sec., varying to 600 m/sec. for a 1 g/liter concentration and 1400 m/sec. for a 5 g/liter concentration.

[1] L. B. Snoddy and J. W. Beams, Phys. Rev. **55**, 879 (1939).
[2] Hugh F. Henry, Phys. Rev. **57**, 939 (1940).

J13. High Velocity Vapor Jets in Sparks at Mercury Electrodes. J. R. HAYNES, *Bell Telephone Laboratories, Inc.*—Photographs show that when sparks of microsecond duration are made to pass in hydrogen gas to a mercury surface, a jet of high velocity vapor is ejected from the mercury regardless of polarity. Measurements of the velocity of these jets were made through the use of a photo-multiplier cell. It was found that the jet from a mercury cathode has an initial velocity of 1.9×10^5 cm/sec. and that from the anode is 1.5×10^5 cm/sec. These velocities are found independent of current or gas pressure, but decrease linearly with distance from the electrodes. Through Stark effect broadening of the hydrogen β line the ionization is shown to be of the order of 30 percent. These jet velocities may be accounted for on the assumption that the momentum of the anode jet is acquired by positive ions in the anode drop, and that of the cathode jet by both negative and positive ions in the cathode drop. A close relationship exists between these jets and those found by Tanberg in the vacuum arc.

K2. Absorption in Oxygen at One-Half cm. ROBERT BERINGER,* *Radiation Laboratory, Massachusetts Institute of Technology.*—The absorption of $\frac{1}{2}$ cm electromagnetic waves in gaseous O_2 and several O_2–N_2 mixtures has been measured as a function of wave-length and pressure. Microwave radio techniques were used and will be described. The theory of Van Vleck predicts a band of resonant absorption lines in the region of $\frac{1}{2}$ cm wave-lengths. Although these lines are not resolved at atmospheric pressure, the collision-width of the individual lines can be deduced from a comparison with the observations. At atmospheric pressure a collision-width (half-width at half-intensity) in the range .02 to .05 cm^{-1} brings the theoretical and observed absorption coefficients into good agreement, both as regards absolute value and variation with wave-length. Furthermore, the agreement is excellent at .54 cm where the theoretical absorption coefficient is quite insensitive to the collision-width. The observed pressure dependence of the absorption coefficients is also in good agreement with the theory, and it is found empirically that the absorption per O_2 molecule is a function of the total gas pressure alone. The sensitivity of the apparatus was not great enough to measure the absorption at low pressures where the lines are resolved.

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K3. A Radiometer for Measuring Thermal Radiation at Microwave Frequencies.[1] R. H. Dicke,[2] *Radiation Laboratory, Massachusetts Institute of Technology.*—In addition to the usual power sensitivity, a microwave radiometer may be given a temperature sensitivity rating. The temperature sensitivity of a radiometer is defined as the minimum change in the temperature of a black body which can be detected. The minimum detectable power of the radiometer to be described is 10^{-16} watts. Its measured temperature sensitivity is $\frac{1}{2}$°C. The radiometer operated in the region of 1 cm, but the same techniques are applicable at longer wave-lengths. The radiometer consists of a superheterodyne receiver with a wide band intermediate frequency amplifier followed by a second detector and narrow band 30 c/sec. amplifier. The input circuit to the receiver contains a motor-driven eccentrically-mounted modulating wheel which dips 30 times a second into a slot in the wave guide feeding the receiver. When the wheel is out of the wave guide, the radiation intercepted by the antenna is able to get into the receiver. Thus the output from the second detector of the receiver varies by an amount indicative of the difference in the radiation received from the modulator wheel and that received from the antenna. This modulation frequency is then detected by comparison methods.

[1] This paper is based on work done for the Office of Scientific Research and Development under Contract OEMsr-262.
[2] Now with Princeton University.

K4. The Absorption of 1-cm Electromagnetic Waves by Atmospheric Water Vapor.[1] R. L. Kyhl, R. H. Dicke,* and Robert Beringer,** *Radiation Laboratory, Massachusetts Institute of Technology.*—The isolated weak absorption line of water vapor at a wave-length of 1.3 cm has been measured recently by several others, namely J. A. Saxton, J. M. B. Kellogg, and J. W. Miller and R. S. Bender. The present authors have determined the atmospheric absorption indirectly by measuring the thermal radiation from the atmosphere, using the microwave radiometer of R. H. Dicke. With the addition of the humidity and temperature obtained from meteorological soundings it is possible to determine the absorption of the entire atmosphere, and to separate the contribution due to water vapor. Measurements were made at wave-lengths of 1.00 cm, 1.25 cm, and 1.50 cm. The observed atmospheric attenuations due to water vapor at these wave-lengths are, respectively, 0.011, 0.026, and 0.014 db/km/(g H_2O/m^3). From these results it was deduced that the absorption line is centered at a wave-length of 1.34 cm and has a width of 0.11 cm^{-1}. These results are, within the rather broad limits of error, in fair agreement with those of other observers. This absorption was predicted theoretically by Van Vleck, in an unpublished report, using results of infra-red measurements. The observed line width and position are in agreement with the theory but the absolute absorption observed is greater than predicted.

* Now with Princeton University.
** Now at Yale University.
[1] This paper is based on work done for the Office of Scientific Research and Development under Contract OEMsr-262.

K5. Absorption of Microwaves by Water Vapor.* Stanley H. Autler, Gordon E. Becker, and J. M. B. Kellogg, *Columbia Radiation Laboratory, Columbia University.*—A determination of the location and shape of the water vapor absorption line situated in the cm wave-length region has been made by a new method. Radiation is fed into a cubical copper cavity $8\frac{1}{2}$ ft. on an edge. Strings of thermocouples with alternate junctions coated with a "lossy" material are placed at random in the cavity. The e.m.f. of these couples is proportional to the Q of the cavity and its contents (see following abstract), and a measurement of the change in e.m.f. with humidity yields a value for the losses in the water vapor provided the Q of the cavity is known. This quantity may be determined from additional measurements taken with an aperture opened in the side of the cavity. The wave-length range between 0.7 cm and 1.69 cm has been explored. The peak of the absorption curve is at $\lambda = 1.33$ cm and the attenuation there is 0.044 db per nautical mile for 1 g of water vapor per cubic meter.

* This paper is based on work done for the OSRD under Contract OEMsr-485.

K6. Theory of a Microwave Spectroscope.* Willis E. Lamb, Jr., *Columbia Radiation Laboratory, Columbia University.*—The measurement of the absorption of centimeter radiation in water vapor described by Autler, Becker, and Kellogg (preceding abstract) is based on the assumption that the thermocouple readings are proportional to the Q of the cavity and its contents. The conditions for this are investigated theoretically and seem to be well satisfied in this experimental case. An expression for the Q of a hole in the wall of the cavity is derived for use in the measurements of Q's on an absolute scale.

* This paper is based on work done for the OSRD under Contract OEMsr-485.

K7. Absorption of Microwaves by Gases II. John E. Walter and W. D. Hershberger, *RCA Laboratories, Princeton, New Jersey.*—The absorption coefficients and dielectric constants of sixteen gases have been measured at the two wave-lengths $\lambda = 1.24$ cm and $\lambda = 3.18$ cm. The gases are H_2S, SO_2, COS, $(CH_3)_2O$, C_2H_4O, NH_3, six halogenated methanes, and three amines. Certain improvements in waveguide technique are described; these improvements permit detection of absorption coefficients as small as 0.2×10^{-4} cm^{-1} and measurement of larger coefficients with an accuracy of ± 5 percent. The measured dielectric constants at these wave-lengths are essentially equal to the static values. A quantitative interpretation of the absorption coefficients in terms of the known structure and spectra of the individual molecules is given. The theory indicates that all heavy non-planar molecules which possess a permanent dipole moment should show appreciable absorption in the microwave region.

K8. Thermal and Acoustic Effects Attending Absorption of Microwaves by Gases. W. D. HERSHBERGER, *RCA Laboratories, Princeton, New Jersey.*—The conversion of microwave energy into thermal and acoustic energy by the use of any of the gases which absorb microwaves is described. Thermal conversion may be shown by confining an absorbing gas in a cavity resonator which communicates with a manometer, then impressing a microwave field on the gas and noting the temperature rise. In this device, a rise of 0.5 degree per watt of average microwave power is observed. The response is rapid enough to follow line voltage fluctuations and is governed by the thermal capacity of the enclosed gas. Sound, both audible and supersonic, is generated in an absorbing gas liberated in a modulated microwave field, or confined in a rubber container held in a field, with the character of the sound determined by the modulation. A gas-filled resonator capable of detecting 10 milliwatts of microwave power is described which consists of a cavity which resonates electrically to the microwave frequency and acoustically to the modulating frequency. A piezo crystal coupled to one end of this absorbing column is employed and the device functions as a square-law detector.

K9. Interpretation of Cosmic Noise—Radio Waves from Extraterrestrial Sources. CHARLES HARD TOWNES, *Bell Telephone Laboratories, Inc., Murray Hill, New Jersey.*—Interstellar ionized gas is proposed as a source of radio waves observed from the milky way.[1] This gas appears nearly opaque for wave-lengths longer than a few meters, and quite transparent for wave-lengths shorter than a few centimeters as shown by the theoretical formula below. With some simplifying assumptions, the apparent temperature of the milky way at frequency ν is

$$Ta=T\left[1-\exp\left(-8\times10^{-8}\frac{n^2S}{\nu^2}\right)\right],$$

where T = temperature of interstellar gas, S = distance from observer to the milky way boundary in the direction of observation, and n = density of positive ions. Reber's measurements at $\nu=160\times10^6$ and Southworth's failure to find radiation at $\nu=3\times10^9$ agree well with this expression using accepted values of T, n, and S although Jansky's measurements at $\nu=18\times10^6$ give temperatures several times greater than would be expected. Some of the sun's excess radio radiation appears to be explained as similar emission from its corona.

[1] Jansky, Proc. I. R. E. **25**, 1517 (1937). Reber, Astrophys. J. **100**, 279 (1944). Southworth, J. Frank. Inst. **239**, 285 (1945).

K10. The Frequency Dependence of Radar Echoes from the Surface of the Sea. HERBERT GOLDSTEIN,* *Radiation Laboratory, Massachusetts Institute of Technology.*—Under certain conditions microwave radar reflections are obtained from the surface of the sea. It has been variously suggested that the scatterers responsible for this "sea echo" are small spray droplets, or large surfaces of the sea waves. Irrespective of the actual mechanism involved the echo intensity can be specified by a scattering cross section per unit area of the sea surface, denoted by σ. The frequency dependence of σ affords a crucial experiment for distinguishing between the proposed mechanisms. The scattering from small spray droplets would follow the Rayleigh $1/\lambda^4$ law, while the echo from surfaces of dimensions large compared to λ should be sensibly independent of wave-length. Simultaneous absolute measurements of σ have been made at wave-lengths of 9.2, 3.2, and 1.25 cm, for several sea states, using three specially designed radar systems. The observed frequency dependence varied considerably with the state of the sea, but spray drops small enough to obey Rayleigh's law are definitely excluded as the scatterers involved. On the other hand, it is difficult to account for the changes of the cross section with polarization, and the frequency dependence of these changes, solely on the basis of scattering from large sea surfaces.

* Now at Jefferson Physical Laboratory, Harvard University.

L1. Fast Sweep Synchroscope. D. F. WINTER, *Radiation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts** (Introduced by A. G. Hill).—This paper describes the development of a sealed tube cathode-ray oscillograph (synchroscope) used to measure time intervals of 10^{-9} second to ±10 percent. The cathode-ray tube for this instrument was designed in collaboration with the Du Mont Company, and several tubes have been built by them. Such basic problems are discussed as: (1) Effect of electron transit time under the deflecting plates of the cathode-ray tube and its effect on frequency response, (2) coaxial signal input to the deflecting plates, (3) generation of linear sweeps with speeds up to 100 inches/microsecond, (4) photographic recording of single trace writing speeds up to 300 inches/microsecond, (5) sweep speed and writing speed calibration, (6) pulse intensification of the cathode-ray tube, and (7) reduction of time jitter between the transient to be studied and the sweep to 10^{-9} second. Circuits and formulas for producing linear sweeps of any speed are given. Pictures showing simultaneous plate current and r-f build-up in a 3000 mc/sec. pulsed magnetron on a single pulse are presented.

* This paper is based on work done for the Office of Scientific Research and Development under Contract OEMsr-262.

L2. Minimal Noise Amplifiers. E. J. SCHREMP, *Radiation Laboratory, Massachusetts Institute of Technology.*—Various restricted methods of devising minimal noise amplifiers have been published, utilizing controlled variations of passive impedances attached to the low level amplifier tubes. The present unified method, employing a simple principle valid at all frequencies, consists of two successive steps: (1) for each independent *internodal* tube noise generator, apply the constraint that the ratio vanish between its output response and that of the signal source; and (2) introduce small variations from the resulting constraints, to secure a compromise in gain, bandwidth, stability, and noise figure. For a triode at low frequencies there is one such constraint. When the input and output terminals of the stage are electrodes of the triode itself, there result nine basic minimal noise amplifier types, of which three are familiar; namely, the grounded-cathode, grounded-grid, and grounded-plate. Successively wider amplifier classes occur when the terminals are not electrodes, and when the stage includes one or more triodes. For a triode at high frequencies or a pentode[1] at low frequencies there are two independent constraints. The method applies similarly here and in general, at any frequency, when the stage considered includes tubes having one or more grids.

[1] Cf. abstract No. L3.

L3. Equivalent Noise Representation of Multi-Grid Amplifier Tubes. R. Q. TWISS[1] AND E. J. SCHREMP, *Radiation Laboratory, Massachusetts Institute of Technology.*—North and others have given equivalent circuits for the noise generated by multi-grid amplifier tubes, valid at low frequencies when all collector electrodes but one are grounded. These results are here extended to the general case where there are arbitrary impedances in all the electrode leads, by statistical and Fourier transform methods. A simpler, less rigorous derivation is also given.

For a pentode with cathode k, screen s, and anode a, the sources of noise are here represented by three statistically independent constant current generators, located, respectively, between cathode-screen (i_{ks}), screen-anode (i_{sa}), and anode-cathode (i_{ak}). Their mean square values for the frequency interval $d\nu$ are given by

$$\langle i_{ks}^2\rangle_{\mathrm{Av}}d\nu=2eI_s\Gamma^2d\nu, \tag{1a}$$

$$\langle i_{sa}^2\rangle_{\mathrm{Av}}d\nu=2e[I_sI_a/(I_s+I_a)](1-\Gamma^2)d\nu, \tag{1b}$$

$$\langle i_{ak}^2\rangle_{\mathrm{Av}}d\nu=2eI_a\Gamma^2d\nu, \tag{1c}$$

where I_s and I_a are the screen and anode direct currents, Γ^2 is the space-charge reduction factor, and e is the electronic charge. The results for the general multi-grid tube are simple extensions of Eqs. (1).

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L4. The Cylindrical Antenna: Comparison of Theories and Experiment. RONOLD KING AND DAVID MIDDLETON, *Cruft Laboratory, Harvard University.*—The hypotheses and approximations underlying the integral equation of Hallén

$$\int_{-h}^{h}\frac{I_z'}{R_1}\exp\left(-j\beta R_1\right)dz'=-j\frac{4\pi}{So}[C_1\cos\beta z+C_2\sin\beta|z|]$$

are outlined and discussed. The several approximate solutions of the equation including those by Hallén,[1] Gray,[2] and King and Middleton[3] are compared with each other and with experimental results.

[1] E. Hallén, Nova Acta, Roy. Soc. Sci. (Upsala) 11, 1 (1938).
[2] M. C. Gray, J. App. Phys. 15, 61 (1944).
[3] R. King and D. Middleton, Quart. Appl. Math. 3, 302 (1946); J. App. Phys. 17 (April, 1946).

L5. Antenna Impedance Measurement. D. D. KING, *Cruft Laboratory, Harvard University.*—The determination of antenna impedance is considered with reference to cylindrical dipoles. Practical approximations to the theoretical models of dipoles are examined. The elimination and compensation of errors in the associated transmission-line apparatus are discussed together with an innovation in microwave measuring-line design. Curves of recent experimental data give an indication of the present status of measuring technique.

[1] D. D. King, J. App. Phys. 16, 8 (1945); D. D. King, Thesis, Harvard University, 1946.

L6. Electrical Breakdown in Air at Microwave Frequencies. D. Q. POSIN, *Radiation Laboratory Massachusetts Institute of Technology.**—Experiments were conducted on electrical breakdown at microwave frequencies, using air gaps, from 6 to 100 mils, in wave guide. The range in pressures used was 1 cm Hg to 2 atmospheres. The Paschen Law was found to be approximately valid in this range, as in d.c.,[1] though dependent upon the length of time that the microwave field is applied. The dependence of the breakdown field on the time-width of the applied microwave voltage pulse indicates that when breakdown occurs in a finite time the sparking condition of Holstein[2] that rate of ionization is greater than rate of diffusion must be amplified to include the width of the voltage pulse. The breakdown field was found to depend also on the frequency with which voltage pulses are applied to the gap, giving indication of the nature of the electron loss mechanism between pulses. The sparking field was found dependent on the initial ionization, when intense, as in d.c.[3]

* This paper is based on work done for the Office of Scientific Research and Development under Contract OEMsr-262.
[1] D. Q. Posin, Phys. Rev. 50, 650 (1936).
[2] T. Holstein, Phys. Rev. 69, 50A (1946).
[3] Varney, White, Loeb, and Posin, Phys. Rev. 48, 818 (1935); H. J. White, Phys. Rev. 49, 507 (1936).

L7. Complex Conductivity of Electrical Discharge in Gas at Microwave Frequencies. MELVIN A. HERLIN AND SANBORN C. BROWN, *Massachusetts Institute of Technology.*—An electrodeless discharge produced at microwave frequencies in a resonant cavity has been studied. The cavity used is cylindrical and oscillates in the $TM_{0,1}$ mode in which the electric field is parallel to the axis and maximum along the axis. The discharge takes place in a cylindrical glass tube coaxial with the cavity. The tube diameter is limited to the region of nearly uniform field near the axis of the cavity. The cavity and discharge are excited with a tunable continuous wave 3000-megacycle magnetron. The input admittance of the cavity is measured as a function of power by standing wave technique. The complex conductivity of the discharge is determined as a function of power from the measured and computed constants of the cavity. The complex conductivity as a function of power gives the voltage and current characteristic of the discharge. Voltage and complex current characteristics have been studied as a function of cavity dimensions, tube dimensions, and pressure.

L8. Characteristics of the Pre-Corona Discharge and Its Use as a Reference Potential in Voltage Stabilizers. SANBORN C. BROWN, *Massachusetts Institute of Technology.*—The sensitivity of the current to changes in voltage in the pre-corona region of electrical discharges in gases is very high. The current-voltage characteristics of the pre-corona discharge maintained by radiation from radioactive disintegration has been studied extensively. Data will be presented showing the characteristics of this type of discharge between coaxial cylinder electrodes as a function of geometry, gas, radiation source strength, and pressure. Under typical conditions, at 2000 volts the current increases from 10^{-8} amp to 10^{-6} amp for a seven-volt change in potential. The use of this nearly constant voltage pre-corona discharge as a reference potential for simple high impedance electronic voltage stabilizers is discussed. Stabilizers of this type have been tested in routine use for controlling high voltage sources for Geiger-Müller counters. They have proved as reliable and satisfactory as the usual type of electronic stabilizers with much greater circuit simplicity.

L9. The Scattering of Electromagnetic Radiation by a Thin Circular Ring in a Circular Wave Guide. PAULA FEUER AND EDWARD S. AKELEY, *Purdue University*.—The field in a circular wave guide when a TE_{11} wave is scattered by an infinitely thin, perfectly conducting, narrow circular ring is obtained to a certain degree of approximation. Let (r, θ) be polar coordinates in the plane of the ring. The current density in the ring will vary as $C \cos\theta$. The field produced in the guide by this current is determined, and the remaining terms of the scattered field are obtained by requiring that the total tangential electric field vanish on the infinitely conducting walls of the guide. The constant C is evaluated by requiring the tangential electric field, E_θ, to vanish on the ring. The ratio of the scattered field to the incident field at a great distance from the obstacle is computed and also the position and shape of the resonance maximum. At resonance, all the incident radiation is scattered, which means that the intensity far from the ring on the side away from the source, is zero. The position of the maximum is given by the relation $ka = 1-\delta$ where a is the radius of the ring and δ a positive quantity that approaches zero as the width of the ring decreases.

L10. A Theory of the Narrow Resonant Slit in a Wave Guide Partition. EDWARD S. AKELEY, *Purdue University*.—Boundary conditions at the slit can be satisfied by assuming such a distribution of surface magnetic current density j in the slit that the total field on the slit is zero. The following assumptions are made: (1) only the TE_{10} mode can be propagated, its transverse magnetic field being parallel to the slit and (2) the slit is so narrow that the electric vector potential F at a point on the slit is mainly due to j in immediate neighborhood of the point j and F are determined together by a method of successive approximations by making use of the relation $d^2F/dx^2 + k^2F = (a)\mu H \sin \pi x/g$ and the expression of F as an integral of j over the slit and its infinite system of images in the conducting planes. The ratio r of the amplitude of the transmitted radiation at infinity to the incident amplitude is determined. Resonance occurs at $k = \pi/2L$ for infinitely narrow slit and $r = 1$ at resonance. These results are independent of the position of slit in partition. Formulas are given for the determination of the shape of the resonance maximum and shift of same from $k = \pi/2L$.

L11. Pulse Transformer Ratings Based on Energy Considerations, and Methods of Design Based on Thermodynamical Considerations. W. H. BOSTICK, *Radiation Laboratory, Massachusetts Institute of Technology*.—A simple, yet generally applicable, equivalent circuit for most pulse transformers consists of a shunt inductance L_p (representing the core), a series leakage inductance L_L, and an effective distributed capacitance C_D across the load. The sum of the energy α stored in the core and the energy β stored in the coil may be minimized to give the conditions for maximum transfer of pulse energy to a load of impedance Z. These conditions are: (1) $(L_L/C_D)^{\frac{1}{2}} = Z$, (2) the optimum pulse length $\delta_{\mathrm{opt}} = (2L_P C_D)^{\frac{1}{2}}$, and (3) at $\delta = \delta_{\mathrm{opt}}$, $(\alpha+\beta) \equiv (\alpha+\beta)_{\mathrm{opt}} = \mathrm{a}$ minimum. Condition (3) may be achieved with (1) and (2) as constraining conditions by designing a transformer which, at the end of the pulse, is in the lowest possible energy state. The lowest possible energy state may be achieved by choosing equal energy densities, volumes, and perimeters for core and coil. Such a design procedure yields approximate analytical expressions to be used in the calculation of the optimum flux density of the core, optimum core volume, the optimum number of turns, and the value of $(\alpha+\beta)_{\mathrm{opt}}$.

L12. A Circle Diagram for Resonant Microwave Systems. WILLIAM ALTAR, *Westinghouse Research Laboratories*.—A new circle diagram is presented for systems having an isolated single resonant mode, in addition to frequency insensitive structures of arbitrary complexities and ending in an outgoing wave guide or other transmission line. The diagram is obtained from standing wave measurements in the outgoing line performed at three or more frequencies near resonance. The diagram permits the mapping, in the complex plane of load impedances or reflection coefficients, of such contour lines as loaded resonator Q, frequency pulling, and the circuit efficiency when the resonator is electronically excited. The proof of these relations rests on field theory and establishes in effect the validity of general circuit methods in the realm of microwave applications.

L13. Robot Dynamics—Theory of Non-Linear Automatic Control Systems. MELVIN AVRAMY, *Columbia University*.—The theory of *robots* or reproducing power-amplifying systems is considered. After a general orientation the study in the first part is confined to *simple robots*, the theory of which is equivalent to that of non-linear springs with inertia and friction. The alacrity and fidelity of control are well exhibited by studying the behavior of a robot under constant tracking. Among the results obtained are: Criteria for oscillation or overdamping of non-linear robots (these are generalizations of the usual criteria for linear systems). Generally valid results on the asymptotic approach to the steady state, and the steady state itself. Through these, the asymptotic behavior of any faithful robot may be studied in terms of the two limiting cases of proportional and on-off robots which are analyzed in detail. Special emphasis is placed on the specification of conditions for *optimum performance*, i.e., minimum deviation or maximum fidelity after any given time. Charts are given with curves from which the parameter values for optimum performance may be read off. Approximation methods for studying the entire history of non-linear robots are developed.

X1. Low Pressure Gas Discharges in Microwave TR Tubes. LOUIS D. SMULLIN, *Radiation Laboratory, Cambridge, Massachusetts and Federal Telecommunications Laboratory, New York.*—A TR tube is essentially a rapidly acting switch in a radar duplexing circuit. It breaks down in less than 10^{-8} sec. after the beginning of the transmitter pulse. The energy (about 0.5 erg) going to the receiver during this interval is the spike energy. The power going to the receiver after the discharge has formed is the arc leakage power. Both quantities are sensitive to the gas and pressure in which the discharge takes place. Measurement techniques and typical data for 10- and 3-cm TR tubes will be presented. Possible applications of these techniques to further gas studies will be indicated.

X2. Design of Copper Disk Seal TR Tubes. J. W. CLARK, A. E. ANDERSEN, AND A. L. SAMUEL, *Bell Telephone Laboratories.*—The copper disk seal method of construction for microwave vacuum tubes, in which a part of the resonant cavity is outside the vacuum envelop and so is available to the circuit designer for adjustment will be described. Such tubes are well suited for use in physical experiments as they are not restricted to use in particular frequency bands. Design principles of copper disk seal TR tubes will be discussed with reference to optimization of cavity Q and to compensation against undesirable thermal effects. Specific tube designs for use in the vicinity of 1000, 3000, and 10,000 mc will be shown.

X3. The Integral Cavity TR Switch. D. ALPERT AND S. KRASIK, *Westinghouse Research Laboratories.*—An integral cavity TR switch is one in which the resonant circuit used with the discharge gap is included within the vacuum enclosure. This design permits close manufacturing tolerances and a performance otherwise difficult to obtain at frequencies of 10,000 megacycles per second and higher. The design problems of such a switch include electrical tuning, electrical coupling, mechanical mounting, and vacuum sealing. Some of these problems have been solved in the 1B24 TR switch by the introduction of novel techniques.

X4. Gas Discharge Switches for Controlling Low Power Microwave Signals. T'ING-SUI KE* and LOUIS D. SMULLIN,** *Radiation Laboratory, Massachusetts Institute of Technology.*—In a TR tube, the keep-alive electrode is placed comparatively deep inside the lower cone to prevent excessive "keep-alive interaction." The keep-alive was placed nearer to the r-f gap so that electrons furnished from the keep-alive discharge cause an attenuation of the incoming signals. This provides an electronic switch for controlling microwave signals which are not powerful enough to breakdown the gap. Attenuation was found to be proportional to the current. Nitrogen was found to be most suitable as the gas-filling. In a modified 1B24 filled with 12-mm nitrogen, 44-db attenuation was obtained when the keep-alive current was 0.4 ma. No detectable microwave noise was introduced. The ionized gas appears to have a large microwave conductance and a comparatively small susceptance.

* Now at Institute for the Study of Metals, University of Chicago.
** Now at Federal Telecommunications Laboratory, New York.

X5. Recovery Time Measurements on TR Tubes. C. F. CRANDELL,* A. L. SAMUEL, AND J. W. CLARK, *Bell Telephone Laboratories.*—A method used for measuring the recovery time of TR tubes will be described. The principal problem is the accurate measurement of time intervals of the order of 5 to 10 microseconds. Data will be presented showing the relation between loss through the TR cavity and time for several different gases, and showing temperature effects. The variation of recovery time with operation of the tube will be discussed.

* Now at Southwestern Bell Telephone Company, Dallas, Texas.

X6. Phenomenological Theory of the TR Switch Spike. T. HOLSTEIN, *Westinghouse Research Laboratories.*—The essential feature of the initiation of a TR switch spike is the mutual interaction between the ionization in the gas and the electromagnetic field of the cavity. The time variation of the gap voltage is affected by the incident high power pulse, the cavity geometry, and the electron density at the gap; under certain conditions these effects may be described by the equation

$$\frac{2Q_L}{\omega}\dot{V}=(2R_TP_M)^{\frac{1}{2}}\phi(t)-rV.$$

Here, V is the amplitude of the gap voltage, Q_L the loaded Q, $\phi(t)$ the time variation of the incident field amplitude normalized so that $\phi(t)$ is unity when the pulse power has reached its peak, P_M, R_T the transmission shunt resistance and r a quantity proportional to the electron conductivity of the gap. Assuming the phenomenological equation $d\log r/dt=\theta V$, with θ a constant depending upon the gap spacing and the gas, we are able to solve for V for arbitrary $\phi(t)$. Explicit solutions have been obtained for $\phi\sim e^{t/\tau}$.

X7. Conductivity of Electrons in a Gas at Microwave Frequencies. HENRY MARGENAU, *Radiation Laboratory, Cambridge, Massachusetts, and Yale University, New Haven, Connecticut.*—The conductivity of electrons in gases is well understood in two limiting cases: that of low frequencies and high pressures (Langevin's formula), and of high frequencies and low pressures (free electron formula). To provide a satisfactory treatment for intermediate conditions, the distribution-in-energy of electrons in a high frequency field is here derived by kinetic-theory methods. Using the distribution law the complex conductivity is calculated as function of electron density, gas pressure and frequency of the field. From the conductivity, the dielectric constant of the medium, its extinction coefficient, etc., are deduced. Application of these results to the experiments of Montgomery, McMillan, Dearnley, and Pearsall (paper No. X8) clarifies understanding of the fundamental processes taking place in TR-tube recovery.

X8. Cross Sections for Capture of Electrons from TR-tube Recovery Measurements. C. G. MONTGOMERY, F. L. MCMILLAN, I. H. DEARNLEY, AND C. S. PEARSALL, *Radiation Laboratory, Cambridge, Massachusetts.*—To accelerate the disappearance of free electrons from a TR tube after a discharge has taken place it is customary to employ a gas which attaches the electrons to form negative ions. Because of their large masses, negative ions do not absorb energy at microwave frequencies. Observations of the attenuation of a microwave signal as a function of the time after the cessation of a discharge can be used to calculate the capture cross section by means of the theory of H. Margenau (paper No. X7). Within about a microsecond, electrons that have a high energy during the discharge period come into thermal equilibrium with the gas molecules because of elastic collisions. The capture cross sections are thus determined for the thermal energy range. Measurements with water vapor give a value of 10^{-4} per collision. In oxygen, capture takes place to form both O^- and O_2^-. In argon it seems necessary to postulate the formation of A_2^-. Many organic vapors capture electrons readily, but the ions formed are not easily identified.

X9. An Equivalent Circuit for the Microwave TR Tube. A. L. SAMUEL, *Bell Telephone Laboratories.*—A lumped circuit equivalent for a TR cavity will be presented. All the important properties of the TR (except recovery time) can be predicted from this circuit. The point of view here presented is particularly useful in system design, where the opposing considerations of low level and high level performance must be reconciled. Application of the theory to broadband TR and ATR tubes will be given.

X10. The Band-Pass TR Switch. Part I: The Switching Action, MILAN D. FISKE, *Research Laboratory, General Electric Company, Schenectady, New York.*—The band-pass TR switch consists of a number of resonant breakdown gaps uniformly spaced within a wave-guide section which is closed at either end by a resonant window and filled with low pressure gas. During the transmission pulse of the radar set a glow discharge is established across each gap and across the entrant window by the strong electric fields existing during the pulse. The loading of the window and gaps by the conductance of the discharges provides the switching action. Rapid breakdown is assured by a small steady discharge (the "keep-alive") maintained near at least one gap. When the TR is filled with argon at a pressure of 10 mm of mercury, the first gap breaks down within 5×10^{-9} second after initiation of the pulse, limiting leakage of the incident r-f energy through the tube to less than 0.1 erg. Leakage is independent of line powers ranging from 1 watt to more than 30-kw peak. Post-pulse deionization in pure argon requires more than 100 μsec. When a pressure of 0.5 mm of water vapor is added to the argon, the ion density decays to that maintained by the keep-alive in less than 3 μsec.

X11. The Band-Pass TR Switch. Part II: Linear Electrical Characteristics, WALLACE C. CALDWELL, *Radiation Laboratory, Massachusetts Institute of Technology, now at Cornell University.*—Considerable effort has been directed toward the extension of the transmission band of the TR Switch using the scheme proposed by M. D. Fiske.[1] It is possible to combine several resonant circuits in wave guide in such a way that the insertion loss due to reflection is less than 0.5 db over a 12 percent wave-length range. The absorption loss can be made as low as 0.5 db. The elemental resonant structures are described and their equivalent circuit can be regarded as shunt inductance and capacitance across the transmission line. Insertion loss as a function of wave-length are presented for one, two, three, and four resonant elements spaced along the line at equal intervals of a quarter guide wave-length.

[1] Milan D. Fiske, "A Broad-Band T-R Switch," General Electric Report (October 1943).

X12. Microwave Duplexing Circuits. H. K. FARR, *Radiation Laboratory, Cambridge, Massachusetts, and General Electric Company, Pittsfield, Massachusetts.*—The "duplex" radar system which uses the same antenna for transmitting and receiving ordinarily employs automatic electronic switches to connect the antenna alternately to transmitter and receiver. Two separate switches are frequently used although one may suffice if the transmitting oscillator satisfies certain conditions when quiescent. The techniques are discussed for connecting these switches to the radar components by wave-guide or coaxial transmission lines, and the properties of the wave-guide junctions used are described. Methods of achieving good efficiency over a range of wave-lengths are considered, especially with regard to the most serious problem, the loss of received signal. Several examples are presented of circuits for 1.25, 3, and 10 centimeter wave-lengths.

Y1. Improvements in the Stability of the FP-54 Electrometer Tube. J. M. LAFFERTY AND K. H. KINGDON, *General Electric Company.*—It was found that a considerable portion of the instability in the FP-54 is due to variations in emission from the thoriated tungsten filament. Operation of the filament at a current which neither activates nor deactivates it was found to be a good criterion for adjusting the circuits employing these tubes. Large fluctuations were observed in emission immediately after activation of the filament. Greater stability was obtained by increasing the activation time from 8 to 40 minutes. Filament end shields improved the stability, showing that some rapid fluctuations in emission occur at the poorly activated end portions of the filaments. Long-time drifts were not improved by end shields. Tubes with oxide-coated filaments gave greater sensitivity and less grid current than tubes with thoriated tungsten filaments. These tubes, however, had a tendency to drift. A split type of FP-54 was constructed with a common filament and space-charge grid, but with twin control grids and plates. Both oxide-coated and thoriated tungsten filaments were used. Operation of these tubes in a bridge type circuit eliminated long-time drift and decreased the amplitude of rapid fluctuations by a factor of ten.

Y2. Influence of Space-Charge on the Bunching of Electron Beams. L. BRILLOUIN, *Cruft Laboratory, Harvard University.*—A rigorous computation of electron trajectories within plane structures may be made, with the inclusion of space-charge effects, by use of the Llewellyn method of integration. These computations can be used for a discussion of conditions leading to intercrossing trajectories, i.e., bunching. The discussion has been carried out for a conventional plane diode, for a diode wherein electrons are injected with a given initial velocity, for a velocity-modulated beam, for a plane magnetron and for a plane magnetron with velocity modulation. In many cases it can be proved that trajectories intercross not once but twice, thus disentangling themselves after a while. This occurs only for weak bunching and disappears for strong bunching.

Y3. The Maximum Efficiency of Reflex Oscillators. E. G. LINDER AND R. L. SPROULL, *RCA Laboratories, Princeton, New Jersey.*—The theory of velocity-modulation reflex oscillators is developed and extended. The maximum efficiency with optimum electron bunching and optimum loading is shown to be

$$\eta_0 = 0.17 M^2 R_c i_1 / V_0,$$

where M is the gap efficiency, R_c is the unloaded shunt resistance, i_1 is the beam current, and V_0 is the beam voltage. Possible methods of increasing efficiency are investigated, including the use of multiple transits. The relationship between efficiency, range of electronic frequency modulation, and load resistance is discussed.

Y4. Theory of the Diode. JULIAN K. KNIPP, *Radiation Laboratory, Massachusetts Institute of Technology.*—A theory is developed for the r-f behavior of a region bounded by parallel plane grids into which electrons are injected at the first grid and none or some are reflected. The small amplitude approximation is made and variations parallel to the grids are neglected. However, the distribution in velocity of the electrons is taken fully into account and effects of space charge are included. The r-f phenomena are completely described in terms of the total r-f current (as determined by the load), the injected r-f electronic current distribution (as determined by the preceding regions), and certain impedance and transfer coefficients which are explicit functions of a resolving kernel. The resolving kernel is the solution of a Fredholm integral equation the kernel of which is calculated from the d.c. component of the injected current distribution and phase factors containing products of the r-f frequency and times of passage of electrons to planes within the region, calculated in the absence of the r-f field.

Y5. Principles of Operation of the Resnatron. F. W. BOGGS, *Westinghouse Research Laboratories.*—During the war there was developed at Westinghouse a tube for ultra-high frequency generation which, although it has many features in common with the Class C oscillator, differs from it sufficiently to warrant special consideration. This tube, which has proved to be the most powerful source of ultra-high frequencies yet constructed, is characterized by the fact that it operates with a substantial transit time, by the unusual design of its grid, and by the use of resonant cavities in the vacuum envelope. It can be shown by means of trajectory plots that a gain in efficiency can be achieved by placing a high voltage screen between the anode and the grid; and it can be further shown that better efficiencies will be obtained when the voltage of the screen is close to that on the anode. The tracing of electron trajectories through the grid shows that its action is to focus the electron beam away from the grid and the screen; and that the effective grid-cathode spacing is very small. At the same time the massive construction of the grid makes it much easier to cool.

Y6. Modulation and Tuning of Cavity Oscillators by Electron Beams.* DAVID S. SAXON,** *Radiation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.*—The frequency of cavity oscillators such as the magnetron can be shifted by sending a beam of electrons through the cavity or through an auxiliary cavity which is tightly coupled to the oscillator.[1] Calculations of the frequency shift produced in this way have been carried out for simple rectangular geometries.[1,2] The theory has now been generalized so that it applies when the electron beam is sent parallel to the axis of a cylindrical cavity of arbitrary cross section which is operating in any of its H (or TE) modes. The detailed nature of the cross section enters only through a proportionality constant—the ratio of electric energy stored in the volume of the system occupied by the beam to that stored in the entire system. Since this ratio is less than unity, upper limits to the tuning can be established and the design features can be discussed from a general point of view.

* This paper is based on work done for the OSRD under contract OEMsr-262 with the Massachusetts Institute of Technology.
** Now at Philips Laboratories, Inc., Irvington, New York.
[1] L. P. Smith and C. Shulman, RCA Technical Report PTR-22C (2/14/45).
[2] A. Banos, Jr. and D. S. Saxon, Radiation Laboratory Report 748 (5/26/45).

Y7. Energy Build-Up in Magnetrons. L. P. HUNTER, *Westinghouse Research Laboratories.*—An analysis of the operation of resonant cavity magnetrons is made without regard to the mechanism of conversion of the d.c. input power into the r-f output power. The magnetron is represented by its equivalent circuit and is assumed to be essentially in equilibrium at every point of its energy build-up curve. The last assumption is shown to be reasonable on the basis of measured starting times. From the data of load impedance charts and the rise of the r-f pulse, the relation between power generated and vane voltage is deduced. By considering the division of the energy between that stored in the resonant system, and that dissipated in the load, the law of build-up is derived. The dependence of starting time on load is calculated and agrees with experiment when the extra energy stored in the connecting line is taken into account. The starting time is affected slightly by the initial noise level and becomes infinite below a minimum Q. For high Q values the starting time can be varied only by changing the energy stored in the line, which may enable one to design a line for "mode" suppression.

Y8. "Crown of Thorns" Tuning of Magnetrons.* SIMON SONKIN, *Columbia Radiation Laboratory, Columbia University.*—A mechanically tunable vane type magnetron is described. The tuning mechanism consists of a set of pins or rods ("crown of thorns") mounted so that they can be introduced into the cavities of the magnetron anode without touching the walls. Curves of the variations of wave-length and power output as a function of pin penetration are given for a magnetron in the centimeter wave-length range. Tuning of the order of 10 percent was obtained and found to be quite linear. Causes and elimination of variations in power output with wave-length are discussed.

* This paper is based on work done for the OSRD under Contract OEMsr-485.

Y9. Development of the Rising Sun Magnetron Anode Structure,* SIDNEY MILLMAN AND ARNOLD NORDSIECK, *Columbia Radiation Laboratory, Columbia University.*—Modern magnetron anode structures for generating centimeter waves are very tiny and must have a very large number of segments. Because of the many segments the problem of keeping the operating "plus-minus" mode sufficiently separated in frequency from other resonant modes of the structure is a severe one. The small size makes it difficult and costly to secure mode separation by "strapping," i.e., inserting metallic connectors between alternate segments. Some time ago, the authors engaged in a program to improve the operation of unstrapped magnetrons oscillating in a mode other than the plus-minus mode by introducing regular asymmetries in the anode structure. This led to a scheme for solving the mode separation problem for the plus-minus mode by making the resonator cavities alternately large and small, with the ratio of the resonant wave-lengths of large and small cavities in the range of about 1.5 to 2.5. The mode spectrum of such an oscillating system is described. The advantages and limitations of magnetrons possessing this anode structure are discussed. Very successful magnetron oscillators of this design have been built in the wave-length regions of one and three centimeters.

* This paper is based on work done for the OSRD under Contract OEMsr-485.

Y10. Theory of the Rising Sun Magnetron Anode.* NORMAN KROLL AND WILLIS E. LAMB, JR., *Columbia Radiation Laboratory, Columbia University.*—An electromagnetic field theory for the rising sun type magnetron anode block has been developed, from which the wave-length spectrum and the electromagnetic fields can be computed. The method is analogous to that developed by Clogston for the symmetric anode. The anode block is divided into regions of simple geometry, namely the cathode-anode space and the side resonators. In each of these regions it is possible to find a solution of Maxwell's equations for any specified boundary values of E_T, the tangential electric field. At a junction between regions of different geometry the behavior of E_T must be such that a frequency exists for which the resultant magnetic fields are continuous. E_T is partially guessed, resonance being determined by the condition that the average value of the magnetic field over the various junctions be continuous. The computed spectrum is a sufficiently good representation of the observed spectrum to be of great use in magnetron design. The method has been generalized to discuss anodes having different symmetry from the rising sun.

* This paper is based on work done for the OSRD under Contract OEMsr-485.

Y11. One Centimeter Rising Sun Magnetrons with 26 and 38 Cavities.* A. V. HOLLENBERG, S. MILLMAN, AND N. KROLL, *Columbia Radiation Laboratory, Columbia University.*—The advantages of large numbers of cavities for very short wave-length magnetrons are discussed. Difficulties of realizing operation in the plus-minus mode without disturbance from other modes are shown in a discussion of the rising sun mode spectrum. The solution of these difficulties by closing the ends of the anode is described. Pulsed operation of 26 and 38 cavity closed end magnetrons in the one to two centimeter wave-length range is described.

* This paper is based on work done for the OSRD under Contract OEMsr-485.

Y12. Space-Charge Frequency Dependence of a Magnetron Cavity.* M. PHILLIPS AND W. E. LAMB, JR., *Columbia Radiation Laboratory, Columbia University.*—The effect on the resonant frequencies of a magnetron cavity produced by the presence of a thin layer of charge surrounding the cathode is investigated. The corresponding experimental procedure is the "cold impedance testing" of a magnetron with a hot cathode in the presence of a magnetic field and a low d.c. cathode-anode voltage. A small amplitude theory is used, based on the single stream steady state. The correction to the frequency of the empty cavity due to a thin cloud of charge surrounding the cathode is given by a resonance type formula about the "cyclotron frequency," $eB/2\pi m$. The validity of the theory is limited to low level oscillations, but the comparison of theory with experimental results seems to support the existence of the single stream steady state for non-operating magnetrons.

* This paper is based on work done for the OSRD under Contract OEMsr-485.

Y13. A High Power Rising Sun Magnetron.* ARTHUR ASHKIN, *Columbia Radiation Laboratory, Columbia University.*—One of the advantages of the rising sun magnetron design is that the mode separation is independent of the anode length. This permits one to build a magnetron in which the anode is very much longer than that of the conventional strapped magnetrons. Advantage has been taken of this fact in the design of a high power 3-cm region magnetron for pulsed operation at 35 kv and 6500 gauss. Tubes have been constructed which give peak powers of 1 megawatt at an output efficiency of about 45 percent. At lower power levels efficiencies in excess of 55 percent have been observed. The circuit efficiency in these magnetrons is about 75 percent.

* This paper is based on work done for the OSRD under Contract OEMsr-485.

SP1. Enhanced Thermionic Emission from Oxide Cathodes. J. B. JOHNSON, *Bell Telephone Laboratories.*[1]—When an oxide-coated cathode in the temperature range of thermionic emission is bombarded by short pulses of electrons, current of three kinds is emitted: (1) The original thermionic current, (2) The relatively constant secondary current, and (3) A current which rises at a decreasing rate during the pulse and persists with decreasing amplitude after the end of the pulse. As seen on an oscilloscope, the emission of the third kind induced by a pulse a few microseconds in length can be observed to persist for many microseconds. It may be larger or smaller than the original thermionic current, depending on the bombarding current and voltage, on the length of pulse and on the state of the cathode. The enhanced emission follows roughly Richardson's law with the same value of b as the original emission. Its origin cannot be that of the Malter effect for the resistivity of the hot oxide is too low to support a surface charge. Similarly, rise of surface temperature owing to the bombardment is far too small to account for the increase in emission. One must conclude that the bombardment temporarily increases the thermionic activity of the oxide-coated cathode.

[1] To be presented after session J if time permits.

SP2. Radioautography With P^{32} and Sr^{89}. DANIEL Q. POSIN,* *University of Montana.*[1]—Studies were conducted on the nature and intensity of the self-rays or radioautographs produced by radiophosphorus and radiostrontium when pictures are made by rats born radioactive, eggs laid radioactive; and bacteria *E. coli* rendered radioactive by growth in a synthetic medium in which the disodium phosphate is radioactive. Approximate figures are given for radiation density and time of exposure to the negatives for producing satisfactory self-rays.

* Now at Radiation Laboratory, Massachusetts Institute of Technology.
[1] To be presented after session H if time permits.

SP3. Electron Orbits in the Synchrotron. DAVID S. SAXON* AND JULIAN SCHWINGER, *Radiation Laboratory, Massachusetts Institute of Technology and Harvard University.*[1]—Equations for the electron orbital motion in synchrotrons have been derived by a method which avoids the inaccuracies of previous treatments.[2,3] The localized accelerating field is replaced by an equivalent rotating electric field in the mathematical analysis. This situation could be physically realized in a microwave synchrotron. For small deviations from the equilibrium orbit, a fourth-order differential equation for the motion of the electron phase relative to that of the electric field is obtained which includes the effect of the changing magnetic field and of radiation losses. This equation enables one to discuss the phase motion in the various regions of operation of a device which, as has been suggested, is operated initially as a betatron. The new features are the transient effects accompanying the switching on of the electric field and of the failure of the betatron flux condition preceding operation as a synchrotron. A discussion of the characteristics of the various regimes will be given.

* Now at Philips Laboratories, Inc., Irvington, New York.
[1] To be presented after session B if time permits.
[2] V. Veksler, J. Phys. USSR 9, 153 (1945).
[3] E. M. McMillan, Phys. Rev. **68**, 143 (1945).

T1. Astrophysical Phenomena and the Magnetic Current. FELIX EHRENHAFT, *New York City.*—The constant magnetic current as visualized by Hertz and experimentally demonstrated by the author permits the performance of model experiments of astronomical phenomena in the darkfield of the microscope. Ultimately no more can be done in science than to correlate phenomena and to trace them back to a common cause. The author asks whether the following is acceptable to astronomers. The photographs of spiral nebulae resemble photographs of helical photophoretic movements in the field of radiation. Phenomena similiar to the separation of Schmidt's nebula* (see also Bredichin), apparently can be explained as separation by light-positive and light-negative photophoretic movements. The formation of circulating rings in gases and liquids occurring around magnets, analogous to Saturn's rings, seem due to electric action of magnetic currents. Could not the simultaneously direct and retrograde movement of Jupiters and Saturns moons be explained in this way? Sunspots are sources of magnetic discharges, from them a magnetic current is flowing. The electric vortices in them are due to electric action of magnetic currents. A model experiment was performed demonstrating the reversibility or occasional non-reversibility of these electric vortices associated with changes of magnetic polarity. This is in accord with new results showing reciprocal effects between changes of magnetic fields and electric charges and in accord with phenomena in the sunspots.

* Physik. Zeits. **20**, 93 (1919).

T2. The Measurement of Ultra-Short Time Differences. S. H. NEDDERMEYER, *Los Alamos, New Mexico.*—A device has been constructed[1] which utilizes the superposition of electromagnetic pulses to determine the time interval between the pulses.[2] The present arrangement consists of a coaxial line bent into a closed loop, and a detector coupled to any desired point on one section. Pulses are introduced at the center of the opposite section by discharging a short length of line through a matching network so that equal pulses are sent simultaneously in opposite directions. A simple two-stage detector discriminates the superposition region nicely so that when output is plotted against position, the center is located to about ± 0.5 cm. This implies that time differences can be measured to an accuracy of about $\pm 3\times 10^{-11}$ sec. That the instrument behaves properly has been verified by noting: (a) disappearance of the superposition region when one side of the line is cut and terminated, and (b) shifting of the superposition locus when a lag is introduced on either side by inserting dielectric.

[1] Dubbed a "chronotron."
[2] Same principle has been used in a different way by M. Newman, Phys. Rev. **52**, 652 (1937). It occurred to the writer independently as the electromagnetic version of the Dautriche method of comparing detonation rates in explosives.