Proceedings of the American Physical Society

1946 Annual Meeting at New York, January 30, 31 and February 1, 1947

THE largest meeting in the history of the American Physical Society was its 277th, the 1946 Annual Meeting held at Columbia University on Thursday, Friday, and Saturday, January thirtieth and thirty-first and February first, 1947. No fewer than 1536 registration cards were filled out, surpassing by over two hundred the previous record set in the same place just one year before. Some of these go to the credit of the American Association of Physics Teachers, which held joint and concurrent meetings with ours; the Division of High-Polymer Physics and the Committee on Fluid Dynamics drew many, the exact number being unknowable. In spite of the huge attendance, the congestion was noticeably less than a year ago, because of the distribution of the sessions among several buildings with adequate auditoriums: we drew upon the Department of Chemistry for the Havemeyer lecture-hall, upon Teachers College for Horace Mann Auditorium and upon Columbia University for daily use of McMillin Theatre. Nevertheless the four-ring circuses which our meetings have become, with their multiple and irreconcilable claims upon the time of the members, form in some ways a dismal contrast with the small congenial meetings of old, and pose insoluble problems. The mere problem of managing so vast a meeting would have been insoluble, but that the junior members of the Department of Physics at Columbia University gave up literally all their time for several days. Special credit is due N. F. Ramsey, Chairman of the Local Committee; to W. W. Havens, G. R. Becker, and to W. S. Gorton of the Bell Telephone Laboratories who provided the acoustical equipment; and to the staff of the American Institute of Physics which tended the registration desk. These brief but needed services can never be repaid except by evanescent words.

The Retiring Presidential Address of E. U. Condon was given under the title "The Franck-Condon Principle and Some Related Topics." This formed a part of the joint session of Friday afternoon with the AAPT, the rest of which comprised the presentation of the Oersted Medal to Duane Roller and the delivery of the Richtmyer Lecture by J. R. Oppenheimer. On Thursday afternoon there was a symposium under the joint sponsorship of the Society and the AAPT, at which General H. S. Aurand and Admiral P. F. Lee spoke, respectively, on "Research and Development in the War Department" and "Research Programmes of the Office of Naval Research in the Physical Sciences." On Friday evening after the dinner D. W. Bronk acquainted his audience with "The Role of the National Research Council in American Science and Education." Nine invited papers on a variety of subjects were interspersed throughout the three days: the speakers and the titles are listed hereinafter. There were ninety-two contributed papers in the general programme of the Society: their abstracts follow.

The Division of High-Polymer Physics held four sessions, and abstracts of all but one of the papers, invited and contributed alike, are printed at the end of these Minutes. The Committee on Fluid Dynamics (R. J. Seeger, Chairman), with the co-sponsorship of the American Mathematical Society, held also four sessions, including a Symposium on Recent Developments in Compressible Flow: abstracts of most of its papers, invited and contributed alike, are printed hereinafter.

The dinner of the Society was divided into two sections, one in the familiar precincts of the Mens' Faculty Club and the other in the no less appreciated John Jay Hall, with a total attendance approaching 550.

At the Business Meeting of the Society, which was held on Friday morning, the Tellers reported the following elections to terms of office commencing at the end of the Annual Meeting: L. A DuBridge, *President;* J. R. Oppenheimer, *Vice President;* K. K. Darrow, *Secretary;* G. B. Pegram, *Treasurer;* J. T. Tate, *Editor* (three-year term); P. M. Morse and J. R. Oppenheimer, *Councillors* (four-year term); H. A. Bethe, L. A. Ridenour, and W. H. Zachariasen, *Members of* *the Board of Editors* (three-year term). The Secretary reported that, presuming acceptance of election by all candidates to membership elected at the Council meeting, the membership of the Society stood at 6050.

The Council, meeting on Thursday evening, elected to Fellowship five candidates (Lyle Borst, Ralph Bown, D. O. North, A. H. Snell, and Katherine Way) and to Membership 214 candidates whose names are appended.

Elected to Membership: Edward J. Althaus, Norman Austern, Oscar Beran, Abraham S. Berman, Milton J. Bernstein, William Bernstein, Donald E. Billings, Converse Herrick Blanchard, Sidney A. Bludman, Richard W. Blue, Robert J. Bobber, Sidney Borowitz, Ben Braun, Stuart R. Brinkley, Jr., Herbert Broida, Frederick C. Brown, Robert Reginald Brown, Merle Thomas Burgy, Edwin J. Callan, Jessie Y. Cann, Ann Chamberlain, Herman H. Chanowitz, C. Harmon Chapman, John B. Cladis, John M. Cleveland, Kenneth D. Coleman, Gerald Cohen, Daniel Isaac Cooper, Walter G. Countryman, Clyde L. Cowan, Jr., William Slayter Cowort, Jr., Thomas W. Dakin, Laurence B. Deen, Jr., Charles H. Donelson, Robert G. Dorsch, John J. Dropkin, Stanley L. Ehrlich, C. Eijkman, Roy Arnold Elkind, Willard L. Erickson, Ragnar Ericsson, John L. Everett, John J. Faris, Sherwood L. Fawcett, Lawrence Feldman, Simon Freed, Melvin S. Freedman, Douglas M. French, Gerhart Friedlander, Robert H. Frost, Dudley D. Fuller, James M. Garner, Jr., John E. Garrett, David M. Gates, Lawrence Seymour Germain, Frank E. E. Germann, Thomas Gilmartin, Jacob Burrill Gilstein, Norman Jerome Golden, Stanford Goldman, Morris Goran, Gordon Gould, John R. Green, Melville Saul Green, Joseph Greenspan, John L. Greenstadt, Burgoyne L. Griffing, John J. Guarrera, Glenn Edward Hagen, George B. Harris, Jr., Edward W. Hart, Albert Jerold Hatch, Warren E. Henry, Robert V. Higdon, Bertram L. Hoffman, Ralph E. Hightower, Benjamin Gregory Hogg, Gunnar Hok, Donald F. Hornig, Wendell A. Horning, Paul Von Campen Hough, Erle Howell, Jr., Harry C. Hoyt, Jack A. Hunter, James F. Hurlbut, Carol B. Hyatt, Peter J. Isaacs, Irvin Isenberg, James Madison Jackson, Stanley Anthony Jashemski, Robert Sawyer John, Jr., Gustave Joyet, Edward T. Jurney, Leonard Anthony Kalal, Hugh J. Karr, Jr., Elmer L. Kelly, William Clark Kelly, Donald B. Kerr, J. Kistemaker, Walter Kiszenicky, Murray S. Klamken, George D. Kneip, Jr., Ray L. Kramer, Frank E. Kruesi, Jr., George Czeslaw Kuczynski, Alfred B. Laponsky, Richard A. Laubenstein, Margaret N. Lewis, Leon J. Lidofsky, Hans Wolfgang Liepmann, Arthur Linz, Jr., Robert Lionel Lipton, John Knox Logan, Edward D. Lowry, Joaquin Mazdak Luttinger, Torsten Magnusson, Stephen F. Malakev, Jr., Charles Manneback, Ruth Margolin, Ray W. Mayhew, John R. McCartney, James Prentiss McClellan, Thomas R. McGuire, Lazarus T. Medveson, Edwin P. Meiners, Jr., Harry E. Moses, George M. Muller, Charles J. Munda, Jr., Rodger V. Neidigh, Paul F. Nemenyi, Herman Newhouse, Karl W. Ninnemann, Perley G. Nutting, Jr., George B. Olmsted, Wylie J. Oosterkamp, Alan L. Orvis, George E. Owen, Robert H. Park, Vincent E. Parker, John R. Pasta, Norman Pearlman, Enrico Persico, Ben Petree, Oreste Piccioni, William John Pietenpol, William R. Polye, David Samuel Potter, Ray M. Potter, Robert Clay Prim, III, Sol Raboy, Charles H. Raeth, Russell F. Raitt, Paul I. Richards, Harold N. Ritland, Norman H. Roberts, Y. Rocard, Fritz Rohrlick, Carl L. Rollinson, Harlan Rosenblatt, Morris Rubinoff, Zella Ruthberg, L. A. Sanderman, Tsien San-Tsiang, James Schenek, Huburt W. Schlevning, Warner W. Schultz, Robert N. Schwartz, Harner Selvidge, Philip Anderson Shaffer, Jr., Daniel Shanks, Gerald Shapiro, Jacob Shapiro, Charles Sheer, George William Sherard, Norman Steven Shiren, Jerry Shmoys, W. Sichak, Kai Siegbahn, Siegfried Fred Singer, Lewis Slack, Bernard Smaller, Elmer H. Smith, Harold D. Smith, Newell Hart Smith, James Newton Snyder, William Sollfrey, Irvin L. Sparks, David S. Stacey, John S. Stanton, Ernest J. Sternglass, Richard Griffith Stoner, M. W. P. Strandberg, Max Sucher, Chain Swiatycki, Theodor Teichmann, Jay W. Thornhill, Harold K. Ticho, Bernard E. Tiffany, David Van Meter, Francis Arthur Vick, Walter Geoffrey Wadey, Claude E. Walker, Ernest Wantuch, Paul E. Weiler, Alfred Weissler, Harold Wergeland, William L. Whittemore, Robert W. Willmott, James R. Wilson, Stanislas David Winter, Albert William Wotring, Courtney Wright, Keith H. Wycoff, and Fu-Chun Yu.

The Society has lost through death G. W. Kenrick (Watson Laboratories).

Karl K. Darrow, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Invited Papers on the General Programme

Higher-Order Tyndall Spectra in Mono-Disperse Colloids. V. K. LAMER AND DAVID SINCLAIR, *Columbia University.*

The Production of Ice Crystals in Artificial and in Natural Clouds. IRVING LANGMUIR, V. J. SCHAEFER, AND BERNARD VONNEGUT, *General Electric Company.*

Theories of Helium II. J. G. MAYER, *University of Chicago.*

Behavior of Fission Products and of Very Heavy Elements in Biological Phenomena. J. G. HAMILTON, *University of California.*

The Entropy of Liquids and Solutions. J. H. HILDEBRAND, *University of California.*

Creation and Destruction of Mesons. J. R. OPPENHEIMER, *University of California.*

Operation of a 70-Mev Synchrotron. H. C. POLLOCK, R. V. LANGMUIR, AND F. R. ELDER, *General Electric Company.*

The Use of Electron Multiplier Tubes in Experimental Nuclear Physics. J. S. ALLEN, *University of Chicago.*

Attenuator Materials, Attenuators, and Terminators for Microwaves. G. K. TEAL, M. D. RIGTERINK, AND C. J. FROSCH, *Bell Telephone Laboratories.*

Symposium of the Committee on Fluid Dynamics

Recent Developments in Compressible Flow. Papers by JOHN VON NEUMANN, *Institute for Advanced Study;* G. F. J. TEMPLE, Fluid Motion Committee, *Aeronautical Research Council, London, England;* and THEODORE VON KARMAN, *California Institute of Technology.*

A1. The Variation with Altitude and Latitude of the Vertical Component of the Cosmic Radiation Passing through 15 cm of Lead. W. F. G. SWANN AND PETER A. MORRIS, *Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania.*—Under the auspices of the National Geographic Society and the Army Air Corps, vertically directed cosmic-ray telescopes, covered with 15 cm of lead, were flown in a B-29 bomber from 58°N magnetic latitude to the magnetic equator in flights at 5000, 15,000, at 25,000, and 33,000 feet with the following results: 1. The ratio of intensity at 58°N to that at the equator was 1.34 at 33,000 ft. and 1.51 at 25,000 ft. At the lower altitudes it was equal to unity within the limit of accuracy of the experiments. 2. However, the actual difference between the intensity at 58°N and at the equator increased in the ratio 1.50 to unity from 25,000 ft. to 33,000 ft. 3. Insofar as the knee of the latitude curve represents a well defined point at all, it occurs at about 48°N magnetic latitude, with no marked variation with altitude from 25,000 ft. to 33,000 ft. Facts (1) and (2) are in harmony with the view that, superposed upon the portion of the hard component originating from a field-sensitive primary, we have a component arising from a non-field-sensitive primary, which is absorbed rapidly (presumably by the creation of mesotrons) between 33,000 ft. and 25,000 ft. and lower. These conclusions are in harmony with the observations of Schein and Wilson.[1]

[1] Schein and Wilson, Phys. Rev. 54, 304 (1938).

A2. Azimuthal Variations of Cosmic Radiation at Lahore. PIARA SINGH GILL,* *Forman Christian College, Lahore, India.*—A study of the azimuthal variations of the cosmic radiation at Lahore (22°N magnetic latitude) shows a large azimuthal effect. The azimuthal effect in the Northwest Quadrant for a constant zenith angle of 60° is in general agreement with theoretical prediction. These observations lead to the conclusion that (1) primary cosmic-ray particles are positively charged; (2) the energy spectrum of the primary cosmic rays within the energy range 7.84×10^9 ev and 14×10^9 ev (for protons) obeys the law $Be^{-\gamma}$ where $\gamma=2.8$.

* At present at the University of Chicago.

A3. Meson Showers under Lead at Sea-Level. WILLIAM B. FRETTER, *University of California, Berkeley.*—Eleven photographs of meson showers under 30 cm of lead have been obtained using two cloud chambers. One was in a magnetic field, while the other, which contained eight one-half-inch lead plates, was vertically in line below and was simultaneously tripped by counters. Penetrating particles were clearly identified in the lower chamber, and curvature-ionization observations were made in the upper chamber. In two pictures mesons were identified in large electron showers which were associated with heavily ionizing particles in the upper or lower chamber. Few electrons were associated with most of the meson showers in the lower chamber, but heavy tracks often were visible in both chambers. Presence of these heavy tracks indicates that even at sea level meson showers are often accompanied by non-cascade radiation capable of producing nuclear events.

A4. Mechanism of Absorption of Negative Mesons. JOHN A. WHEELER, *Princeton University.*—Under the electrostatic attraction of a nucleus of charge Z, a negative meson can execute a Bohr orbit. The radius is smaller than that of the corresponding electronic orbit by the mass ratio 200, but even in the case of K-orbits is larger than nuclear dimensions for Z less than about 35. The energy release calculated for capture of a thermal meson into the lowest Bohr orbit of iron, for example, is 1.8 Mev; $2s$ or $2p$ orbit, 0.45 Mev. The capture probability is the additive resultant of three effects: emission of the available energy as a photon; transfer of the energy to an atomic electron (Auger effect); transfer to a negative energy electron to cause pair production (only possible for calcium and heavier nuclei). In solid material the calculated life with respect to such *atomic* capture is far less than the normal life, 2×10^{-6} seconds, with respect to radioactive decay. Subsequent *nuclear* capture of a meson from a K-orbit will be expected to have a probability proportional to Z^4, whether by emission of the mass energy of the meson as a photon or by star formation. Thus, to the extent that direct capture of a thermal meson into the nucleus can be neglected, the probability for decay of a negative meson stopped in a solid element will be expected to depend on atomic number as $[1+(Z/Z_0)^4]^{-1}$, where Z_0 is a constant which must be determined experimentally.

A5. A New Determination of the Mean Life of Mesotrons at an Altitude of 11,500 Feet. HAROLD K. TICHO, *University of Chicago* (Introduced by Marcel Schein).—The mean life of mesotrons stopped in 10 cm of Al was measured at Chicago and Climax (altitude 11,500 ft.). The method consisted essentially of a direct comparison between the time interval due to the decay of each individual mesotron and the period of an accurately calibrated quartz crystal. The crystal frequency of 100 kc per second produced a circular sweep and each time interval appeared as an arc on the oscillograph screen. Exponential disintegration curves were obtained at both altitudes and yielded a mean life of $1.97\pm0.15\times10^{-6}$ sec. at Chicago and $1.78\pm0.10\times10^{-6}$ sec. at Climax. Further experiments are in progress at Chicago. Both values seem lower than those obtained by Nereson and Rossi.[1] Such a difference might be caused by a finite capture probability for negative mesotrons in light materials like Al.

[1] N. Nereson and B. Rossi, Phys. Rev. **64**, 199 (1943).

A6. Production of Cosmic-Ray Stars. EUGENE GROSS, SHUICHI KUSAKA, AND GEORGE SNOW, *Princeton University*.—Data on cosmic-ray stars obtained from cloud-chamber studies and photographic plates by various investigators are analyzed and possible mechanisms for their production studied. The observations are rather meager and not entirely consistent, but the results can be summarized roughly as follows: They occur with a frequency of about 10^{-9} per cc per sec. in air at sea level and increase by a factor of about 50 in going up to an altitude of 14,000 feet. Bagge has attributed the production to γ-rays, but numerical estimates show that the star frequency is about a factor of 100, too large to be accounted for by this process. Lukirsky and Perfilov have considered the production to be caused by absorption of slow negative mesons by air nuclei. This process can account for the number of stars observed at sea level, but not the altitude dependence. Powell has suggested the neutrons as the producers of stars. Calculations made with the assumption that energetic neutrons arise by a cascade process from primary protons show that this hypothesis gives the right order of magnitude both for the number and altitude dependence of stars.

A7. Thermal Neutron Activation Cross Sections.* LEO SEREN,** HERBERT N. FRIEDLANDER, SOLOMON H. TURKEL, *Argonne National Laboratory*.—A survey has been made of cross sections for those nuclei which give rise to radioactive isotopes upon thermal neutron capture. This survey covered 67 elements and cross sections for 133 of the known 160 induced activities. The smallest and largest atomic cross sections measured were 4×10^{-7} barns (10^{-24} cm^2) for the production of 31-second $_8O^{19}$ and 725 barns for the production of 140-minute $_{66}Dy^{165}$. The source of neutrons was the graphite pile and the heavy water pile at the Argonne Laboratory. Incident neutron flux was measured by activated monitors which had previously been calibrated in a standard graphite pile. Captured neutron flux was measured by counting the absolute number of beta-decay particles after irradiation, and reducing this decay rate to a saturated value. The complete table of cross sections will be published soon in *The Physical Review*.

* Work was completed October 1944. This document is based on work performed under Contract No. W-7401-eng-37 for the Manhattan Project at the Argonne National Laboratory.
** Now at General Electric Research Laboratory, Schenectady, New York.

A8. On the Theory of Slowing Down Neutrons in Substances with Periodic Absorption Lines. S. H. BROWNE AND T. DANTZIG, *North American Aviation, Inc.*—The general integral equation for the stationary energy distribution for slowing down of neutrons, as derived by G. Placzek,[1] is applied to the problem of slowing down in an infinite medium in which both $1/v$-capture and capture by resonance absorption lines occur simultaneously. The energy distribution at low energies is obtained from a series solution of the integral equation. To simplify the mathematical problem, instead of the usual expression for cross section for resonance absorption, a trigonometric type of periodic function is used which is applicable to uniformly spaced absorption lines and can be made to agree closely with available experimental data by proper choice of the parameters involved. The energy distribution of neutrons for all energies is discussed. The results are compared with those obtained by the approximation for absorption lines indicated by Placzek, and with his solutions for slowing down without capture and of slowing down with $1/v$-capture. An attempt is made to extend the method to include the case of a medium of finite size.

[1] G. Placzek, Phys. Rev. **69**, 423 (1946).

A9. High Energy Gamma-Rays from U(235) Fission Products. S. BERNSTEIN, W. M. PRESTON, G. WOLFE, R. E. SLATTERY, *Clinton Laboratories*.—The photo-disintegration of the deuteron has been used to study the hard γ-rays emitted by fission products of U^{235}. The neutrons created in the process were used as the indicator of the presence of hard γ-rays. The fission products were placed at the center of a 10″ radius sphere of heavy water. Conclusions about the periods and yields of the hard γ-rays were made from the total number of photo-neutrons being captured in a large tank of oil surrounding the sphere of heavy water. Eight half-lives were found: 2.5 sec., 41 sec., 2.4 min., 7.7 min., 27 min., 1.6 hr., 4.4 hr., and 53 hr. The shortest one and longest one of these are least reliable. Eighty-five percent of the photo-neutrons appear in the two shortest half-lives, the 2.5-sec. component being three times as intense as the 30-sec. component. The total saturated activity of the photo-neutrons for an infinite amount of heavy water was calculated from the 10″ radius sphere measurements to be about 16.5 percent of the saturated delayed neutron activity. It is calculated that there must be of the order of one to two photons of energy above 2.2 Mev emitted per fission by fission products with half-lives greater than one second.

[1] This abstract is based on work performed under Contract No. W-35-058-eng-71 for the Manhattan Project.
[2] This abstract appeared in the Bulletin of the American Physical Society, Vol. 21, No. 6, dated November 29, 1946, but the paper could not be presented at the 275th meeting.

A10. Photographic Neutron Detection.* R. A. PECK, JR., *Yale University*.—For the photographic method of neutron detection and energy measurement,[1] the Eastman fine grain alpha-particle emulsion is the only one readily available in this country. However, this exhibits a large pre-exposure background, which introduces ambiguity in the identification of the beginning of proton tracks. Preliminary "defogging" treatment is thus required. As shown by Perfilov,[2] the defogging oxidizer used (potassium permanganate) must be strong enough to remove background grains, yet not strong enough to desensitize the emulsion for proton detection. Within this concentration range, the $KMnO_4$ even exhibits a sensitizing effect, substantially increasing the visible length of proton tracks. The optimum treatment has been determined for the Eastman emulsion, an 18-minute bath in $KMnO_4$ of concentration 0.66 g/liter. A lead camera is necessary to shield the plates from the high gamma-ray background of the cyclotron. The Li(dn) reaction, investigated by Richards,[3] is used to determine the stopping power of the Eastman emulsion as a function of proton energy.

* This work is conducted as a part of O.N.R. contract N60NR44 Task Order V.
[1] Powell et. al., Proc. Roy. Soc. 183, 1, 64 (1944).
[2] Perfilov, J. Phys. U.S.S.R. X, No. 1, 1 (1946).
[3] Richards, Phys. Rev. 59, 796 (1941).

A11. Use of Threshold Detectors for Fast Neutron Studies. BERNARD T. FELD,[1] R. SCALETTAR,[2] AND L. SZILARD.[3] *Metallurgical Laboratory, University of Chicago, Chicago, Illinois*.—Light element (n, p) and (n, α) reactions can be used to compare, qualitatively, the energy distributions of the fast neutrons emitted by various neutron sources. Experiments are described in which a Ra-α-Be and Ra-α-B neutron source are compared by observing their relative activation of a number of light element reactions. Table I summarizes the experimental results. The thresholds for the reactions were calculated by using the best available values of the isotopic masses. The probability for penetration of the Coulomb barrier by the product proton or alpha-particle was calculated from the Gamow formula. The relative values of the activities in the same column have no meaning, since the detectors were not intercalibrated.

TABLE I.

Reaction	Half-life	Calculated threshold (Mev)	Calculated energy for 0.1 penetration (Mev)	Calculated energy for 0.5 penetration (Mev)	Activity Ra-α-Be	Activity $S^{32}(n, p)P^{32}$ Ra-α-B
$S^{32}(n, p)P^{32}$	14.3*d*	.93	2.9	4.0	1.000	1.000
$P^{31}(n, p)Si^{31}$	170*m*	1.02	2.9	3.9	.63	.51
$Al^{27}(n, p)Mg^{27}$	10.2*m*	1.95	3.6	4.6	.29	.058
$Si^{28}(n, p)Al^{28}$	2.4*m*	2.69	4.5	5.5	.95	≤.017
$P^{31}(n, \alpha)Al^{28}$	2.4*m*	.90	6.6	8.3	.24	<.004
$Al^{27}(n, \alpha)Na^{24}$	14.8*h*	2.39	7.5	9.1	.079	<.003

[1] Now at the Massachusetts Institute of Technology, Cambridge, Massachusetts.
[2] Now at Cornell University, Ithaca, New York.
[3] Now at University of Chicago, Chicago, Illinois.

A12. The Scattering of Thermal Neutrons in Polycrystalline Materials. R. M. LANGER AND J. F. DALY, *Bureau of Ships*.—The data of Nix and Clement[1] on thermal neutron scattering in copper can be interpreted quantitatively in terms of the crystal grain size S, the amorphous mass scattering coefficient μ_a/ρ, the rocking angle $\Delta\theta$ through which a crystal grain can be rotated about the Bragg angle without losing its Bragg reflection effectiveness, and finally the crystal thickness S_0 required for a crystal at the Bragg angle to reduce a homogeneous neutron beam by a factor e. The effective mass scattering coefficient μ/ρ including the Bragg scattering is given by the expression

$$\mu/\rho = \mu_a/\rho + \frac{1-\exp[-(2S/S_0)]\,AJ\Delta\theta}{2SN}\left(\frac{2m^3}{\pi k^3 T^3}\right)^{\frac{1}{2}} \int_{h/2dm}^{\infty} \exp[-(mv^2/2kT)]\,v\left(v^2-\left(\frac{h}{2dm}\right)^2\right)^{\frac{1}{2}}\cdot dv.$$

Here J is related to the symmetry number of the crystal, ρ is the density, and the other symbols have their customary significance. The second term in the formula is about as large as the atomic mass scattering term μ_a/ρ for grain sizes S less than 10^{-2} cm in the three substances examined so far.

[1] F. C. Nix and G. F. Clement, Phys. Rev. 68, 159 (1945).

F1. Interferometry of Faster-Than-Sound Phenomena.* RUDOLF LADENBURG, *Princeton University* (30 min.).—Interferometric measurements of supersonic ("faster-than-sound") gas streams enable one to determine the distribution of density, pressure, temperature and gas velocity in the stream throughout the field of view, provided the phenomenon under investigation is two-dimensional or has axial symmetry. Also the apparently discontinuous rise of density, pressure, velocity, etc., through a shock wave can be measured by interferometry. So far studied are: (1) Air flow around bullets in flight (Cranz, Schardin, and others); (2) homogeneous air-streams escaping through a Laval nozzle into the atmosphere ("open wind tunnel") and the air flow around various objects supported in the stream[1]); (3) inhomogeneous air jets escaping from pressure tanks through various circular nozzles at pressure ratios up to 100; and (4) air flow and boundary layers in two-dimensional channel flow. New results with inhomogeneous air jets at widely varying pressure ratios have been obtained by letting the air discharge from a pressure tank into a vacuum tank. Of special interest is the change in the shock formation from a cone with oblique shocks to a kind of truncated cone where a strong plane shock intersects with two conical shocks. The measured angles and shock strengths are compared with the present theory of von Neumann. Further, the information obtained about distribution of density, temperature and velocity in a two-dimensional channel and especially in the boundary layer, when flow is supersonic, will be discussed.

* This work was done in Palmer Physical Laboratory under the sponsorship of the Navy Department, Bureau of Ordnance.
[1] R. Ladenburg, C. C. VanVoorhis, and J. Winckler, Phys. Rev. 69 251(A), 1946.

F2. Refraction of Shocks in Ideal Gases.* A. H. Taub, *University of Washington* (20 min.).—It is assumed that when a plane shock is incident on an interface between two gases of different densities ρ and ρ_1 and different ratios of specific heats γ and γ_1, respectively, a three-shock configuration results, involving an incident shock, a reflected shock, and a transmitted shock. It is further assumed that in the various angular domains the pressure is constant. The Rankine-Hugoniot equations may be used to formulate the following boundary conditions: (1) the pressure across the interface is continuous and (2) the deflection of the flow caused by the incident and reflected wave is equal to that caused by the transmitted wave. Rational polynomial equations of twelfth degree are obtained, the roots of which determine the position and strength of the reflected and transmitted wave as functions of the strength and angle of incidence of the incident wave. Ranges of these parameters where certain types of solutions are possible are determined by analytical methods. The equations were solved numerically, for various values of ρ_1/ρ and γ_1/γ, on the Eniac which was made available through the cooperation of the Army Ordnance department. Mrs. Adele Goldstine superintended the computations.

* This work was begun while the author was employed at Princeton University on work sponsored by the Office of Naval Research.

F3. On the Interaction between Boundary Layer and Shock Waves. H. W. Liepmann, *California Institute of Technology* (20 min.).—Hydrodynamics of real fluids has been, to a large extent, governed by the concept of the boundary layer initiated by Prandtl in 1904. The existence of a boundary layer and the possibility of dividing the solution of a fluid flow problem into two parts, an "outer" inviscid solution giving the pressures and an "inner" solution including viscosity or turbulence giving the shear forces, has become almost self-evident. The extension of fluid mechanics to problems involving supersonic flow requires, however, a critical analysis of the applicability of the classical boundary layer concept. The assumptions underlying the classical theory are certainly not correct near the base of a shock wave and recent experiments have shown that boundary layer effects in transonic flow have a considerable influence upon the external flow field and the form of the shock wave. Hence, there exists a shock wave-boundary layer interaction which makes, at least in some cases, a simultaneous solution of the outer and inner fields of flow necessary. Further experiments have been carried out to clarify the interaction problem and to pave the way for a rational theoretical analysis of this typical non-linear problem.

F4. The Formation and Stability of Normal Shock Waves in Channel Flows. Arthur Kantrowitz, *Cornell University* (20 min.).—There is experimental evidence that channel flows involving shock-free deceleration through the speed of sound are unstable. This paper presents an analysis of non-viscous unsteady channel flow which was made to gain some insight into this apparent instability and to study the closely related (small shock intensity) stable flows. In Part I, Riemann's theory of the propagation of finite amplitude disturbances in a homogeneous medium is extended to the case where upstream moving pulses are superposed on a decelerating transonic channel flow. Shock waves are formed as the pulse is propagated, as in Riemann's problem. If it is assumed that the intensity of the shocks is very small, then the pulse approaches a "trapped" state in which a portion of the decelerating channel flow is converted to an accelerating flow which is an alternate steady-state solution for the channel. In Part II, the assumption of weak shocks is dropped to study the later development of the trapped pulses. It is concluded that smooth transonic deceleration is unstable to compression pulses coming from the rear of the channel and that the shock position is stable in diverging channels and unstable in converging channels.

F5. Notes on the Thermodynamic Propulsion of Wind Tunnels. Francis Clauser, *Johns Hopkins University* (20 min.).—In view of the current trend toward wind tunnels of very great cost and power for supersonic research, this paper undertakes to investigate the feasibility of using thermodynamic propulsion for such tunnels. This is based on the experience with aircraft and missiles that thermodynamic propulsion systems (ram jets, turbo jets, pulse jets, etc.) have been able to supply large amounts of power with relatively simple installations. The present paper deals largely with purely thermodynamic means of propulsion (i.e., without compressors or turbines). It is shown that a ram jet cannot be used to furnish the sustaining motive power for a tunnel. However, the analysis shows what combinations of thermodynamic systems can be used for sustained wind tunnel propulsion. Several installations are analyzed with a view toward practical utilization, and it is concluded that there is hope for success. However, the aerodynamic design of such installations must be carefully considered because they are so constituted that the losses can easily outweigh the gains.

F6. Variation of Aerodynamic Lift in the Transonic Speed Range. W. F. Hilton, *Johns Hopkins University* (20 min.).—Certain difficulties are experienced when attempting free flight in the transonic speed range (0.8 to 1.2 of the speed of sound). These difficulties fall into two main classes: namely, (1) overcoming the somewhat high air resistance by means of improvements in engine design; and (2) balancing the aircraft for stable horizontal flight. The latter problem is considered in the paper. Changes of trim are caused by sudden loss of wing lift in the transonic range, decreasing the downwash over the tail, and possibly resulting in an uncontrollable nose-heavy dive. A qualitative explanation is given of the observed changes of lift, and an approximate calculation of the magnitude of the effect has been made. A method of minimizing these effects is indicated and is found to be verified by wind tunnel experiments.

B1. The Width of the Nuclear Magnetic Resonance Absorption Line in Gases, Liquids, and Solids. N. Bloembergen, R. V. Pound, and E. M. Purcell, *Harvard University.*—Magnetic resonance absorption and dispersion were observed, at 30 Mc/sec., in various substances containing hydrogen or fluorine. The strong field H_0 (approximately 7000 gauss) was modulated with adjustable amplitude at 30 c.p.s., allowing observation of the entire absorption or dispersion curve on an oscilloscope or point-by-point measurement of the slope of either curve with a lock-in amplifier. In water, many other liquids, and hydrogen gas, the line width is less than 0.15 gauss. This upper limit is set by inhomogeneities in H_0. The narrowness of the line can be understood by noting that the local fields from neighboring nuclear or molecular moments (in magnitude several gauss) must nearly average out as the changes in these fields due to molecular motion are rapid compared to the radio frequency. Moreover an estimate of the intensity of the "local field spectrum" at 30 Mc/sec. permits a prediction of the relaxation time in these substances which is in reasonable agreement with our observations. In a single crystal of CaF_2, by contrast, the observed width of the fluorine resonance agrees with that computed under the assumption of fixed neighbors, displaying the predicted dependence on the angle between H_0 and a crystal axis.

B2. Measurements of Nuclear Quadrupole Interactions. W. A. Nierenberg, N. F. Ramsey, S. B. Brody, *Columbia University.*—The resonance minima of the Na^{23} nucleus in NaCl, NaBr, and NaI have been studied using the molecular beam magnetic resonance method. The resultant resonance patterns of beam intensity *versus* frequency for fixed fields $\sim$9.000 gauss are similar to predicted[1] for the interaction of a nuclear electrical quadrupole moment in the molecular field and for an assumed spin of $\frac{3}{2}$. Comparison with theory[1] yields the values for the interaction $e^2qQ/2h$ of 1.35, 1.17, and 0.97 megacycles/sec. for NaCl, NaBr, and NaI respectively, where Q is the quadrupole moment of the nucleus and q is simply related to the gradient at the nucleus of the electric field intensity of the electrons and the other nucleus of the molecule. A new type of resonance minimum was employed to further the investigation. Minima were observed for a very low (less than 4 gauss) magnetic field. The frequency at which the resonance occurs is due to the electric quadrupole interaction. These minima gave values for the interaction agreeing within 5 percent with those listed above. This technique based on the quadrupole interaction should, in addition, provide a method of determining nuclear spins. However, the theory of the resonance patterns observed in some other compounds is not understood as yet.

[1] B. T. Feld and W. E. Lamb, Jr., Phys. Rev. **67**, 15 (1945).

B3. Determination of Stable Species $_{39}Y^{89}$, $_{40}Zr^{90}$, and $_{56}Ba^{134}$ Produced by Nuclear Transmutations. M. H. Kurbatov and J. D. Kurbatov, *Ohio State University, Columbus.*—An experimental procedure has been developed for determination of stable atoms formed by the nuclear transmutations $_{38}Sr^{88}(d, n)_{39}Y^{89}$; $_{39}Y^{89}(d, n)_{40}Zr^{90}$; and $_{55}Cs^{133}(d, n)_{56}Ba^{134}$, when the products are in quantities below 10^{-8} gram. The aim of the work was to evaluate the yield of the competitive reactions d, n producing stable species and d, p or $d, 2n$ producing radioactive species for a given target. The procedure consists in obtaining by means of radioactive tracers reference coagulation isotherms for $_{39}Y^{89}$ and $_{40}Zr^{90}$ and an adsorption isotherm for $_{56}Ba^{134}$ under such conditions that the fraction coagulated or adsorbed respectively changes with the quantity of stable species present. The unknown quantity of stable species is determined from the isotherm after the fraction coagulated or adsorbed is found by means of radioactive tracer.

B4. Thresholds for the Photo-Disintegration of Li^7, Mg^{24}, Al^{27}, Si^{28}, S^{32}, and Ca^{40}. Robert A. Becker, A. O. Hanson and B. C. Diven, *University of Illinois.*—The photo-thresholds for the production of short-lived activities from several substances have been observed using x-rays from the 20-Mev betatron. The technique was similar to that employed by Baldwin and Koch.[1] With the exception of Li^7 the observed activities were produced by (γ, n) reactions. The thresholds in most cases are not well defined, and the estimates of the thresholds are limited by the observed intensity of the activity as compared to that caused by various backgrounds. The approximate periods and estimated thresholds for the observed reactions are presented in the Table I. The calculated thresholds are based on the masses given in Segre's isotope chart of May 1945. No attempt was made to determine the periods accurately.

Table I.

Reaction	Period (sec.)	Threshold (Mev) Observed	Threshold (Mev) Calculated
$Li^7(\gamma, p)He^6$	1	9.5±.3	10.1
$Mg^{24}(\gamma, n)Mg^{23}$	11	16.4±.3	15.5
$Al^{27}(\gamma, n)Al^{26}$	7	14.4±.3	11.1
$Si^{28}(\gamma, n)Si^{27}$	5	16.9±.3	16.0
$S^{32}(\gamma, n)S^{31}$	3	15.0±.3	16.7
$Ca^{40}(\gamma, n)Ca^{39}$	1	16.0±.3	13.7

[1] Baldwin and Koch, Phys. Rev. **67**, 1 (1945).

B5. Energy Levels in the Nucleus Mn^{56}. A. B. Martin, *Yale University.*—The energies of the protons emitted in the reaction $Mn^{55}(d, p)Mn^{56}$ have been measured by an absorption method. It is found that six distinct groups occur in the energy range from zero to 4.3 Mev above the ground state of Mn^{56}. The nuclear energy change values corresponding to these groups are 0.38, 1.15, 2.28, 2.99, 3.69, and 4.76 Mev. From these results it is seen that the spacings of the most prominent energy levels in the Mn^{56} nucleus which are exhibited in a d, p process are, in order of increasing excitation, 1.07, 0.70, 0.71, 1.13, and 0.77 Mev. The Mn^{56} nucleus contains a sufficient number of particles to render the statistical approach to the problem at least reasonably valid. The lack of agreement between the results quoted and the 5-kev level spacing predicted by theory[1] suggests that strong selection rules are operating to restrict the number of energy levels participating in reactions of this type to a very small fraction of the total number that are theoretically possible. Other work has shown that in practically all cases the level spacings observed for excitations up to 5 Mev are of the order of 1 Mev or greater, while the spacings predicted by theory range from 5 kev to 100 kev.

[1] H. A. Bethe, Rev. Mod. Phys. 9, 86 (1937).

B6. Yields of Protons in Transmutations.* ERNEST POLLARD, *Yale University.*—A survey of proton yields from elements of low and medium atomic weight due to aphal-particle and deuteron bombardment has been carried out in this laboratory. One general trend seems to be definite. The greater the excitation energy the greater the proton yield. To a first-order approximation the yield is given by $Y=Ae^{U/B}$ where A, B are constants for any one element and U is the excitation energy. No consistent evidence for a maximum in the yield as predicted by Volkoff[1] for the O-P process seems to exist. Nor is there apparent any reduction in yield as a result of the emergent Coulomb barrier.

* Work done under Navy Contract N6ori-44.
[1] G. M. Volkoff, Phys. Rev. 57, 866 (1940).

B7. *L*-Converted Isomeric Transition. M. GOLDHABER, C. O. MUEHLHAUSE, AND S. H. TURKEL, *Argonne National Laboratory.*—It is shown that the radioactive isotope with a half-lifetime of 1.5 min.,[1] formed by capture of slow neutrons in Ir, does not decay by β-emission as was previously believed, but by an isomeric transition which is largely converted in the L-shell. L-radiation of Ir has been detected, and the energy of the transition has been determined by absorption of the internal conversion electrons to be approximately 60 kev. A γ-ray component of similar energy has been found. This energy is smaller than the energy needed for conversion in the K-shell of Ir (76 kev).

[1] E. McMillan, M. Kamen, and S. Ruben, Phys. Rev. 52, 375 (1937).

B8. Disintegration Scheme of the 21-Minute Isomer of Mn^{52}. R. K. OSBORNE AND M. DEUTSCH, *Massachusetts Institute of Technology.*—The beta- and gamma-spectra of the 21-minute isomer of Mn^{52} have been studied by the same techniques as reported previously for the 6.5-day isomer.* The positron spectrum is simple with an end point at 2.66 ± 0.05 Mev. For such large disintegration energies, orbital electron capture would not be expected to be important. One gamma-ray (besides annihilation radiation) of energy 1.46 ± 0.04 Mev was observed. Beta-gamma coincidence measurements show that all the positrons are followed by this, and only this, gamma-ray. The same gamma-ray energy occurs in the decay of Mn^{52} (6.5 day) and of V^{52}. Thus all three decays have the 1.46-Mev excited state of Cr^{52} in common. With the established disintegration scheme of the 6.5-day isomer, these data show that the 21-minute level in Mn^{52} lies 0.40 ± 0.05 Mev above the 6.5-day level. Conversion electrons corresponding to a 0.392 ± 0.008-Mev transition were observed in the spectrometer with an intensity of 5×10^{-4} conversion electron per positron. The accompanying gamma-rays were not observed because of their low intensity. Some new details of the decay of Mn^{52} (6.5 day) and V^{52} will be reported.

* Peacock and Deutsch, Phys. Rev. 69, 306 (1946).

B9. Internally Converted Gamma-Radiation from Tantalum (182). JAMES M. CORK AND FRANKLIN B. SHULL, *University of Michigan.*—The beta-radiation from a sample of tantalum, radiated in the pile, is being studied in a large semi-circular focusing magnetic spectrometer. On using a photographic method about 16 sharp lines are observed caused by electrons with energies less than 200 kev. These can be arranged in several K-L-M and L-M groups characteristic of the level differences in tungsten, indicating that in the decay (half-life 97 days) a beta emission is followed by the gamma-radiation. An attempt is made to arrange a level scheme capable of accounting for the many lines.

B10. Neutron-Proton and Proton-Proton Scattering at 200 Mev. J. ASHKIN AND R. E. MARSHAK, *University of Rochester.*—To get some orientation with regard to high energy scattering experiments, the cross section for n-p and p-p scattering at 200 Mev is calculated using the Born approximation. Calculations are performed for the S(symmetrical), C(charged), and N(neutral) theories on the basis of a square well. The constants (range, depth, amount of tensor force, etc.) are taken from Rarita and Schwinger's paper.[1] The total cross section for n-p scattering is 1.0×10^{-26} cm^2 and does not vary more than 10 percent, depending on the theory used. However, the angular distribution is very sensitive to the particular theory. In the S theory, backward scattering (in the c.g. system) is 4 times as great as forward scattering. The C theory gives a backward scattering 400 times as great as the forward scattering. The N theory predicts an angular distribution just the reverse of that predicted by the C theory. The S, C, and N theories do not predict such strikingly different angular distributions for p-p scattering. But the total cross sections for p-p scattering do vary considerably (by a factor of 7). The sensitivity of the results to the shape of the potential will also be discussed.

[1] W. Rarita and J. Schwinger ,Phys. Rev. 59, 436 (1941).

B11. Results of H^3 Bombardments on Ag and Rh. D. N. KUNDU AND M. L. POOL, *Ohio State University.*—H^3 has been used as the bombarding particle to effect nuclear reactions. The 13-hour Pd^{109} activity has been produced by bombarding silver with H^3 according to the reaction $Ag^{109}(H^3, He^3)Pd^{109}$. The assignment[1] of this activity to Pd^{109} and not to Pd^{107} has been further checked by observing that this activity is not produced on prolonged alpha bombardment of Ru. The possibility of a (d, α) reaction leading to any confusion as to results has been obviated. The effect of the reaction $Ag^{109}(n, p)Pd^{109}$ has been estimated and corrected for. There is reason to believe that the reaction (H^3, p) also takes place. The 7.5-day Ag^{111} activity appears to be produced because of $Ag^{109}(H^3, p)Ag^{111}$ and also with a much longer bombardment, the reaction

$Rh^{103}(H^3, p)Rh^{105}$ seems to be evident, resulting in the 35-hour Rh^{105} activity. The energy of the H^3 particles used is approximately 10 Mev.

[1] W. Rall, Phys. Rev. 70, 112 (1946).

B12. The Nuclear Energy Surface. EUGENE FEENBERG, *Washington University*.—The semi-empirical theory of the nuclear energy surface as sum of volume, surface, symmetry, Coulomb, and expansion terms has been subjected to critical revision. A quantitative correlation appears to exist between the windings of the mass valley in the $N-Z$, A-plane and irregularities (plateaus) in the packing fraction curve. The theoretical pf curve and the various energy parameters are fixed within narrow limits by the mass differences of odd isobars ($N-Z=\pm1$) independent, within wide limits, of the value assigned to the compressibility coefficient. Two procedures (the analysis of nuclear fission, the fitting of the theoretical pf curve) yield independent values for the ratio surface energy/Coulomb energy. These values differ, presumably because the first involves the size of the real nucleus, whereas the second, through the assumption $R=r_0A^{\frac{1}{3}}$, refers to a uniform state of nuclear matter as it would be in the absence of internal pressures tending to produce expansion. A reasonable value of the compressibility coefficient, consistent with estimates based on the virial theorem, suffices to account for the computed 10 percent difference. A general proof is found for Wigner's rule that isotopic numbers $N-Z=2n-1$ and $N-Z=2n$ first occur at nearly the same values of A.

C1. Stability of Polyelectrons. EGIL A. HYLLERAAS, *University of Oslo*, AND AADNE ORE, *Yale University*.—Previous calculations gave little evidence for the stability of the four-electron $(++--)$.[1] In the present paper some mathematical simplifications have been obtained, which involve a reduction in the number of independent variables and facilitate the calculation of matrix elements with suitably chosen wave functions. The function

$$\psi\sim\exp-\left[\frac{1+\beta}{2}(r_{1a}+r_{2b})+\frac{1-\beta}{2}(r_{1b}+r_{2a})\right]+\exp-\left[\frac{1-\beta}{2}(r_{1a}+r_{2b})+\frac{1+\beta}{2}(r_{1b}+r_{2a})\right]$$

yields a lower limit for the binding energy of roughly 0.11 ev for $\beta^2=0.50$. (1, 2 and a, b refer to electrons and positrons, respectively.) The dynamical stability of the neutral four-electron has thus been proved and an affirmative answer is thereby given to the rather fundamental question regarding the stability of larger aggregates of positrons and electrons, such as those suggested by Wheeler.

[1] J. A. Wheeler, Ann. New York Acad. Sci. 48, Art. 3, 219 (1946); A. Ore, Phys. Rev. 70, 90 (1946).

C2. On the Heitler Theory of Radiation Damping. JOHN M. BLATT, *Massachusetts Institute of Technology*.—Heitler[1] has developed a method of including radiation damping in scattering problems. It involves an integral equation for the scattered field amplitude far from the scatterer. We derived this integral equation classically for a special group of problems. The essential neglect in our deviation also appears in the usual quantum-mechanical derivation.[2] Our derivation allows a comparison between the Heitler method and the Wentzel-Dirac λ-process. Two simple problems are discussed, involving the interaction of an oscillator with scalar and vector meson fields, respectively. Both problems have exact solutions, which we compare with approximate solutions by the Heitler method. The Heitler method preserves the shape of the resonance, but neglects the shift in resonance frequency caused by the additional mass of the oscillator coming from the coupling to the meson field. The strong radiation damping encountered in vector meson theory appears in the second example, although we assumed no spin interaction. The damping can be traced to the Lorentz condition $\sum_{i=1}^{4}\partial U_i/\partial x_i=0$ on the 4-vector field quantity U_i.

[1] W. Heitler, Proc. Camb. Phil. Soc. 37, 291 (1941).
[2] S. T. Ma and C. F. Hsüeh, Proc. Camb. Phil. Soc. 40, 167 (1944)

C3. A Remark on the Correspondence Treatment of Radiation. W. H. FURRY, *Harvard University*.—If expressions for E and H in the wave zone are calculated from the wave-mechanical formulas for charge and current of an atomic system, an approximately correct account of the emission of radiation can be obtained only if this E and H are still regarded as subject to matrix rules of multiplication. This is most clearly indicated in Pauli's exposition of the treatment by the correspondence principle.[1] One can then raise the question as to what this approach gives for the commutation rules of E and H. When it is assumed that the region in question is surrounded by a distribution of oscillators sufficiently numerous to serve as a complete absorber, it turns out that the commutation rules obtained are just those of quantum electrodynamics. This may be regarded as adding to the evidence that quantum electrodynamics must be accepted as a logical development of the correspondence treatment of radiation.

[1] Pauli, *Handbuch der Physik*, Vol. XXIV, no. 1.

C4. Formula for the Coupling of Nuclear Quadrupole Moments in Symmetrical Polyatomic Molecules. J. H. VAN VLECK, *Harvard University*.—If the nucleus has a quadrupole moment and a spin greater than $\frac{1}{2}$, its various possible orientations cause a hyperfine structure, even if the magnetic effects of the nuclear spin are negligible. The dependence of this structure on the quantum numbers J and K of a "symmetrical top molecule" is calculated by quantum mechanics. The effect of the quantum number K is to introduce an extra factor $1-3K^2/(J^2+J)$ not present in the formulas derived by Kramers or Casimir for molecules with $K=0$. It is assumed that the nucleus with the quadrupole moment is located on the axis of symmetry and that the spin effects of other nuclei are unimportant. The calculations thus apply to NH_3 if the hyperfine structure comes mainly from the N nucleus. The predicted dependence on J and K is confirmed with amazing precision in the measurements of Dailey, Kyhl, Strandberg, and Wilson on the microwave inversion spectrum of ammonia.[1] From the absolute magnitude of the observed structure one concludes that the product of the gradient of the electric field at the N nucleus and the latter's quadrupole moment is eighteen times as large as the corresponding product for the D nucleus in HD.

[1] Dailey, Kyhl, Strandberg, Van Vleck, and Wilson, Phys. Rev. **70**, 984(L) (1946).

C5. Thermal Analog of the High Frequency Electron Distribution.[1] LAWTON M. HARTMAN, *Yale University*.—It has been shown[2] that when only elastic collisions occur between electrons and gas molecules the isotropic part of the distribution function under a high frequency field may under suitable conditions be approximated by a Maxwellian function at an effective temperature T', which is determined by the field strength and frequency and differs from the gas temperature T. This conclusion is extended to include inelastic collisions: if the period of the field is much smaller than the mean free time of the electron, the isotropic part of the distribution function always will be identical with the distribution function in a field free gas whose temperature is T'. Utilizing this fact, the distribution function is obtained for the case of a single type of inelastic encounter, assuming a linear cross section. The result may be expressed in terms of the confluent hypergeometric function for the energy range above the excitation potential and may be computed numerically for smaller values by two quadratures.

[1] Sponsored by Office of Naval Research.
[2] H. Margenau, Phys. Rev. **69**, 508–513 (1946).

C6. Irreversible Processes in Stellar Dynamics. HERBERT JEHLE, *Franklin Institute*.—The discussion of Boltzmann's H-theorem (cf. Ehrenfest, Encyclopaedie der mathematischen Wissenschaften) centered around the inquiry after the cause of irreversibility, i.e., of the trends in the development of a distribution function $f(x_1, x_2, x_3, v_1, v_2, v_3, t)$ in phase space, notwithstanding the reversibility of classical mechanics. It was recognized that a statistical treatment of the interaction between molecules provided for the deduction of the second law of thermodynamics as a statistical law. If the particles move in a smooth field of force, besides interaction (encounter) forces, the force fluctuation method gives account of the irreversible diffusion superimposed on the smooth streaming of representative points in phase space (Brownian motion in a field of force[1]). In stellar dynamics we are not only concerned about time-dependent solutions of Boltzmann-Gibbs' hydrodynamical equation of transport in a given field of force, but in particular about hydrodynamical self-consistent fields, steady and transient solutions, trying to account for trends of development like the flattening of a galactic system. Such a coupling of the hydrodynamical equations with Poisson's equation is non-linear, but so far still reversible. The superimposing of a statistical "tapping effect" originating from force fluctuations (encounter forces), however, brings about the irreversibility we are looking for.

[1] H. A. Kramers, Physica (1940).

C7. Note on the Recurrence Time Problem for the Two-Dimensional Markoffian Random Function. ARNOLD J. F. SIEGERT, *Syracuse University*.—We have shown (for the two-dimensional Markoffian random function[1]) the equivalence of two seemingly different approaches to the problem of finding the conditional probability that a random function $y(t)$, which has a root at t_0, returns to zero for the first time in $(t, t+dt)$. Wiener[2] and Rice[3] have given a formal solution in form of a series, while, generalizing an argument of Schroedinger,[4] one obtains the integral equation

$$\tilde{P}_0(t_0\dot{y}_0/t\dot{y}) = p(t_0\dot{y}_0/t\dot{y}) - \int_{t_0}^{t} d\vartheta \int_{-\infty}^{\infty} d\dot{\eta}\tilde{P}_0(t_0 y_0/\vartheta\dot{\eta})p(\vartheta\dot{\eta}/t\dot{y}),$$

where $\tilde{P}_k(t_0\dot{y}_0/t\dot{y})d\dot{y}dt$ denotes the conditional probability that $y(t)$—after starting from zero at t_0 with derivative $\dot{y}_0$—returns to zero in the interval $(t, t+dt)$ for the $(k+1)$th time; $p(t_0\dot{y}_0/t\dot{y}) = \sum_{k=0}^{\infty} \tilde{P}_k(t_0\dot{y}_0/t\dot{y})$ being easily obtained from $P_2(y_0\dot{y}_0t_0/y\dot{y}t)$. The Wiener-Rice series for this process is obtained from the integral-equation by iteration.

[1] Such as the coordinate of a harmonic oscillator in Brownian motion, M. C. Wang and G. E. Uhlenbeck, Rev. Mod. Phys. **17**, 323 (1945).
[2] N. Wiener, verbal communication.
[3] S. O. Rice, Bur. Stand. J. Research **24**, 46 (1945); Eqs. (3.4–11).
[4] E. Schroedinger, Physik. Zeits. **16**, 289 (1915).

C8. Scattering from Statistically Distributed Scatterers. PETER G. BERGMANN, *Sonar Analysis Group*.—The notion of the self-correlation coefficient, the importance of which was first recognized by N. Wiener, has been applied to scattering problems, when the statistical distribution of the scatterers is such that a spatial self-correlation coefficient can be defined. It is possible to express the intensity of the scattered radiation as a function of the scattering angle in terms of the Fourier transform of the self-correlation coefficient of the scatterers. A few cases which are of interest in x-ray diffraction work have been worked out and will be presented. The principal application of the method lies probably in the interpretation of x-ray patterns of imperfect crystals, polycrystalline materials, and partially ordered matter.

C9. Motion of Charged Particles in Inhomogeneous Anisotropic Media. N. CHAKO, *Kansas State College*.—The equivalence between the path of light rays of geometrical optics in inhomogeneous anisotropic media and the trajectories of charged particles in electromagnetic fields is established by a single function, the characteristic function of Hamilton V, commonly called the *point eiconal*. This function responds to the action function S which appears in the Hamilton-Jacobi theory of classical mechanics. Starting with the action function, $S(x_i, x_i')$, which is a function of both the positional and directional coordinated (generalized coordinates and momenta qi, pi), the equations of motion of charged particles in inhomogeneous anisotropic media and a general expression for the refractive index of the particles are obtained. As a special case, the expression of the refractive index[1] of an electron in an electromagnetic field is obtained, as well as the more general case, where the electron moves according to special relativity theory. Further, the fifth-order theory of image errors is developed and it is applied to axial symmetric electron optical system. Besides the nine (actually ten) errors in geometrical optics obtained by Schwarzschild,[2] one finds 6 additional errors,[3] which are due to the anisotropy of the medium due to the magnetic field. These errors have been studied in an extensive manner with the hope of future application in connection with high energy apparatus.

[1] P. Frank, Phys. Rev. **62**, 241 (1942).
[2] K. Schwarzschild, Untersuchungen zur geometrischen Optik, König. Gess. Wiss. zu Göttingen **4**, 1 (1905–1906).
[3] In general, one obtains for additional errors, but for this particular case they do not appear in the development of the Seidel's eiconal function.

C10. An Investigation of Thick Target X-Ray Production in the Range from 1250 to 2350 kv. W. W. Buechner, R. J. Van de Graaff, E. A. Burrill, and A. Sperduto, *Massachusetts Institute of Technology.*—An experimental investigation has been made of the thick target production of x-rays using electrons from an electrostatic accelerator. Measurements of x-ray intensity at various angles with respect to the incident electron beam were made with an ionization chamber for targets of beryllium, aluminum, copper, silver, tungsten, and gold. The radiation was filtered to reduce the softer components. Various voltages from 1250 to 2350 kv were used and the angular range covered was from 0 to 140 degrees. The radiation intensity and its angular distribution are in agreement with the results of Petrauskas, Van Atta, and Myers[1] for gold. The total radiation intensity, integrated over all angles, is found to be accurately linear with atomic number in this energy range. From these measurements, the efficiency of x-ray production may be calculated. The values of efficiency obtained are in general agreement with the measurements and theoretical calculations of Arcimovic and Chramov[2] for the case of copper and of Ivanov, Walter, Sinelnikov, Taranov, and Abramovich[3] for the case of lead.

[1] Petrauskas, Van Atta, and Myers, Phys. Rev. **63**, 389 (1943).
[2] L. A. Arcimovic and V. A. Chramov, Comptes Rendus Acad. Sci. U.S.S.R. **7**, 415 (1938).
[3] Ivanov, Walter, Sinelnikov, Taranov, and Abramovich, J. Phys. U.S.S.R. **4**, 319 (1941).

C11. Probability of *K*-Ionization of Nickel by Electrons. L. T. Pockman, D. L. Webster, P. Kirkpatrick, and K. Harworth, *Stanford University.*—Absolute *K*-ionization cross sections Φ_k, calculated from our relative measurements[1] of nickel K_α line intensity and an absolute measurement[2] are well expressed empirically by

$$\Phi_k = 7.27(e/V_k^2)(V/V_k)^{-0.837}\log_{10}(V/V_k).$$

V and V_k are bombarding and *K*-ionizing potentials. Burhop's[3] theory fits these absolute cross sections as well as could be expected of a Born-approximation, non-relativistic theory. Since non-relativistic theories make $\Phi_k V_k^2$ nearly the same for nickel and silver at any V/V_k, we ascribe our observed differences[4] to relativity and deduce cross sections for hypothetical non-relativistic nickel. These confirm Burhop still better. Comparison with helium ionization data[5] suggests that each helium electron considerably reduces the cross sections for the other at low voltages.

[1] D. L. Webster, L. T. Pockman, K. Harworth, and P. Kirkpatrick, Phys. Rev. **55**, 682 (1939).
[2] A. E. Smick and P. Kirkpatrick, Phys. Rev. **67**, 153 (1945).
[3] E. H. S. Burhop, Proc. Camb. Phil. Soc. **36**, 43 (1940).
[4] D. L. Webster, W. W. Hansen, and F. B. Duveneck, Phys. Rev. **43**, 839 (1933).
[5] P. T. Smith, Phys. Rev. **36**, 1293 (1930).

C12. Absolute Energy of $K\alpha$ Radiation from Thick Silver Targets. Paul Kirkpatrick and A. V. Baez, *Stanford University.*—$K\alpha$ radiation from a thick silver target bombarded at 40 kv was isolated by Ross filters of 42 Mo and 45 Rh and the total energy measured with a large air-filled ion chamber and found to be 8.6×10^{-12} erg per electron. This standardizes the curve of intensity *vs.* bombardment voltage measured in arbitrary units up to 180 kv by Webster, Hansen, and Duveneck. A quantitative explanation of the curve may be developed upon the basis of the absolute cross section of the silver atom for *K*-ionization by electron impact, known over a considerable range of bombardment voltages from measurements by Webster, Hansen, and Duveneck and by J. C. Clark. From this cross section and the rate of energy loss of the bombardment electron it is possible to determine the number of *K*-ionizations produced by the electron. The radiation energy follows readily after due account has been taken of the silver fluorescence yield, the relative intensities of the several *K* lines, the *K*-ionizations produced by fluorescence, and the bombardment electrons lost by rediffusion. Corresponding ordinates of the calculated and observed curves of absolute $K\alpha$ intensity *vs.* bombardment voltage differ by five to ten percent, which is no more than their probable errors.

G1. Scale Factors in Water Entry. Harold Wayland, *Underwater Ordnance Division, Naval Ordnance Test Station* (20 min.).—In 1943 facilities were constructed by the California Institute of Technology under OSRD contract for the Bureau of Ordnance, Navy Department, for studying water entry of large weapons such as aircraft torpedoes. The existence of these facilities made possible the first critical study of the modeling of water entry phenomena wherein accurate quantitative data were available from large scale objects. Fundamental difficulties in modeling the oblique entry of fine-nosed projectiles were encountered, which were associated with the properties of the atmosphere above the fluid medium. The effect of the atmosphere on cavity behavior had been recognized, but these experiments showed that the force pattern on the projectile nose was seriously modified before the nose was symmetrically wetted. This proved to be due to viscous effects of the gas. In light of these and other anomalies, the general problem of modeling water entry is briefly reviewed.

G2. Fluid Flow Patterns. Garrett Birkhoff and Thomas E. Caywood, *Harvard University* (20 min.).—Quantitative discussion is given of the velocity fields caused by the entry of solids into water. Our main experimental technique used is high speed multiflash photography of 1-mm diameter air bubbles located in a fixed vertical plane; this was first developed by L. B. Slichter. We conjectured from "virtual mass" theory, and verified experimentally, that the air bubbles may move twice as far as the surrounding water, and in a different direction. We developed mathematical "corrections" applicable to various cases, for inferring the water velocity from the air bubble displacement. A modification of Slichter's technique is described, based on silhouette photography of dyed oil drops, which is often much easier to correct. Various specific flow patterns are exhibited, and conclusions reached regarding the physical applicability of certain branches of classical mathematical hydrodynamics—especially so-called Dirichlet flow, wake theory, and jet theory.

G3. The Interaction of Shock-Waves, the Spectra of Cavity Charge Explosions, and the Production of Artificial Meteors. R. W. WOOD, *Johns Hopkins University* (20 min.). —An account is given of the examination of interfering shock-waves in air by "Schlieren" photography, and by the patterns which they trace on plates of smoked glass, in an attempt to verify von Neumann's theory that the armor piercing jet of a cavity charge (Bazooka projectile) was a "Mach wave" of high intensity. Experiments made at the Aberdeen Proving Ground in 1944 on the photography of the spectrum of the exceedingly narrow and very brilliant flash or "jet" of light that shoots up to a height of a hundred or more feet, when the charge is fired on the ground at night, proved that it was a "fireball" or slug of metal, heated to incandescence by air friction—in other words an artificial meteor. Its velocity, found to be around 30,000 feet per second, and its spectrum, obtained by mounting a high intensity replica diffraction grating in front of the lens of a camera, was that of the metal forming the V-shaped liner of the hollow charge. This is the so-called "man made meteor" that is to be fired from the nose of a V2 rocket at White Sands, New Mexico.

(Title not received.) H. W. EMMONS, *Harvard University* (20 min.).

Some Recent Investigations in Hydrodynamic Stability. C. C. LIN, *Brown University* (20 min.).—Much theoretical investigation of the stability of parallel flows has been carried out recently. The results obtained in the case of the boundary layer in an incompressible fluid agree with the excellent experimental work of Schubauer and Skramstad and of Liepmann. L. Lees and the present writer extended the work to include the effect of compressibility, and heat transfer. Periodic disturbances of the usual type are considered, and many results are established analogous to those obtained in the incompressible case. Some further conclusions are reached by L. Lees, three of which are quoted below. (1) The withdrawal of heat from the solid boundary makes the boundary layer more stable, while the addition of heat through the solid boundary makes it less stable. (2) For an insulated boundary, the boundary layer becomes less stable as the Mach number of the free-stream is increased. (3) For supersonic free stream, the flow may be completely stabilized by the removal of heat through the boundary beyond a certain critical rate.

Linearization of Solutions in Supersonic Flow. J. W. TUKEY, *Princeton University* (10 min.).

L1. Hall Effect and Magneto-Resistance in Germanium. W. CRAWFORD DUNLAP, JR. *General Electric Company.*—Resistivity, Hall effect, and magneto-resistance measurements were made upon twelve samples of germanium including both polycrystalline and single crystal specimens. Room temperature resistivity ranged from 2 to 30 ohm cm. Magnetic fields up to 15,000 gauss and temperatures from −195°C to 450°C were used. The Hall coefficient decreased linearly with increasing field in most cases, and by as much as 50 percent at 12,500 gauss. The resistivity increased from 10 to 20 percent at 12,500 gauss and 25°C, and the increase ranged from 40 to 100 percent at −195°C, and the same field. No tendency toward saturation was observed at 15,000 gauss. $\Delta\rho/\rho_0$ decreased with temperature increase roughly proportional to the mobility (R/ρ). The room temperature mobility ranged from 1200 to 3000 cm^2/volt sec. The magneto-resistance effect in germanium appears to be at least an order of magnitude larger than is expected from the free electron theory for semi-conductors, which predicts saturation at 12 percent. A discussion is given of possible sources of the discrepancy.

L2. Temperature Dependence of the Diamagnetic Susceptibility of Gamma-Brasses.* JULES A. MARCUS, *Yale University.*—The temperature dependence (14-290°K) of the magnetic susceptibility of gamma-brass has been measured for several polycrystalline specimens synthesized from copper and zinc of highest purity. The susceptibility was determined relative to that of a pure bismuth standard by measuring the force in an inhomogeneous magnetic field. The forces of order two dynes were measured by means of a Sucksmith ring balance. At room temperature the susceptibility varied linearly with composition in agreement with the results of other investigators. At the copper-rich end of the phase, the susceptibility decreased almost linearly with decrease in temperature, the total decrease being 10 percent; at the zinc-rich end, the susceptibility increased with decrease in temperature, the total increase being only 3 percent. The band theory of metals indicates that the gamma-phase should be very similar magnetically to bismuth and accounts for the large diamagnetic susceptibility at room temperature. However, the above results show that the temperature coefficient of susceptibility for gamma-brass at low temperatures is considerably less than for bismuth. Also, the susceptibility of gamma-brass was found to be independent of field strength at 14°K.

* The research described in this abstract was supported by the Office of Research and Inventions of the U. S. Navy under contract N6Ori-44.

L3. Magnetic Transition Curves in Superconducting Tantalum.* ROBERT T. WEBBER, *Yale University.*—The behavior of thin wires of pure (99.9+ percent Fansteel) tantalum in uniform, longitudinal magnetic fields has been measured at the temperatures of liquid helium. The resistances of the wires were measured by the potentiometer method, the potential drop being recorded by a Brown potentiometer. In unannealed wires containing a small, but unknown, quantity of absorbed gas, the results were in some respects more similar to alloy behavior than to that of a pure metal. The zero field transition temperature was 4.16°K. The slope of the critical field was $dH_c/dT = 1300$ Gauss per degree, in fair agreement with the results of Mendelssohn and Moore,[1] but much larger than the results of induction measurements of Daunt and Mendelssohn.[2]

We found no hysteresis, but considerable evidence of intermediate state, particularly at the lowest temperatures studied. The effect of annealing and outgassing the wires at high temperature and high vacuum was also determined. Preliminary results will also be given on an attempt to determine the relaxation time occuring in the transitions of the wires under pulsed magnetic fields.

* Work done under Navy Contract N6Ori-44.
[1] K. Mendelssohn and J. R. Moore, Phil. Mag. [7] **21**, 532 (1936).
[2] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. **160**, 127 (1937).

L4. A Method to Measure Complex Permeabilities of Metals at UHF. M. H. Johnson, G. T. Rado, and M. Maloof, *Naval Research Laboratory.*—Complex permeabilities in the surface layer of ferromagnetics with known d.c. resistivity can be computed from the attenuation and phase velocity in a coaxial line whose center conductor is ferromagnetic. These quantities can be found experimentally by measuring simultaneously the change in Q and in the resonant frequency ($\sim$.01 percent) when a metal is substituted for the ferromagnetic portion of the center conductor in a coaxial resonator. A mechanical substitution invariably produces a greater change in resonant frequency by alteration of geometrical conditions than by removal of the ferromagnetism. The difficulty can be circumvented with the use of a polarizing field which is parallel to the small r-f field and is strong enough to completely saturate the ferromagnetic material. It is thus possible to compare resonant frequencies (and Q's) for the actual permeability and for unit permeability without altering the geometrical conditions. High power dissipation and the transient skin effect of the current producing the polarizing field in the center conductor require, respectively, pulse technique and millisecond periods. Application of the method at 200 Mc to magnetic iron and Mo-permalloy show that their permeabilities ($\sim$100) are much smaller than the d.c. values and have a large out-of-phase component.

L5. Complex Permeability of Magnetic Iron at 200 Mc as a Function of Polarizing Field. G. T. Rado, M. H. Johnson, and M. Maloof, *Naval Research Laboratory.*—The method of the previous abstract can readily be extended to determine the complex permeability[1] in the surface layer of a ferromagnetic metal as a function of the polarizing magnetic field. It is only necessary to compare the Q and the resonant frequency of the cavity for any polarizing field with the corresponding quantities for a saturating field ($\sim$1000 oersteds). In this way the real and imaginary components of the permeability of magnetic iron have been determined from zero to saturating fields. The r-f permeability shows no appreciable change until the d.c. magnetization is well beyond the knee of the magnetization curve. Hence the domain changes (wall displacements) supposedly responsible for the d.c. susceptibility below the knee have already become inoperative at 200 Mc. In high polarizing fields the imaginary component becomes small compared to the real component. The correlation between r-f and incremental d.c. permeabilities and the interpretation of the experimental results will be discussed.

[1] The complex permeability, $\mu_1 - i\mu_2$, is defined as the ratio of B to H in the metal. $\mu_2 \neq 0$ means that the magnetization and the magnetizing field are not in phase.

L6. A New Material of High Permeability. O. L. Boothby and R. M. Bozorth, *Bell Telephone Laboratories.*—Magnetic permeabilities of over one million, and initial permeabilities of over 150,000, have been obtained in an alloy containing iron, nickel, and molybdenum (79 Ni, 5 Mo, 15 iron, <1 Mn). Representative properties of specimens 0.014 in. thick are: maximum permeability, 800,000; initial permeability, 100,000; coercive force, 0.003 oersted; hysteresis loss, 4 ergs/cm^3/cycle at $B_m = 5000$; saturation induction, 8000; resistivity, 65 microhm-cm. The alloy is prepared by vacuum melting of commercial materials of high purity, fabrication in the usual way, heat treatment in pure dry hydrogen at about 1300°C, and cooling at a critical rate. The purity and the cooling rate are both essential for good magnetic quality. The cooling rate appears to control the amount of atomic ordering present, and the hypothesis is made that, when a critical amount of ordering is present, the magnetostriction and the magnetic crystal anisotropy both tend toward zero in the alloy of this composition. The material has been named supermalloy (su-perm′-al-loy).

L7. Pulsed Ultrasonic Measurements on Some Single Crystals.* H. B. Huntington, *Rensselaer Polytechnic Institute.*—Measurements of acoustic velocity and attenuation have been made at 10 Mc/sec. by a pulsed technique on Rochelle salt and several alkali halides. Values of elastic moduli for LiF, NaCl, KBr, and KI will be reported. The attenuation of the ultrasonic beam in these media is small. Corresponding measurements on the elastic moduli of Rochelle salt have been carried out. Under the assumption of plane wave transmission many of these observed moduli automatically correspond to those measured on foiled crystals by other methods. Attenuation is considerable in Rochelle salt and appears to be excessively high for transmission involving the temperature-dependent C_{44} (foiled case). As a result, it has not yet been possible to carry out a direct measurement of this quantity for a temperature range within 2°C of the upper Curie point. Where this modulus is involved, marked effects have been observed from electric bias and mechanical pressure. A complete set of elastic moduli have been obtained and used to calculate the corresponding values for the moduli of compliance.

* Based on work done for the Office of Scientific Research and Development under OSRD Contract OEMsr-262 with Massachusetts Institute of Technology.

L8. The Transmission of Energy from Radiation on Silicon Crystals. F. C. Brown, *Massachusetts Institute of Technology.*—Pulsed radiation, of duration 3 to 60 μ sec. on silicon crystals produces an effect that is propagated along the crystal with velocity of 400 meters/sec. The effect is detected and measured through change of resistance. Since the velocity is of the same order of magnitude as a thermal pulse, further experiments were conducted. A thermocouple showed a transmitted temperature rise accounting largely for the resistance change. There was inappreciable transmission if metal flats, extending between electrodes and point of impingement of radiation, pressed against opposite crystal faces. Neither black paint nor opaque wax on crystal materially altered the so-called photo-effect—i.e., the effect depends on energy received. Finally, the pulsed energy was transmitted to the crystal electrode contact over a tungsten wire and repeated by transmission over a nickel wire. The resistance changes were almost identical to the transmission over the silicon crystal. The velocity in tungsten is 730 meters/sec., and in nickel 250 meters/sec. It would seem that the photoconductivity in silicon crystals can be more readily explained as a thermal effect.

L9. Infra-Red Vibrations in NaCl. JORDAN J. MARKHAM, *Brown University*.*—A theoretical study has been made of the propagation properties of the lattice vibrations in NaCl. The phase velocity, the group velocity, displacement angle (angle between the particle displacement and the direction of propagation), and the displacement ratio were calculated as a function of wave-length for three directions of propagation. In these calculations, Born's theory was used. The transmission characteristic of the crystal resembles a filter with a low pass band (acoustical) and an upper band (optical). At the lowest frequency, the waves are simply elastic ones. As the frequency increases, the structure exhibits strong dispersion. In the limit of shortest wave-length, the group velocity approaches zero. The optical branch is highly dispersive at all frequencies. The group velocity is negative (on the single zone scheme), and is zero at both the short and long wave-length limits. Generally, for both branches at the short wave-length limit the particle displacement lines up along the direction of nearest neighbors. Exceptions to this occur for propagation along some highly symmetrical direction.

* Now at Clinton Laboratories, Oak Ridge, Tennessee.

L10. Total-Energy Distributions of Photoelectrons from Polycrystalline Tungsten. L. APKER, E. TAFT, AND J. DICKEY, *General Electric Company*.—The total-energy distributions of photoelectrons from an aged polycrystalline tungsten ribbon were determined at $\lambda 2138$ and $\lambda 2537$.[1] Shields for the ribbon supports eliminated extraneous contact potentials in the usual type of spherical-condenser photo-cell, which was magnetically shielded in this case. Data were obtained within 30 seconds after flashing at 2900°K. Current-voltage curves could be divided into three regions: (1) the high-energy portion investigated by DuBridge and Roehr[2]; (2) a portion showing a parabolic approach to a pseudo-saturation point independent of wave-length; (3) a pseudo-saturation portion characterized by the well-known slow increase of current with voltage. Region 2 is of interest in evaluating the effects of non-uniform work function[3] and of electron reflection at the graphite anode. Extraneous contact potentials of only a few tenths of a volt distorted the curves seriously.

[1] We are indebted to the University of Rochester Physics Department for the loan of a monochromator.
[2] L. A. DuBridge, Phys. Rev. **43**, 727 (1933); W. W. Roehr, *ibid.* **44**, 866 (1933).
[3] R. P. Johnson and W. Shockley, Phys. Rev. **49**, 436 (1936); C. E. Mendenhall and C. F. DeVoe, *ibid.* **51**, 346 (1937); M. H. Nichols, *ibid.* **57**, 297 (1940).

L11. A Study of the Barium Silicate Interface of Oxide Coated Cathodes. A. EISENSTEIN,* *Massachusetts Institute of Technology*.—Previous studies[1] have shown (1) the presence of a crystalline material at the interface of oxide cathodes prepared on a Si-Ni base metal and (2) the existence of an anomalous voltage at the interface region under certain conditions of pulsed measurements. The interface compound which is formed in the case of a BaO or (BaSr)O coating on a Si-Ni base is believed to be Ba_2SiO_4 rather than $BaSiO_3$ as previously reported.[1] The relationship between (1) and (2) above has been investigated by comparing the electrical conductivities of (BaSr)O and Ba_2SiO_4 in the temperature range 1100°K to 1300°K. Conductivities were determined for materials activated by (a) high d-c current drain, (b) CH_4 gas, and (c) H_2 gas and deactivated in CO_2 gas. In general, the specific conductivity of the silicate is lower than that of the oxide by a factor of 10 to 1000. The thickness of the interface, found in actual cathodes, has been determined by an x-ray method[2] to lie in the range 5×10^{-4} to 10^{-3} cm. The relationship of the interface to the thermionic emission characteristics will be discussed.

* Frank B. Jewett Fellow.
[1] A. Fineman and A. Eisenstein, J. App. Phys. **17**, 663 (1946).
[2] A. Eisenstein, J. App. Phys. **17**, 874 (1946).

H1. On the Hydraulic Analogy between Surface Waves on a Liquid and Pressure Waves in a Compressible Fluid. H. A. EINSTEIN, *California Institute of Technology*.—The intersection of strong shock waves in compressible fluids is being studied by means of this analogy. As the linear approximation cannot be used for strong waves, the validity of the analogy must first be proved. It is found that only the combinations of p and v can be duplicated by surface waves for which the condition $[1-(\pi/p)][1-(b/v)]=1$ is fulfilled. The introduction of this additional condition made it desirable to solve mathematically the intersection problem of two identical surface shock waves. The case of the regular intersection with constant state between shock waves has been solved in general and the numerical solutions for a number of wave heights and for some angles of intersection are tabulated. Also, the extreme angle which allows a regular intersection is found. All these values duplicate very closely the corresponding results for pressure waves. The experimental check of these solutions was accomplished by the study of transient shock waves in a shallow tank with still water. The "extreme" solution (maximum angle at which a regular intersection is possible) very closely checks the beginning of a Mach-type intersection. Also, the water depth (pressure) immediately behind the intersection duplicates very closely the calculated value. The angle of the reflected waves, however, never could be checked because the reflected waves had a curved front with a corresponding pressure drop along the front.

H2. On Nearly Glancing Reflection of Shocks.* V. BARGMANN, *Princeton University*.—The oblique reflection of plane shocks from a plane rigid wall follows a simple pattern—that of "regular reflection"—as long as the angle of incidence α is smaller than a critical angle depending on the strength of the incident shock. For larger values of α the more complex pattern of the "Mach reflection" is observed. A detailed hydrodynamical treatment of Mach reflection seems extremely difficult, and therefore the discussion has been generally confined to the immediate neighborhood of the intersection of the three shocks. In the limiting case of nearly glancing incidence, however, it has been possible to obtain an approximate solution of the hydrodynamical equations, and to derive explicit expressions for the pressure distribution behind the shocks.

* Work carried out under an OSRD contract at the Institute for Advanced Study, Princeton, New Jersey.

H3. Compressible Flows with Degenerate Hodographs. John H. Giese, *Ballistic Research Laboratories* (*Introduced by R. H. Kent*).—Non-linearized, three-dimensional, steady, isentropic, compressible, potential flows for which the maps of the physical space on to the hodograph space have fewer than three dimensions have been systematically studied by applying a Legendre transformation to the equation of the velocity potential. This leads naturally to a synthesis of a number of familiar types of flows, such as (1) Prandtl-Meyer expansion around a corner; (2) Ringleb's or Binnie's and Hooker's spiral flows; (3) general plane flow; (4) Busemann's cylindrical and general conical flows, including Taylor-Maccoll flow. The most general flow with a one-dimensional map is a straightforward generalization of (1). Flows with two-dimensional maps must be either of types (4) or of modified conical type. The differential geometry of these flows has been thoroughly investigated to find analogues for many of the well-known properties of plane flow. As an example, all axisymmetric flows with degenerate hodographs have been determined.

H4. On an Operator Method in the Theory of Two-Dimensional Flows of a Compressible Fluid.* Stefan Bergman, *Harvard University*.—Using the hodograph method, the author represents the stream lines of an adiabatic two-dimensional flow of a compressible fluid in an implicit form $x=x(f, g)$, $y=y(f, g)$, $\psi(f, g)=\text{const}$, $f(\xi)$ and $g(\eta)$ are functions of one variable $\xi=(\theta+i\lambda(M))$ and $\eta=(\theta-i\lambda(M))$, respectively. In the subsonic case, f and $g=\bar{f}$ are conjugate complex functions of a complex variable; in the supersonic case λ becomes purely imaginary, f and g are two independent functions of a real variable. ψ satisfies the equation $\psi_{\lambda\lambda}+\psi_{\theta\theta}+N(\lambda)\psi_\lambda=0$ where $N(\lambda)$ is a known function.[1] The representation obtained is used for the study of the behavior of the solutions in the neighborhood of $\lambda=0$, which corresponds to Mach number $M=1$. This investigation is particularly simplified if N is approximated by $C\lambda^{-1}$, where C is a properly chosen constant. The author indicates how the functions f, g have to be chosen in order to obtain a flow around a contour which approximates the boundary curve given in the physical plane. The considerations show that for certain contours no solutions of a certain kind exist without shock-waves.

* Work done under contract with Bureau of Ordnance, Navy Department.
[1] See also N.A.C.A.; Tec. Notes 972, 973, 1018, 1096.

H5. Some Remarks on the Limitations of Linearized Theory of Supersonic Flow Around Cones. Zdeněk Kopal, *Massachusetts Institute of Technology*.—The purpose of these notes is to compare the consequences of Karman-Moore's linearized equations of axial flow, and of their extension, by Tsien, to non-axial flow, with the corresponding rigorous solutions of non-linear equations in the case of a supersonic flow around cones. The outcome of such a comparison may be summarized as follows: 1. The linearized equations do not predict the existence of a shock-wave in front of a solid cone in supersonic flight. 2. In the neighborhood of the sonic velocity, they lead to a solution for every Mach number larger than one—and therefore fail to predict the non-existence of a conical regime for Mach numbers in the neighborhood of unity. 3. They fail to lead to a solution for velocities high enough for the Mach cone to become smaller than the solid—whereas, in reality, the solution does exist up to infinite velocities. 4. For axial flow, they lead to head-drags which are systematically too small, and their errors increase with increasing velocity as well as increasing angle of the cone. 5. For non-axial flow, they make the coefficients of normal force to decrease with increasing Mach number, and to vanish when the Mach cone becomes identical with the solid, whereas the coefficients derived from the non-linear theory are found to behave in exactly the opposite way and would not vanish even should the Mach number become infinite. 6. The fact that the linearized equations predict correctly the order of magnitude of both drags can be quoted as the only point on their credit side.

H6. Supersonic Problems in Astronomy. Fred L. Whipple (*Introduced by R. J. Seeger*).—Until recently the meteor problem has represented the most obvious case of supersonic ballistic problem in Astronomy. The V-2 experiments and laboratory experiments on shaped charges are in the process of bridging the gap between the theories of the meteoric and the ballistic processes. The types of observations and the theoretical approach needed or anticipated in this field are outlined briefly. Other supersonic processes of importance in Astronomy are, however, recognized. The atmosphere of the Sun shows a complex of supersonic motions. Novae, supernovae, and certain other variable stars represent atmospheric motions with tremendous velocities. There is also good reason to suspect that the interiors of the stars are in a state of great turbulence, and possibly a considerable amount of energy and momentum are transmitted from the interiors by shock-waves. On a much greater scale of dimensions the interstellar medium of gas and dust also shows evidence of shock-wave phenomena, which probably play important roles in galactic, stellar, and planetary evolution problems as well as in the production of observed radiation. The nature of each of these astronomical problems is discussed and related to the more familiar physical point of view.

H7. Comments on the Motion of a Solid Body at High Velocity through a Compressible Medium. R. N. Thomas, *Harvard Observatory*.—The motion of a solid body through a resisting medium provides one phase of a general astronomical interest in the motion of a body of one density through a medium of another, and arises directly in the motion of a meteor through the atmosphere. There exists a wide gap between the laboratory experimental ballistic case, and the meteor case. To the limit of the ballistic velocities yet reached, and in atmospheric conditions, the theoretical formulation of the ballistic problem may be said to describe satisfactorily the situation. Ballistics provides essentially no information, however, on the high velocity important process of heating of the body to evaporation. The work of Whipple at Harvard provides the only analysis of the meteor case from adequate experimental data. Recent V-2 soundings indicate surprisingly exact agreement with the "meteoric" atmosphere. A detailed discussion is made of the explicity inferences which may be drawn from the Whipple analysis concerning the details of the interaction between medium and meteor.

H8. Laminar Boundary-Layer Oscillations and Stability of Laminar Flow. H. K. SKRAMSTAD AND G. B. SCHUBAUER *National Bureau of Standards.*—An experimental investigation carried out in 1940 and 1941 in a wind tunnel of very low turbulence led to the discovery of sinusoidal velocity fluctuations in the laminar boundary layer of a flat plate. The characteristics of these fluctuations were found to agree with those predicted earlier by the stability theory of Tollmein and Schlichting, throwing new light on the causes of transition from laminar to turbulent flow. The fluctuations are termed "laminar boundary layer oscillations" to distinguish them from the irregular velocity fluctuations previously observed by other investigators. In earlier investigations these oscillations were not found, probably because of the high turbulence in the wind tunnels in which the investigations were conducted. Methods were found to produce these oscillations artificially in the boundary layer, and studies were made of the frequency, wave-length, amplitude, and amplification or damping of the natural and the artificially produced oscillations. Transition occurred where conditions in the boundary layer were such that these oscillations had been amplified to a sufficiently large value to cause a breaking into irregular high frequency fluctuations characteristic of turbulent flow. This work was done with the cooperation and financial assistance of the National Advisory Committee for Aeronautics.

H9. Drag Coefficient of Steel Spheres Entering Water. ALBERT MAY AND JEAN C. WOODHULL, *Naval Ordnance Laboratory.*—The drag coefficient has been measured for steel spheres in the cavity stage after entering water normally. Data were obtained from high speed motion pictures of 77 shots of $\frac{1}{4}''$ to $1\frac{1}{2}''$ spheres with entrance velocities of 16 to 126 ft./sec. giving a range of Reynold's number from 0.3×10^5 to 15×10^5. Before using $1/v$ *versus* t plots, it was found necessary, on most shots, to correct for gravity, for hydrostatic pressure due to depth, and for the pressure in the cavity behind the sphere. The last of these corrections requires a knowledge of the time at which the cavity closes near the water surface. Analysis shows this time to be considerably later than the time at which the spray dome appears to close. The drag coefficient was found to increase with the Reynold's number at water entry from about 0.28 to 0.33 over the range investigated. The curve of drag coefficient *versus* $\log R$ appears to be concave upwards and the standard deviation from this curve was 0.012.

H10. Drag and Cavity of Fast Spheres Shot into Water.* J. HOWARD MCMILLEN** AND E. NEWTON HARVEY, *Princeton University.*—Drag forces and cavity formation for fast spheres entering water vertically were studied by means of high speed motion pictures. The impact velocity was varied from 800 to 3300 ft./sec. and sphere diameter from $\frac{1}{16}''$ to $\frac{1}{4}''$. The drag coefficient in the cavity stage was 0.297 ± 0.01 for steel spheres, 0.318 ± 0.011 for aluminum spheres. The unimportance of viscous forces in this velocity range was verified by measuring drag in a syrup which was 2100 times more viscous than water; the measured drag coefficient showed only a 60 percent increase over water. The small effect of structural forces in this velocity range was revealed in the measurement of the drag coefficient in 20 percent gelatin gel at 24°C; it was found to be 0.35. The cavity in water was observed to expand laterally to about sixteen sphere diameters for the highest velocities. The maximum cross-sectional area of this cavity at any level was found to be proportional to the space rate at which the sphere lost energy at that level, the constant being 8.92×10^{-7} cm^3/erg. A large portion of the cavity became detached to from a bubble resembling the bubble of underwater explosions. This "explosive" bubble was observed to oscillate with a period proportional to the cube root of the impact energy, the constant being 0.8×10^{-6} sec. erg$^{-\frac{1}{3}}$.

* Work done under contract with the Office of Scientific Research and Development, the Committee on Medical Research.
** Now at Naval Ordnance Laboratory, Washington, D. C.

H11. Impact Pressure Produced by Flat Plate Striking Water Surface. P. N. METZELAAR AND D. E. ALLMAND, *Naval Ordnance Laboratory, Washington, D. C.* (*Introduced by J. Howard McMillen*).—Measurements were made of the peak pressure which a flat-nosed cylinder experiences when the cylinder is shot end foremost into water with a near-sonic velocity. The velocities V ranged from 1000 to 2000 ft./sec. and the pressures were measured by means of diaphragm gauges. These gauges consisted of 0.015″ sheet of steel stretched over holes having diameters ranging from 0.016″ to 0.031″. The gauges were calibrated statically up to 130,000 p.s.i. and their response time calculated to be less than ten microseconds, the time depending on the magnitude of the deformation. The peak pressure at 2000 ft./sec. was found to be 125,000 p.s.i. According to the simple theory the peak pressure should be equal to RV or $d^{\frac{1}{2}}Ve^{\frac{1}{2}}$ where e and R are the elastic constant and acoustic impedance, and d is the density of the liquid, respectively. It was found that the measured peak pressure followed the simple theory curve with a standard deviation of 7300 p.s.i. The effect of shear-rate on performance of the gauge will be discussed. Shots into ether and glycerine, having acoustic impedances equal to 0.5 and 1.7 that of water, show the expected dependence of impact pressure on acoustic impedance.

H12. On the Characterization of Fields of Diabatic Flow. BRUCE L. HICKS, *Ballistic Research Laboratories*.—In continuing the previously reported investigations of steady diabatic flow,[1] the transformation $\bar{N}=\bar{V}/[g(N)RT]^{\frac{1}{2}}$, $N=|\bar{N}|$ has been introduced. The Crocco vector $\bar{N}_w\bar{W}=(\bar{V}/V_t)$,

$$\left(g_W=\frac{2\gamma}{\gamma-1}(1-W^2)^{-1}\right)$$

is in the general case the best $\bar{N}$ to use in describing a steady, *rotational*, diabatic field of flow. There is an infinite number of distinguishable types of *irrotational* diabatic flows determined by $g(N)$ and $F(\varphi_N)$, an arbitrary function appearing in the p.d.e. for the $\bar{N}$ potential, φ_N. Specification of $g(N)$ determines the change of (mathematical) type of the flow which may, for example, be always elliptic, of mixed type, partially hyperbolic, etc., irrespective of the ratio of the Mach number to unity. By contrast, in adiabatic compressible flow, the flow always changes type at $M=1$ from elliptic to hyperbolic. Specification of both $g(N)$ and $F(\varphi_N)$ restricts the nature of the distribution of heat sources q_N within the fluid by requiring that a relation be satisfied among $F(\varphi_N)$, q_N and $\nabla\cdot\bar{s}$, the fractional rate of variation of stream-tube area along a stream line. A number of types of irrotational diabatic flow have been studied as illustrations of these characteristics.

[1] B. L. Hicks, Phys. Rev. **69**, 135(A), 250(A) (1946).

H13. On the Initial Motion of a Strong Spherical Shock. Y. H. KUO, *Cornell University*.—A special problem of the production and of the propagation of a spherical shock wave is studied by considering the motion produced by a spherical shell expanding with a prescribed motion given by $x_2=\text{const. } t^\beta$ during a short time interval. G. I. Taylor[1] considered the case $\beta=0$ and in the present case $\beta=-\frac{1}{2}$. A shock wave, according to a previous paper,[2] is assumed to be formed instantly and to propagate into still air with a velocity $\dot{x}_1=\text{const. } t^{-\frac{1}{2}}$. The solution is so chosen that it satisfies exactly the boundary conditions at the spherical shell and approximately at the shock wave. In the case of a very strong shock, the error introduced through the latter condition is believed to be negligible. The shock strength decays according to the law $p=\text{const. } x^{-2}$, x being the instantaneous radius of the shock.

[1] G. I. Taylor, Proc. Roy. Soc. **186A**, 243 (1946).
[2] Y. H. Kuo, Quart. App. Math. (January 1947).

W1. Some New Results on the Recrystallization of Quartz. D. D'EUSTACHIO, *Collman Manufacturing Corporation*.—The recrystallization of thin single crystals of quartz on moderate heating has been previously reported.[1] An improved x-ray technique for observing the phenomenon will be described. The new method makes possible the observation of much smaller changes and permits quantitative measurement of the extent to which recrystallization has taken place. As a result, marked changes have been observed in plates up to .07 mm thick. The magnitude of the effect in crystals 0.2 mm thick (if it exists at all) is less than one-tenth of that observed with crystals .07 mm thick. The major portion of the change occurs within a few microns of the surface when the wafers are more than 20 microns thick, but throughout the entire volume when they are thinner than 10–15 microns. The argument put forth by D'Eustachio[2] for the formation of "polycrystalline" surface layers on valence crystals can easily be extended to explain thermal recrystallization, but it alone cannot account for the dependence of the effect on thickness.

[1] D. D'Eustachio and S. Greenwald, Phys. Rev. **69**, 532 (1946).
[2] D. D'Eustachio, Phys. Rev. **70**, 522 (1946).

W2. The Band Theory of Graphite. P. R. WALLACE, *Chalk River Laboratory*.*—Electronic energy bands are calculated by the "tight binding" approximation[1] for the $2p$ electrons in graphite having their nodes in the graphite planes. For a single hexagonal plane, the electronic energy level splits into two bands separated by a zero energy gap. To the lower band corresponds a hexagonal Brillouin zone containing one electron per atom. When interactions between layers are taken into account, the zone becomes a hexagonal "pill-box," the zero energy gap remains, and inside and outside energy correspond at twelve points on the vertical edges of the pill-box. Thus graphite may be considered a semi-conductor with zero activation energy. The surfaces of constant energy near the zone boundary are very anisotropic, which gives rise to very anisotropic conductivity; at room temperatures, about 100 times as great in the layers as across them. The anisotropy increases for decreasing temperature. Also, a strong diamagnetic susceptibility is predicted, which is anisotropic but somewhat less so than the conductivity. In addition, the zero energy gap ensures a volume optical absorption stretching from the longest wave-lengths down into the ultraviolet.

* Now at McGill University, Montreal.
[1] Mott and Jones, *Properties of Metals and Alloys*, p. 65.

W3. The Effect of X-Rays on the Elastic Constants of Quartz.* VIRGIL E. BOTTOM, *Colorado A & M College*.—The resonance frequencies of certain quartz oscillator plates are decreased by irradiation with x-rays. The magnitude of the frequency change depends upon the orientation of the plate with respect to the crystallographic axes. The effect, which is attributable to changes in the elastic constants, is accompanied by a change in the color of the quartz. Both effects differ widely in different samples of quartz. The magnitude of the changes in certain of the elastic constants have been determined. It is found that irradiation to saturation causes a change of -0.013×10^{10} dynes/cm² or -0.07 percent in c_{14}; -0.020 dynes/cm² or -0.03 percent in c_{44} and -0.008 dyne/cm² or -0.02 percent in c_{66}.

* This paper is based on work done at the Signal Corps Laboratories at Fort Monmouth, New Jersey.

W4. The Structure of Evaporated Antimony Films. H. LEVINSTEIN AND H. R. CRANE, *University of Michigan*.—The structure of evaporated antimony films as a function of rate of evaporation and substrate has been investigated by transmission electron diffraction and by electron microscopy. When antimony is evaporated rapidly on collodion the film consists of very small particles, all crystalline and oriented preferentially with respect to the substrate. When antimony is evaporated slowly large amorphous patches are formed. While most of these amorphous patches are stable, some crystallize after several days or weeks. These crystallites generally have no preferred orientation. Crystallization of individual patches is often produced by the electron beam in the electron microscope and may be followed visually on the viewing screen. Variation of substrate does not affect crystal structure, but changes the size and appearance of the patches composing the film. These effects may be explained on a basis of varying degrees of mobility of antimony molecules on different substrates.

W5. Temperature Dependence of "Second Sound" Velocity.* HENRY FAIRBANK, WILLIAM FAIRBANK, AND C. T. LANE, *Yale University*.—According to theoretical predictions of Tisza and Landau, two types of wave motion are possible in liquid helium II, i.e., pressure waves (sound) and temperature waves ("second sound"). We have measured this second sound velocity as a function of temperature using the following resonance method. A cylindrical Lucite cavity, containing a resistance heater at the bottom as a source and a magnetic microphone at the top as a detector was partially filled with liquid helium. The second sound induced in the liquid is converted into normal sound in the vapor and hence second sound resonances in the liquid are detectable. Knowing the length of the liquid column at each resonance and the frequency of the source, we are able to determine the velocity of the "second sound" to within ± 0.5 percent. The velocity is 0 at the λ-point, a maximum of 20.5 m/sec. at 1.70°K and decreases to a value of 19.8 m/sec. at 1.43°K, the lowest temperature reached. These results are in excellent agreement with those obtained by Peshkov, using a different method, and the agreement with theory is very good. In the low temperature region where Landau and Tisza disagreed, the decrease in velocity tends to confirm Tisza's prediction. The high Q of the resonating liquid column indicates a low transmission coefficient at the liquid surface, and the dissipation in the liquid appears to be small.

* Work done under Navy Contract N6ori-44.

W6. Pressure and Temperature Waves in Liquid Helium.* C. T. LANE, WILLIAM FAIRBANK, AND HENRY FAIRBANK, *Yale University*.—In connection with our second sound measurements in liquid helium II (see previous abstract) a number of subsidiary effects have been observed. In one experiment the resonant cavity was completely filled with liquid helium so that there was no observable vapor space between the microphone diaphragm and the liquid. The temperature was set at 1.75°K and allowed to rise slowly to the λ-point, the frequency of excitation remaining constant. A series of resonant peaks were observed, each peak corresponding to a temperature at which the second sound velocity was such as to render the fixed cavity resonant. These resonances were observed to disappear at the λ-point. A possible mechanism whereby temperature (second sound) waves are converted into pressure fluctuations capable of affecting the microphone diaphragm will be discussed. In addition it was found possible to excite normal sound vibrations in liquid hydrogen, liquid helium I, and possibly liquid helium II by using a fluctuating temperature source. In the case of hydrogen and helium I, this is caused by their comparatively large coefficient of expansion (thermophone effect). In helium II the effect is probably caused by normal sound in the vapor, produced by second sound in the liquid, in turn exciting normal sound in the liquid.

* Work done under Navy Contract N6ori-44.

W7. Ultrasonic Absorption and Velocity Measurements in Liquid Helium. J. R. PELLAM AND C. F. SQUIRE, *Massachusetts Institute of Technology*.—Electronic pulsed-circuit techniques have been applied to the measurement of absorption and velocity of ordinary sound waves in liquid He I and He II at 15 mc/sec. Short pulses (a few microseconds) are generated by a transducer, which also picks up the resultant echoes from a plane reflector. Velocity is determined from the increased time delay introduced in the echo by an increased sonic path length. Absorption is determined by keeping the ultrasonic attenuation within the liquid helium compensated electrically; i.e., the echo signal strength is held constant as the reflector is moved. Velocity measurements obtained agree with values reported[1] by investigators using continuous wave methods. Absorption coefficients measured above the λ-point (2.19°K) are in order-of-magnitude agreement with theoretically computed values based on viscous and thermal losses. A complete disappearance of the echo is observed in the immediate region of the λ-point. Absorption coefficients just below the λ-point have values comparable with those above the λ-point.

[1] J. C. Findlay, A. Pitt, H. Grayson Smith, and J. O. Wilhelm, Phys. Rev. 54, 506 (1938); 56, 122 (1939).

W8. On the Theory of "Second Sound" in Helium II. L. TISZA, *Massachusetts Institute of Technology*.—According to the theory based on Bose-Einstein condensation, He II is a mixture of a superfluid and a normal fluid with additive densities $\rho=\rho_s+\rho_n$. A gas type viscosity and an osmotic pressure P_n is associated with the normal fluid. In 1938, the author[1] concluded that inhomogeneities in the temperature will propagate in the form of waves (second sound) with the velocity

$$u_2=[dP_n/d\rho_n(\rho_s/\rho)]^{\frac{1}{2}}.$$

Subsequently Landau[2] advanced a theory based on quantum hydrodynamics leading to similar results and to the expression

$$u_2=[-d(1/s)/dT(\rho_n/\rho_s)]^{-\frac{1}{2}}$$

(s is the specific entropy). Recent measurements of Peshkov are in good agreement with the first expression, whereas Landau's formula shows considerable discrepancies. The author has rederived most of his earlier results from very general assumptions with a quasi-thermodynamic method. The two expressions for u_2 prove to be rigorously equivalent provided that Landau's interpretation of the entropy is modified. With this proviso, the hydrodynamic model will conform to the requirements of the thermodynamic theory which thus admits two different molecular interpretations. A detailed paper is being completed.

[1] L. Tisza, Comptes rendus **207**, 1035 (1938), J. de Physique [8] **1**, 164, 350 (1940).
[2] L. Landau, J. Phys. **5**, 71 (1941), E. Lifschitz, *ibid.* **8**, 110 (1944)

W9. The Quantum Corrections for the Second Virial Coefficient of Water. VERNON MYERS, *Yale University*.—The second virial coefficient for water has been calculated recently neglecting quantum effects.[1] The only quantum correction of any importance for moderate temperatures is that caused by the exchange of energy between the translational and rotational motions of the molecules caused by the angular dependence of the forces between the permanent electric moments borne by the water molecules. Using the method of Kirkwood,[2] this effect has been calculated in the 400°K–700°K temperature interval and is found to alter appreciably the previous results. The repulsive potential is assumed to be of the central field type in the present calculations. The discrepancy between the observed values of the second virial coefficient and the calculated values, including the quantum correction, is +6.7 percent for 400°K and −8.7 percent for 700°K. Better agreement with experiment could probably be obtained if an angularly dependent repulsive force were introduced in addition to the central force.

[1] H. Margenau and V. Myers, Phys. Rev. **66**, 307 (1944)
[2] J. G. Kirkwood, J. Chem. Phys. **1**, 597 (1933).

X1. The Distribution in Energy of Fission Fragments Near the Fast Fission Threshold.* DAVID H. FRISCH, *Los Alamos Laboratory, Los Alamos, New Mexico*.[1]—The distribution in kinetic energy of fission fragments from the compound nucleus ${}_{93}Np^{238}$ has been studied as a function of the energy of the neutrons causing fission. Mean neutron energies of 375, 475, 700, and 890 kev were used, covering a range of fission cross sections from approximately $.1\times10^{-24}$ to 1.2×10^{-24} cm^2, respectively 15 and $\frac{3}{4}$ of the high energy cross section. The energy distribution of uncollimated fragments from a thin foil was studied by differential recording of pulse heights in an electron-collecting ionization chamber. Only the high energy peak was recorded, and the resolution was limited by both the finite channel width of the discriminator and the spread in response of the ionization chamber. The latter was estimated by comparison of the observed minimum in the ${}_{92}U^{236}$ fragment distribution with that reported elsewhere.[2] Within the limits of resolution of the present experiment, there is no dependence of the distribution from ${}_{93}Np^{238}$ on neutron energy near the fission threshold. This work was carried out under contract between the University of California and the Manhattan District, Corps of Engineers, War Department.

* To be called for after paper X11 if time permits.
[1] Now at Massachusetts Institute of Technology.
[2] R. Sherr, Phys. Rev. **70**, 450 (1946), M. Deutsch, unpublished Los Alamos Report 510.

X2. Statistics of Single and Plural Scattering. S. A. GOUDSMIT AND H. S. SNYDER, *Northwestern University*.—It is generally assumed in scattering experiments that large deflections are caused by single scattering, small deflections to multiple, and the intermediate region to "plural" scattering. This implies that the statistical behavior of multiple scattering approaches the single scattering law for large deflections. A more precise analysis has shown that this is not necessarily so and that the scattering intensity for large deflections depends in a sensitive way upon the behavior of the single scattering law. Only if the second derivative of the logarithm of the single scattering law is positive, can the multiple scattering approach single scattering for large deflections. For example, if the single scattering law is Gaussian, this condition is not fulfilled. For this case large angle scattering is entirely caused by highly multiple small angle deflections. It is possible to write n-fold scattering as a series in which the successive terms represent contributions of single, double, triple, etc., scattering. For Rutherford scattering at large angles the multiple scattering approaches single scattering. The deviations from single scattering are caused by many small angle scatterings and not to double or triple scattering. It seems therefore impossible to define a region of "plural" scattering in this case.

X3. Theory of Multiple Scattering. H. S. SNYDER, *Northwestern University*.—A solution of the Fokker-Planck equation for the scattering of particles by a foil is found. If $W(\mathbf{v}, x)|v_x|d\mathbf{v}$ is the probable number of times a single incident particle will cross the plane x=constant having its velocity components lying in $d\mathbf{v}$, then $W(\mathbf{v}, x)$ can be written $W(\mathbf{v}, x)=W_0(\mathbf{v}, x)+W_1(\mathbf{v}, x)+\cdots$ in which $W_n(\mathbf{v}, x)$ determines the distribution for particles which have scattered n times. We find

$$W_n(\mathbf{v}, x)=\frac{1}{v_x}\int_0^x dx'\exp[-k(\mathbf{v})(x'-x)/v_x] \int d\mathbf{v}' f(\mathbf{v}, \mathbf{v}')W_{n-1}(\mathbf{v}', x')$$

for $v_x>0$, $0>x>a$. $f(\mathbf{v}, \mathbf{v}')d\mathbf{v}d\mathbf{v}'$ is rate of scattering from $d\mathbf{v}'$ to $d\mathbf{v}$, a is the thickness of the foil and $h(v)=\int f(\mathbf{v}', \mathbf{v})d\mathbf{v}'$. In an appropriate approximation this solution reduces to the one given by Goudsmit and Saunderson.[1] This solution should be particularly useful for determining the deviations from the single scattering law due to multiple scattering for neutrons scattered by any substance due to the fact that for neutrons the total scattering plus absorption cross-sections is sufficiently small so that for reasonable thickness of foil only the first few terms in the expansion of $W(\mathbf{v}, x)$ are important.

[1] Phys. Rev. **57**, 24 (1940); **58**, 36 (1940).

X4. Ionization Chamber Techniques in Measurement of C^{14}. W. P. JESSE, L. A. HANNUM, H. FORSTAT, AND A. L. HART, *Argonne National Laboratory*.—With the purpose of determining the reliability of the method and its limit of sensitivity, ionization chamber measurements have been carried out with the vibrating reed electrometer of Palevsky, Swank, and Grenchik and also a type of Lindemann electrometer as the measuring instrument. In each case, the rate of drift method was used. A few measurements on thin solid samples showed self-consistent results. A greater number of measurements were carried out with gaseous CO_2 in a chamber of 150 cc volume at about one atmosphere pressure. An already dilute gas sample of approximate activity of 4×10^{-7} curie/g of carbon was successively diluted with inactive CO_2 by the use of calibrated volumes. For a further dilution of 420 times, the ionization current on vibrating reed agreed with the value calculated from the dilution to within 5 percent for runs of about an hour. At dilution of 5720 times an agreement within 20 percent was obtained. The arrangement with the Lindemann electrometer gives less accuracy but shows great promise as a very simple method for most measurements.

X5. Delays in Firing Time of Geiger-Müller Counters. CHALMERS W. SHERWIN, *University of Illinois*.—The average transit time of secondary electrons is measured by sending β-rays through a thin wall counter, through a slotted mask, and then into a mica window counter where their paths are parallel to the central wire, at known distances from the wire. The radial secondary electron velocity (cm/sec.) is represented empirically by $v=k(E/p)^{\frac{1}{2}}$, where E, the electric field, is in volts/cm; p, the pressure of the 92 percent argon, 8 percent amyl acetate mixture, is in millimeters of Hg; and k equals 4.5×10^6. The maximum transit time for a counter with 2.2 cm diameter cylinder and 0.012 cm diameter wire ($p=100$ mm) is 9.5×10^{-8} second. Furthermore, the average relative firing time of two counters is not zero even when the β-rays go near the wires of both counters so the secondary electron transit time is negligible. The average relative firing time varied in one case from one to 20×10^{-8} second as the over-voltage of one counter varied from 240 volts to zero volts. The counter fires sooner at high over-voltages.

X6. Spectroscopic Study of the Role of Hydrogen Peroxide in the Thermal Combination of Hydrogen and Oxygen. R. B. HOLT AND O. OLDENBERG, *Research Laboratory of Physics, Harvard University*.—The steady thermal combination of hydrogen and oxygen flowing through a hot vessel results in the presence of appreciable amounts of H_2O_2 in the exit gases.* It is questionable whether this is formed *in the reaction itself* since H_2O_2 should be too unstable at the high temperature. The alternative explanation assuming that it is formed *in the trap* from radicals swept out of the hot reaction vessel is hardly preferable since the most plausible radical, hydroxyl, does not build up a noticeable concentration in the reacting mixture. The question was decided by observing the absorption spectrum of the mixture itself during the progress of the reaction. This reveals the presence of H_2O_2 in fairly large concentration in the mixture in spite of the rapid decomposition it is sure to undergo under the conditions of the experiment. This result shows that H_2O_2 is the outstanding product of the chain reaction between hydrogen and oxygen. It is possible to follow the H_2O_2 concentration spectroscopically under varying conditions (temperature, ratio of reactants, etc.) and to correlate the observed concentrations with the amounts of H_2O_2 found by chemical analysis of the exit gases.

* R. N. Pease, J. Am. Chem. Soc. **52**, 5106 (1930).

X7. Absolute Intensities of Molecular Vibrational Absorption Bands. E. BRIGHT WILSON, JR. AND A. M. THORNDIKE.—The absolute intensities, $A=\int\alpha(\nu)d\nu$, of the infrared active fundamental vibrations of CH_4, C_2H_4, and N_2O have been measured using the method[1] of extrapolation to zero partial pressure of the absorbing gas in the presence of considerable inert gas pressure. (For N_2O and C_2H_4 one atmosphere of N_2; for CH_4 about five atmospheres of NH_3, which is several times as effective as non-polar gases.) The observed intensities are (all in cycles per cm-atmosphere): CH_4: 1304 cm^{-1} band—450×10^{10}, 3020 cm^{-1} band—900×10^{10}. C_2H_4: 950 and 995 cm^{-1} bands unresolved—1540×10^{10}, 1444 cm^{-1} band—210×10^{10}, 2990 and 3105 cm^{-1} bands unresolved—840×10^{10}. N_2O: 590 cm^{-1} band—120×10^{10}, 1285 cm^{-1} band—1150×10^{10}, 2224 cm^{-1} band —5600×10^{10}. The values for CH_4 agree within experimental error with 444×10^{10} and 967×10^{10} found by Rollefson and Havens[2] from measurements of infra-red dispersion. The values for C_2H_4 and N_2O are consistant with earlier results obtained by Wells.[3] These intensities correspond to "effective charges" on the vibrating atoms of from 0.05 to 2.0 times the charge on an electron.

[1] E. Bright Wilson, Jr. and A. J. Wells, J. Chem. Phys. **14**, 578 (1946)
[2] R. Rollefson and R. Havens, Phys. Rev. **57**, 710 (1940).
[3] A. J. Wells, Thesis, Harvard, 1941.

X8. Rotational Spectra of Some Linear Molecules Near 1 cm Wave-Length and Nuclear Quadrupole Moments of Br and Cl. C. H. TOWNES, A. N. HOLDEN, AND F. R. MERRITT, *Bell Telephone Laboratories, Murray Hill, New Jersey*.—Absorption lines due to the rotational transitions $J=1\rightarrow J=2$ for ClCN and $J=2\rightarrow J=3$ for the BrCN molecule have been observed at wave-lengths near 1.25 cm. A number of lines are found associated with each isotope of Cl and Br. Neither nuclear dipole moments nor molecular vibrational excitation appear responsible for the multiple lines. General features of these multiplets are explained by assuming the splitting is caused by electric quadrupole moments of the Cl and Br nuclei, and that the effect of any quadrupole moment of the N^{14} nucleus is small. On this basis, the two isotopes of Cl have nearly equal quadrupole moments, the moments for the two Br isotopes being also approximately equal but considerably larger than those for Cl. In addition the data allow a determination of moments of inertia for these molecules and internuclear distances. A comparison of the moments of inertia with electron diffraction data[1] shows that both molecules are cyanides rather than isocyanides. The distances are C—N = 1.15A, Br—C = 1.79A, Cl—C = 1.64A, which are consistent with previous measurements.[1]

[1] J. Y. Beach and A. Turkevich, J. Am. Chem. Soc. **61**, 299 (1939).

X9. A Precision Ultrasonic Interferometer.* I. F. ZARTMAN, *Johns Hopkins University, and Muhlenberg College*.—A precision type ultrasonic interferometer has been developed. This interferometer is of the resonator type, the theory of which was developed by Hubbard.[1] This instrument incorporates high sensitivity, extreme stability, and is capable of yielding velocity, absorption, and reflection data of precision in gases and vapors from ordinary pressures to those less than one centimeter of mercury. The temperature range of operation covers that from the lowest obtainable up to that permitted by the piezoelectric properties of the crystal plate. With the ability to use piezoelectric crystals of greatly differing frequencies measurements may be made over an extremely wide range of frequency to pressure ratios. Preliminary results using a 500-kilocycle quartz plate in CO_2 and H_2 at a temperature of 38°C yield data as a function of pressure to values less than one centimeter of mercury, i.e., f/p ratios of 30 megacycles per atmosphere. Evidence for molecular dispersion and absorption in these gases are presented.

* This work is supported by Contract NOrd 8036, U. S. Navy and a Research Corporation grant.

[1] J. C. Hubbard, Phys. Rev. 38, 1011 (1931); Phys. Rev. 41, 523 (1932).

X10. On the Existence of Single Magnetic Poles. Elliot T. Benedikt and Herta R. Leng, *Rensselaer Polytechnic Institute, Troy, New York.*—The present paper describes experiments devised to verify the existence of single magnetic poles as claimed by F. Ehrenhaft.[1] The method used was based on the observation of the motion of ferromagnetic particles under the action of a magnetic field generated by an electric current. If single magnetic poles were present, the magnetic field would cause motion in the direction of the closed lines of magnetic force. Observations were performed on a colloidal solution of Fe_3O_4[2] and with colloidal solutions of iron and nickel (approximate size of particles of order of 20 mμ). The solution was placed in an ebonite container in the center of which a straight conductor carrying a current of 3000 amperes was placed. The particles were illuminated by means of a carbon-arc lamp, and the scattered light was observed through a microscope. In the region of observation, the field was about 350 gauss. No motion such as would be expected from single magnetic poles was observed. Analysis of results shows no evidence of existence of single magnetic poles exceeding 1.5×10^{-12} e.m.u.

[1] F. Ehrenhaft, Phys. Rev. 60, 169 (1941); 61, 733 (1942); 63, 216 and 461 (1943); 64, 43 (1943).

[2] W. C. Elmore, Phys. Rev. 54, 309 and 1092 (1938).

X11. The General Movement of Matter Possessing Six Degrees of Freedom in Fields is Helical. Felix Ehrenhaft, *New York City.**—It has been experimentally proven and published in *ca.* 30 abstracts that single magnetic poles, north or south, do exist as predicted by Hertz (div $B \gtreqless 0$). This fact has been confirmed, no other explanation being valid.** The unipolar magnetic charge can in no way be explained away electrically, neither by Ampere's circuital currents nor by the spin of electrons, and thereby magnetic charges become equally important as electric charges. This broadened concept has to enter the whole of physics. Photomicrographs demonstrate that matter possessing six degrees of freedom moves in or against the direction of homogeneous constant magnetic and electric fields following helical paths with regularly spaced turns and reversing in direction with the reversal of the field. Movements of similar nature are observable in homogeneous constant beams of light (longitudinal and also transversal photophoresis). These facts have also been confirmed.** In view of the similarity of helical paths in magnetic fields and light, it is clear that there must be a much closer connection between the two than heretofore believed. The author asserts that all these facts are irreconcilable with present theories.*** Some unpublished experimental details will appear in European scientific journals.

* The author can be reached during February and March 1947 c/o Professor John Plesch, 40 Hereford House, Park Lane, London W 1; beginning in April he will stay in Vienna.

** P. Tauzin; P. Tauzin, and L. Rault, Soc. Fran. de Physique, Nov. 16 (1945); May 17 (1946); Comptes rendus 222, 1037 (1946).

*** F. Ehrenhaft, Comptes rendus 222, 1100, 1345 (1946).

Y1. Fluctuations of Ionization Yield. U. Fano, *National Bureau of Standards.*—An ionizing radiation produces in a gas a number of ions closely proportional to the amount of energy absorbed, almost independent of the quality of the radiation, but subject to statistical fluctuations even when all pertinent factors are kept constant. The expected variance of the number of ionizations produced by a charged particle of energy E is FE/ϵ, where ϵ is the average energy absorbed per ionization and F is to be estimated. (If the number of ions were governed by a Poisson distribution, then $F=1$.) In general, $F=(\Sigma_p\, s_p(n_p-E_p/\epsilon)^2)/(\Sigma_p\, s_p n_p)$, where s_p is the cross section for an impact from which n_p ionizations arise and in which the energy E_p is spent. Following the method introduced in § 4 of a previous paper[1]

$$F=\Big(\sum_j^{E_j<I} s_j(E_j/\epsilon)^2+\sum_j^{I\le E_j<2I} s_j(1-E_j/\epsilon)^2 + \sum_j^{E_j\ge 2I} s_j(1-I/\epsilon)^2\Big)\Big/E_j \gtreqless I\Sigma_j\, s_j,$$

where s_j is the cross section for an impact in which a molecule (together with all its electrons) absorbs the energy E_j, and I is the first ionization potential. F should be averaged over the energy of the impinging particle. Its order of magnitude is $\frac{1}{2}$ to $\frac{1}{3}$.

[1] U. Fano, Phys. Rev. 70, 44 (1946).

Y2. Microwave Studies of Dielectric Properties of Arcs. Donald E. Kerr, Sanborn C. Brown, Walter P. Kern, *Massachusetts Institute of Technology.*—If the conductivity and dielectric constant of the center conductor of a coaxial transmission line are varied while the conductivity of the outer wall remains very high, the resulting transmission properties of the line vary widely. With high conductivity in the center conductor the line acts in the customary manner, transmitting all frequencies; but with zero conductivity the line becomes a circular wave guide with dielectric center rod, and has a cut-off frequency. If an arc is used as the center conductor, the current may be used to control the effective conductivity and dielectric constant, which may be determined through measurement of the propagation constant by standing wave techniques. These results may be used to study fundamental arc properties such as electron density and mean time between collisions. At a particular current density a rapid transition occurs between propagation of an exponentially attenuated wave and a guided transverse magnetic wave, the propagation constant of which is a continuous function of arc current. These properties suggest a means for obtaining a radio-frequency switch, a modulator, or an attenuator with variable slope.

Y3. High Frequency Probe Measurements of Electron Attachment and Ambipolar Diffusion. MANFRED A. BIONDI, SANBORN C. BROWN, *Massachusetts Institute of Technology.* —An electrodeless method of measuring electron attachment and diffusion in gases has been developed. An r-f field is used to break down a gas in a glass bottle inside a cavity resonant at 3000 Mc. This field is applied for 1000 microseconds, then turned off for 4000 microseconds. The electrons produced in the discharge then diffuse or attach depending on the gas used. If a small CW field is applied to the cavity, the free electrons will oscillate without having their energy distribution disturbed. The electron oscillation causes a shift of the resonant frequency of the cavity proportional to the number of free electrons. Thus the CW field may be used as a probe to detect the free electrons. The probe signal is set to a higher frequency than the resonance of the cavity in the absence of free electrons. The signal will undergo maximum transmission through the cavity when the effect of the free electrons plus the cavity constants give a resultant resonant frequency equal to that of the probe signal. By measuring the time at which maximum transmission occurs for various probe signal frequencies, the clean-up of electrons in the gas is determined. Data on the measured diffusion and attachment constants at thermal energies of various gases will be given.

Y4. Harmonic Components in a.c. Discharges.[1] LAWTON M. HARTMAN AND HENRY MARGENAU, *Yale University.*—In dealing with alternating current discharges in gases it is usually assumed that the electron distribution function consists of a time-constant part and a time-dependent part varying with the frequency of the impressed field. Actually, all frequencies should appear in the discharge, and the simple treatment is but an approximation. To determine its validity, the distribution function is here expanded as a Fourier series in the time and as a series of Legendre functions in the electron velocities. Differential equations relating all members of the expansion may be obtained with the use of the Boltzmann transfer equation, and approximate solutions for the second Fourier components, valid under different conditions of frequency, gas pressure and field strength, have been derived. These lead to a better appreciation of the limits of the "first-order treatment," which is on the whole correct. The results also show how for small frequencies of the external field, the distribution function alternates between the Maxwell form and the Druyvesteyn form, twice per cycle.

[1] Assisted by the Office of Naval Research under Contract N6ori-44.

Y5. Retrograde Motion of an Arc Cathode Spot in a Magnetic Field. C. J. GALLAGHER AND J. D. COBINE, *General Electric Company.*—A mercury arc cathode spot under the influence of a magnetic field perpendicular to the arc axis may be made to move contrary to the direction predicted by electromagnetic theory.[1] We have found this retrograde effect to exist not only in the mercury arc, but also in arcs between solid electrodes with different gases, including helium, argon, nitrogen, hydrogen, oxygen, and carbon dioxide. Electrode materials studied include carbon, tungsten, molybdenum, nickel, copper, aluminum, and cadmium. For retrograde motion, the arc column and anode spot tend to move in the conventional direction, but are "dragged" in the reverse direction by the cathode spot. Conditions for reversal for a particular gas-electrode combination are determined by pressure, magnetic field (B) and current. At constant current, the critical reversal pressure is proportional to B. Increasing current at constant B decreases the value of critical pressure. In general, gases with higher critical potentials have higher reversing pressures. Currents ranged from 2 to 10 amperes, magnetic fields from 10 to 450 gauss and reversal pressures from 60 to 0.8 cm Hg. In general, it was necessary to oxidize the electrodes to maintain a stable arc.

[1] C. G. Smith, Phys. Rev. 62, 48–54 (1942); 69, 96–100 (1946).

Y6. Gyroscopic Effects in a Vibratory System.* G. S. BENNETT, *Naval Ordnance Laboratory.*—An analytical investigation is made of the influence on a vibrating elastic system of a high speed rotating element. A fundamental condition for the presence of any gyroscopic effect is that the vibration be such as to produce a tilt of the spin vector of the rotor. Equations are derived showing (a) that if precession be prevented, no gyroscopic effects are present; and (b) that if precession be permitted, the gyroscopic action contributes a force opposed to the tilt, and proportional to the angle of tilt, in effect increasing the stiffness of the elastic system. Calculations based on an arbitrarily chosen rotor intended to approximate a typical small motor armature indicate that this additive spring force is small, and that the increase in natural frequency due to the added stiffness is exceedingly small—of the order of 0.1 percent—in the case where the precessional motion is not restrained.

* This work was done at Naval Research Laboratory, Washington, D. C.

Y7. An Experimental Investigation of Forced Vibrations in a Mechanical System Having a Non-Linear Restoring Force. CARL A. LUDEKE, *University of Cincinnati.*—This paper introduces a mechanical apparatus capable of generating and recording forced vibrations in a system having a non-linear restoring force. The experimental wave forms are then compared with the theoretical results given by three graphical methods. These are the methods of Martienssen, Hartog, and Rauscher. Provided a suitable first guess for the amplitude can be made, one application of Rauscher's method gives better results than the other methods. A graph is made of the experimental amplitude as a function of the disturbing frequency. These results are compared with the theoretical results of the above three methods. Again one application of Rauscher's method gives satisfactory results. In all experimental results it is noted that even though the restoring force is distinctly non-linear, the wave forms of the resulting motion are nearly sinusoidal as long as the frequency of the observed motion is the same as the frequency of the disturbing force. However, steady oscillations can be maintained for which the observed frequency is a sub-multiple of the disturbing frequency. Two such subharmonics were recorded and the experimental wave forms are shown.

Y8. A Linear Amplifier for General Laboratory Use. W. H. JORDAN AND P. R. BELL, *Clinton Laboratories.*—Twelve linear amplifiers have been built for general laboratory use. Feedback circuits have been used to stabilize the gain and improve the linearity. The high frequency cut-off of the amplifier can be varied by means of a three-position switch that changes the amount of capacitance and resistance in the feedback network. The low frequency cut-off is determined by a simple resistance-capacitance differentiator that is switched to match the high frequency response. The response of the amplifier to a voltage step applied to the input is a single pulse of fairly symmetric shape. The pulse rise time (10 percent to 90 percent) is 0.15 μsec. for the wide-band position, 0.7 μsec. for the medium-band position, and 4 μsec. in the narrow-band position. The amplifier will deliver pulses up to 100 volts for direct oscilloscope deflection, or 5 volts for driving a low impedance line. A pulse height selector is included on the amplifier chassis. It has been designed to measure accurately pulse heights up to 100 volts, independent of pulse duration or duty cycle. It delivers a pulse 3 volts high and 0.5 μsec. in length for scaler operation.

Y9. A Static Method of Simulating Accelerations Above One g. JOHN J. GILVARRY AND S. F. EYESTONE, *North American Aviation.*—In the developmental testing of accelerometers, accelerations above one g are usually simulated by a rotating table. A static method of simulating such accelerations is described. The accelerometer's moving element is assumed representable by an equivalent mass m such that accelerations are measured by determining the force on this mass. If a parameter i in the force-measuring unit is used as an acceleration index, a curve of i against acceleration can be constructed up to one g by tilting the accelerometer at various angles to the vertical. This curve is not necessarily linear but is assumed known. To simulate accelerations above one g, the accelerometer is turned so the earth's gravitation is not effective, and a force is applied to the moving member by a horizontal string passing over a pulley to a mass M_0. The mass M_0 is chosen so the corresponding parameter reading i_0 is in the range of the calibration curve below one g. If i_0 on this curve corresponds to g_0, the equivalent accelerometer mass is $m=M_0g/g_0$. If now the mass M_0 is replaced by an arbitrary mass M, the simulated acceleration is Mg_0/M_0. By suddenly cutting the thread, the step-function response can be obtained.

Y10. Fringing Flux Corrections for Magnetic Focusing Devices. NORMAN D. COGGESHALL, *Gulf Research & Development Company.*—In such an instrument as a sector type mass spectrometer the ions pass from a magnetic field free region into, through, and out of a region of uniform magnetic field. In calculating ion trajectories for such a system the physical boundaries of the magnet pole faces cannot be used for the boundaries of the uniform field region because of the fringing flux which is effective for some distance away from the pole faces. Therefore, the pole faces must be considered to have virtual boundaries which are displaced outwards from the actual boundaries. An analytical method of determining this displacement has been developed. The principal ray leaving the ion source travels on the median plane between the two pole faces. Since the fringing magnetic field on this plane may to a good approximation be represented as a function of one variable, the distance normal to the pole faces, the path of the principal ray may be calculated using the methods developed for ions moving in non-uniform magnetic fields.[1] The displacement d, of the virtual field boundary from the pole face boundary is found to be $d=r-\bar{x}$ where $\bar{x}$ satisfies the equation: $\int_{x_0}^{\bar{x}} h(x)dx=r$, r is the radius of curvature of the ion paths in the uniform field region; the origin for the x coordinate is coincident with the edge of the pole faces; the unit length in the coordinate system is one gap width; x_0 is the value of the x coordinate at the ion source; and $h(x)$ is the function which expresses the magnetic field on the median plane in fractional value of the uniform field value. Using the Schwarz-Christoffel transformation to obtain $h(x)$ a number of specific cases have been evaluated and will be discussed.

[1] N. D. Coggeshall and M. Muskat, Phys. Rev. **66**, 187 (1944).

Y11. Alternating Current Probe for the Measurement of Magnetic Fields. E. C. GREGG, *Case School of Applied Science.*—A method of measuring magnetic field strengths is described which utilizes the change in alternating current permeability of a small Permalloy core transformer with superposed steady state magnetic fields.* One such transformer probe used for the measurement of the field of a scale model betatron consisted simply of a 150-turn primary and a 100-turn secondary wound on a 0.1 inch length of 0.01 inch diameter Permalloy wire. The completed probe had the dimensions of a cylinder 0.1 inch long and 0.08 inch in diameter. The primary winding was driven both with alternating and direct current while the secondary was connected to an amplifier and null indicator. The reference voltage for the null indicator was derived from the driving signal in order to minimize errors arising from drifts in this signal. The use of the null scheme and superposed primary direct current allowed the selection of any given magnetic field as a reference point and eliminated the necessity of calibrating the probe. The unknown magnetic field could then be determined in terms of the direct current through the probe required to return the probe to its initial condition. While the accuracy of this probe was about 0.2 percent, it is possible to improve this figure by increasing the gain and stability of the associated electronic equipment.

* G. W. Elmen, Bell Sys. Tech. J., January 1936.

Y12. Arterial Pulse Wave Velocities. ALLEN L. KING, *Dartmouth College, Hanover, New Hampshire.*—An expression for the instantaneous pulse pressure in terms of the radius of an elastomeric tube is inserted in the general differential equation for a pulse wave, and from the result a relation for pulse wave velocities is obtained. Numerical values of velocities for human aortas are computed by using data from an earlier paper* and the increase of velocity with mean blood pressure and age is shown. Results for other large arteries are given and a comparison of them with directly measured values found in the literature is made. The Moens-Korteweg formula is shown to be inappropriate for tubes such as blood vessels.

* A. L. King, J. App. Phys. 17, 501 (1946).

Z1. A High Performance Photo-Galvanometer Feedback Amplifier. DEMETRIUS G. JELATIS, *Central Research Laboratories** and *Massachusetts Institute of Technology.*—The instrument described utilizes inverse feedback applied to a galvanometer to obtain a high current amplification combined with improved response and impedance characteristics. Using a commercial galvanometer (0.0005 microamperes per mm at 1 m) as the basic element, full scale output of 5 milliamperes is produced by 0.001 microampere input with thermal noise level less than one percent of full scale. Effective input resistance is reduced from 550 ohms to 0.1 ohm, and the critically damped response time from 6 seconds to under 0.1 second. Linearity is better than 0.1 percent over the entire range. The feedback current is derived from a d.c. amplifier actuated by a pair of balanced vacuum phototubes and normally contains two components: one proportional to the angular deflection, and the second to the angular velocity of the moving coil. Full output of 5 milliamperes is obtainable with a coil deflection of 0.1 microradian (0.0002 mm at 1 m). The shunt feedback circuit with the properties given above is useful in work with low level crystal rectifiers and boundary layer photocells where low input resistance is essential. For use with low impedance "voltage" sources, a series feedback arrangement can provide a full scale sensitivity of 0.1 microvolt with 0.1 megohm effective input resistance.

* Present location.

Z2. Wave Guides for Slow Waves. L. BRILLOUIN, *Harvard University.*—Many applications of T.M. waves in wave guides have been recently suggested for linear accelerators or decelerators of electrons. In order to obtain a good efficiency, it is necessary to match the wave velocity with electron velocity. Such a condition means that the phase velocity of the wave must be lower than c (light velocity) while ordinary wave guides yield a phase velocity larger than c. The present paper is devoted to a discussion of pipes fitted with equidistant diaphragms. These structures behave as band-pass filters and exhibit a very strong variation of the phase velocity with respect to frequency. Some special cases are completely discussed and serve as examples of a general method that can be applied to this class of problems.

Z3. Specular Reflection from Mercury Vapor. J. M. HANSEN AND H. W. WEBB, *Columbia University.*—The transition from diffuse scattering of the 2537A resonance line of mercury occurring at low vapor pressure to the specular reflection occurring at high pressure has been investigated by two methods: (1) Measurement upon a plane quartz—mercury vapor surface, using collimators to separate the specularly reflected from the diffusely scattered radiation, to determine their variation with pressure. (2) A study of the time elapsing between the incidence of the radiation on the vapor and its re-emission, using a modification of the method previously employed in this laboratory for measuring persistence of radiation.[1] These measurements show that diffuse scattering is inappreciable (less than 0.5 percent) at pressures above 247 mm (condensed mercury temperature 300°C), specular reflection is inappreciable below 0.27 mm (100°C), and both occur over the range 100°C–300°C. From the variation of the reflectivity with the angle of incidence, the optical constants of the vapor for the 2537A line were calculated. Persistence of radiation remains unchanged as diffuse scattering declines over the pressure range 0.066 mm to 2.8 mm (75°C to 150°C). Persistence of specular reflection is less than 1/40 of the lifetime of the excited state involved.

[1] H. W. Webb and H. A. Messenger, Phys. Rev. 66, 77 (1944).

Z4. The Decay Scheme of Cs^{134}. KAI SIEGBAHN AND MARTIN DEUTSCH, *Massachusetts Institute of Technology.*—The long-lived isomer of Cs^{134} has been studied by magnetic spectrometer and coincidence techniques, with a view to its use as a radioactive standard. The great majority of the disintegrations—about 95 percent—proceed by the emission of beta-particles of (0.645 ± 0.02) Mev maximum energy to an excited state of Ba^{134} with (1.36 ± 0.03) Mev excitation energy, followed by the successive emission of two gamma-rays of (0.584 ± 0.012) Mev and (0.776 ± 0.015) Mev, respectively. In a few percent of the disintegrations a gamma-ray of (1.35 ± 0.03) Mev is emitted. This is probably due to single-quantum de-excitation of the same excited state.

Z5. Pairs of Fission Fragments. PIERRE DEMERS,* *Chalk River Laboratory.*—Using new photographic emulsions[1] and a three-layer technique,[2] the tracks starting in a central U layer are recorded in two adjacent layers, with a short gap marking the origin. (1) The two tracks are most often (98 percent of cases) unequal. Mean values of the difference D between long (L) and short (S) tracks, of L, of S and of $T=L+S$, are as follows: D: 3.2 μ, 5.3 mm of air; L: 14.3 μ, 24.0 mm; S: 11.2 μ, 18.7 mm; T: 25.5 μ, 42.7 mm. Ionization along L near the origin is usually greater than along S. (2) A few long α tracks accompanying fission have been seen; spatial coincidence of the origin of the three tracks shows coincidence of emission in time within 2.10^{-14} second. (3) Three main kinds of recoils are recognized: Ag, Br; C, N, O; H. From rare H recoils a few μ long, a range velocity curve can be obtained for L and for S. Velocity can also be inferred as in Ref. 3 from the distribution of numerous very short protons (<0.5 μ, <75 kv) which are occasionally visible.

* Now at University of Montreal.
[1] Demers, Phys. Rev. 70, 86(L) (1946). Can. J. Research (to be published).
[2] Demers, Phys. Rev. 70, 974 (1946).
[3] Boggild, Brostrom, Lauritsen, D. K. Danske, V. S. Mfm. 18, 4 (1940).

Z6. Low Temperature Resistivity of Germanium Semi-Conductors. V. A. JOHNSON AND K. LARK-HOROVITZ, *Purdue University.*—Degeneracy criteria for the free electron gas in semi-conductors have been applied to various germanium samples, indicating that usually both at high and low temperatures the electron gas is not degenerate. In a few cases, however, degeneracy occurs at about 150°K. Interpretation of resistance measurement at low temperatures[1] shows that a high purity germanium sample and an N-type sample (n electrons/cc at room temperature $\sim 4.10^{17}$) behave as expected from the theory of semi-conductors; the resistance increases at low temperatures. However, the P-type sample ($n \sim 5.10^{18}$) shows a behavior which cannot be accounted for by combining resistivities due to lattice scattering and impurity scattering. To account on this basis for the observed resistivity, one would have to assume Hall constant increasing with decreasing T, or if n remains constant throughout this range, a temperature independent resistance contribution similar to the so-called Mathiessen resistance in alloys seems to exist at these temperatures in semi-conductors. In the N-type sample, it is possible by extrapolating the Hall curve to low T to obtain a reproduction of the resistance curve, combining impurity and lattice scattering, using classical statistics. This is in agreement with the fact that this sample has a degeneracy temperature of about 10°K.

[1] See preceding abstract.

Z7. Resistivity of Germanium at Low Temperatures and the Effect of Additions. I. Estermann, A. Foner, and J. A. Randall, *Carnegie Institute of Technology.**—The resistivity ρ of several germanium samples** was measured between room temperature and 13°K. The purest sample shows a very steep increase of resistivity with cooling at temperatures below 30°K, giving a linear relation between

Table I.

Sample	Type	Resistivity in ohm-cm at 273°K	180°K	90°K	60°K	20°K	14°K	13°K
"pure"	—	17.5	19.2	11.2	9.2	73	1840	
P added	N	0.0242	0.0234	0.0301	0.0384	0.0551	0.0560	0.0560
0.006 at % Al	P	0.0324	—	—	0.0330	0.0641	0.0723	0.0712
0.04 at % Al (first run)	P	0.00510	0.00472	0.00520	0.00585	—	—	—
0.04 at % Al (fourth run)	P	0.00937	—	0.0086	0.0086	0.0088	0.0087	0.0087

$\log\rho$ and $1/T$. The samples with low impurity concentration (both N and P type), e.g., 0.006 atmos. percent Al, show a slight decrease in resistivity on cooling from room temperature to about 150°K, followed by an increase to about $2\frac{1}{2}$ times the minimum value at 13°K. The sample with higher impurity concentration (0.04 atmos. percent Al) shows practically no change in resistivity over the whole temperature range. In this sample, however, the resistivity at all temperatures increased substantially after the first four cooling and warming up operations; the same effect, but to a much lesser degree, was observed in other samples. Typical results are given in Table I.

* This work has been carried out under Contract N6ori-47 with the Office of Naval Research.

** The samples were prepared at the Physics Department of Purdue University. Measurements of their properties at temperatures above 90°K were carried out at Purdue and are being correlated with our low temperature measurements.

Z8. Neutron Spectra of Li, Al, and Be Bombarded with 10-Mev Deuterons. J. S. Laughlin and P. G. Kruger, *University of Illinois.*—A high pressure cloud chamber filled with methane gas has been used to detect neutrons above 2 Mev emitted from Li, Al, and Be thin targets bombarded with 10-Mev deuterons. In the first experimental arrangement the neutrons entered the cloud chamber after passing through a collimating hole in the water tanks. The lengths and scattering angles of the recoil protons were measured to obtain the neutron energies. In order to observe any influence of the collimator the beryllium spectrum measurement was repeated without collimation and with a minimum of scattering material near the target and chamber. 300 recoil protons were observed from Li, 400 from Al, and 1600 from Be. A single (d, n) reaction occurs with Be and Al targets and these neutron spectra have been used to plot the average level density *vs.* excitation energy for B^{10} and Si^{28}. The level densities increase in a regular manner with the excitation energy. The collimator appears to have no appreciable influence on the high energy neutron distribution. There is some evidence that a few low levels of B^{10} have been located. The number of neutrons detectable above 15 Mev from a lithium target is not greater than 2 percent of those below 7 Mev.

Z9. The Infra-Red Absorption Spectrum of H_2S. Robert H. Noble and Harald H. Nielsen, *Ohio State University.*—The infra-red absorption bands of H_2S have been re-measured using an evacuated spectrometer with higher resolution than had been employed in previously published work. Data have been tabulated for the bands near 1290, 2440, 3790, and 5140 cm^{-1}. A careful survey of the included region resulted in the discovery of no bands or sub-bands not previously reported. Particular attention was paid to the region on the low frequency side of the band near 2694 cm^{-1}. King and Hainer[1] have suggested that this band should be interpreted as an "R" branch of a vibrational transition associated with a change in electric moment parallel to the axis of the least moment of inertia. Absorption of proper intensity for "Q" and "P" branches was not found. Tentative assignments of the measured bands have been made.

[1] G. W. King and R. M. Hainer, Abstract of paper given at the Chicago meeting of the American Chemical Society, September 1946.

SUPPLEMENTARY PROGRAMME

SP1. A Possible Effect of the Sun Upon Cosmic Radiation. W. F. G. SWANN, *Bartol Research Foundation.**—During the B-29 flights for the determination of latitude variation of the mesotron intensity reported in another paper, it was found that in one flight, made on June 18, the intensity continued to rise with increasing latitude beyond the knee of the curve as determined by other flights. Considerable sun-spot activity occurred during the period in question, culminating in other abnormal effects which have been cited by other observers. Our own apparatus gave considerable evidence of shower phenomena in the penetrating radiation. The paper comprises a discussion of these matters in relation to the sun as a possible origin (probably through betatron activity) of part, and possibly a considerable part, of the hard component of the cosmic radiation.

* To be given after paper A12 if time permits.

SP2. Piezoelectric Vibrations of Rochelle Salt Plates. N. CHAKO, *Kansas State College.**—The theory of vibration of Rochelle salt crystal plates is developed and the modes of vibration of square and rectangular plates with free edges are obtained. Since Rochelle salt has nine independent elastic constants and three priezolectric constants the natural modes of vibration of such a crystal are not of a simple harmonic type as one finds in the quartz crystal plates. However, for certain orientations of the plate (cut) the vibrations can be made simple harmonic. However, the frequencies in general are found to depend on four elastic constants c_{11}, c_{12}, c_{22}, and c_{66}, the last being the shearing constant along the x-y plane of the plate. The thickness vibrations were calculated and it was found that the Christoffel determinant was separable into a linear and one quadratic equation, thus giving rise to three independent frequencies. It was found that the lowest frequency for a plate of 1 cm thickness was approximately 93 kilo Hertz and that the highest frequency in the neighborhood of 102 kilo Hertz. Calculations have also been made for clamped edges and circular plates.

* To be given after paper L11 if time permits.

SP3. On the First Passage Time Problem for the Stationary Markoffian Random Function. A. J. F. SIEGERT, *Syracuse University.*[1]—A stationary Markoffian random function* $y(t)$ is completely defined by $P_2(y_0/y, t)dy$, the conditional probability, that $y<y(t)<y+dy$, provided that $y(0)=y_0$. The function $W(y_0/t, a)dt$ is defined as the conditional probability that $y(t)$ passes the value $a>y_0$ for the first time between $t>0$ and $t+dt$, provided that $y(0)=y_0$.

An adaptation of an argument of Schroedinger** yields the integral equation

$$\tfrac{1}{2}W(y_0/t, a)=U(y_0/t, a)-\int_0^t W(y_0/\vartheta a)U(a/t-\vartheta, a)d\vartheta$$

where $U(y_0/t, a)=-\dfrac{\partial}{\partial t}\displaystyle\int_{-\infty}^a P_2(y_0/y, t)dy$. Solving the integral equation by Laplace transformation, we obtain

$$\tilde{W}(y_0/\lambda a)=\tilde{U}(y_0/\lambda a)/[\tfrac{1}{2}+\tilde{U}(a/\lambda a)],$$

where $\tilde{W}(y_0/\lambda a)$ and $\tilde{U}(y_0/\lambda a)$ are the Laplace transforms of $W(y_0/ta)$ and $U(y_0/ta)$, respectively.

[1] To be given after paper C12 if time permits.
* M. C. Wang and G. E. Uhlenbeck, Rev. Mod. Phys. **17**, 323, 325 (1945).
** E. Schroedinger, Physik. Zeits. **16**, 289 (1915). I am indebted to Prof. Uhlenbeck for calling my attention to this method.

PROGRAMME OF THE DIVISION OF HIGH-POLYMER PHYSICS

M1. Address of Retiring Chairman. H. A. ROBINSON, *Armstrong Cork Company* (45 min.).

M2. The Determination of Macromolecular Configurations in Dilute Solution by Light Scattering. P. M. DOTY,* W. A. AFFENS, AND B. H. ZIMM,** *Polytechnic Institute of Brooklyn* (30 min.).—The interference pattern produced by monochromatic light scattered from solutions of fractionated polystyrene has been studied. In particular, the dissymmetry coefficient of Debye, the fractional difference of the intensities of the light scattered at two different angles, has been investigated as a function of concentration, of solvent, and of molecular weight of the polymer. The variation with concentration is large and is characteristic of the particular solution, but it was found possible to extrapolate to infinite dilution to obtain a coefficient characteristic of the polymer alone. From this limiting or "intrinsic" coefficient the root-mean-square distance, R, between the ends of the chain molecule may be calculated by exact equations. It was found that R varied as the square root of the molecular weight, as predicted by the theories of chain statistics, but that it was only slightly dependent on the nature of the solvent. On the other hand, the intrinsic viscosity of the same materials was markedly dependent on the nature of the solvent. Some typical data are shown below:

Polystyrene molecular weight	Solvent	R	Mol. wt./R^2	Intrinsic viscosity
4,800,000	Toluene	2370A	—	7.6
4,800,000	Butanone	2100	1.10	2.3
11,800,000	Butanone	2770	1.53	4.10
2,100,00	Butanone	1230	1.38	1.45

* Present Address: Department of Colloid Science, Cambridge University, Cambridge, England.
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M3. The Relation between Intrinsic Viscosity and Molecular Weight in Polymer Solutions. P. DEBYE, *Cornell University* (30 min.).—If a polymer molecule of the coiling type suspended in a liquid is exposed to forces caused by a flow pattern of the liquid as used in viscosity measurements, its center of gravity will move with the liquid and at the same time the molecule as a whole will rotate with an angular velocity determined by the velocity gradient. Notwithstanding this adaptation of the motion of the molecule to that of the liquid a relative flow of the liquid with respect to the molecule remains. With the assumption that the average density in space of the polymer molecule is so small that its disturbing effect on the motion of the liquid can be neglected, it can be shown that the intrinsic viscosity of a solution will be proportional to the average square of the distance of the average monomer group of the chain from the center of gravity of the whole molecule. This means that in this approximation Staudinger's rule should hold which makes the intrinsic viscosity proportional to the molecular weight. However, neglecting the disturbing effect of the molecule on the regular flow pattern of the liquid is too poor an approximation. A mathematical method has been developed which makes it possible to take care of this disturbance. The final conclusion is that the intrinsic viscosity depends on 2 fundamental constants, each of the dimension of a length, which characterize the molecule. The first of these constants is the familiar average distance D between the two ends of the chain or the corresponding spherical volume proportional to the third power of D, which can be taken to represent a measure for the average volume occupied by the polymer molecule in the solution. The second constant is a length L, determined by the average density with which the molecule fills its allotted space. It is a measure for the distance over which the outside velocity distribution makes itself felt into the interior of this space. The intrinsic viscosity is represented by a product of which the first factor is the specific volume of the molecule defined as the volume occupied divided by the mass of the polymer molecule. The second factor is a relatively simple function of the quotient D/L, a quantity which I would like to call the "shielding ratio." It turns out that for a linear polymer the intrinsic viscosity is proportional to the molecular weight (Staudinger's rule) for small values of the shielding ratio, whereas for large values of this ratio it becomes proportional to the square root of the molecular weight. In an intermediate case the curve can be approximated over a large range of molecular weights by the customary power-function. The exponent has some value intermediate between 1 and $\frac{1}{2}$ and is determined by the shielding ratio. Discussed in this way measurements on intrinsic viscosity give information about the actual size of the polymer molecule in solution and its changes with the solvent. As already indicated by measurements on the dissymmetry of light scattering it is found again that D is a good deal larger than would be expected from Eyring's theoretical formula (no interaction, free rotation). The way is also opened to the use of viscosity measurements in order to obtain information about branching, since branching will affect the space-density of the polymer molecule, which determines the shielding ratio.

M4. Time-Dependent Strain Birefringence in Viscoelastic Materials. TURNER ALFREY, JR., *Polytechnic Institute of Brooklyn* (30 min.).—The phenomenological theory of strain birefringence in viscoelastic materials is developed. The material is assumed to be homogeneous, amorphous, and (in the unstrained state) isotropic. The purely mechanical behavior is assumed to be representable in terms of a distribution of mechanical relaxation times—i.e., the material obeys the Boltzmann superposition principle. Each molecular mechanism of mechanical response to stress will have associated with it a certain strain-optical constant. This results in a definite pattern of (time-dependent) birefringence when stresses are applied. The theory has two possible applications: the use of photoelastic creep studies in the investigation of *molecular mechanisms* of viscoelastic behavior, and analysis of the optical creep effects which may occur when imperfectly elastic materials are used in photoelastic studies of stress distributions.

N1. Velocity and Attenuation of Sound in Rubber. W. B. THOMPSON, B. A. MROWCA, AND EUGENE GUTH, *University of Notre Dame* (30 min.).—Velocity and attenuation of sound in rubber strips were investigated by the standing wave method suggested by Bridgman and Trueblood, developed to measure the dynamic modulus by Silverman and Ballou, and extended by us and Nolle and Bolt (M.I.T.) to measure also attenuation. Amplitude of vibration in this method is below 0.001 percent. Velocity and attenuation of sound both decrease with temperature and with frequency in the range 500–6000 cycles per second for Hevea and synthetic gum stocks. From the velocity and attenuation of sound the dynamic modulus and internal friction constant were derived, assuming a proportionality of the viscous forces to the rate of deformation. Both the dynamic modulus and internal friction decrease with increasing temperature. The former fact is in contrast to the increase of the static and dynamic modulus at larger amplitudes predicted by the statistical theory of rubber elasticity and confirmed by experiment. Probably for such small amplitudes the intermolecular theories chiefly determine the temperature dependence of the dynamic modulus for rubber just as for all other materials. Although the measurements at Notre Dame were checked by those at M.I.T., both groups feel that more accurate data are needed before final conclusions can be reached, particularly about the temperature dependence of dynamic modulus. Financial support of ONR, Navy Department, is gratefully acknowledged.

N2. Elastic Losses of Natural and Synthetic Rubber as a Function of Frequency and Temperature.* H. S. SACK AND H. L. RAUB, *Cornell University* (30 min.).—The elastic losses of unloaded samples of natural rubber and synthetic rubber of the GRS types containing different amounts of styrene were measured. The sample, in the form of a reed, is acted upon by an alternating force of constant amplitude and adjustable frequency. The motion of the end of the reed is observed by means of an optical method. Signals proportional to and in phase with the force and the elongation, respectively, are obtained and applied to the two pairs of deflecting plates of an oscilloscope. Thus, a picture of the elastic hysteresis loop is obtained. The area of this loop is a measure for the elastic losses in the sample. Observations were made in a frequency range from 300 to 4000 c.p.s. and at temperatures from $-60°C$ to $+35°C$. The results can be qualitatively interpreted by a relaxation theory, the relaxation time varying very strongly with temperature and with the styrene content. The crystallization of the samples is accompanied by a strong increase in the losses when the temperature decreases and then a decrease at still lower temperatures.

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N3. The Torsion of a Rubber Cylinder. R. S. RIVLIN,* *British Rubber Producers' Research Association* (30 min.).—In a series of papers pending publication[1] a mathematical formalism has been developed for the solution of problems concerning the deformation of highly elastic materials. The present paper is concerned with the experimental verification of the predictions of one paper of this series, in which the torsion of a rubber cylinder is discussed on the basis of this theory and it is found that, in order to produce pure torsion in a rubber cylinder, a compressive longitudinal thrust must be applied over the plane ends of the cylinder, in addition to the torsional couple. The distribution of this thrust over the ends of the cylinder and its dependence on torsion are investigated experimentally in the present paper and agreement with the theoretical conclusions is obtained.

* At present guest worker at the National Bureau of Standards.
[1] Rivlin, Phil. Trans. Roy. Soc. A.

N4. Heat Conductivity of Natural and Synthetic Rubbers under Stretch and at Low Temperatures. H. D. SMITH, T. McC. DAUPHINEE, AND D. G. IVEY, *University of British Columbia, Canada* (*Introduced by Eugene Guth*) (30 min.).—Heat conductivity of natural and synthetic rubbers was studied in the range from $+50°$ to $-160°C$. and from 0 to 100 percent stretch for two different cures and ages. The apparatus was a greatly modified version of one designed by Schallamach. Both for natural and synthetic rubbers, the value of the heat conductivity measured perpendicular to the direction of stretch was smaller and the rate of change of conductivity larger in the stretched than in the unstretched state. On lowering the temperature and raising it again natural rubber shows very complicated hysteresis phenomena due to progressing or regressing crystallization. Synthetic rubber shows a simpler behavior exhibiting a hysteresis loop caused by the transition of second-order from elastic to brittle, glassy material. The hysteresis phenomena for both types of rubber show great similarity (in particular in thermal conductivity near th brittle point) to the drop in specific heat observed by Bekkedahl and associates. The effect of cure and the effect of aging depends on the position of the temperature with regard to the transition temperature. Above and below the transition region, the heat conductivity decreases approximately linearly with temperature as one may expect from theory. Theoretical approaches to heat conductivity of polymers will be discussed briefly. Financial support by the National Research Council of Canada is gratefully acknowledged.

N5. Relaxation of Stress in Plastic Materials. M. MOCHULSKY, R. D. ANDREWS, AND A. V. TOBOLSKY, *Princeton University* (30 min.).—Studies of relaxation of stress at constant extension over a wide range of temperatures were extended from rubbery to plastic materials. These studies were interpreted in terms of such variables as molecular weight, cross linkage, chain stiffness, crystallinity, and interchain interaction. The effect of plasticizer was also investigated. Decay of stress due to chemical scission was observed in at least one linear thermoplastic.

P1. Six Rules for Analyzing Stress-Strain Curves. GEORGE HALSEY, *Textile Research Institute* (30 min.).—In the analysis of the stress-strain properties of a material there is a certain advantage to the making of haphazard stress-strain curves following no particular pattern. As more painstaking analyses are attempted and as the model is refined, this procedure becomes very wasteful. The writer has attempted to improve the situation by setting up a series of six rules for the analysis of the stress-strain curves. In the present paper the general distribution of non-Newtonian relaxation times is included in the scheme of analysis. Also, the existence of multiple equilibrium positions at the same value of the flow coordinate is discussed. The paper is organized into six rules of procedure, each containing a simplifying criterion. If all six criteria are obeyed, then the material under study is representable by a hyperbolic sine-law model. The six rules suggest an orderly mode of experiment.

P2. Studies of Cellulose Acetate with the Ultracentrifuge. S. SINGER AND H. MARK, *Polytechnic Institute of Brooklyn* (30 min.).—Measurements on a series of fractions of cellulose acetate in acetone have been performed with the velocity ultracentrifuge combined with free diffusion experiments. The molecular weights, M, of these fractions varied from 10,000 to 200,000, and in this range the sedimentation constant s varied considerably with M. In a system where s is independent of M, the particles may be considered "free-draining," that is, solvent freely penetrates the molecule. For particles that are impermeable to solvent and are randomly coiled, s is proportional to $M^{\frac{1}{2}}$. Our results indicate that the cellulose acetates are intermediate between these two cases. Moreover, on the assumption that the molecules may be satisfactorily represented by ellipsoids of revolution, axis ratios are calculated from sedimentation data and viscosity data independently, by Perrin's and Simha's equations respectively. The axis ratios so calculated differ by factors outside of experimental error, and indicate that the model is not a quantitative one for cellulose acetate in acetone.

P3. An Instrument for Measuring Particle Diameters and Constructing Histograms from Electron Micrographs. E. E. HANSON AND J. H. DANIEL, *Firestone Tire and Rubber Company* (30 min.).—An instrument for shortening the time and labor required in constructing particle size histograms from electron micrographs is described. Representative histograms obtained with the instrument for GR-S latices are shown. Linear, surface, and volume-equivalent diameters of non-spherical particles are defined, and variations in the instrument for plotting such diameters are proposed.

P4. A Sound Velocity Method for Determination of Molecular Weight of Liquid Polymers. ALFRED WEISSLER, J. W. FITZGERALD, AND IRVING RESNICK, *Naval Research Laboratory*.—The molecular sound velocity $R = Mv^{\frac{1}{3}}/d$ (where M is molecular weight, d is density, and v is sound velocity in the liquid) has been shown by Rao to be (a) a temperature-independent constant for most pure liquids; (b) an additive property of the atoms in a molecule; and (c) therefore a linear function of molecular weight in each of several homologous series. Further, in each series, linear relationships were found by Lagemann and Dunbar to exist between any two of the following properties: molecular sound velocity, molecular refraction, parachor, molecular magnetic rotation, critical volume, Souders' molecular viscosity, and van der Waals b. Of these, the first two may be determined experimentally with relative ease and accuracy, by means of the acoustic interferometer using a frequency of one megacycle and the Abbe refractometer. These relations were utilized in the present work to give an expression for molecular weight:

$$M = \frac{Bd}{v^{\frac{1}{3}} - A\left(\dfrac{n^2-1}{n^2+2}\right)}.$$

This expression has yielded accurate results for the molecular weights of several pure members and commercial mixtures of the polyethylene glycol series. Comparisons are made between these results and the number average and weight average molecular weights. Excellent agreement was also observed for the calculated and experimental values of the slope A and for the calculated and observed values of the molecular sound velocities of these compounds.

P5. Diffraction of Visible Radiation by Cellulose Acetate Yarn. EMMETT MARTIN, *Tennessee Eastman Corporation*.—Filaments of cellulose acetate yarn have been found, under certain conditions at least, to have the property of diffracting visible radiation. The yarns in which this phenomenon has been observed were drafted at elevated temperatures to from 2 to 5 times their original length. When these yarns, either single or multiple filaments, are immersed in a colorless liquid having an index of refraction close to that of the yarn, and illuminated with approximately parallel white light incident on the fibers normal to their long axis, the fibers will appear to be colored when viewed at various angles from points in the plane containing both the fibers and the incident beam of light. The color at a particular angle is determined from the grating formula $\eta\lambda = d\sin\theta$, and does not depend upon the index of refraction of the immersion medium, except that the index of the medium should be near that of the fibers to reduce the white light scattering enough to make the colors visible. The distance apart of the diffracting centers, d, is directly proportional to draft factor, and varies from about 0.2 micron for undrafted fibers to approximately 1 micron for those drafted by a factor of 5.

Q1. Some Dielectric Properties of Butadiene-containing Polymers and Copolymers. R. F. BOYER, E. B. BAKER, AND P. C. WOODLAND, *Dow Chemical Company* (30 min.).—A study of the dielectric properties of mixtures of polystyrene and polybutadiene revealed a peak in the power factor-frequency curve at 100 megacycles. This peak was first ascribed to vinyl side groups, but it was then found that purified, natural rubber also showed a peak of about the same magnitude and at the same frequency. Consideration was next given to the idea that a long chain of conjugated double bonds is a perfect electrical conductor.[1] It was thought that a regular distribution of double bonds, as along a chain of polyisoprene, might cause dielectric dispersion when the transit time of electrons along the polymer chain was equal to the frequency of the applied field. Dispersions of carbon black in polyethylene were made to simulate roughly the proposed mechanism of dielectric loss. Such systems showed both a low frequency as well as a high frequency power factor peak. Both peaks depended in magnitude on the orientation of the carbon black particles with respect to the electric field being smaller when the long axis of the particle was perpendicular to the field.

[1] F. London, *Surface Chemistry* (American Assoc. for the Advancement of Science, Washington, D. C., 1943), p. 144.

Q2. Dielectric Properties of Rubber—Particularly of Loaded Stock. L. V. HOLROYD, B. A. MROWCA, AND EUGENE GUTH, *University of Notre Dame* (30 min.).—Dielectric constants and losses were measured in the range from 0–200 mc. In general, dielectric constants decrease with increasing frequency, with a drop corresponding to the peak in the loss-frequency curve. The peaks observed in the loss-frequency curve at low frequencies may be interpreted as caused by oxidation and to fillers, at high frequencies as caused by dipoles caused by the bonding of sulphur in vulcanization. Changes of dielectric constants and of losses, in particular shifts in peaks with temperature in the range from 0–70°C were also studied. Dielectric constants of rubber-carbon black mixtures from 0–25 percent volume concentration were observed and compared with theory of spherical particles indicated by Guth.[1] An extension of this theory to ellipsoids was also used in the interpretation of the data. Infinite conductivity of carbon black as compared to that of rubber was assumed. Results may be interpreted by assuming that carbon black particles preferentially form doublets. This result on doublets is also indicated in data kindly communicated to us by Dr. Breckenridge in von Hippel's laboratory (M.I.T.). Financial support by ONR, Navy Department, is gratefully acknowledged.

[1] J. App. Phys. (1944).

Q3. Frequency Response Characteristics of Dielectric Materials and Their Interpretation. A. VON HIPPEL, H. B. CALLEN AND W. B. WESTPHAL, *Massachusetts Institute of*

Technology (45 min.).—The paper presents dielectric constant and loss characteristics of gases, liquids, and solids measured over a broad frequency range and considers their interpretation in terms of molecular physics.

Q4. The Electrical Resistivity of Conducting Rubber. PAUL E. WACK, *University of Notre Dame* (30 min.).—The electrical resistivity of Gr-S loaded with Shawinigan and Continental R-40 carbon blacks was determined as a function of temperature, elongation, time, and percentage volume leading. The resistivity of Gr-S–Shawinigan mixes first increases with elongation, and then decreases, the peak occurring between 10 and 20 percent, but the resistivity of Gr-S–R-40 mixes increases for all elongations. The resistivity of all stretched samples decreased exponentially with time. The resistivity-temperature curves exhibited hysteresis loops for samples stretched to low elongations or for samples of low volume loadings, but did not show loops for samples stretched to high elongations or highly loaded. A plot of log-conductivity versus $1/T$ yielded straight lines. The temperature coefficient of resistivity for unstretched samples loaded with Shawinigan black is positive for all loadings investigated, and increases with loading. Both Shawinigan and R-40 blacks have a negative temperature coefficient of resistivity. Both positive and negative temperature coefficients were observed for unstretched samples loaded with R-40, the coefficient being negative for low loadings and positive for higher loadings. Log-resistivity versus carbon concentration yielded an exponentially decreasing curve and log-resistivity *vs.* log-concentration an approximately linear relationship. Interpretation of data will be discussed. Financial support of ONR, Navy Department, is gratefully acknowledged.

Q5. Measurements of the Refractive Index of Films. FRED W. BILLMEYER, JR., *E. I. duPont de Nemours and Company* (30 min.).—The refractive index of a film of transparent or translucent material may be determined by immersing the film in a suitable liquid mixture and observing the intensity of light reflected from the surface of the specimen. The composition of the immersion liquid is varied, and a record is made of its refractive index (measured on a refractometer) and of the reflected light intensity. The refractive index of the film is the same as that of the immersion liquid giving the lowest reflected intensity. This has been confirmed by experiments with a glass plate, whose refractive index was known. According to Fresnel's laws of reflection, the experimental data should fit a parabola with its minimum at the refractive index of the film. On fitting the data by the method of least squares, the minimum is obtained with a standard deviation of the order of 0.002 refractive index units. The method has been applied to several plastic materials.