Proceedings of the American Physical Society

Minutes of the 1948 Annual Meeting at New York, January 26–29, 1949

THE biggest meeting in the history of the American Physical Society, being the 288th of the series and the 1948 Annual Meeting, is now a thing of the past. It was held in the buildings of Columbia University, New York City, on January 26th, 27th, 28th, and 29th, 1949. Measured by number of papers it was larger by about forty percent than our previous record meeting (Washington, 1948) and it was more than twice as large as the corresponding meeting two years earlier. Measured by registration (an unknowable fraction of which is to be credited to the AAPT) it was no bigger than the corresponding meeting of one year ago; but this suggests to the Secretary that 1900 may be an asymptotic value which registration cannot surpass, because the registration desk becomes too difficult of access. We were forced to have six sessions at a time, while the AAPT furnished a seventh. This meeting may have been the last at which the halls of Columbia University will have sufficed for us; these we still hope to be able to use, but some of the sessions of the Divisions or even of the Society may have to seek quarters afield. The housing and servicing of this vast meeting was most ably handled by the Local Committee, headed by W. W. Havens and comprising Alfred Mann, John Nafe, and Albert Prodell; lantern operators were provided by other institutions of the metropolitan area.

The Retiring Presidential Address of J. R. Oppenheimer, under the title "Fields and Quanta," was heard by an audience entirely filling McMillin Theatre. The after-dinner speeches of 27 January, in the Grand Ballroom of the Hotel New Yorker, were heard by four hundred and twenty-five who attended the banquet. These were "Freedom *versus* Security in the Modern World" by Robert E. Cushman, Goldwin Smith Professor of Government in Cornell University; and "Sentimental Democracy and the Forgotten Physicist" (the title was deplorably distorted in the Bulletin) by P. W. Bridgman, Hollis Professor of Natural Philosophy in Harvard University.

Invited papers on the general programme were good but few, because the plans of the Divisions and the apprehension of a huge number of ten-minute papers deterred us from asking for many. They are listed hereinafter. The Division of Electron Physics and the Division of Fluid Dynamics each arranged two half-day sessions of invited papers, the Division of High-Polymer Physics no fewer than five. The titles of the invited papers of the first two Divisions are listed underneath; the papers of the Division of High-Polymer Physics are included among the contributed papers, because they were provided with abstracts (the Council ruled on 28 January that abstracts of invited papers shall not be printed hereafter). There were no fewer than 247 contributed ten-minute papers (and 35 invited papers of the Division of High-Polymer Physics), of which the abstracts are printed hereinafter. The total number of papers at this meeting was 308.

New Officers. At the Business Meeting of the Society, which was held on 29 January, the Tellers announced the election of the following candidates to office: *President*, F. W. Loomis; *Vice-President*, I. I. Rabi; *Secretary*, K. K. Darrow; *Treasurer*, G. B. Pegram; *Members of the Council* (four-year terms), L. W. Alvarez and V. F. Weiskopf; *Members of the Board of Editors* (three-year terms), John Bardeen, R. G. Herb, and W. E. Lamb, Jr. All took office at the end of this Annual Meeting.

Advent of the inevitable. At the Council meeting, which was held on 28 January, the Councillors confronted a sombre financial situation which is certain to entail the disappearance during 1949 of nearly half of the accumulated surplus of the Society. Be it emphatically stated that this situation is due to the hugeness of the *Physical Review*, which, when account is taken of the sharp increase in unit printing costs, forebodes a deficit far larger than the positive margin of income over all of the other expenditures of the Society (which also have increased in this era of the "fifty-cent dollar"). This does not mean that our members are publishing more pages *per capita* than they used to; the quotient *pages/members* is less at present than it was before the war, but this is not a consoling thought, as we suspect that the quotient is destined to rise to the former figure. Certain steps to mitigate the deficit could be taken by the Council of its own authority, and accordingly the subscription rate of *Physical Review* to non-members will be lifted and the page charge also. The major remedy, however, needed action by the Society assembled in its Business Meeting, for the

amount of the dues is stipulated in the By-Laws. The Council recommended that the dues for Members be increased to $15 and the dues for Fellows to $20, these new rates to enter into force for 1950. The Business Meeting made the requisite Amendment to the By-Laws without one dissenting vote. The Council felt obliged to say that it makes no guarantee that the new scale of dues will be sufficient; it hopes for the best.

Also from motives of economy the Council decided that the *abstracts of contributed (ten-minute) papers presented at the meetings are no longer to be published in the Physical Review.* This change in policy will not affect the abstracts of the first three meetings of 1949 (those at New York, Berkeley, and Cleveland); whether or not it will affect the Washington abstracts has not been decided. Abstracts of *invited* papers are no longer to be published in the Bulletin or elsewhere.

Other amendments to the By-Laws. At the request of the Council, the Society at its Business Meeting authorized two other changes in the By-Laws. One of these pertains to the entry of newly elected candidates into the privileges of membership in the Society; a candidate whose dues are received at the office of the Society before the first of August of the year of his election will receive his journals from the first of January of that year, but a candidate whose dues are received later on in the year will not receive his journals until the following year. The other enables a member to enter upon the Retired List before attaining the formerly stipulated age of 65 years, if he is forced to retire through disability, or if the retirement age for his position is less than 65. The new texts of the amended By-Laws are printed hereinafter.

The Council further nominated J. R. Oppenheimer and G. B. Pegram to three-year terms on the Governing Board of the American Institute of Physics, and appointed to the 1949 Nominating Committee (which will propose candidates to office in the Society for terms beginning in 1950) J. R. Oppenheimer (Chairman), Walker Bleakney, R. M. Bozorth, P. W. Bridgman, J. W. Liska, W. B. Nottingham, V. Rojansky, J. T. Tate, and M. A. Tuve.

According to reports reaching the office of the Society, we have lost these members through death: E. Baecklin (Upsala), E. F. Burton (Toronto), R. J. Dery (Bureau of Mines), R. L. Jones (Bell Telephone Laboratories), A. H. Pfund (Johns Hopkins), Fernando Sanford (Stanford), A. K. Stauffacher (South Carolina), R. C. Tolman (California Institute of Technology), H. J. Van der Bijl (Johannesburg), and Edna Meacham (Mrs. Lars A. Welo, New Orleans).

The Council elected 328 candidates to Membership and 20 to Fellowship; their names are appended.

Alterations in Its By-Laws Adopted by the American Physical Society in January, 1949

Article I, Section I of the By-Laws is amended to read as follows: (In its new form it takes effect on the dues for 1950 and subsequent years.)

The annual dues of Fellows shall be twenty dollars and of Members fifteen dollars, payable on the first of January.

Article I, Section 2 of the By-Laws is amended to read as follows: (In its new form it is applicable to all candidates elected to membership in 1949 and thenceforward.)

The membership of a newly elected Fellow or Member, with respect to membership subscriptions and reduced-rate subscriptions, shall commence on the first of January of the year of his election if his annual dues are received before August first of that year, and shall commence on the first of January of the year following his election if his annual dues are received after July thirty-first of the year of his election.

The first sentence of Article I, Section 3 of the By-Laws is amended to read as follows:

A Member or Fellow who has retired from his position either because of disability or because of having reached the age limit for that position, and who has been a member of the Society not less than ten years, may upon his request to the Council be placed upon a Retired List and exempted from the payment of regular dues.

Elected to Fellowship: G. D. Adams, R. A. Becker, H. A. Boorse, Sergio de Benedetti, R. B. Duffield, G. H. Fett, H. M. Foley, Gertrude S. Goldhaber, Felix Gutmann, R. D. Hill, H. W. Koch, J. S. Laughlin, K. S. Pitzer, C. S. Robinson, Jr., M. E. Rose, R. G. Sachs, A. L. Samuel, L. S. Skaggs, C. H. Townes, H. Yukawa.

Elected to Membership: Sol Aisenberg, James R. Allen, Pennaraju Ammiraju, Roy S. Anderson, Martin Annis, P. Edward Argyle, Ingemar B. Artholdsson, Robert H. Asendorf, Winston C. Backstrand, Edward J. Bair, David K. Baker, Ephraim Banks, Norman E. Barnett, Gordon M. Barrow, Andrew A. Batza, George B. Beard, Olof Beckman, Charles O. Beckmann, Robert E. Bell, William R. Bennett, Mortimer Bercovitch, Jay M. Berger, Seth Berglund, Allan Bergstedt, Seymour Berler, Isadore B. Berlman, Richard Bersohn, Lawrence R. Bickford, Jr. James N. Bierly, George Birnbaum, Robert U. Blaser, Erik Blomgren, Thomas E. Bortner, Clarence H. Bower, Charles H. Braden, Harold I. Breidenbach, Jr., Gosta Brogren, James R. Brown, Henry Brysk, Layton E. Butts, John R. Cameron, Lowell F. Cardenas, James E. Carothers, LaRoy N. Castor, Jr., Giulie Certini, Jack Charnick, Warren B. Cheston, Richard S. Claassen, Donald L. Clark, Malcolm A. Clark, A. G. Clavier, Donald F. Clifton, Richard T. Cook, Thomas B. Cook, Jr., Robert E. Cote, Arthur F. R. Cotton, Mason C. Cox, Donald S. Craig, Franklyn G. Creese, Martin R. Dachs, Harry M. Daggett, Jr., John M. Danskin, Benjamin B. Dayton, Georges A. Deschamps, Louis E. Diamond, Francis J. Donahoe, George J. Doyle, Allen H. Drayner, Charles A. Duboc,

George E. Duvall, Raymond D. Ellison, Trudy B. Enzer, Joyce Epstein, Adolf Eriksson, Ralph A. Evans, Irving Feister, Gaetano Ferlazzo, Maurice C. Ferre, Paulo L. Ferreira, Bruno G. Ferretti, Edward L. Fireman, George Fischer, Frederick C. Flack, Grant R. Fowles, Karl G. Friskopp, Per Olof Froman, Stanley C. Fultz, Roger E. Gaumer, Hervey P. Gauvin, Robert B. Gibney, Irwin Ginsburgh, Jonathan I. Gittleman, Michael J. Glaubman, Lettie Ann Glover, Robert H. Goeckermann, David E. Goldman, Jack S. Goldstein, Martin R. Goodman, Harry E. Gove, H. Graenicher, George W. Griffing, Edward G. Grimsal, William Gross, George M. Grover, Fricis Gulbis, Eugene V. Haake, Emory E. Hackman, Hans Hakansson, Kenyon C. Hammack, Preston C. Hammer, Lennart Hansson, James G. Harlow, Howard Haselkorn, Henrietta S. Hayden, Frank W. Hayward, Kenneth W. Hedberg, Clifford V. Heer, Luise Herzberg, John S. Hickman, Richard S. Hill, Wallace A. Hilton, Norton M. Hintz, Morris Hodara, Mark E. Hoehne, Josef A. Hofmann, Norman R. S. Hollie, David K. Holmes, Wayne B. Holmes, Gunnar Holte, William F. Hornyak, Jerome J. Howland, Jr., Richard H. Hughes, Leo F. Ingram, Abraham D. Isaacs, Edward Jamgochian, Alfred C. Jason, Carson D. Jeffries, Georg Joos, David L. Judd, Nathan Kaplan, Henry B. Karplus, Frederick Kaufman, George R. Keepin, Jr., Bruce A. Kenyon, John O. Kessler, Richard W. King, Bernard B. Kinsey, Abraham Klein, Robert H. Kraichnan, Marvin E. Krasnow, John Kronsbein, John R. Lamarsh, James E. Lamport, George J. Laurent, Richard B. Lawrance, Robert S. Ledley, Charles A. Lee, Ernest H. Lehmann, W. J. Leivo, Robert M. LeLacheur, Sven Lennander, Abraham Liboff, David S. Lieberman, Alan B. Lillie, Paul H. Lindenmeyer, William N. Lipscomb, Salomon E. Liverhant, Torbjorn Ljunggren, Charles C. Loomis, Everett W. Lothrop, Jr., Per-Olov Lowdin, John E. Mack, John S. Malik, David E. Mann, Dillon Mapother, Alma Marcus, Grace Marmor, William M. Martin, Claude Marty, Hasse Mattsson, John M. Mays, Earl W. McDaniel, James A. McFadden, James A. McLennan, Jr., David B. Medved, Marion L. Meeks, Meir Menes, Eugen Merzbacher, De Forrest Metcalf, Jr., Max Metlay, Donald I. Meyer, Hans A. Meyer, Roy Middleton, Charles E. Miller, Charles W. Miller, Solomon L. Miller, Dale El Nielsen, Waldo J. Nielsen, Ake Nilsson, Hla Nyunt, D. G. O'Connor, Hugh Odishaw, Elmer L. Offenbacher, Sophie Oleksa, Richard K. Osborn, Kenneth J. Palmer, Charles H. Papas, Bartholow Park, Jonathan Parsons, Wade S. Paxton, Edgar A. Pearlstein, Rudolph E. Peierls, Erik M. Pell, Jerome K. Percus, Roman C. Pergiel, Axel H. Peterson, Chester Peterson, Murray G. Phillips, David Pines, William A. Pliskin, Benjamin Post, R. Potier, Sheila C. Power, R. W. Pringle, A. Proca, Thomas E. Putnam, Italo F. Quercia, Pierre Radvanyi, Edward M. Reilley III, Walter Reininger, Erling S. Reque, Carl Reutersward, Carl H. Reynolds III, Avril Rhys, John M. Richardson, Robert J. Riddell, Jr., Ira C. Roberts, Berol L. Robinson, Robert H. Rohrer, H. W. Rollmann, Bruce Rosenblum, Herbert B. Rosenstock, John S. Ross, Aubey Rotenberg, I. Warren Ruderman, R. E. Rundle, George S. Rushbrooke, James R. P. Sackinger, Paul L. Sagalyn, Arne Sandstrom, Wayne M. Sandstrom, Pierre Savel, Charles H. Schauer, Milton D. Scheer, Ralph Schiller, Harold W. Schmitt, Herman F. Schulz, George Schwachheim, John M. C. Scott, Russell B. Scott, Ross E. Scroggs, Jr., Arch C. Scurlock, Louis Shapiro, Raymond K. Sheline, Robert E. Sheriff, Kalman Shure, Anthony A. Silvidi, Edward E. Simmons, Jr., Merrill Skolnik, Richard E. Slattery, Rudolf E. Slovacek, Daniel Smith, Lloyd Smith, James T. Smith, Welborn H. Smith, William A. Snyder, Leland T. Sogn, Harold E. Soisson, Anson D. Solem, Benjamin F. Spencer, Claude K. Stambaugh, Malcolm L. Stitch, Walter C. Stolov, John P. Strange, Robert Stump, Francis Suzor, Per Svenonius, Charles J. Swift, Chen-To Tai, Champ B. Tanner, Gerald E. Tauber, Jack H. Taylor, Robert C. Taylor, Thomas T. Taylor, Henry C. Thomas, Charles R. Tieman, Donald E. Tilley, Jayme Tiomno, Alvin V. Tollestrup, Richard H. Tourin, Helge Tyren, Ervin R. Van Artsdalen, Pieter J. van Heerden, Albert W. Van Horn, J. S. van Wieringen, Lawrence J. Varnerin, Jr., E. H. Vestine, J. B. Wachtman, Jr., Lloyd W. Walter, Jr., Lynn A. K. Watt, Henry M. Watts, Herbert G. Webb, Hyman Weinshanker, Philip R. Westlake, John C. Wheatley, Gilbert V. Wheeler, James A. Whitney, Benjamin Widom, Charles W. Williams, Kenneth R. Williams, Alfred B. Willoughby, Pat M. Windham, Henry Wise, Wilbur H. Wright, Andrew S. Yeiser, Serge J. Zaroodny, Joseph Zelle, Edward J. Zimmerman.

KARL K. DARROW, *Secretary*
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Invited Papers on the General Programme

Interaction between waves and electrons traveling together. L. BRILLOUIN, *Harvard University.*

A general treatment of methods for the production of polarized neutrons. MORTON HAMMERMESH, *Argonne National Laboratory.*

Kinetics of nucleation applied to solid-state problems. J. H. HOLLOMON, *General Electric Company.*

Special properties of active isotopes identified by the mass spectrometer. MARK INGHRAM, *Argonne National Laboratory.*

The elasticity of soft body tissues. A. L. KING AND R. W. LAWTON, *Dartmouth College.*

Some current misconceptions of N. L. Sadi Carnot's memoir and cycle. V. K. LAMER, *Columbia University.*

π-μ-meson-distinction with G-M counters. ORESTE PICCIONI, *Brookhaven National Laboratory.*

The early work of Willard Gibbs. L. P. WHEELER (*retired from Yale University*).

Models and methods in the meson theory. H. YUKAWA, *Institute for Advanced Study.*

Symposium of the Division of Electron Physics

Electronic storage of information. L. E. FLORY, *RCA Laboratories.*

Thermionic emission from oxide cathodes: retarding and accelerating fields. C. S. HUNG, *Purdue University.*

High current-density electron beams. R. G. E. HUTTER AND S. W. HARRISON, *Sylvania Electric Products Company.*

Initiation and maintenance fields of a microwave discharge. S. KRASIK, D. ALPERT, AND A. O. MCCOUBREY, *Westinghouse Electric Corporation.*

Polymorphism and anion rotational disorder in alkaline earth carbonates. J. J. LANDER, *Bell Telephone Laboratories.*

Electron affinities from equilibrium measurements. J. E. MAYER, *University of Chicago.*

A broad-band oscilloscope tube. J. R. PIERCE, *Bell Telephone Laboratories.*

Electronic theory of the transistor. W. SHOCKLEY, *Bell Telephone Laboratories.*

Preparation and electrical conductivity of barium oxide crystals. R. L. SPROULL, *Cornell University.*

Symposium on Turbulence (Division of Fluid Dynamics)

Some measurements in a round turbulent jet. STANLEY CORRSIN, *Johns Hopkins University.*

Statistical analysis of random functions. MARK KAC, *Cornell University.*

Statistical theory of isotropic turbulence. T. VON KÁRMÁN, *California Institute of Technology*, and C. C. LIN, *M.I.T.*

Optical methods of measuring turbulence. L. S. G. KOVASZNAY, *Johns Hopkins University.*

Turbulence in the atmosphere of stars. MARTIN SCHWARZSCHILD, *Princeton University.*

Combustion-generated turbulence in relation to flame propagation. G. C. WILLIAMS, *M.I.T.*

Non-Metallic Crystals

BA1. On the Structure of Ammonium Halides and the Nature of the λ-Point Transition. E. L. WAGNER AND D. F. HORNIG, *Brown University.*—The infra-red spectra of thin films of ammonium and deutero-ammonium halides were studied at 28°C, −78°C, and −190°C. The spectra of the low temperature modification of the chlorides and bromides are compatible with structures in which the space groups are T_d^1 and D_{4h}^7, respectively. The corresponding ion symmetries are T_d and V_d. These are the simplest models consistent with the reported x-ray, optical, and piezoelectric properties of the compounds. The −190°C spectrum of ND_4Br shows a loss of symmetry consistent with a reported phase change at −100°C. Simple selection rules appear to be obeyed. Neither chloride nor bromide show the reported rotational structure in the 5.6μ-band. Instead there is strong evidence that at least in the chloride this band is an allowed combination involving the torsional vibration of the ammonium ion in the lattice, occurring at 390 cm^{-1} and 280 cm^{-1} in the chlorides. The situation in the bromides is more complicated. Since this peak also occurs at room temperature there can be no rotation above the λ-point. The λ-point transition appears to be a simple order-disorder transition. The double maximum in the 3μ-region is probably due to Fermi resonance.

BA2. Low Frequency Dispersion in Ionic Crystals Containing Foreign Ions.* R. G. BRECKENRIDGE, *Massachusetts Institute of Technology.*—The new dielectric absorption recently found in simple ionic crystals at low frequencies[1] has been studied in alkali halides containing foreign ions. The results obtained shed considerable light on the nature of the phenomenon in the pure crystals and, in addition, indicate that it is possible to study the diffusion of foreign ions in ionic crystals by this method. Measurements on sodium chloride containing a divalent impurity ion suggest that the anomalous effect is due to paired vacancies since no absorption is observed if the crystal is not heat-treated to introduce negative ion vacancies in addition to the positive ion vacancies produced by the foreign ion. After heat treatment, however, three anomalous response regions are found. One of these corresponds to that found in the pure crystal; another is tentatively assigned to the motion of the foreign ion, and from it the activation energy for the ionic motion may be found; and the third is attributed to the motion of a sodium ion in the vicinity of an impurity ion.

* This work was supported jointly by the Navy Department (Office of Naval Research), the Army Signal Corps, and the Army Air Forces (Air Matériel Command).

[1] R. G. Breckenridge, J. Chem. Phys. **16**, 959 (1948).

BA3. Electric Breakdown in Ionic Crystals.* H. B. CALLEN,** *Massachusetts Institute of Technology.*—The electric breakdown strength of ionic crystals has been calculated using von Hippel's low energy breakdown criterion and Fröhlich's treatment of the interaction between the electrons and the vibrational modes. Both the absolute magnitude of the breakdown strength and the temperature coefficient (which is smaller than that obtained with Fröhlich's high energy criterion) are in good agreement with experimental values. The slow electrons, which determine the breakdown strength, are scattered only by vibrational modes of small wave number and are thus insensitive to the crystallographic directions. The fast electrons, which are mainly responsible for the production of the breakdown paths, are scattered by vibrational modes with wave vectors near the Brillouin zone boundaries, and are thus direction-sensitive. The breakdown strength is direction-independent, and the breakdown path directions are governed by the symmetry of the reciprocal lattice, as found experimentally by von Hippel and Davisson.

* This work was supported jointly by the Navy Department (Office of Naval Research), the Army Signal Corps, and the Army Air Forces (Air Matériel Command).

** Now at the Randal Morgan Laboratory of Physics, University of Pennsylvania.

BA4. Breakdown of Solid Dielectrics by Electron Avalanches.* A. VON HIPPEL AND R. S. ALGER, *Massachusetts Institute of Technology.*—In gases breakdown occurs when the avalanche produced by one primary electron regenerates with certainty the initiating carrier (Townsend condition). In ionic crystals the breakdown strength appears to be determined by the probability of exciting lattice vibrations without reference to the electron supply. The theory predicts an increase of the breakdown strength with temperature. Experimentally we found previously with d.c. an increase followed by a decrease, while Malmlöw, working with a.c., obtained no temperature effect.[1] New measurements with d.c. and a.c. confirm our previous findings. Measurements with transients of variable rise times show in addition, that the decrease is probably caused by space, charge formation. The build-up and decay of space charges and the influence of the electrodes on the breakdown strength have been investigated.

* This work was supported jointly by the Navy Department (Office of Naval Research), the Army Signal Corps, and the Air Forces (Air Matériel Command) under ONR Contract N5ori-07801.

[1] G. Malmlöw and F. Seitz, Phys. Rev. **71**, 125 (1947).

BA5. Theory of Electron Multiplication in Crystals.* FREDERICK SEITZ, *Carnegie Institute of Technology.*—The multiplication of free electrons in strong electrostatic fields is examined. This problem is related to that of dielectric breakdown if the latter problem is approached from von Hippel's viewpoint of ionization by impact. Let E_H be the electrostatic field for which an electron gains energy from the field more rapidly than it loses it in exciting lattice vibrations. The present work shows that avalanches sufficient to produce breakdown could occur at a field of about $0.2E_H$ through statistical fluctuations. The size of the average avalanche grows by 10^{12} as the field is increased by about 25 percent if the electrons ionized belong to the bulk material. It is concluded however that the avalanches observed by Haworth and Bozorth and others in the prebreakdown region are probably connected with impact ionization of impurity atoms. It is also concluded that the interaction between electrons and non-polar lattice vibrations, hitherto ignored in ionic crystals though not in nonpolar crystals, is important in polar crystals. This interaction makes von Hippel's and Fröhlich's criteria for breakdown nearly identical; however, both are too stringent.

* Contribution to a program supported by the Bureau of Ships in cooperation with the Office of Naval Research.

BA6. Measurement of the Piezoelectric Constants of Alpha- and Beta-Quartz. RICHARD K. COOK AND PEARL G. WEISSLER, *National Bureau of Standards.*—The piezoelectric constants d_{11} and d_{14} of alpha-quartz have been measured between room temperature and about 565°C. At the latter temperature, d_{11} is about $\frac{2}{3}$ of its room temperature value, whereas d_{14} has increased by a factor of approximately $2\frac{1}{2}$. At a temperature of 573°C (the inversion temperature), the crystal structure changes to that of beta-quartz, and d_{11} vanishes. The constant d_{14} for beta-quartz has been measured between about 585°C and 620°C. d_{14} appears to be substantially constant over this short range of temperature, and differs from d_{14} for alpha-quartz at 565°C by only a few percent. The piezoelectric constants were deduced from measurements of the equivalent circuits of long thin bars driven electrically at frequencies near the resonance frequency for the fundamental longitudinal mode. The bars were cut with flat faces perpendicular to the x axis, and the flat faces were gold plated and used as electrodes. The long dimensions of the bars lay in the yz plane, and made known angles with the y axis. The equivalent circuits were determined with a Q-meter technique, and the circuit constants needed for calculation of the piezoelectric constants depended only on the measurement of frequencies and of changes in capacitance.

BA7. Some Properties and X-Ray Diffraction Pattern of Some Inorganic Salts Crystallized by the Critical Temperature of Water as Solvent. ZABOJ V. HARVALIK, *University of Arkansas.*—Certain inorganic salts as sodium chloride, sodium sulfate, barium chloride, and barium nitrate have been precipitated in an autoclave at the critical temperature of water as solvent. The precipitated salts were recovered by slow expansion of the solvent (water) while the autoclave temperature was held a few degrees above the critical temperature of water.[1] X-ray diffraction patterns were made on a North American Phillips recording x-ray diffraction unit and revealed that the crystals obtained by this method are somewhat different from crystals obtained by conventional means of crystallization. Lattice calculations indicate that the salts crystallized at the critical temperature of water approach an x-ray diffraction pattern closer to the theoretical values and are without internal strain.[2] The crystals are about 3 to 5 microns in size, although larger aggregates have been observed. The crystals have been used as seeds for conventional crystallization at temperatures lower than the normal boiling point of water. Attempts have been made to obtain larger crystals at the critical temperature of water by using temperature pulsation, with and without mother liquor supply. The crystals thus obtained are larger (0.01 mm to 1.0 mm) and do not show any difference from crystals grown under conventional conditions, as far as the microscopic inspection is concerned. No x-ray diffraction patterns have been made yet.

[1] Paper presented by Z. V. Harvalik at the 112th meeting of Am. Chem. Soc., New York, 1947.
[2] J. W. Buttrey, Thesis at University of Missouri, MSM (1948).

BA8. The Vibrational Spectrum of Crystalline Benzene. R. D. MAIR AND D. F. HORNIG, *Brown University.*—The infra-red spectrum of crystalline benzene was studied at −12°C, −68°C, and −170°C and the liquid at 28°C. As predicted theoretically,[1] the lines are extremely sharp, the mean line width for fundamentals being but 7 cm^{-1} in the crystal. In three cases it is less than the spectral slit width (4.5 cm^{-1}). All out-of-plane degenerate modes are split by about 10 cm^{-1}. Selection rules agree with the x-ray structure. All ungerade fundamentals are observed directly, some for the first time. The assignments of Ingold *et al.*[2] are confirmed except for the B_{2u} species. There is strong evidence for changing ν_{15} by about 3 percent. Forty-one combination lines are observed. One of these, an extremely sharp line at 1311 cm^{-1}, appears to violate selection rules. We suggest that it is ν_{14} and that the Raman line observed at 2618 cm^{-1} is its overtone. An allowed combination with ν_8 is observed at 2907 cm^{-1}. Ingold's other data can also be satisfactorily accounted for on this basis. Combination lines involving torsional lattice modes are observed at −170°C.

[1] D. F. Hornig, J. Chem. Phys. 16, 1063 (1948).
[2] N. Herzfeld, C. K. Ingold, and H. G. Poole, J. Chem. Soc. Pt. 1, 316 (1946).

BA9. Symmetry Coordinates in Molecules and Crystals.* WILLIAM J. TAYLOR, *Ohio State University.*—In the treatment of the vibrations of a symmetrical molecule or crystal symmetry coordinates may be formed from sets of equivalent coordinates so as to reduce the point group of the molecule or the factor group of the space group of the crystal lattice. The reduced representations of a set of equivalent coordinates in the group may be found by general methods. A set of coordinates may be divided into equivalent subsets which are in one-to-one correspondence with a set of equivalent points (in the molecule or unit cell). There is a set of conjugate subgroups which leave the points invariant. The representation of the set of coordinates in the group is completely characterized by the nature of the set of points (and subgroups) and by the representation of a typical subset in the associated subgroup. Compact tables may be prepared showing the reduced representation in the group for each possible set of points and for

each representation in the associated subgroups. This is a generalization by group-theoretical methods of the work of Brester.[1]

[1] C. J. Brester, Zeits. f. Physik **24**, 324 (1924).
* This work was carried out under contract between the Office of Naval Research and The Ohio State University Research Foundation.

BA10. Structure and Growth of Evaporated LiF Films on Amorphous Substrates. L. G. SCHULZ, *University of Chicago.*—Thin films of LiF were prepared by evaporation in a vacuum and studied by means of electron diffraction, electron microscopy, x-ray diffraction, and optical methods. It was found that on an amorphous substrate deposits thinner than a few hundred angstroms showed random crystal orientation but as the thickness was increased there was a transition to a [111] orientation. The extent of this orientation both on the surface and in the interior was studied in relation to crystal growth. Electron microscope photographs of the film surfaces showed that the individual LiF crystals were cubic in shape and increased in size as the thickness of the deposit was increased. These cubic crystals had considerable vacant space between each other making the film porous in texture.

C1. Velocity and Attenuation of Sound in Butyl and Gr-S Rubbers.* R. S. WITTE, B. A. MROWCA, AND E. GUTH, *University of Notre Dame.*—Measurements were made in thin strips of rubber from 0.5 to 5 Kc and from −5° to 90°C to extend the temperature range of previous work. Above room temperature velocity and attenuation are higher in Butyl gum than in *GR-S*. In all cases the velocity increases with decreasing temperature and increasing frequency. The attenuation shows a peak with temperature. For Butyl the peaks are broad and occur at higher temperatures than for *GR-S*. For both stocks an increase in frequency gives peaks which are higher and sharper, and shifted to higher temperatures. In some instances there are indications of peaks in the attenuation at frequencies beyond our range of measurement. The behavior of the dynamic modulus in the temperature and frequency range studied is similar to that of the velocity. These results combined with low temperature static measurements and very low frequency dynamic measurements at Notre Dame indicate a U-shaped modulus-temperature curve whose minimum broadens and shifts to higher temperatures with increasing frequency. The U-shaped curve can be explained by a generalization of the kinetic theory of rubber elasticity taking into account intra- (and inter-) molecular forces, while the original theory gives only the ascending branch. The generalized kinetic theory is an analogue of the so-called Ising model used in the theory of ferromagnetism and surface adsorption.

* Supported in part by the Office of Naval Research.

C2. Velocity and Attenuation of Supersonic Waves in Natural and Synthetic Rubbers.* D. G. IVEY, B. A. MROWCA, AND E. GUTH, *University of Notre Dame.*—The propagation of supersonic waves in some bulk rubbers was studied by Nolle and Mowry[1] at 10 Mc. A similar study from 50 Kc to 10 Mc and from −50°C to 60°C was made for Hevea, *GR-S* and Butyl gum and tread stocks. Peaks in attenuation *versus* temperature were observed. These peaks shift to lower temperatures with decreasing frequency. At a given frequency the peaks in Butyl occur about 40°C higher than those in Hevea. The attenuation peaks for Butyl (a "high loss" rubber) are broader and higher than for the other ("lower loss") rubbers. For all stocks the velocity increases with frequency or decreases with temperature, levelling off at low temperatures. These results are in qualitative agreement with data obtained by the strip method at much lower frequencies. However, for bulk waves the real and imaginary parts of two elastic constants (bulk and shear moduli) determine sound velocity and attenuation. Comparison with low frequency data requires independent measurement of the shear properties as a function of frequency. In the absence of such measurements only qualitative comparisons can be made. These measurements extend the frequency range studied by the strip method (cf. preceding abstract) over several decades, and thus give a qualitative knowledge of the relaxation spectrum over a wide range. The interpretation of the preceding abstract also holds for this extended range.

* Supported in part by the Office of Naval Research.
[1] A. W. Nolle and S. C. Mowry, J. Acous. Soc. Am. **20**, 432 (1948).

C3. Rigidities of Polyisobutylene and Polyvinyl Acetate Solutions from Wave Propagation Measurements. JOHN D. FERRY, J. N. ASHWORTH, AND W. M. SAWYER, *University of Wisconsin.*—Although concentrated solutions of linear high polymers behave as viscous liquids in steady flow, they support transverse waves at audio frequencies. The wave propagation is characterized by the wave shear modulus, $\bar{G}$, and the damping index, λ/x_0. In polyisobutylene solutions, $\bar{G}$ increases only slightly with frequency, is independent of temperature at constant volume concentration (c), is proportional to c^3, and depends comparatively little on the choice of solvent. In polyvinyl acetate solutions, $\bar{G}$ increases considerably with frequency, falls off with increasing temperature, is proportional to c^3, and is markedly different in different solvents. The results are interpreted in terms of a transient network structure formed by random entanglements of the long chain molecules.

C4. Dynamic Mechanical Properties of Some High Polymers. R. BUCHDAHL, L. E. NIELSEN, AND RITA LEVREAULT, *Monsanto Chemical Company.*—The dynamic elastic modulus and mechanical dissipation factor for a series of high polymers have been determined as a function of temperature. Data were obtained by different methods: (a) electromagnetic vibrators, (b) torsion pendulum, and (c) rotating cantilever beams. The frequency of applied stress varied from 0.04 to 100 cycles per second. Among the materials investigated were polystyrene, polyvinyl chloride, and cellulose acetate. Most of the materials are characterized by a transition over a limited temperature range in which the modulus changes rapidly with temperature and the dissipation factor goes through a maximum. This transition is slightly frequency dependent. The results of the dynamic tests are compared with other mechanical properties of the materials studied. Some discussion of the mechanisms of deformation and damping is given for high polymers.

C5. Acoustic Measurements of Polymer Physical Properties. J. W. BALLOU AND J. C. SMITH, *E. I. du Pont de Nemours & Co.*—Acoustic methods for measuring the elastic and dissipative properties of high polymers in fiber

and film form over four decades of frequency (3 to 30,000 cycles per second) are described. The experimental quantities resulting from the three different techniques necessary to cover this range are shown to be related, and are unified by deriving in each case the parameters of an equivalent Voigt Model (elastic and viscous element in parallel) which would behave in the same way as the polymer sample. Examples of the application of these techniques to the characterization of high polymers are given. The effect of frequency and chemical and physical structure on the derived parameters are discussed, along with the question of heat losses resulting from cyclical differential deformation. In addition, the application of two of the methods to the characterization of the stiffness-temperature behavior of high polymers is described.

C6. Measurement of the Mechanical Properties of Polymer Liquids by Ultrasonic Methods. W. P. MASON, W. O. BAKER, H. J. MCSKIMIN, AND J. H. HEISS, *Bell Telephone Laboratories.*—In order to investigate the molecular processes which determine the mechanical behavior of high polymer liquids, longitudinal and shear wave ultrasonic measurements have been made for polyisobutylene liquids for a variety of temperature, chain length and frequency conditions. To aid in these measurements two new shear wave techniques have been developed. These are the torsional crystal method and the balanced shear wave-reflection method. The torsional crystal method has demonstrated the presence of shear elasticity of the quasi-configurational type in the medium frequency range, whereas the balanced shear wave-reflection method has shown the presence of high shear stiffness of the crystalline type at high megacycle frequencies. These measurements have been correlated with longitudinal wave measurements which show a velocity and attenuation dispersion in the high megacycle range and the cause of the dispersion has been shown to be due to the appearance of crystalline shear elasticity at the high frequencies. The measurements have been correlated by a mechanical and potential well model. To completely account for all the longitudinal loss, a compressional viscosity, an appreciable fraction of the second shear viscosity, has to be postulated.

C7. Elastic Losses of Elastomers at Ultrasonic Frequencies.* H. S. SACK AND R. W. ALDRICH, *Cornell University.*—The elastic losses in the frequency range of 0.5 to 6 Mc were determined by measuring the absorption of plane ultrasonic waves in sheets of the material of different thicknesses. In order to avoid the difficulties caused by standing waves, frequency modulated waves were used. The results were checked in some cases by using a pulsed ultrasonic beam. All the measurements were made with the samples immersed in water. The samples studied were natural rubber, butadiene-styrene copolymers of different concentration (85–15, to 60–40), without and with carbon black (gum stock and tread stock). In general, the absorption (per wave-length) increases with increasing frequency, but the increase is less rapid at higher frequencies. The loaded samples have a higher absorption. As in the low frequency range, the losses in the copolymers increase with increasing styrene content and with decreasing temperature (1°C–50°C). The curve shapes can be explained by relaxation phenomena with one or two relaxation times of the order of 10^{-7} seconds. For a more quantitative interpretation measurements at higher frequencies are desirable.

* This research has been supported by the Office of Naval Research.

C8. Creep and Damping Properties of Polystyrene. JOHN A. SAUER AND JOSEPH MARIN, *Pennsylvania State College.*—Creep-time measurements are made on polystyrene specimens for various values of stress. The data are given for specimens subject to tension loading, torsion loading and also pure bending. Analysis of the data indicates that the log of the creep rate is proportional to the log of the stress amplitude, and that the torsion and bending creep properties can be approximately estimated from the creep properties in tension. The damping properties of polystyrene under alternating tension-compression loading have been determined by use of a resonant method. The results indicate that the damping capacity varies approximately as the stress to the 2.4 power. Tests made on other high polymers, including both thermoplastic and thermosetting materials, show a similar dependence of damping capacity on stress amplitude. These data are used for assessing the relative merits of plastic materials when operating at resonance.

Beta-Radioactive Substances

D1. Beta-Decay of Be^{10} and Theory of Beta-Decay. R. E. MARSHAK, *University of Rochester* —It is extremely likely that the beta-decay of Be^{10} involves a spin change of three units in view of the measurement [1] of the spin of B^{10} and the absence of a gamma-ray in the beta transition.[2] The predicted energy spectra and minimum half-lives corresponding to a spin change of three have been calculated on the basis of the five possible interactions, for both like and unlike parity. The Fermi constant is taken from the decay of He^6 which is treated as an allowed transition. It turns out that all matrix elements except four lead to minimum half-lives much too long to be reconciled with the observed half-life of three million years. The four matrix elements which are consistent with the observed half-life lead to exactly the same forbidden energy spectrum which is very different from the allowed. If preliminary measurements are confirmed (see following abstract), present theories of beta-decay will have to undergo serious modification. The effect of a correct knowledge of the neutron half-life on the above arguments will be discussed.

[1] Gordy, Ring and Burg, Phys. Rev. **74**, 1191 (1948).
[2] D. J. Hughes and C. Eggler, private communication.

D2. The Spectrum of Be^{10} by Absorption. D. J. HUGHES AND C. EGGLER, *Argonne National Laboratory.*—Marshak has shown that the interactions of beta-theory which can explain the half-life of Be^{10} all lead to a unique spectrum shape. In view of the resulting importance of the Be^{10} spectrum to beta-theory, it seems pertinent to report results which can be obtained from the Be^{10} beta-absorption curve concerning the shape (D_2) calculated by Marshak. The absorption curve method, already described briefly,[1] was designed to give an approximate spectrum shape for samples such as Be^{10} too weak for conventional beta-spectroscopy. It is based on the comparison of an accurate absorption curve of the Be^{10} betas with curves of standard substances of known spectral shape. The experimental

details of the method will be described and its validity discussed using well-known spectra as examples. The results for Be^{10} show a shape within experimental error of the allowed distribution, and in definite disagreement with Marshak's D_2 shape.

[1] D. J. Hughes and C. Eggler, Phys. Rev. **74**, 1239A (1948).

D3. Coincidences in Be^{10} Beta-Rays.* S. G. HUGHES AND W. E. STEPHENS, *University of Pennsylvania.*—Previous absorption measurements[1] of the radiations from Be^{10} [2] had indicated a tail on the beta-ray spectrum suggesting either internal bremsstrahlung or gamma-rays. To clear this up, coincidences have been looked for and observed with a pair of thin wall Geiger counters and a coincidence circuit of resolving time $5\cdot10^{-6}$ sec. An absorption curve of the coincidences indicates that one component is absorbed in about 20 mg/cm² of aluminum. This component is at least a few percent of the total beta-rays. Since a level in B^{10} has been reported[3] at 411 kev, it seems probable that the beta-ray spectrum of Be^{10} is complex, with end points at about 563 kev and 151 kev. Further measurements are under way.

* Supported in part by the joint program of the ONR and AEC, and partly by grants from Committee on Advancement of Research of the University of Pennsylvania.
[1] Stephens and Bottoms, Phys. Rev. **73**, 1269A (1948).
[2] The Be^{10} was kindly supplied by Professors A. L. Hughes and F. N. D. Kurie from Washington University.
[3] Lauritsen, Dougherty, and Rasmussen, Phys. Rev. **74**, 1566A (1948).

D4. Beta-Ray Spectra of C^{14}. L. FELDMAN AND C. S. WU.—The beta-ray spectrum of C^{14} was investigated with the use of a helical focusing magnetic spectrometer. The very high specific activity carbon 14[1] (40 atom percent of C^{14}) was made available to us in the form of $BaCO_3$ by Norris and Snell of Oak Ridge. $BaCO_3$ was made into extremely thin and uniform sources of thickness around 15μ g/cm² by utilizing an ultrasonic vibrator. Methods[2] of reducing $BaCO_3$ to elementary form of carbon were extensively investigated. The counter window used is less than 30μ g/cm². The Fermi plot of the results give a straight line from upper energy limit down to 25 kev. Below 25 kev, the Fermi plot begins to deviate slightly below the straight line, probably due to the counter window effect. The end point obtained was 155 ± 1 kev which is in good agreement with results reported from other laboratories.[3] This allowed distribution of the beta-ray spectra of C^{14} is reconcilable with the theoretical distribution for $\Delta I=1$ (yes) for both Fermi and Gamow-Teller selection rules.

[1] L. D. Norris and A. H. Snell, Bull. Am. Phys. Soc. No. 3, p. 46 (1948).
[2] I. W. Ruderman and C. S. Wu, in press.
[3] Berggren and Osborne, Bull. Am. Phys. Soc. No. 3, p. 46 (1948); Cook, Langer and Price, Jr., Phys. Rev. **74**, 548 (1948).

D5. Production of Radioactive Gases by Deuteron Bombardment of Gaseous Targets. H. BROWN AND V. PEREZ-MENDEZ.—For the investigation of the beta-decay of short half-lives (less than 2 min.), a probe through which gases may be circulated has been constructed for use with the 36-in. cyclotron. The gases were bombarded through a thin window in the probe, using modulated beams of average intensity up to 15 μa. These gases were then pumped to a disintegration chamber, which was isolated by stopcocks for the purpose of taking half-life data and measuring the concentrations of the activities. Some of the reactions used with the corresponding measured half-lives are: $N^{14}(d,n)O^{15}$, 118 ± 1 sec.; $O^{16}(d,n)F^{17}$, 66 ± 1 sec.; $Ne^{22}(d,p)Ne^{23}$, 40 ± 1 sec. The concentrations of active nuclei obtained agree roughly with those to be expected from (d,n) and (d,p) reactions at this energy (8 Mev) in this region of mass number. They correspond to cross sections of about 2×10^{-25} cm². Additional experiments are in progress and will be reported.

D6. Radioactive Scandium and Vanadium. N. L. KRISBERG AND M. L. POOL, *Ohio State University.*—Comparison has been made of the decay periods obtained from the bombardment of titanium of standard isotopic composition and the periods obtained by bombarding separate samples of titanium electromagnetically enriched with Ti^{46}, Ti^{47}, Ti^{49}, and Ti^{50} [1] respectively. Direct comparison of intensities was facilitated by mounting pairs of samples on a rotating target. Proton bombardment of standard Ti and subsequent chemical separation showed the V fraction to decay with half-lives of 33 minutes and 16 days. No other periods have been observed in V with proton bombardment. The 33-minute period was produced by the reaction $Ti^{47}(p,n)$ with approximately ten times the intensity with which it was produced by the reaction $Ti^{46}(p,\gamma)$ and is assigned V^{47}. Assignment of the 3.4 day half-life to Sc^{47} was definitely confirmed by comparing the reactions $Ti^{49}(d,\alpha)$ and $Ti^{50}(d,\alpha)$. The half-life was determined to be $3.43\pm.02$ days. The $Ti^{50}(d,\alpha)$ reaction was shown to give the 1.83 day half-life of Sc^{48}.

[1] Supplied by the Y-12 plant, Carbide and Carbon Chemicals Corporation through the Isotopes Division, U. S. Atomic Energy Commission, Oak Ridge, Tennessee.

D7. The Beta-Ray Spectra of Cu^{64}. R. D. ALBERT AND C. S. WU.—Positron and negatron spectra of Cu^{64} have been investigated in the Columbia helical focusing beta-ray spectrometer.[1] By using thinner and more uniform sources and employing a more rigorous Coulomb correction factor,[2] the deviation at the low energy region was greatly reduced as compared with previous work[3] reported from other laboratories. The observed electron distribution agrees with the theory from upper energy limit down to ~70 kev. The deviation in the case of positron appears to start at a much higher energy ~200 kev. However, the difference of the area under the momentum distribution curves between the experimental and theoretical distribution for both positrons and electrons is only about 1–2 percent of the total emission. It seems probable that the remaining small observed deviation is instrumental and the Cu^{64} spectra are in good agreement with Fermi theory. Further work on Cu^{64} is in progress.

[1] Wu, Havens, Albert, and Grimm, Phys. Rev. **73**, 1259(A) (1948).
[2] C. Longmire and H. Brown, in press.
[3] J. Backus, Phys. Rev. **68**, 59 (1945); C. S. Cook and L. M. Langer, Phys. Rev. **73**, 601 (1948); G. E. Owen and H. Primakoff, Phys. Rev. **74**, 1406 (1948).

D8. The Slow Neutron Induced Activities of Germanium.* Y. H. WOO,** C. E. MANDEVILLE, M. V. SCHERB,*** AND W. B. KEIGHTON, *Bartol Research Foundation.*—GeO_2 was irradiated by slow neutrons in the Oak Ridge pile on three successive occasions. The 12-hour, 40-hour, and 11-day periods have been noted on decay curves. The 12-hour Ge^{77} emits beta-rays having a visual limit at 1.74 Mev. A small number of beta-gamma and gamma-gamma coincidences were observed to decay with the 12-

hour period, indicating the presence of soft gamma-rays. Absorption measurements showed that the beta-rays of the 11-day activity are conversion electrons. A comparison of the absorption curve with that of the conversion electrons of $*In^{115}$ yields a gamma-ray energy of 0.32 Mev. Coincidences were found between the conversion electrons and the soft x-rays of the germanium-gallium region. Critical absorption measurements in zinc and copper confirmed[1] the presence of the gallium $K\alpha$ line. No beta-beta, beta-gamma, or gamma-gamma coincidences were found, suggesting that a single highly converted gamma-ray of energy 0.32 Mev is emitted in the 11-day activity.

* Assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission.
** National Central University and Academia Sinica, Nanking, China.
*** Princeton University.
[1] McCown, Woodward, Pool, and Finston, Phys. Rev. **74**, 1263 (1948).

D9. Disintegration of Ag 110 into Isobars Pd 110 and Cd 110. FU-CHUN YU, LIN-SHENG CHENG, AND J. D. KURBATOV, *Ohio State University.*—It was previously reported that Ag 110 of 225 days half-life disintegrates by emission of electrons of complex spectra with upper energy limit of 0.59 Mev, and by emission of three gamma-rays of energies 0.66, 0.90 and 1.4 Mev. Since two stable isobars Pd 110 and Cd 110 are known, the radiations of Ag 110 were studied in the present work to establish the mode of disintegration. The presence of x-rays of ~20 Kev was found in the complex radiations of Ag 110. Coincidence absorption of gamma-rays produced a simple exponential drop of the number of (γ, γ) coincidences against lead absorber thickness with total μ equal to the sum of μ_1 of 0.66 Mev gamma-ray and μ_2 of 0.90 Mev gamma-ray, showing that these two gamma-rays are emitted in cascade. No coincidences were observed for the gamma-ray of 1.4 Mev with the two previous gamma-rays. A scheme of disintegration of Ag 110 will be proposed.

D10. Beta- and Gamma-Rays of Antimony 125. BERNARD D. KERN,[1] A. C. G. MITCHELL, AND DANIEL J. ZAFFARANO, *Indiana University.*—The nuclear spectrum of Sb^{125} (2.7 years half-life) has been measured with a magnetic lens spectrometer. The source, obtained from Oak Ridge, was made by bombarding tin with neutrons. The Sb^{125} grows from Sn^{125}. The gamma-ray spectrum was obtained by measuring the energies of photoelectrons ejected from a thin lead radiator. Photo lines corresponding to gamma-rays of energies 0.638, 0.614, 0.478, 0.432, and 0.172 Mev were observed. The beta-ray spectrum contains, in addition to the disintegration electrons internal conversion lines corresponding to gamma-rays of energies 0.110, 0.125, 0.174, and 0.431 Mev. The beta-ray spectrum appears to be complex with end points at 0.659, 0.281 Mev, and perhaps one or more lower energy groups. The metastable Te^{125} (of some two months half-life[2]) was separated from an aged Sb^{125} source. Its spectrum consists of one internally converted gamma-ray of energy approximately 0.110 Mev. The K/L ratio for this line was found to be 1.2. This work was assisted by the joint program of the Office of Naval Research and Atomic Energy Commission.

[1] Atomic Energy Commission Fellow.
[2] Friedlander, Goldhaber, and Scharff-Goldhaber, Phys. Rev. **74**, 981 (1948).

D11. Presence of a New Long-Lived Cs Isotope in Fission.* NATHAN SUGARMAN, *Los Alamos Scientific Laboratory* and *University of Chicago.*—Radioactivity from four fission products believed to be long-lived, namely, Se^{79}, Pd^{107}, I^{129}, and Cs^{135} has hitherto not been observed.[1] The radiations of a long-lived Cs activity extracted from fission product gases have now been detected. The timing of the experiments was such as to indicate that the new activity is Cs^{135}, the daughter of 9.2-hour Xe^{135}. Two samples of Xe^{135}, 36 curies and 30 curies, containing some 5.3-day Xe^{133} were prepared at the homogeneous pile at Los Alamos. The gas and the container were washed and the solution was analyzed radio-chemically. A new Cs activity was found, the maximum energy of the β-radiations being 0.21 ± 0.01 Mev as determined by Feather analysis. No γ radiation was detected. On the assumption that the new Cs activity is of mass 135, the half-life of Cs^{135} is $(2.1 \pm 0.5) \times 10^6$ years. The cross section for pile neutron activation of Cs^{135} to give 13.7-day Cs^{136} was also measured and is ~15 barns.[2]

* Assisted by the joint program of ONR and the AEC.
[1] J. Am. Chem. Soc. **68**, 2411 (1946); Rev. Mod. Phys. **18**, 441 (1946).
[2] This determination was made at the Argonne National Laboratory, Chicago, Illinois.

D12. The Characteristic Radiations of Praseodymium (142).* C. E. MANDEVILLE, *Bartol Research Foundation.*—The 19.3-hour[1] period was activated when PrO_2 was bombarded by slow neutrons for two hours in the Oak Ridge pile. Measurements were commenced twenty-five hours after removal of the irradiated material from the pile. No chemical separations were performed. An aluminum absorption curve gave a maximum beta-ray energy of 2.22 Mev. A coincidence absorption experiment showed the presence of a hard gamma-ray at 1.74 Mev. This gamma ray has been previously observed.[1,2] Using very high counting rates in the beta-ray counter and a coincidence resolving time of 0.10 microsecond, a small beta-gamma coincidence rate was detected which decreased to zero at 0.049 g/cm^2 in aluminum placed before the beta-ray counter, indicative of a soft beta-ray spectrum (end point 215 Kev) of low intensity coupled with gamma-radiation. The hard beta-rays lead to the ground state of the residual nucleus. A lead absorption curve gave evidence of a soft gamma-ray as well as the hard radiation. Gamma-gamma coincidences were observed and measured, but no beta-beta coincidences were found.

* Assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission.
[1] DeWire, Pool, and Kurbatov, Phys. Rev. **61**, 564 (1942).
[2] Mandeville, unpublished data, 1943.

D13. Gamma-Radiation from Neutron Activated Ytterbium.* J. M. CORK, H. B. KELLER, J. SAZYNSKI, A. STODDARD, AND W. C. RUTLEDGE, *University of Michigan.*—A specimen of ytterbium oxide, supposedly chemically pure, was irradiated in the Oak Ridge pile for 2 months, and subsequently studied in photographic beta-spectrometers and with ionization electrometers. To obtain satisfactory resolution in a wide region of energies, photograms were taken in each of three permanent magnet spectrometers set at 173, 290, and 386 gauss, respectively. The yield of electron lines due to the internal conversion of gamma-rays was surprisingly abundant, there being in all about 40 lines observed. If the gamma-emission follows

the beta-emission from ytterbium ($Z=70$), then the $K-L-M$ differences of the conversion groups should be characteristic of lutecium, ($Z=71$). It appears that the many electron lines are resolvable into two groups some of which have a short half-life and the others a long decay period (~105 days). By noting the fit obtained with the $K-L-M$ energies all lines were found to satisfy well the differences to be expected if the source contained not only ytterbium but also erbium. In all, about ten gamma-rays are found for each element. Their energies and their associated half-lives have been precisely determined.

* This project was supported by the Atomic Energy Commission and the Office of Naval Research.

D14. The Beta-Ray Spectrum of RaE. R. MORRISSEY AND C. S. WU. Investigations made in this laboratory of the β-ray spectra of Cu^{64} and S^{35} using very thin sources and backings and employing a refined Coulomb correction factor showed close agreement with Fermi theory from the upper energy limit down to the very low energy region. This led to a re-examination of the β-ray spectrum of RaE under similar experimental conditions. Carrier free RaE sources were prepared by electroplating RaE on a platinum electrode from a solution of RaD and E and then redissolving and depositing the RaE solution on a thin collodin backing (~6μ g/cm^2). The Fermi plot of the results after correcting for atomic screening effects still showed marked continuous curvature away from the energy axis over the entire region. This is in good agreement with the data of G. J. Neary[1] from upper energy limit to ~180 kev. Below 180 kev our Fermi plot continues to curve concave upward while Neary's reaches a maximum and then drops off rapidly. The fitting of C_{2T} (the second forbidden correction factor for tensor interaction) to RaE data will be discussed.

[1] G. J. Neary, Proc. Royal Soc. A, 175, 71 (1940).

Brookhaven Equipment; General Nuclear Physics

E1. Design of the Brookhaven High Energy Proton Synchrotron.* M. G. WHITE, *Princeton University.*—Final design specifications have been completed for most of the components of a 75-foot proton synchrotron which will yield 2–3 Bev protons or 4–6 Bev alpha-particles. The useful acceleration aperture will be approximately $7''\times30''$. Ions accelerated to 3–4 Mev by an electrostatic generator will be injected when the magnetic field reaches 300 gauss; acceleration to high energy will be accomplished by a large radiofrequency transformer surrounding the ion orbit. The shape of the magnetic field in the gap will be controlled by running currents through pole face windings. From model magnet tests it is known that very little pole face corrective current will be required at injection time and none over the rest of the cycle up to about 9000 gauss. Above 9000 gauss saturation effects will require considerable, but not unreasonable power, for field correction. Calculations on the effects of gas scattering show that the residual air pressure must be kept below 2×10^{-6} mm of Hg. Several of the large components are under construction by subcontractors and the magnet foundation is now being laid.

* Work done at Brookhaven National Laboratory, under the auspices of the Atomic Energy Commission.

E2. Ferromagnetic Ferrites for a Cosmotron Accelerating Unit.* MARTIN PLOTKIN AND JOHN P. BLEWETT, *Brookhaven National Laboratory.*—The accelerating unit in the Brookhaven Cosmotron will consist of a ferromagnetic core excited by a primary winding which is fed from a variable frequency source. The proton beam will be accelerated by the electric field associated with the alternating flux in the core. For our frequency range of 0.3 to 4.2 megacycles the best material for the core appears to be one of the recently developed ferromagnetic ferrites in which permeabilities of the order of 1000 are available. The permeability is found to be a function of frequency, temperature, signal amplitude, size and shape of the sample. The permeability has a complex value; at high frequencies the imaginary component becomes appreciable while the real part drops rapidly. The behavior of permeability vs. frequency is principally due to a combination of eddy current and magnetic resonance effects. When air gaps are introduced into the magnetic circuit, anomalous effects appear due to the complex permeability. Measurements will be reported on resistivity, specific heat, thermal-conductivity and losses at operating frequencies and power levels. The resistivity measurements have been made as a function of frequency and temperature.

* Work done at Brookhaven National Laboratory, under the auspices of the Atomic Energy Commission.

E3. Propagation of Electromagnetic Waves guided by Magnetic Materials.* JOHN P. BLEWETT, *Brookhaven National Laboratory.*—A perfect analogy exists between transmission lines in which current flows in conductors, electric fields are normal to the conductors, and magnetic fields are tangent to the conductors, and transmission lines in which magnetic flux carried in ferromagnetic "conductors" replaces the current and the directions of the electric and magnetic fields are interchanged from the usual direction. Two cases of the latter type of transmission will be discussed, one in which the radiation is guided by a parallel "conductor" line, the other in which the guiding medium is a thin sheet of ferromagnetic material. The velocity of propagation and the attenuation can be computed as functions of the properties and dimensions of the material. Experimental checks of the theory will be presented and propagation effects in the accelerating unit of the Cosmotron will be discussed.

* Work done at Brookhaven National Laboratory, under the auspices of the Atomic Energy Commission.

E4. Effects of Eddy Currents on the Field of the Cosmotron Magnet.* M. HILDRED BLEWETT, *Brookhaven National Laboratory.*—In order to minimize eddy current effects, the C-shaped magnet of the Cosmotron will be constructed of half-inch laminations. However, eddy currents can cause appreciable changes in the distribution of the magnetic field particularly early in the cycle, near injection. An approximate calculation has been made of these eddy current phenomena. The usual one-dimensional analysis of the rate of penetration of flux across the laminations has been made and the relaxation method has been applied to obtain a field-plot of the spatial distribution of flux throughout the iron of the magnet. From these computations, have been obtained the changes in the distribution of the magnetic field in the gap near the central

orbit. The final results are in reasonable agreement with the experimental measurements on a model magnet, reported in the next abstract. Fortunately, the remanent field in the magnetic gap has such a distribution that a large part of the eddy current effect is compensated.

* Work done at Brookhaven National Laboratory, under the auspices of the Atomic Energy Commission.

E5. Dynamic Magnetic Measurements on Cosmotron Magnet Model.* G. K. GREEN, H. S. SNYDER, AND L. W. SMITH, *Brookhaven National Laboratory.*—The pulsed magnet of a proton synchrotron type accelerator must maintain an accurately shaped field over a wide range of values (275 to 14,000 gauss in the Brookhaven Cosmotron). One-third scale models of a C-magnet arc subtending $7\frac{1}{2}°$ have been measured dynamically over a scaled operating cycle. Measurements of the first few milliseconds of the pulse cycle indicate that half-inch lamination thickness can be used, and that the remanence of the magnet almost exactly cancels the eddy current transient. At higher fields the effects of saturation are so large as to require heavy compensating currents on the pole faces. The measurements have been made with a differential flux coil and integrator technique. Steady state measurements of the model are made with a servo-flux meter of variable magnification arranged to draw field curves automatically.

* Work done at Brookhaven National Laboratory, under the auspices of the Atomic Energy Commission.

E6. Experimental Facilities to be Available at the Brookhaven Nuclear Reactor, CLARKE WILLIAMS, *Brookhaven.*—The Brookhaven reactor, which will be available for experiments the latter half of this year, is air cooled, graphite moderated, and fueled with normal uranium. With this design a number of simultaneous independent experiments can be performed. For experiments, one hole 12-inches square into the center of the reactor, and several 4-inch square holes at various levels, running 38 ft. clear through the graphite and both shields, permit the installation of apparatus inside the pile or allow a collimated neutron beam out. A number of automatic devices are installed allowing controlled irradiation of samples for periods as short as 10 seconds. The top shield consists of 4 feet square blocks removable to accommodate thermal columns or other large equipment. The thermal neutron flux available ranges from 5×10^{12} at the center to around 10^{11} neutrons/cm^2 sec at the graphite surface. Laboratories specially designed for physical, chemical, biological and medical research, accommodating over eighty scientists and technicians, are a part of the reactor building. A hot laboratory in which amounts of radioactive material emitting up to fifty curies of 2 Mev gammas can be manipulated, is being built nearby.

E7. Nuclear Reaction Energies as Integral Multiples of a Natural Unit. ENOS E. WITMER, *University of Pennsylvania.*—The writer[1] has pointed out before that the masses of stable nuclei in the ground state appear to be integral multiples of a natural unit of mass, which he designates the *prout.* The prout is defined to be the nuclear mass of O^{16} divided by 82012. Actually the masses of some of the unstable nuclei in the ground state appear to conform to the integral multiple rule also. Among these is the mass of the neutron. It follows that nuclear reaction energies involving stable nuclei and neutrons should be integral multiples of the prout. This should also be true of some reactions involving unstable nuclei. This is confirmed by the thirteen most accurately measured reaction energies in the Nuclear Physics Tables of Mattauch and Fluegge. Seven of these reaction energies are in the recent table of reaction energies in Bainbridge's Isotopic Weights of the Fundamental Isotopes. Wherever there is a change from one table to the other it is toward better agreement with the integral multiple rule. A complete table will list other accurate measurements of nuclear reaction energies.

[1] Enos E. Witmer, Proc. Nat. Acad. Sci. **32**, 283 (1946).

E8. The Masses of Nuclei from Neon to Chlorine. H. T. MOTZ AND R. F. HUMPHREYS, *Yale University.**—Between $A=20$ and $A=35$ some sixty nuclear reactions have been reported in the literature. In addition, the masses of neon 20 and 22, aluminum 27, sulphur 32 and 34, and chlorine 35 have been determined by mass spectrograph measurements. Employing these as anchor points a diagram of mass differences obtained from nuclear reaction Q values is constructed. The internal consistency is made readily evident by the closed polygons appearing in the mass chain. In several cases three or four independent checks on a Q value are possible. Discrepancies of the order of 0.5 Mev are revealed, while the neon reactions show an even larger inconsistency. New measurements of the Q values for Mg(dp)Mg and Si(dp)Si (using enriched silicon targets**) will be presented which, at least in part, remove some of the difficulties in establishing the nuclear mass values.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
** Enriched silicon produced by Carbide and Chemical Corporation and obtained on allocation from the Isotopes Div., U.S.A.E.C.

E9. On the Production of ± Electron Pairs in the Field of an Electron.*,[1] J. A. PHILLIPS AND P. GERALD KRUGER, *University of Illinois.*—Only two[2] γ-ray energies of 6.13 $\pm$0.14 and 7.12$\pm$0.2 Mev are observed from CaF_2 bombarded with 5 Mev protons by examining 84 electron pairs formed in CH_4 in a cloud chamber. The intensity ratio is $\sim\frac{1}{2}$. These values are based on new magnetic field measurements using a flip coil and proton magnetic moment techniques. The ratio of pair to triplet production is CZ^2/Z where C for these data is 3.63 for CH_4 (1430 pairs, 97 triplets); 3.97 for air (3441 pairs, 118 triplets); 4.11 for argon (6484 pairs, 89 triplets); with a most probable value of 3.92$\pm$10 percent. The energy distribution of the low energy negative electron of the triplet has been measured for triplets in CH_4 and in air.

* This work in part supported by the Office of Naval Research.
[1] Phillips and Kruger, Phys. Rev. **74**, 1259 (1948).
[2] Phillips and Kruger, Phys. Rev. **72**, 164 (1947).

E10. Luminescent Spectra of Phosphors Useful in Scintillation Counters. J. C D. MILTON AND R. HOFSTADTER,* *Princeton University.*—We have examined by means of a small Hilger quartz spectrograph the luminescent spectra of the more important organic and inorganic materials currently used in scintillation counters. The phosphors were irradiated with the gamma rays from a 1.8 or a 25 mc Ra source. Eastman 103-0 plates were used.

Exposures varied from 2 hours for the inorganic to 72 hours for some of the organic phosphors. The results are shown in the following table.

Crystal phosphor	Center of band of emitted light A	Width at half maximum A
Naphthalene	3450±50	150
Anthracene	4440	60
Phenanthrene	4100	100
	4300	110
Stilbene(E.K. Co.)	4200 (weak)	360
	4080 (strong)	100
NaI(Tl)	4100	850±100
KI(Tl)	4000	600±100

It is of interest to note that the spectra of anthracene and phenanthrene are composed of narrow bands. There is some agreement with the luminescence emitted after ultra violet excitation.[1]

* This work was assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
[1] J. Stark, Physik. Zeits. **8**, 481 (1908); W. von Meyeren, Zeits. f. Physik **61**, 329 (1930).

E11. Pulse Size Distributions in Scintillation Counters.* R. HOFSTADTER, J. C. D. MILTON, AND J. A. MCINTYRE, *Princeton University.*—A ten channel discriminator and 501 amplifier have been used to obtain distributions of pulse size in various scintillation counters for incident Co^{60} gamma-radiation. The curves of counting rate in any channel *vs.* photomultiplier voltage are characterized by maxima displaced towards higher voltage in the higher channels. Such behavior is expected when counting a fixed number of events. The curves do not come down to zero at the higher voltages where photomultiplier noise sets in. However, the accuracy of measured points is not good at these voltages since large backgrounds must be subtracted from the data. We have noticed quite large changes for NaI(Tl) in the measured curves by employing a collimated beam of gamma-rays. These changes tend to move the higher voltage regions of the curves towards zero counting rate. This observation suggests that scattered gamma-rays from the surroundings are counted when gamma-ray beam precautions are not taken. With such precautions, flat regions are observed in total counting rate plotted against voltage. Results will be given for NaI(Tl), anthracene and stilbene.† Stilbene pulses, incidentally, have decay times less than our ultra fast amplifier constant (2×10^{-8} seconds).

* This work was assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
† Name of original discoverer unknown to us.

E12. Resolving Times of Naphthalene and Polystyrene[1] Counters. WILLIAM J. MACINTYRE, *Yale University.**—In the application of crystal counters to particle detection it has been found that the characteristic high efficiency and low resolving time has made them adaptable to coincidence counting. Resolving times of naphthalene and polystyrene counters have been investigated by delaying the pulses produced by the crystal counter-electron multiplier tube and coincidence counting with pulses from a proportional counter of known resolution. In this method beta particles travel through the proportional counter and penetrate the crystal. When coincidences per unit time are plotted against delay time the resolving time of the combined counters is obtained, from which the resolving time of the crystal counter can be found. In the coincidence circuit employed several stages of differentiating units are used, thus the initial rise time of the pulse is the principal factor involved. For naphthalene this time has been observed as less than 6×10^{-8} seconds and for polystyrene as less than 4×10^{-8} seconds.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
[1] Polystyrene as a crystal counter is being investigated by J. A. Rich (private communication).

E13. Waveforms Associated with the Discharge of a Geiger Tube. G. G. KELLEY, W. H. JORDAN, AND P. R. BELL, *Oak Ridge.*—The shape of the current pulse from a self quenching Geiger tube has been measured and compared with the theoretically predicted shape. We observe a sharp rise in current at the beginning of the discharge and a sudden decrease at the end. If the current due to the motion of the positive ions is calculated and subtracted from the observed waveform, there remains a square pulse of current which is attributed to electron collection. This amounts to about twenty percent of the total and lasts for the duration of the discharge. These results are somewhat different from the observations of Alder *et al.*[1] On the other hand we are using a much faster amplifier (rise time ~0.02 μsec.) and record single traces.

[1] Alder, Baldinger, Huber, and Metzger, Hel. Phys. Acta **20**, 73 (1947).

Reactions of Transmutation

F1. Angular Distribution of Photo-Neutrons from Deuterium and Beryllium. BERNARD HAMERMESH AND ALBERT WATTENBERG, *Argonne National Laboratory.*—Preliminary measurements have been made of the angular distribution of photo-neutrons from deuterium and beryllium with Na^{24} γ-rays (2.76 Mev). Sources of approximately 40 curies were employed. The detector was a BF_3 counter embedded in paraffin. The detector and source subtended half angles of less than 9° at the target. The angle between the incident γ-rays and the emitted neutrons was varied by moving the γ-ray source. Measurements were taken at 0°, 20°, 40°, 55°, 75°, and 90°. The data for both deuterium and beryllium[1] were found to fit a curve of the form $a+b\sin^2\theta$ within experimental error. For deuterium a preliminary value of a/b of 0.24 was found in agreement with N. O. Lassen.[2] For beryllium a/b is found to be about 1.5. The data have been corrected for the finite angles subtended by source and counter, for room scattering of the neutrons, and for the neutrons produced in the deuterium naturally contained in the paraffin. These corrections are being subjected to further investigation.

[1] E. Guth and C. T. Mullin, Phys. Rev. **74**, 833 (1948).
[2] N. O. Lassen, Phys. Rev. **74**, 1533 (1948).

F2. Photodisintegration of Deuterium and Beryllium by the Gamma-Rays of Na^{24} and Ga^{72}. ARTHUR H. SNELL, E. C. BARKER AND R. L. STERNBERG, *Oak Ridge National Laboratory.*—Samples of pile-activated Na and Ga were inserted in spheres of D_2O and Be, and the resulting photoneutron sources were placed in the center of a spherical air cavity in a large block of paraffin. The photoneutron outputs were measured with parabolic indium foils placed in the paraffin. (As a standard for comparison, S. Bernstein supplied a Ra-γ-Be source which had been compared, directly or indirectly, with other sources which had been

absolutely calibrated in three independent measurements.) The Na and Ga sources were then dissolved, and their strengths were determined by beta-counting of aliquots. Following a few corrections, simple theory leads to the derivation from these measurements of the quantities $\Sigma_i \alpha_i \sigma_i$ where α_i is the relative intensity (mean number of quanta per disintegration) of the ith gamma-ray above the photoneutron threshold, and σ_i is the associated photodisintegration cross section. The results for $\Sigma_i \alpha_i \sigma_i$ are as follows:

$Na-D_2O: 14.5\times10^{-28}$	$Ga-D_2O: 2.84\times10^{-28}$
$Na-Be: 6.82\times10^{-28}$	$Ga-Be: 2.18\times10^{-28}$

For Na, $\alpha=1$ and the figures give the cross sections in cm^2 for 2.76 Mev gamma-rays. For Ga, the results will be compared with the published disintegration schemes of Haynes[1] and Mitchell, Zaffarano, and Kern.[2] In absolute precision, the figures are thought to be correct within 10 percent.

[1] S. K. Haynes, Phys. Rev. **74**, 423 (1948).
[2] A. C. G. Mitchell, D. J. Zaffarano, and B. D. Kern, Phys. Rev. **73**, 1424 (1948).

F3. The Interaction of Protons with Tritium. A. HEMMENDINGER, G. A. JARVIS, AND R. F. TASCHEK, *Los Alamos Scientific Laboratory.*—Tritium gas was stored as uranium tritide, evolved by heating, compressed by a mercury lift into the gas target of the Los Alamos 2.5 Mev electrostatic accelerator, and recombined with uranium when evacuation of the target was desired. The target gas was confined by 0.1-mil thick aluminum foil; suitable precautions were taken to save the gas in the event of failure of the foil. The gas samples were invariably contaminated with varying amounts of hydrogen, and the fraction of hydrogen present was determined by measurements of proton-proton scattering from tritium and hydrogen targets at known pressures. A few measurements of the proton-triton differential scattering cross section, a by-product of these experiments, will be reported. The reaction $T^3(p,n)He^3$ proves to be a useful monoergic laboratory source of neutrons with (calculated) threshold at 986 kev and a yield curve which rises continually up to 2.5 Mev, the highest energy at which observations were made. The total cross section at 2 Mev proton energy is 0.4 barn.

F4. Spectrum and Angular Distribution of Neutrons from Be+p.* P. C. GUGELOT, *Princeton University.*—An internal cyclotron target of Beryllium of 1 Mev stopping power was bombarded with 16 Mev protons. The spectrum of the neutrons emitted from the reaction Be^9+p was studied by means of the recoil protons in Ilford B2 100μ photographic emulsions. To investigate the angular distribution for the neutrons 12 aluminum detectors (threshold for the $Al^{27}(n,p)Mg^{27}$ reaction is 2 Mev) were activated in a semicircle of 9 cm radius around the Be target. The detector intensity distribution curve was compared with a semitheoretical distribution curve calculated in the following way. It was assumed that the neutrons were emitted isotropically in the center of gravity of Be+p. The neutron spectrum, which was obtained at 0° with respect to the proton beam, was accordingly transformed for the other angles. The theoretical cross section of Al as given by an extrapolation from the statistical theory of Weisskopf and Ewing[1] for elements of medium A, was then used with the neutron spectrum at a particular angle to give the relative activity of Mg^{27} at that angle. The calculated detector activity distribution agreed with the experiments.

* This work was assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
[1] V. F. Weisskopf and D. H. Ewing, Phys. Rev. **57**, 472 (1940).

F5. Comparison of Li(p,γ) with a F(p,γ) Resonance.* EMMETT L. HUDSPETH AND CHARLES P. SWANN, *Bartol Research Foundation.*—A standard of voltage calibration with the Li(p,γ) resonance at 440 kev has been questioned,[1] and more recent work[2] again indicates that this value is too low. However, the 440 kev value is implied in other[3] recent experiments. In the course of calibrating our generating voltmeter, we have compared the "862 kev" resonance in the F(p,γ) reaction with the "440 kev" resonance in Li(p,γ) as observed with the diatomic beam. Thick and thin targets of LiF have been used for this work, and hence the two reactions were observed in each instance with the same target. The results depend on assuming linearity of our generating voltmeter over only a very limited range. It is found that the Li(p,γ) resonance occurs with a diatomic beam whose energy is 20 ± 6 kev higher than the atomic beam which produces the F(p,γ) reaction. This yields (449 ± 3)–878 kev[1,2] or (441 ± 3)–862 kev[3] as values for this resonance pair.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
[1] A. O. Hanson and D. L. Benedict, Phys. Rev. **65**, 33 (1944).
[2] R. G. Herb, S. C. Snowden, and O. Sala, Phys. Rev. **74**, 1256A (1948).
[3] S. Rubin, C. W. Snyder, C. C. Lauritsen, and W. A. Fowler, Phys. Rev. **74**, 1564A (1948).

F6. Angular Distribution of $Li^6(d,\alpha)\alpha$. ROBERT RESNICK AND D. R. INGLIS, *The Johns Hopkins University.*—The intensity of the reaction $Li^6(d,\alpha)\alpha$ varies with angle as $1+A(E)\cos^2\theta+B(E)\cos^4\theta$, just as in the case of $Li^7(p,\alpha)\alpha$ for which an analysis has already been given. For $Li^6(d,\alpha)\alpha$ it is again the Bose statistics of the alphas that makes analysis possible. It is assumed that Li^6 has even parity so that only $s,d\cdots$deuterons are relevant here, in contrast to $Li^7(p,\alpha)\alpha$ in which $p,f\cdots$protons are involved. The two analyses differ also in the spin combinations, but are similar in the assumption of only two contributing states of the compound nucleus, with angular momentum quantum numbers 0 and 2. The $Li^6(d,\alpha)\alpha$ treatment with two sharp levels is compared with that for one sharp and one broad level. The latter is found simpler and adequate for obtaining agreement with the experimental $A(E)$ and $B(E)$. The theoretical formulas rather naturally give the general form of the experimental results, including the feature that both $A(E)$ and $B(E)$ rise more slowly in the $Li^6(d,\alpha)\alpha$ reaction than in the $Li^7(p,\alpha)\alpha$ reaction as the bombarding energy is increased from zero, a consequence of the spherical symmetry of the entering s waves which participate in the Li^6 reaction only.

F7. Neutrons from the $Be^9(d,n)B^{10}$ Reaction.* J. W. BUTLER, J. E. EVANS,** C. W. MALICH,*** AND J. R. RISSER, *Rice Institute.*—Measurements of the thin target excitation curve for the production of neutrons from the bombardment of beryllium by deuterons[1] have been made, using as detectors argon or proton recoils in propor-

tional counters containing these gases. The angular distribution of the neutrons was also determined for a number of bombarding energies up to 1.75 Mev with a polyethylene foil counter. No narrow resonances are found. There is evidence for a broad resonance at about 1.1 Mev bombarding energy and a new neutron group with a Q-value of about -0.7 Mev. To check on the existence of this new group, proton recoils are being studied in a high pressure cloud chamber containing ethane.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
** Now at Los Alamos Scientific Laboratory, Los Alamos, New Mexico.
*** Now at Naval Research Laboratory, Washington, D. C.
[1] Malich and Risser, Phys. Rev. 73, 648A (1948).

F8. Q Values from Alpha-Particle Bombardment of Boron. R. J. CREAGAN, *Yale University.**—Observations of $B(\alpha p)C$ reactions so far has been made using natural alpha-particles and poor geometry. In spite of careful attempts the maximum energy measured for protons emitted at 0° falls short of calculations based on mass spectrographic data of B^{10} and C^{13}. A target has been bombarded with 7.4-Mev alphas produced in a cyclotron and attempt has been made to observe the maximum energy protons. It was found at 90° that a Q of 3.9 Mev resulted, which is within experimental error of checking mass spectrographic data. At 0° maximum energy protons correspond to a lower Q value. It appears that there is a strong assymetry in yield of protons from the group, which makes it difficult to measure maximum energy at 0°. From results at 90°, it appears that no serious discrepancy exists for this reaction. Other Q values observed are: $+0.8$ Mev, -0.5 Mev, -1.1 Mev.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

F9. Angular Distribution of End-Group Protons from $B^{10}+d$. W. C. REDMAN, *Yale University.**—A combination bombardment and photographic detection chamber was used to record the end-group protons from a solid B_2O_3 target which was bombarded by deuterons ranging from 1.1 to 3.1 Mev energy, in increments of 0.7 Mev. Approximately 600 tracks per angle were measured for some 12 angles lying between 10° and 165°. The observed distributions are complex, exhibiting marked asymmetry with the yield predominantly in the forward direction. A peak near 90° appears and seems to persist with varying bombarding energy. Attempts to fit the distribution curves with a fourth order cosine series have proved unsuccessful.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

F10. Angular Yield of Protons from $N^{14}(dp)N^{15}$. L. D. WYLY, *Yale University.**—Recent studies of the angular distribution of particles emitted in transmutations have shown that there may be not only a high variability in yield with angle but also marked changed in the distribution as the energy of the bombarding particle is changed. In order to extend these studies to other elements a gaseous bombardment chamber has been constructed to study the angular distribution of the long range protons emitted from the bombardment of N^{14} by deuterons. Observations made between 15° and 135° for five different deuteron energies between 1.5 Mev and 3 Mev give smooth curves of yield as a function of the cosine of the angle in the center of mass system. The yield, however, is in general not symmetric with respect to the 90° point with the greatest yield in the forward direction. The curves, while simple in character, are not easily analyzed. Disintegration protons at 90° were observed by a proportional counter as a monitor for the reaction.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

F11. Ionization Chamber Observation of the Reaction $N^{14}(n,p)C^{14}$.* W. FRANZEN, J. HALPERN, AND W. E. STEPHENS, *University of Pennsylvania.*—An attempt has been made to achieve high resolution in the measurement of the Q of slow neutron (n,p) reactions by use of a cylindrical ionization chamber with electron collection. The bandwidth of the linear amplifier used with the chamber is chosen so as to produce the best possible signal-to-noise ratio while retaining the advantages arising from the use of electron collection. For the purpose, the "rise time" of the linear amplifier used with the chamber is adjusted to be 7.5 μsec; while the "clipping time" is about 5 μsec. A test of the system by observation of the pulse height distribution arising from the $N^{14}(n,p)C^{14}$ reaction induced by slow neutrons shows that the contribution of the amplifier noise to the half-width of the distribution curve is of the order of 2 percent of the total pulse height. A comparison of the total ionization produced by Po-alpha-particles to that produced in $N^{14}(n,p)C^{14}$ gives a Q value for the reaction somewhat larger than a number of previously published values if proportionality between total ionization and energy is assumed.

* This work was supported by a Joint Program of the Atomic Energy Commission and the Office of Naval Research.

F12. Proton Energies from $K^{39,41}(d,p)K^{40,42}$. V. L. SAILOR, *Yale University.**—Targets of natural potassium iodide have been bombarded with 4 Mev deuterons and the energies of the protons emitted by the reactions at 90° to the incident beam have been measured. The Q-values which have been calculated from the observed proton groups and the relative intensities of these groups are listed in the table.

Mev	Relative intensity	Mev	Relative intensity
8.2 ±0.2	0.02	2.8±0.1	1.8
7.6 ±0.2	0.04	2.2±0.1	2.5
5.51±0.05	1.0	2.0±0.1	3.5
4.62±0.05	1.2	1.3±0.1	7.5
3.38±0.05	6.0	0.6±0.1	6.0

All of these groups may be attributed to $K^{39}(d,p)K^{40}$ or $K^{41}(d,p)K^{42}$ since a target of PbI_2 was found to have no appreciable yield.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

F13. Stopping of Fission Fragments in Gases. E. C. CAMPBELL, W. M. GOOD, AND W. A. STRAUSER, *Oak Ridge National Laboratory.*—Studies of the range in air of those fission fragments of U^{235} emitting delayed neutrons have been reported.[1] Results have now been obtained by the same method for the absolute ranges R_{22} and R_{55} and straggling parameters of the 22 and 55 second delayed

neutron emitters in hydrogen, deuterium, helium and argon. The influence on the straggling and range of the source-detector geometry and of the source thickness has been investigated. The observed fission fragment ranges are shorter in H_2 than in D_2 at the same pressure. In both gases the ranges are anomalously short, as observed by other workers. The relative straggling increases with the mass number of the stopping gas. These results are in accord with the theory of Bohr,[2] and show clearly the importance of nuclear collisions in the stopping of heavy particles. Results are given in the table.

	H_2	D_2	He	Air	A
R_{22} in mg/cm²	.676	1.43	2.07	2.42	3.31
R_{22} in cm N.T.P.	7.60	8.00	11.6	1.87	1.86
R_{55} in mg/cm²	.854	1.78	2.44	3.07	4.48
R_{55} in cm N.T.P.	9.60	9.95	13.7	2.38	2.52

[1] W. M. Good, E. O. Wollan, W. A. Strauser, Bull. Am. Phys. Soc. 23, 29 (1948).
[2] N. Bohr, Phys. Rev. 59, 270 (1941).

Contributed Papers on Fluid Dynamics

FA1. Recent Continuum Theories of Fluid Dynamics. C. TRUESDELL, *Naval Research Laboratory.*—In recent years, three generalizations of the Navier-Stokes equations by continuum treatments have been brought forward: Reiner's theory of compressible fluids; Rivlin's theory of incompressible fluids; and the author's general theory. Expressions for the stress given by the two former are quite similar to each other, but quite different from that calculated from the last, which yields a generalization of Burnett's equations in the kinetic theory of gases. The author's theory is based upon principles of invariance, both dimensional and tensorial, while the Reiner-Rivlin theory is based upon tensorial invariance alone, without recourse to dimensional principles. The present paper compares and contrasts the Reiner-Rivlin theory with the author's theory, by discussing the dimensions of the coefficients occurring in the former. It is demonstrated that the Reiner-Rivlin theory must employ in addition to the usual viscosity a modulus t_0 of the dimension *time*, and thus is essentially a relaxation time theory. Such a modulus is not admitted in the author's theory, in which there occurs the modulus $\mathfrak{R}$, whose dimensions are (length)²/(time)² (temp.) and which for perfect gases may be taken as the gas constant ($p=\mathfrak{R}\rho\theta$). It is shown that if in the author's definition of a fluid $\mathfrak{R}$ be replaced by t_0, all the remainder of the definition being left as it is, then the Reiner-Rivlin theory results.

FA2. Calculation of Compressible Flow Past an Ellipsoid of Revolution by an Integral Method. M. M. KLEIN AND W. PERL, *National Advisory Committee for Aeronautics.*—Some calculations of the continuous potential flow past ellipsoids of revolution have been made by an integral method[1] for free-stream Mach numbers up to the limiting value M_l for which a solution exists by this method. The streamline curvature function was chosen to make the disturbance velocities at small thickness ratio τ and small Mach number M proportional[2] to $\tau^2\log\sqrt{\mu\tau}$. The potential limit Mach numbers M_l are much closer to unity for the ellipsoid of revolution than for the same two-dimensional profile. Thus, for $\tau=0.3$, M_l is about 0.98, with higher (subsonic) values for lower τ. For the same thickness elliptic cylinder, $M_l=0.76$. The lower critical Mach number for $\tau=0.3$ is 0.85 (ellipsoid) and 0.65 (elliptic cylinder). These and further calculations may indicate that the actual breakdown of potential flow, as evidenced by the steep drag rise, should occur about 0.14, 0.18, and 0.21 Mach number later for bodies of revolution of $\tau=0.1$, 0.2, and 0.3, respectively, than for the corresponding two-dimensional profiles.

[1] W. Perl, *Calculation of Compressible Flow Past Aerodynamic Shapes by Use of the Streamline Curvature*, NACA TN No. 1328, June, 1947.
[2] W. R. Sears, Quart. App. Math. 5, No. 1 (April, 1947).

FA3. On Converging Viscous Flow in a Wedge. S. A. SCHAAF AND P. L. CHAMBRE, *University of California, Berkeley.*—It is shown that steady state radial purely converging flow in a wedge does not exist for all wedge angles when the Reynolds number based on centerline velocity and the radial distance is less than 2.71. An expression is obtained for the maximum wedge angle as a function of Reynolds number. In the limit for zero Reynolds number, the maximum wedge angle is 180°.

FA4. On the Correlation Tensors in Compressible Fluids. M. Z. KRZYWOBLOCKI, *Naval Ordnance Laboratory and University of Illinois.*—Von Kármán and Howarth derived the correlation tensors of second and third ranks in an incompressible fluid. In the present paper the author derives the analogous tensors in a compressible fluid. The velocity components are substituted by the "flow density" components. With the assumption that the density is constant, the author's second rank correlation tensor transforms into von Kármán's form.

FA5. The Reversal Theorem of Linearized Supersonic Aerodynamics. MAX M. MUNK, *Naval Ordnance Laboratory.*—According to this theorem, the drag and the lift slope of an airfoil does not change if the direction of forward motion is exactly reverse. A simple proof of this reversal theorem based on dynamic principles is presented.

FA6. A New Superposition Principle in Gas Dynamics. R. C. PRIM, *Naval Ordnance Laboratory and Princeton University.*—The following superposition principle is established for steady flows of frictionless, thermally nonconductive gases having a state equation of the form $\rho=P(p)S(s)$ (ρ = density, p = pressure, s = specific entropy): Let W_p be the reduced velocity vector of a plane flow field in which n is a unit normal vector. Let Q be any scalar function in the plane which satisfies

$$W_p\cdot\text{grad}Q=0$$

(that is, Q is constant along each individual streamline of W_p). Then, spatial reduced velocity fields are given for all such W_p and Q (for which $0\leqq w^2\leqq 1$) by

$$W=(1-Q^2)^{\frac{1}{2}}W_p+nQ.$$

Each of these spatial reduced velocity fields is associated in turn (by the author's extension of the Munk-Prim Substitution Principle) with the vast variety of actual velocity fields obtainable by assigning the ultimate velocity magnitude arbitrarily for each streamline.

FA7. On Transonic Flows. ALEXANDER WEINSTEIN, *Naval Ordnance Laboratory.*—From recent results it appears that Tricomi equation $yz_{xx}+z_{yy}=0$ is equivalent, in the

subsonic regime, to the equation (*) $u_{xx}+u_{yy}+(3y)^{-1}u_y=0$ of an axially symmetric generalized potential in a fictitious space of two and one-third dimensions (see A. Weinstein, Trans. Am. Math. Soc. **63**, 342–354 (1948)). Several solutions of (*), including the fundamental solution, remain valid in the supersonic regime and give new examples of transonic flows.

FA8. Theory of the Shock Tube. G. N. PATTERSON, *Naval Ordnance Laboratory* and *University of Toronto.*—In its simplest form the shock tube consists of a straight tube inside of which is a diaphragm that separates two compartments containing gases at different pressure and temperature. Such an instrument can be used for the study of (a) the properties of non-stationary plane shock waves (reflection, refraction, etc.); or (b) stationary flow patterns at high Mach number. The object of this investigation was to develop a simple, reliable theory of the operation of a shock tube to facilitate the design and future development of this instrument. The theory is based on the following wave system which follows the rupture of the diaphragm: (a) a centered rarefaction wave with a front moving to the left (say), (b) a shock wave moving to the right, and (c) a surface of density discontinuity (contact surface) following the shock wave to the right. Using this wave pattern, based on experimental evidence, calculations were made to relate the pressure ratio across the shock wave to the initial conditions in the tube. From this relation the full performance of the tube can be determined. The special conditions of pressure, temperature and gas combination required to produce very strong shock wave sor very high Mach number have been calculated.

FA9. On the Refraction of a Shock-Wave at an Air-Water Interface. H. POLACHEK AND R. J. SEEGER, *Naval Ordnance Laboratory.*—The characteristics of shock-wave refraction at an air-water interface are of practical importance for military purposes. These characteristics must be known in order to be able to estimate the effect of bomb bursts above the surface of the water upon submerged bodies. The equations governing the refraction of a plane, step shock-wave entering water from air at an arbitrary angle are formulated. Numerical results giving the strengths and positions of the resulting wave configurations for a moderately strong incident shock wave are presented. An approximate, explicit solution is derived on the basis of a linearized theory. The results indicate that for shock waves of moderate strength, such as are obtainable in a shock tube, the deviations from rigid-wall reflection are relatively small. Significant deviations, however, do occur in the neighborhood of the extreme angle of incidence, where some discrepancies from theoretical predictions have been observed in the Princeton shock-tube experiments for regular reflection from a "rigid" wall. It is suggested that these discrepancies may be due partially to the fact that the reflecting surface was not entirely rigid.

FA10. The Detached Shock Wave in Front of a Conical Nose at Supersonic Speeds. E. V. LAITONE, *University of California, Berkeley.*—The potential equation for supersonic gas flow and the Rankine-Hugoniot shock-wave relations are combined to give a first order solution for the location of the detached shock wave formed upstream of a conical nose of finite length. The detached shock wave is formed whenever the conical nose angle is greater than a given limiting angle for each free stream Mach number. The upstream location of this detached shock wave is then found to increase directly with the length of the conical nose and with the square of the conical nose angle. As the free stream Mach number approaches unity, it is found that the shock wave is formed at an unlimited distance ahead of the nose.

FA11. The Thickness of a Shock Front in a Gas. G. R. COWAN AND D. F. HORNIG, *Brown University.*—Reflection of light from a shock front has been observed when a one-dimensional shock, produced by a bursting diaphragm in a cylindrical tube, intersects a beam of light from a carbon arc, the reflected pulse being detected by a photomultiplier tube. Reflectivity was studied as a function of wave-length, angle of incidence, and over-all pressure, and was found to increase with increasing wave-length, and rapidly with increasing angle and pressure. The data are interpreted on the basis of an approximate reflectivity equation which is quite accurate for the extremely small reflectivities obtained (approximately 10^{-5}). Although in principle the detailed shape of the shock front may be completely determined from the reflectivity spectrum, the precision of the data is sufficient to determine only one parameter. The data fit an assumed S-shaped density function better than a simple linear function. On the basis of the S-shaped function, the front thickness of a 60 p.s.i. shock propagating in nitrogen at 85 p.s.i. and 25°C was found to be 1.7×10^{-5} cm, within an error of about 25 percent. The theory of Becker, corrected by Thomas,[1] predicts the value 1.0×10^{-5} cm.

[1] L. H. Thomas, J. Phys. Chem. **12**, 449 (1944).

FA12. A Shock Tube for the Study of Transient Gas Flow.* C. H. FLETCHER, D. K. WEIMER, AND W. BLEAKNEY, *Princeton University.*—A new shock tube of improved design has been constructed for the purpose of studying gas flow problems. The tube has a rectangular cross section 17 inches high and 4 inches wide. The chamber into which the gas expands is 31 feet long and the chamber which holds the gas before the diaphragm is broken is 2 feet long. Observations are made through circular windows 5 inches in diameter located with their centers 7 inches from the end, and 4 inches from the top of the tube. Numerous ports for installation of auxiliary apparatus are provided in the sides and along the top of the tube. The velocity of the traveling shock is measured by means of a chronograph which uses signals from light screens located on a baseline of 17 inches near the observation windows. Observations are made by the light from a magnesium spark which is fired by a delayed pulse from the light screen. Observations may consist of shadowgrams, schlieren pictures or interferograms. These latter are formed by an interferometer of the Mach-Zehnder type with circular plates 5 inches in diameter and rectangular light paths 17×23 inches in length. White light fringes may be used or an interference filter with a pass band at 4460A has been used.

* This work is supported in part by Navy Contract.

FA13. Experimental Measurement of the Density Field in the Mach Reflection of Shock Waves.* W. BLEAKNEY,

D. K. WEIMER, AND C. H. FLETCHER, *Princeton University.*—It is well known that the phenomena of Mach reflection cannot as yet be satisfactorily explained. In order to get some insight into the difficulty, the density field has been measured in the neighborhood of the intersection of the incident, reflected and Mach shocks when a plane shock wave is reflected on an inclined barrier in the shock tube described in the preceding paper. Using spark photography and the interferometer isopycnals (contours of constant density) have been determined for the first time for such a transient phenomenon. The results indicate that conditions are very uniform in front of the incident and Mach shocks, and in the angular region between the incident and reflected shocks. In the rest of the field, however, a considerable variation is observed for weak shocks. The density behind the Mach wave falls in some regions with distance behind the wave, whereas the reverse is true just behind the reflected wave. In the neighborhood of the intersection something very close to an angular variation in the density is observed. The "single fringe" adjustment of the interferometer brings out these features very strikingly. Examples of such interferograms will be shown.

* This work was supported in part by Navy Contract.

Neutron Velocity Spectrometer Results; Theory of Nuclear Scattering; Theory of Heavy Nuclei

G1. A Precise Determination of the Slow Neutron Cross Section for the Free Proton. EDWARD MELKONIAN, L. J. RAINWATER, AND W. W. HAVENS, JR., *Columbia University.*—The free $n-p$ cross section measurements[1] using the Columbia Neutron Spectrometer have been considerably improved. Inconsistencies in separate measurements led to the development of a "standard filter" technique to eliminate the effect of a slight variation of detector efficiency with counting rate. These inconsistencies have now been eliminated and the result is significantly shifted. The technique used (to be described) compared the sample transmission with the geometric factor of a B_4C aperture system. Experimental results for H_2 gas for $E>1$ ev show a $1/E$ slope of 0.67, as predicted by Placzek, and give $\sigma_0=20.37$ barns. Measurements using n-butane and H_2O confirm this, giving 20.34 and 20.35 respectively after multiple scattering corrections have been made. These corrections have been taken as $+0.03$ for the gases. However the much larger value, $+0.10$, used for H_2O, will be discussed. The best value of the free proton cross section from these measurements is $\sigma_0=20.36\pm0.10$.

[1] Phys. Rev. **73**, 1265(A) (1948).

G2. Theory of Slow Neutron Scattering. G. PLACZEK,* *General Electric Research Laboratory.*—The customary method for determining the energy dependence of scattering cross sections, for slow neutrons, of nuclei bound in molecules or crystals consists in computing separately the contributions from all transitions in the system. In cases where the collision leads to a large number of transitions this procedure becomes, in general, impracticable. It is shown that under such conditions the energy dependence of the cross section can be determined from the distribution of coordinates and momenta of the nuclei in the initial state and depends only on rather general properties of the system. The limits of validity of this method have been investigated. Results will be applied to a discussion of recent measurements for the determination of the free neutron-proton cross section[1] as well as of attempts to obtain evidence for an interaction between neutrons and electrons from neutron scattering experiments in liquids.[2]

* Now on leave at the Institute for Advanced Study, Princeton, New Jersey.

[1] Jones, Phys. Rev. **74**, 364, 1948; Melkonian, this meeting, Abstract No. G1.

[2] Havens, Rabi, and Rainwater, Phys. Rev. **72**, 634 (1947).

G3. Interaction of Neutrons with Electrons in Bismuth. L. J. RAINWATER, I. I. RABI, AND W. W. HAVENS, JR., *Columbia University.*—The neutron-electron interaction (non-magnetic) can be determined from the dependence on neutron wave-length of the slow neutron cross section of liquid lead or bismuth. Preliminary investigations using molten lead were previously reported.[1] These studies have been continued using molten bismuth which has an unusually small absorption cross section and no observed resonances. One main possible source of systematic error has been eliminated by the use of a standard filter comparison technique (described by Melkonian in a previous abstract on the free neutron-proton cross section). The neutron-electron cross section can be expressed in terms of the Born formula by specifying an equivalent interaction potential, V, acting over a volume τ. Choosing $\tau=4/3\pi a^3=9.3\times10^{-38}$ cm^3, where $a=2.8\times10^{-13}$ cm (for simplicity), the value of V was previously given[1] as 2500 ev with considerable uncertainty. The present measurements give a somewhat larger value which is several times the experimental uncertainty. The measurements are being continued and the best result will be announced.

[1] W. W. Havens, Jr., I. I. Rabi, and L. J. Rainwater, Phys. Rev. **72**, 634 (1947).

G4. The Neutron-Electron Interaction. M. SLOTNICK,* *Columbia University.*—The interaction between a neutron and the electrostatic field of an electron is examined on the basis of pseudoscalar meson theory and compared with the experiments by Rainwater, Rabi, and Havens described in the preceding abstract. The calculation is carried out relativistically, with nucleon and pseudoscalar fields both subjected to second quantization and the electron represented by a fixed Coulomb field. The Hamiltonian of the nucleon-meson system is diagonalized to second order in the coupling parameter by two canonical transformations—the divergent self-energy being absorbed into the experimental mass—and transitions induced between neutron states by the electron field are investigated. The pseudoscalar coupling term gives rise to a convergent "equivalent interaction potential" (see preceding abstract) of about -7 kev for the pure charged and -15 kev for the symmetrical meson theory. (The coupling constant is evaluated from the neutron-proton singlet scattering length, thus avoiding the high singularity of the tensor force.) It is also shown that the range of the interaction is about $\frac{1}{3}$ the classical electron radius, and the connection with "non-relativistic" methods of calculation is investigated. If pseudovector coupling is assumed, a logarithmically divergent interaction is obtained.

* AEC Predoctoral Fellow.

G5. Slow Neutron Velocity Spectrometer Studies: Al, Cr, C, Fe, Ni. W. W. HAVENS, JR. AND L. J. RAINWATER, *Columbia University.*—Aluminium shows strong resonances at 2300 ev and above 10,000 ev strong crystal interference effects in the thermal region are observed. Chromium shows a strong resonance at 4200 ev and weak dips at 12 ev and 18 ev which may be due to impurities. Below 10 ev the cross section closely follows the line $\sigma=(4.0+0.54E^{-\frac{1}{2}})$ (*barns*). The carbon cross section is constant at (4.70 $\pm$0.05) above 1 ev. Strong crystal effects are obtained in the thermal region with large "breaks" in the cross section at the critical wave-lengths. The cross section of iron below about 15,000 ev is well represented by the relation $\sigma=(11.2+1.02E^{-\frac{1}{2}})$ except in the thermal region where interference "breaks" are observed at $\lambda=2.3$, 2.8 and 4.1A. Beyond 4.1A the cross section drops from 19.0 to 6.5. Above 15,000 ev the Fe cross section decreases to about 5 at zero time of flight. Ni shows a resonance at 3600 ev with the cross section remaining above 16 below 1000 ev.

G6. The Scattering of Slow Neutrons by Paramagnetic Crystals. I. W. RUDERMAN, W. W. HAVENS, JR., T. I. TAYLOR, AND L. J. RAINWATER, *Columbia University.*—The paramagnetic scattering of neutrons by anhydrous crystals of manganese fluoride, manganese oxide, and manganese sulfate has been studied using slow neutron transmission data obtained with the Columbia velocity spectrometer for neutron wave-lengths up to 6.2A. The paramagnetic cross section, σ_{pm}, may be separated from the total cross section in regions where there are no interfering crystal diffraction effects. The results indicate a large paramagnetic cross section for the Mn^{++} ion in the compounds studied, in agreement with the theoretical calculations of Halpern and Johnson.[1] The observed dependence of σ_{pm} on the neutron wave-length has the predicted form. In the low energy region ($\lambda>4$A) it was necessary to use Be and BeO filters to reduce interference from fast neutrons. This paper is based on work performed for the Atomic Energy Commission.

[1] O. Halpern and M. H. Johnson, Phys. Rev. **51**, 992 (1937); *ibid.* **52**, 52 (1937); *ibid.* **55**, 898 (1939).

G7. New Calculations of Multiple Scattering.* H. S. SNYDER AND W. T. SCOTT,** *Brookhaven National Laboratory.*—The multiple scattering of particles passing through thin foils has been calculated with greater accuracy than heretofore. The small-angle approximation and the Born approximation for a potential $V=Ze^2/r\exp(-r/a)$ are used. The use of the Fokker-Planck type of diffusion equation that yields a Gaussian distribution is avoided, the integral equation being solved by Fourier transforms. The results are expressed in terms of dimensionless variables η and z, representing respectively the ratio of the angular deflection to a "minimum" angle determined by the screening, and the ratio of foil thickness to the mean free path for scattering. Numerical calculations for values of z from 100 to 84,000, and the complete range for η, have been carried out, and tables are being made available. The matching between the approximately Gaussian result for small angles and the Rutherford single scattering formula for large angles is clearly shown. The deviations of the new results from each of these limiting values is quite large over a wide range of angle. An explicit asymptotic formula for large η will be given.

* Work performed under the auspices of the Atomic Energy Commission.
** Now at Smith College.

G8. On Proton-Proton Scattering Models. L. GOLDSTEIN AND W. H. LANE, *Los Alamos Scientific Laboratory.*—An account will be given of a series of studies on the scattering of protons by protons in the approximation where the mutual electrostatic and nuclear fields are supposed to scatter separately. This approximation tends to become asymptotically correct with increasing kinetic energy of the incident protons. The nuclear interaction is represented by a square well-shaped mutual potential energy, whose characteristics in the two spin states are assumed to be the same as for a neutron-proton system. The well ranges studied varied between 1.5×10^{-13} to 2.8×10^{-13} cm, while the proton kinetic energy interval extends from 7 to 90 Mev. The nuclear interaction types used here include both the ordinary and exchange couplings. These studies represent an extension of similar work done on neutron-proton scattering models.[1]

[1] L. Goldstein and D. W. Sweeney, Los Alamos Declassified Reports, No. LADC-497 and -576, cf. also Phys. Rev. **74**, 1565 (1948).

G9. Some Calculations on Proton Proton Scattering. J. D. JACKSON AND J. M. BLATT, *Massachusetts Institute Technology.*—The Schwinger variational method[1] gives a rigorous justification for the Landau[2] analysis of proton proton scattering data. The data yield a perfectly straight line when analyzed in this way, showing that to a good approximation any short-tailed well with adjustable intrinsic range and depth can be made to fit the data. The size of higher, shape-dependent terms is limited by the experimental data. The results will be discussed in reference to the Yukawa well shape. The earlier work in this field[3] is confirmed by the present analysis.

[1] J. Schwinger, Phys. Rev. **72**, 742 (1947).
[2] L. Landau and J. Smorodinsky, J. Physics, U.S.S.R. **8**, 154 (1944).
[3] G. Breit, H. M. Thaxton, and L. Eisenbud, Phys. Rev. **55**, 1018 (1939).

G10. Water Drop Model of Radioactive Alpha-Decay. B. T. DARLING AND J. E. GARVEY, *The Ohio State University.*—An analysis has been made of the low energy alpha-particle spectra[1] associated with the transition $_{88}Ra^{226}\rightarrow\alpha+_{86}Rn^{222}$. The incompressible water droplet model of Bohr was adopted for the daughter nucleus. For the alpha-particle a rectangular potential well was assumed and then considered as perturbed by surface vibrations of the daughter nucleus. The J.B.W.K. method was used throughout to calculate the alpha-particle wave functions. A wave-packet function was formed inside the nucleus to describe the virtual normal alpha-particle state and transition probabilities calculated from this state to other levels of the continuum with the daughter nucleus excited. A power series expansion of the initial and final wave functions was used in the neighborhood of the varying nuclear radius to assist evaluation of the matrix elements of the perturbing surface vibration potential. The intensity ratios of the transitions to that associated with normal alpha-decay were calculated for various nuclear radii and various angular momenta of the emitted alpha-particle. An association of the energies of the emitted alpha-particle

with particular modes of surface vibration and angular momenta is made. Similar calculations on Polonium are in progress.

[1] W. Y. Chang, Phys. Rev. **69**, 60 (1946); **70**, 632 (1946).

G11. Calculation of Interaction Integrals in Wigner's Theory of Heavy Nuclei. DAVID H. FRISCH, *Brookhaven National Laboratory.**—Wigner[1] has calculated from observed nuclear binding energies the two interaction integrals I_s and I_a corresponding to space-symmetry and antisymmetry, respectively, of the nuclear wave function under interchange of two nucleons. An attempt may be made with somewhat the same model to calculate these quantities from different sources of information: (1) the magnitude of the observed two-body interaction in $p-p$ scattering, and (2) the stability of nuclei at the observed radii.[2] The magnitude and mass dependence of the average interaction integral $\frac{1}{2}(I_s+I_a)$ computed between nucleons in a finite sphere of Fermi gas excised from an infinite medium agrees fairly well with the same quantity obtained from observed binding energies. The ratio I_a/I_s must be approximately $\frac{1}{3}$ to give stability at the observed radii, whereas it must be even smaller to give the best fit to the total binding energy of heavy nuclei.

* Summer visitor, 1948; permanent address: Department of Physics, Massachusetts Institute of Technology.
[1] E. Wigner, Phys. Rev. **51**, 106 (1937); Phys. Rev. **51**, 947 (1937); and University of Pennsylvania Bicentennial Conference, "Nuclear Physics," University of Pennsylvania Press, Philadelphia (1941).
[2] See, for example, H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. 153 (April, 1937), and H. Euler, Zeits. f. Phys. **105**, 553 (1937).

G12. Application of Charge-Symmetrical Nuclear Forces to Wigner's Theory of Heavy Nuclei.* V. F. WEISSKOPF AND DAVID H. FRISCH, *Massachusetts Institute of Technology.*—Wigner's statistical theory[1] of heavy nuclei was developed for an arbitrary mixture of Majorana and ordinary forces. The effect of using the charge-symmetric force, the symmetry properties of which are given by the $\sigma^i\cdot\sigma^j\tau^i\cdot\tau^j$ operator, has been investigated in the hope of improving the agreement between theory and experiment, particularly for medium weight even nuclei. The number of interactions between pairs of nucleons corresponding to each eigenvalue of the operator has been evaluated in terms of the S, T, and Y quantum numbers. Even if these were good quantum numbers, it would be impossible to improve the predictions of energy released in β-transitions between isobars, without spoiling the rough predictions of total binding energy by the same theory. That S, T, and Y are not good quantum numbers for the $\sigma^i\cdot\sigma^j\tau^i\cdot\tau^j$ operator[2] can only make any possible difference between $\sigma^i\cdot\sigma^j\tau^i\cdot\tau^j$ and Wigner's mixture less pronounced, so that (1) Wigner's Majorana plus ordinary mixture gives as good a fit as can be obtained with any reasonable combination of forces, and (2) $\sigma^i\cdot\sigma^j\tau^i\cdot\tau^j$ gives as good results only if the repulsive interactions are quite small.

* Assisted by the Joint Program of the O.N.R. and the A.E.C.
[1] E. Wigner, Phys. Rev. **51**, 106 (1937); Phys. Rev. **51**, 947 (1937); and University of Pennsylvania Bicentennial Conference, "Nuclear Physics," University of Pennsylvania Press, Philadelphia (1941).
[2] J. Blatt (Private communication) has shown that S, T, and Y cannot be good quantum numbers for the $\sigma^i\cdot\sigma^j\tau^i\cdot\tau^j$ operator in particular, and for any three or more eigenvalue operator in general.

G13. Spins, Moments, and Shells in Nuclei. L. W. NORDHEIM, *Duke University.*—Known values of spins and magnetic moments can be used to assign orbital quantum numbers to the last odd particle in a nucleus. The order of the orbits is in the main given by the sequence $(1s)(2p)(2s3d)(4f3p4d)(5g5f)$, $(6h3s\cdots)$ which is close to the order of levels in a potential well. The bracketed combinations form the successive shells of 2, 6, 12, 30, and 32 particles (neutrons or protons) that are known to be particularly stable. The sequence is not strictly adhered to in the building-up process of shells, but new orbits never deviate much from it. There are some differences in the behavior of protons and neutrons for high atomic numbers. Besides an interpretation of the general trends shown by nuclear spins, an explanation is also obtained for the allowed or forbidden character of β-transitions of nuclei with odd mass numbers. A rule that is adhered to in a great majority of cases is that isomeric states occur mostly when nuclear shells are not completely filled. The scheme permits the correlation of a wide variety of nuclear data and fits generally much better than one would have expected.

G14. Classification of Isomeric Transitions. P. AXEL AND S. M. DANCOFF, *University of Illinois.**—An attempt has been made to classify the known nuclear isomeric transitions into groups according to the multipole order of the γ-ray involved. This classification is based on the relation between the γ-ray lifetime and the excitation energy. Since internal conversion competes with γ-ray emission, the experimentally observed lifetimes must be corrected by the formula $\tau_\gamma=\tau_{\exp}(1+\alpha)$ where $\alpha\equiv$theoretical internal conversion coefficient. The corrected data for 50 isomeric transitions are shown to define two fairly distinct groups corresponding to 2^4 and 2^5 electric multipoles. The data are compared with the classically derived formula for the rate of 2^L pole radiation from a current distribution:

$$\tau_\gamma=3(L!)^2\rho^{-2L}(\hbar c/e^2)^{2L+1}(W)^{-2L-1}(\hbar/mc^2)$$

where $\rho\equiv$nuclear radius in units of e^2/mc^2, and $W\equiv$energy of transition in units of mc^2. Reasonable agreement is shown with regard to both functional dependence and absolute numerical coefficient.

* Assisted by the Joint Program of the Office of Naval Research and Atomic Energy Commission.

Ferromagnetism, Ferroelectricity, Order-Disorder

H1. Field or Search Coils Combining Loops and Solenoids. MILAN W. GARRETT, *Swarthmore College.*—Calculations previously reported are extended to combinations of thin loops with solenoids, and to coils of large section. Some combinations are better than any previously reported using the same number of elements. Maxwell, Lyle, and McKeehan have eliminated one or more second-order section errors. Further improvement results when the appropriate coefficients of internal or external magnetic moment (for field and search coils respectively) are integrated over the section; loops and solenoids then become identical. The integrals are simple polynomials; when nine or ten orders are tabulated it appears that refinement of coil design is limited principally by the time allotted to computation. Coils may be designed so massive that the elements fuse. Using two pairs of elements, one percent error limits approach half the mean radius for field coils, and 2.5 times the mean radius for search coils. Three

successive coefficients may be removed leaving errors of eighth order. For given uniformity, these designs yield stronger fields or gradients than any previously available without iron. The dipole search coils for point field measurements appear far simpler to construct than the "fluxball," especially in small sizes, while simple quadrupole designs permit point measurements of gradient.

H2. Magnetic Properties of a Ferromagnetic Ferrite (Part I). FRANK G. BROCKMAN, P. H. DOWLING, AND WALTER G. STENECK, *Philips Laboratories.*—In investigating the magnetic behavior of one of the ferromagnetic ferrites developed by Philips, Eindhoven, under the trade name FERROXCUBE, we have established the fact that the resonant frequency which has previously been found[1] in this material and which has usually been attributed to magnetic resonance is a function of the linear dimensions of the sample. We have therefore concluded that this resonance is not due to a true magnetic resonance. We have found also that the behavior exhibited can be explained if the conductivity of the material is complex as will be developed in the following paper. Experimentally the effect has been demonstrated not only with magnetic cores of various dimensions but also with cores of the same gross dimensions but differing in that one was solid and the other laminated. Typical results from measurements on specimens of this material are as follows: initial permeability 1000, specific resistivity 100 ohm cm, dielectric constant, real part, 50,000, and dielectric constant, imaginary part, 20,000.

[1] J. L. Snoek, Physica **14**, 207–217 (1948).

H3. Magnetic Properties of a Ferromagnetic Ferrite (Part II). P. H. DOWLING AND FRANK G. BROCKMAN, *Philips Laboratories.*—Equations have been developed for the equivalent series reactance and resistance for sinusoidal currents in a coil wound on a toroidal core having dielectric, magnetic and ohmic conducting properties. The dielectric constant is taken to be complex while the magnetic permeability is taken to be a real quantity only. The magnetic permeability, both components of the dielectric constant, and the ohmic conductivity are assumed to be independent of the frequency and magnitude of the current in the coil. The equations are rigorous and include the skin effect in the core. When suitable values, consistent with experimental measurements, are taken for the dielectric constants, the permeability, and the conductivity, the form of the resulting reactance-frequency and resistance-frequency curves are strikingly similar to the experimental curves described in the preceding paper for one of the ferromagnetic ferrites. It appears that the major features of the magnetic behavior of this material can be accounted for, at least in the absence of superimposed magnetic fields and up to 100 megacycles, without the assumption of true magnetic resonance.

H4. Statistics of the Three-Dimensional Ferromagnet. D. TER HAAR AND B. MARTIN, *Purdue University.*—An attempt is made to apply the variational method of Kramers[1] to the three-dimensional ferromagnet. In this case, it is necessary to reduce the partition function twice. Each of these two reductions leads to an eigenvalue problem, the solution of which can be approximated by the Ritz method. The final secular equations which have to be solved are of the sixteenth and fourth degree. The solution of the fourth degree equation has been given by Kramers and Wannier[1] or Groen.[2] The other equation can be reduced to a sixth degree equation, if one uses the symmetry properties of the matrix involved. It will be shown how one can obtain a power series for the partition function in the way indicated by Groen[2] and how the Curie point can be calculated from these equations. It will also be shown that the rigorous solution of the two-dimensional ferromagnet given by Onsager[3] can be used to simplify the calculations.

[1] H. A. Kramers and G. H. Wannier, Phys. Rev. **60**, 252 (1941).
[2] P. Groen, "Orde en Wanorde in de Eenvoudigste Roosters," Thesis, Amsterdam, 1942.
[3] L. Onsager, Phys. Rev. **65**, 117 (1944).

H5. A Mathematical Model of a Ferromagnet. M. KAC AND T. H. BERLIN, *Cornell University and Northwestern University.*—A mathematical model of a ferromagnet for which the partition function can be explicitly evaluated will be presented. The model is a modification of the Ising model of a ferromagnet. Whereas the Ising model requires the summation of the Boltzmann factor over all spin configurations with the condition $\mu_i = \pm 1$, $i = 1, 2, \cdots, N$, where μ_i is the spin at the ith lattice site, the present model modifies the condition to $\Sigma_{i=1}^{N} \mu_i^2 = N$, where each spin is allowed to range continuously from $-N^{\frac{1}{2}}$ to $+N^{\frac{1}{2}}$. The partition function and magnetic equation of state have been obtained for the linear chain, square mesh, and simple cubic lattices all with nearest neighbor interaction. (The nearest neighbor and simple lattice restrictions are unnecessary for the evaluation of the partition function of this model.) The cubic lattice exhibits an order-disorder transition with a finite specific heat. The magnetic equation of state is essentially the same as that of the Weiss phenomenological theory of magnetism. No order-disorder transition is exhibited by the square mesh and by the linear chain.

H6. Magnetic Resonance Absorption in Magnetite as a Function of Temperature.* L. R. BICKFORD, JR., *Massachusetts Institute of Technology.*—Magnetite is known to undergo a transition at -160°C characterized by anomalous effects in specific heat, conductivity and magnetization. The initial permeability goes through a sharp maximum 30° higher than this. Resonance absorption measurements were made at 9000 megacycles with thin circular disks cut from the (100) plane of natural single crystals of magnetite mounted on a wall of a resonant cavity. Values of magnetic field strength corresponding to the absorption maximum were obtained as a function of temperature and of the angular displacement of the [100] direction of the crystal from the d.c. magnetic field direction. From this information, and the saturation magnetization, values of g and anisotropy constant K_1 can be calculated.[1] Upon lowering the temperature, K_1 varies from about -10^5 at room temperature to $+6\times10^4$ at -160°C, rising abruptly through zero near -140°C. That is, the material is magnetically isotropic near the temperature at which the initial permeability passes through a maximum. The resonance absorption increases with decreasing temperature to a maximum

at −157°, falls steeply in the transition region, and is undetectable below −163°C.

* This work was supported jointly by the Navy Department (Office of Naval Research), the Army Signal Corps, and the Army Air Forces (Air Matériel Command).

[1] C. Kittel, Phys. Rev. **73**, 155 (1948).

H7. Effect of Ordering on Magnetostriction and Magnetization. J. E. GOLDMAN, *Westinghouse Research Laboratories* AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology*.—The effect of an order-disorder transformation on the saturation moment and magnetostriction of a 50 atomic percent Iron-Cobalt alloy has been investigated. The magnetization measurements were made using a double coil method with the sample placed in one of them and the pair of coils placed in the uniform field of the Westinghouse Research electromagnet. Moments were measured on a ballistic galvanometer to an accuracy of 0.25 percent at fields up to 14,000 Oersteds. Magnetostriction measurements were made with the resistance strain gauge technique previously described.[1] Measurements of electrical resistivity and neutron diffraction were carried out (the latter at Oak Ridge by Dr. S. Siegel) to indicate the degree of order. An increase in both the magnetization and magnetostriction is observed on ordering. The increase in saturation moment is of the order of 4 percent rising from a value of 2.25 Bohr magnetrons per atom in the disordered state to 2.35 when ordered. The observed increase in saturation magnetostriction is of the order of 40 percent.

[1] J. E. Goldman, Phys. Rev. **72**, 529 (1947).

H8. Theory of the Effect of Ordering on Magnetic Properties. R. SMOLUCHOWSKI, *Carnegie Institute of Technology* AND J. E. GOLDMAN, *Westinghouse Research Laboratories*.—A theory has been developed to account for the observed increase in magnetostriction and magnetization of a 50-50 Iron-Cobalt alloy on ordering.[1] The calculations are based essentially on the dipole model in which the effective magnetic moments are computed on the basis of the average electron density of individual pairs of atoms. The probabilities of various local electron concentrations are obtained and the corresponding magnetic moments assigned according to the band theory. The resulting moments for the ordered and disordered alloys are 2.37 and 2.27 in good agreement with experiment. The magnetostriction is obtained using the interaction between dipoles in nearest and second nearest positions. Due to the dependence of the magnetic moments on order, the magnetostriction for the perfectly ordered state appears to be 85 percent higher than for the completely random state. This compares favorably with the observed increase of 40 percent. The discrepancy can be explained as resulting from the imperfect state of order and disorder in the experimental samples. Similar agreement is obtained for the 45 Fe, 55 Co alloy for which the theoretical increase of 70 percent is to be compared with the experimental value of 30 percent.

[1] J. E. Goldman and R. Smoluchowski, see previous abstract.

H9. Disorder in Thin Films of Silver and Silver Iodide Formed on Silver Bromide Crystals. CHESTER R. BERRY, *Eastman Kodak Company*.—The electron diffraction reflection method has been used to examine thin deposits formed on large single crystals of silver bromide. Evaporated silver was deposited to an average depth of about one and a half atomic diameters. Silver iodide layers were formed to a depth of roughly 100A by reaction of the silver bromide in dilute solutions of potassium iodide and of a cyanine iodide dye. That part of the silver deposit which is highly oriented is in several preferred orientations. The number of orientations observed from a diffraction pattern depends on the identity of the face on which the deposit is made and on the direction of the electron beam in that face. Four orientations was the maximum observed. When silver iodide is formed on the substrate, several orientations may occur, often in both the cubic and hexagonal modifications. The various orientations and structures of these thin films may be accounted for by assuming the coating layers to be built up by a disordered stacking of close-packed layers on minute octahedral faces of the substrate.

H10. The Dielectric Properties of Barium Titanate at Low Temperatures.* R. F. BLUNT,** W. F. LOVE, AND E. N. SKOMAL, *Rice Institute*.—The complex dielectric constant, K, of several specimens of multicrystalline barium titanate was measured at radio frequencies from room temperature down to 2.38°K. The real part, K', has a value of about 1100 at 300°K rising to a maximum of 1300 at 275°K and falling parabolically as the temperature decreases, reaching a value of 96 at 2.38°K. The temperature coefficient has the remarkably high value of 10^{-2} degree^{-1} in the 2–5 degree region. For 500 kc the imaginary part, K'', is small at room temperature rising to a very broad maximum at 200°K and decreasing to a small value at 4°K. The measurements were made with a radio frequency bridge and also with a "Q" meter. Most work was done at 500 kc. The specimens were in the form of parallel plate condensers which were kindly supplied to us by the Bell Telephone Laboratories. A physical interpretation and measurements on diluted specimens will be discussed.

* This work was supported in part by Navy Contract.
** Socony-Vacuum Fellow in Physics.

H11. The Phase Transitions in Barium Titanate.* P. W. FORSBERGH, JR., *Massachusetts Institute of Technology*.—In ferroelectric $BaTiO_3$ marked optical changes are observed at 5°C and −70°C. These can be completely accounted for if one supposes that between 5°C and −70°C the eccentric displacement of the titanium ions is along a [101] direction of the original cube, giving rise to an orthorhombic distortion Cmm, while below −70°C it is along a [111] direction, producing a trigonal lattice R3m. Unlike the second-order transition at the Curie point (120°C), these two transitions are of the first order, although all three involve no order-disorder effects. Consideration of the temperature dependence of the Gibbs free energy curves indicated by the nature of the transitions yields the main features of many properties, such as the much larger dielectric constant perpendicular to the polar axis, the small dielectric peaks at 5°C and −70°C in the ceramic and their enhancement by larger fields, the sensitivity of the optical properties to lattice strains, the shape of hysteresis loops, and the changes in birefringence down to −150°C.

* This work was supported jointly by the Navy Department (Office of Naval Research), the Army Signal Corps, and the Army Air Forces (Air Materiel Command).

J1. Non-Linear Viscous Elasticity and Secondary Bond Rupture. G. D. HALSEY, JR., *Harvard University.*—In the study of the visco-elastic behavior of wool and rubber-like materials, the spring-dashpot model is discarded in favor of models based on the rupture of secondary bonds. If these bonds are connected in series the typical rubber-like stress-strain curve results. The exact nature of the curve depends on how these bonds break and reform. The resulting stress-strain curves cannot be explained with a spring-dashpot model, even including non-linear elements. Further study shows the presence of bonds in parallel, on which the stress concentrates owing to breakage. The presence of these bonds allows thixotropic humps and rupture to be explained. The various conditions under which these different explanations are valid and required are discussed.

J2. Reinforcement and Swelling of Butyl Rubber-Filler Systems. ROBERT L. ZAPP, *Standard Oil Development Company,* AND EUGENE GUTH, *University of Notre Dame.*—This study is an attempt to gain further insight into the reinforcement of polymeric networks by filler particles through the agency of volume swelling of Butyl rubber vulcanizates. Because of its low chemical unsaturation, a maximum state of cure can be realized with all types of filler loadings while the network remains in a soft and elastic condition. Thus filler reinforcement is compared in networks of equal concentration of chemical cross-links. In this study carbon blacks of varying particle diameter are compared to representative types of mineral fillers. In the case of carbon blacks, as the volume loading is increased the volume swelling of the purse hydrocarbon polymer is reduced. With mineral fillers this effect is not as evident, and in some cases there is little or no change of volume swelling (over a non-pigmented control) as volume loading of the mineral filler increases. Comparisons between the volume swellings of a pigment network and its elastic properties indicate that there is a direct correlation between the increase in elastic modulus and the reduction in volume swelling. A comparison between the contribution of chemical cross-links and secondary filler forces to network rigidity is discussed. An analysis of the relative contributions of carbon blacks and mineral fillers based upon the actual surface area added per volume of polymer shows the superiority of the carbon surface (regardless of particle size) over mineral pigment surfaces. Photomicroscopic evidence corroborates the data on filler surfaces.

J3. A Kinetic Concept of Elasticity. R. S. BARKER, W. O. SEIFERT, AND J. H. DILLON, *Textile Research Institute.*—Prediction of the mechanical behavior of high polymeric materials under stress has received much attention of late years. Several workers have given attention to such materials as natural rubber, polyethylene, and cellulose derivatives. Such considerations led to network theories for rubber. Tobolsky, Eyring, Halsey, *et al.*, applied modern reaction rate theory to their mechanical concept of materials exhibiting time dependency. This work gave good results for cellulose derivative fibers, but seemed inapplicable in its simple form to many other important polymeric materials. The Office of Naval Research has sponsored a program of study on the Resilience of Fibers in the Princeton laboratories of the Textile Foundation. In connection with this program, experimental and theoretical studies were made on materials showing, in the terms of previous theories, an anomolous behavior. A new concept of flowing molecular chain deformations in the amorphous regions of fibrous materials has resulted in the formulation of a new theory of elasticity. The mathematical formulations of stress-strain-time relations based on this kinetic viewpoint coupling the chemical structure of polyamides and the energetics of their deformation have resulted in equations which not only conform to the experimental data, but also allow the prediction of the behavior of the given polymeric material under stress. The results of x-ray diffraction studies lend validity to the theory.

J4. The Dependence of the Tensile Strength of Vulcanized Rubber on the Degree of Cross-Linking.* PAUL J. FLORY, NORMAN RABJOHN, AND MARCIA C. SHAFFER, *Cornell University.*—Tensile strengths of natural rubber samples quantitatively cross-linked with decomethylene dis-methyl azodicarboxylate have been determined. The rapid increase in tensile strength with the degree of cross-linking ρ for small values of this quantity is consistent with the hypothesis that the tensile strength is directly related to the fraction of the structure which is permanently oriented by stretching. At higher degrees of cross-linking ($100\rho = 1.0$ to 1.5, depending on the molecular weight of the rubber) the tensile strength passes through a maximum and then declines steadily to quite low values for higher ρ's. This adverse effect of higher degrees of cross-linking is believed to result from the diminished elongation at which crystallization sets in and, hence, the smaller fraction of the network elements sufficiently oriented to participate in crystallite formation. Modification of up to 7 percent of the isoprene units of the rubber with the monofunctional compound, ethyl azodicarboxylate, depresses the tensile strength of the dis-azo vulcanized rubber relatively little. Evidently, the limited extent to which these modified chains may enter into crystallization is adequate to bring about high tensile strength. Deviations from the mean for 262 tests are well represented by a Gaussian error function.

* The work presented in this paper was carried out at the Goodyear Research Laboratory under contract to the Office of Naval Research.

J5. Equation of State for Polystyrene. R. S. SPENCER AND G. D. GILMORE, *Dow Chemical Company.*—Practical considerations emphasize the desirability of formulating an adequate equation of state for polystyrene. A fairly satisfactory one is this simplified version of van der Waal's equation,

$$(P+\pi)(V-\omega)=nRT$$

where π is the internal pressure (or cohesive energy density) and ω is the volume at absolute zero, by extrapolation. Evaluating constants from thermal expansion data[1] and expressing P in p.s.i., V in ccs per gram, and T in degrees Kelvin, this becomes

$$(P+27{,}000)(V-0.822)=11.6T.$$

Agreement with compressibility measurements, which are described in some detail, is good. Discrepancies with room temperature values of sound velocity and cohesive energy density by swelling measurements[2] are discussed briefly.

[1] R. S. Spencer and R. F. Boyer, J. Applied Phys. **17**, 398 (1948).
[2] R. F. Boyer and R. S. Spencer, J. Polymer Sci. **3**, 97 (1948).

J6. Dynamics of Polymer Solutions and the Deformation of Separate Macromolecules. W. O. BAKER, W. P. MASON, AND J. H. HEISS, *Bell Telephone Laboratories.*—Mechanical properties in shear of dilute (0-1 g/100 cc) solutions of polyisobutylene, polystyrene, natural rubber, and polybutadiene microgel have been investigated at 20, 40 and 80 kc and at 7.5, 25 and 60°C. These frequencies, provided by torsionally vibrating piezo-electric crystals, correspond to times near the "macro constellation changing time" with which Kuhn proposed to characterize hypothetical shape changes in individual chain molecules. These shape changes cause entropy changes which ultimately lead to high elasticity. Accordingly, definite rigidity, μ, as well as dynamic viscosity, should be observed even in most dilute solutions; indications of such rigidity previously have been at such low frequencies that chain interaction has seemed responsible. However, significant μ-values which are analyzed to increase practically linearly with polymer concentration have now been found for all the systems listed. For instance, polyisobutylene of $\bar{M}_\eta = 1.18\times10^6$ has $\mu\sim800$ dynes/cm² at 20 kc, ~1300 dynes/cm² at 40 kc and ~1500 dynes/cm² at 80 kc in a 1 percent solution at 25°C. Several fold variations in average molecular weight affect μ very little; it is also temperature insensitive, often increasing slightly at higher temperatures (as contrasted to exponential *decrease* for μ of pure polyisobutylene). μ is sensitive to structure; compared to the internally-hindered polyisobutylene, polystyrene in benzene (with $\bar{M}_\eta = 234{,}000$) at 40 kc has $\mu\sim700$ dynes/cm². Polybutadiene microgel ($\bar{M}_w = 18.6\times10^6$), with its own tiny network, has $\mu\sim1800$ dynes/cm² at 40 kc, again in a 1 percent solution of cyclohexane, at 25°C.

J7. Relationship Between Structure, Mechanical Properties and Birefringence in Polymeric Materials. R. S. STEIN, S. KRIMM, AND A. V. TOBOLSKY, *Princeton University.*—A thermodynamic analysis of the stretching properties of polyvinyl chloride and lactoprene is made by use of reversible stress temperature data. Simultaneous birefringence measurements are used to infer configurational changes of these polymers during stretching. Configurational changes accompanying "second-order transitions" are discussed in terms of the experimental data.

Neutron Physics

K1. Determination of Absolute Neutron Intensities.[1] ROGER W. PAINE, JR., JOHN E. DACEY, *U. S. Navy* AND CLARK GOODMAN, *Massachusetts Institute of Technology.*—Through the cooperation of the ORNL, the neutron intensity of a 1.03-gram Ra−Be source has been determined and the neutron flux has been standardized. Gold and indium foils, bare and cadmium covered, were activated in the ORNL standard pile. The gold activity (2.7 day) was measured in Cambridge and the indium activity (54 min.) at Oak Ridge. By exposing the same foils near the Ra−Be source in an effectively infinite water medium, the absolute thermal and indium resonance fluxes throughout this medium were determined. The slowing-down density at indium resonance was graphically integrated over all space, and divided by the resonance escape probability to obtain the absolute source strength. Foil depression corrections for disc detectors in thermal fluxes were applied using the formula derived by Bothe.[2] Bothe's formula was verified experimentally to an accuracy of better than one percent for indium foils in a water medium.

[1] The work herein reported was supported in part by the Office of Naval Research.
[2] W. Bothe, Zeits. f. Physik **120**, 437 (1943).

K2. Nuclear Shielding Studies.[1] JOHN E. DACEY, ROGER W. PAINE, JR., *U. S. Navy* AND CLARK GOODMAN, *Massachusetts Institute of Technology.*—The effectiveness of composite shields against neutrons and γ-rays was investigated with a 1.03-gram Ra−Be source centered in a spherical steel shell (6-, 4-, and 2-inch radii) centrally positioned in a 4-foot cubical tank. Shielding materials in the shell: Pb, Fe, W, WC, B_2O_3, B_4C, H_3BO_3, sand, air, water, brine. Media in the tank: water, saturated brine, sea water, boric acid solutions. The spatial distributions of thermal and resonance neutrons were determined with indium foils; the γ-ray intensities were measured with pocket-type dosimeters. Calibrations enabled the neutron fluxes to be expressed in absolute units. Minimum shields (weight and size) were determined. Estimates of average inelastic scattering cross sections were obtained using Marshak's[2] and Flügge's[3] calculations by comparing the resonance distribution for air in the shell with that for heavy scatterer in the shell. An attempt has been made to interpret the experimental results by means of slowing-down and diffusion theories for hydrogenous media.

[1] The work herein reported was supported in part by the Office of Naval Research.
[2] R. E. Marshak, Rev. Mod. Phys. **19**, 185–238 (1947).
[3] S. Flügge, Phys. Zeits. **44**, 445–455 (1943).

K3. Shielding Measurements in Concrete.[1] VICTOR DELANO *U. S. Navy*, AND CLARK GOODMAN, *Massachusetts Institute of Technology.*—The effectiveness of the new four-foot concrete shield of the MIT cyclotron has been measured using circular foils for neutron detection and duPont 552 films for total gamma-measurements. Fast neutrons were measured for thresholds of 4.3, 6.9 and 7.7 Mev (calculated from Bethe's penetrability function[2]) by counting the beta-active products of $Al^{27}(n, p)Mg^{27}(10.2^m)$, $Fe^{56}(n, p)Mn^{56}(2.59^h)$ and $Al^{27}(n, \alpha)Na^{24}(14.8^h)$ respectively. Al foils: 165 mg/cm², Fe foils: 200 mg/cm². Thermal activation was eliminated by Cd holders. Resonance (1.44 ev) and thermal neutron distributions measured by Cd-In-Cd and In, corrected according to Bothe,[3] were reduced to absolute intensities by the method described by Paine, Dacey, and Goodman. Measurements were made with cylindrical concrete blocks 2 inches and 4 inches in length which fitted into a $4\frac{1}{2}$-inches diameter hole whose axis was about 22° with the direction of the deuteron beam at the cyclotron target and which extended through the concrete wall. Each block was recessed at one end to hold a foil or film. Preliminary results indicate a relaxation length of about 14 cm for the fast neutron component.

[1] The work herein reported was supported in part by the Office of Naval Research.
[2] H. A. Bethe, Rev. Mod. Phys. **9**, 166 (1937).
[3] W. Bothe, Zeits. f. Physik **120**, 437 (1943).

K4. Photographic Neutron Detector of High Sensitivity. THOMAS H. JOHNSON,* *Brookhaven National Laboratory.*—When a parallel plate Geiger counter containing a quenching vapor is discharged by an ionizing ray a minute spark, characterized by a brilliant glow on the cathode, jumps between the electrodes, at the point where the discharge is

initiated. In the present device this phenomenon has been utilized for obtaining a photographic reproduction of the areas of an indium foil which have been activated by slow neutron irradiation. After activation the indium foil is mounted as the cathode of a counter whose anode is a plate of conducting NESA glass. While the counter is discharging, an ordinary photograph is taken with the camera looking perpendicularly through the glass anode. Since indium, itself, seems unsuitable as a cathode material, although it appears to function satisfactorily as an anode with NESA as cathode, the indium has been covered with a thin foil of pure tin. Satisfactory results have been obtained in preliminary tests with shadow graphs of a cadmium mask. The smearing of the spark pattern due to scattered beta-rays from the indium and to secondary x-rays has been studied by means of a composite cathode containing a sharply demarcated pattern of lead inlaid into the indium. Suggested applications for the detector include the recording of neutron diffraction and scattering patterns, pinhole camera photographs of neutron sources, and neutron shadow graphs.

* Research carried out at Brookhaven National Laboratory under the auspices of the Atomic Energy Commission.

K5. Total Cross Sections of Small Samples of Hf, Er, Ni^{58} and Ni^{60} from Neutron Crystal Spectrometer Measurements. S. BERNSTEIN, J. B. DIAL, C. P. STANFORD, AND T. E. STEPHENSON, *Oak Ridge National Laboratory.*—A focusing type spectrometer using a variable curvature quartz crystal as originally described[1] by L. Borst, *et al.*, has been developed further for measuring total cross sections *versus* energy of small samples of rare elements and separated isotopes. Samples having cross sections from 0.1 to 1.0 square millimeters have been used as absorbers. The main features of the new instrument are described. Test runs were made on normal cobalt, whose total cross section was found to fit the formula, $\sigma(\text{barns}) = 5.8 + 6.17\ (E \text{ in ev})^{-\frac{1}{2}}$, in fair agreement with earlier results.[2] A resonance at about 1 ev attributed in the literature to zirconium was found to belong to hafnium. Erbium was found to have a neutron resonance at about 0.5 ev Ni^{58} was found to be the isotope primarily responsible for the anomalously high scattering cross section of normal nickel, confirming the recent (unpublished) results from neutron diffraction studies of C. G. Shull, E. O. Wollan, and M. C. Marney, at Oak Ridge National Laboratory. Results are given also for Ni^{60}.

[1] L. B. Borst, A. J. Ulrich, C. L. Osborne, and B. Hasbrouck, Phys. Rev. **70**, 108 (1946).
[2] C. S. Wu, L. J. Rainwater, and W. W. Havens, MDDC 480.

K6. On the Absorption of Slow Neutrons by He_3 Nuclei. L. D. P. KING AND LOUIS GOLDSTEIN, *Los Alamos Scientific Laboratory.*—Using the enriched uranium pile of this Laboratory, the absorption of thermal and subthermal neutrons by He_3 nuclei was studied in the average neutron energy range of $16k \leqslant kT \leqslant 425k$, k being Boltzmann's constant. The subthermal energy neutrons have been obtained by filtration through increasing thicknesses of graphite. It is found that the total absorption cross section of He_3 for these neutrons obeys the "$1/v$" law in this energy range. The value of the product $(\sigma_a \times v)$ averaged always over the velocity distribution of the incident neutron beam, σ_a denoting the absorption cross section and v the neutron velocity, was found to be $(11.2 \pm 0.5) \times 10^6$ barns $\times$ meters $\times$ second^{-1}. The error indicated results from a very conservative estimation of this quantity. The thermal neutron ($293k$) absorption cross section turns out to be about 5000 barns, in good agreement with a direct measurement of the $He_3(n, p)H_3$ reaction cross section obtained in this laboratory by J. H. Coon. Within the precision of the absorption measurements, there is evidently room for elastic scattering or other types of cross sections at these low energies. It is planned to extend these studies to higher energy neutrons corresponding to the resonance groups of a number of nuclei.

K7. On the Interpretation of Neutron Inelastic Scattering Data. BERNARD T. FELD, *Massachusetts Institute of Technology.*—Data on inelastic scattering of fast neutrons, mainly due to the Los Alamos group,[1] yield the following information: (1) For incident energies up to 3 Mev, the distribution of inelastically scattered neutrons from Fe can be understood in terms of a simple system of levels spaced $\sim$0.8 Mev apart, together with reasonable cross sections for their excitation. Other data confirm this level scheme. (2) The distributions of inelastically scattered neutrons from W and Au agree well with the predictions of Weisskopf's statistical theory,[2] assuming a reasonable, $\sim$50 kev, spacing of the lowest levels. (3) The Pb data require an interpretation similar to Fe, with approximately the same ($\sim$0.8 Mev) level spacing indicated. The data of Dunlap and Little[3] on the inelastic scattering of 2.5 Mev neutrons are consistent with this interpretation. Because of the large level spacing, the statistical theory is not meant to be applicable to Fe or Pb at low incident neutron energies. These results further confirm the observation that the nuclear characteristics of Pb are in many respects those of a "light" element.

[1] H. H. Barschall, M. E. Battat, W. C. Bright, E. R. Graves, T. Jorgensen, and J. H. Manley, Phys. Rev. **72**, 881 (1947).
[2] V. Weisskopf, Phys. Rev. **52**, 295 (1937).
[3] H. F. Dunlap and R. N. Little, Phys. Rev. **60**, 693 (1941).

K8. Spin-Dependent Neutron Scattering by Various Nuclei. C. G. SHULL AND E. O. WOLLAN, *Oak Ridge National Laboratory.*—In the scattering of neutrons by protons, it has been shown by several independent experiments[1,2] that the scattering amplitudes for the two spin states are markedly different. Similar conclusions concerning the presence or absence of spin-dependent scattering by other nuclei can be derived from a determination of the coherent scattering cross section in neutron diffraction experiments. If the coherent scattering cross section is measurably smaller than the total scattering cross section for a specific nucleus, it can be concluded that the incoherence is caused by spin-dependent scattering. From measurements performed on 17 specific nuclei possessing nuclear spin, it has been found that 10 of these show pronounced differences in these two cross sections. These include H, D, Li^7, N, Na, V, Mn, Co, As and Cs. On the other hand, Be, F, Al, Cb, I, Au and Bi show little or no spin incoherence and hence the scattering amplitudes for the two spin states must not be appreciably different for these nuclei.

[1] R. B. Sutton, T. Hall, *et al.*, Phys. Rev. **72**, 1147 (1947).
[2] C. G. Shull, E. O. Wollan, G. A. Morton, and W. L. Davidson, Phys. Rev. **73**, 830 (1948).

K9. On the Delayed Neutron Emitter $_7N^{17}$.* K. H. SUN, B. JENNINGS, W. E. SHOUPP, *Westinghouse Research Laboratories*, AND A. ALLEN, *University of Pittsburgh.*—The

formation of N^{17}, the only known light nucleus that emits delayed neutrons (half-life 4.14 sec.), was reported by the University of California group.[1] It was made by bombarding oxygen and elements immediately above it with 195 Mev deuterons. By using 30 Mev or lower α-particles from the University of Pittsburgh cyclotron, we were able to induce the reaction $C^{14}(\alpha, p)N^{17}$. The half-life of the delayed neutrons from the N^{17} formed was observed to be 4.6 sec. ± 1 sec. The upper limit of the threshold for the α-particles of the above reaction is about 16 Mev and the cross section for 28 Mev α-particles is about 0.06 barn. The formation of N^{17} by other processes and the possibility of other delayed neutron emitters are being investigated.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

[1] N. Knable, E. O. Lawrence, C. E. Leith, B. J. Moyer, and R. L. Thornton, Bull. Am. Phys. Soc. **23** (3), 20 (1948); W. E. Chupp and E. M. McMillan, Bull. Am. Phys. Soc. **23** (3), 20 (1948); L. W. Alvarez, Bull. Am. Phys. Soc. **23** (3), 20 (1948).

K10. Coincidence Measurement of Neutron Energies. D. C. WORTH, *Yale University.**—A coincidence technique has been developed by means of which the energy of neutrons may be determined. Protons which originate as recoils from the incident neutrons in a hydrogen-filled proportional counter pass through a variable amount of absorption into a second proportional counter. Coincidences between the two counters are registered on the output of a medium resolution coincidence circuit, and are normalized to the counting rate in the first counter. A plot of coincidence rate as a function of absorption gives the extrapolated range and energy of the scattered protons, hence of the neutrons. This technique has been applied to the $C^{12}(dn)N^{13}$ reaction with the result that several groups have appeared, one of which may be identified as the ground state of N^{13}.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

Physics of Liquids; X-Rays

L1. The Conductivity of Dilute Water Solutions Near the Critical Temperature. G. E. OWEN, *Antioch College.*—The impedance of dilute NaCl solutions and of the vapor above the solutions has been continuously recorded on a Micromax recorder which also recorded the temperature of the bomb. Curves are shown for various degrees of filling of the bomb. When the bomb contains $N/40$ NaCl solution (30 percent charge) with air above it, the impedance of the liquid phase decreases with rising temperature to a minimum at about 325°C and then rises. At 375°C it rises very sharply to a higher value. The vapor shows very high impedance, until the temperature 375°C is reached when it suddenly drops to 100–200 ohms, of the same order of magnitude but not the same value reached by the phase in the bottom of the bomb at the same temperature. A difference between impedances at top and bottom of the bomb continues for at least 10° above the critical temperature. If the air is removed from the bomb, the curves for the top phase are about the same but those for the bottom show constant impedance from about 300°C to 390°C or higher. There is no sudden change at 375°C. Similar results are shown for distilled water. The investigation is part of a research project sponsored by the U. S. Army Signal Corps.

L2. Density of Water as Function of Temperature. GEORGE ANTONOFF AND ROBERT J. CONAN, N. Y. U.—It was shown by the author that densities of liquids change with temperature discontinually.[1] The densities of water as given in all tables appear to be an exception to the rule, because the curve is smooth. Experiments below 80°C showed that the curve is just like all other liquids. It shows a kink just above 50°C, another at about 47°C and so on. The results are well reproducible. The data given in tables have been apparently smoothed owing to interpolation.

[1] G. Antonoff, Phil. Mag. **1**, 265 (1925).

L3. Efficiency of the Electrolytic Separation of Nitrogen Isotopes.* DWIGHT A. HUTCHISON, *Argonne National Laboratory.*—The electrolytic separation coefficient, α, has been determined for the nitrogen isotope separation in the electrolysis of aqueous solutions of ammonium chloride at a flowing mercury cathode. A mass spectrometer[1] with a 60° magnetic analyzer was employed in determining isotopic changes. The electrolytic separation factor was found to be 1.008 ± 0.001 for the temperature interval of 30°–70°C, and within the limits of error of the experiments was independent of temperature, of the fraction electrolyzed, of the concentration of electrolyte, and of the amount of back reaction at the cathode. A plot of α's for elements[2] thus far investigated against their atomic weights yields a smooth curve which approaches zero slope at about mass 25 and extends to mass 40. If extrapolation to high masses is permissible, then an electrolytic process for separating high masses appears more efficient than, for example, a diffusion process.

* The experimental work on this problem was done at the Georgia School of Technology.

[1] D. A. Hutchison, Research Engineer **VIII**, 3 (1946).

[2] For a review of previous work see D. A. Hutchison, J. Chem. Phys. **14**, 401 (1946).

L4. Critical Point Fluctuations.* MARTIN J. KLEIN AND L. TISZA, *Massachusetts Institute of Technology.*—It is well known that the fluctuations in particle density of a fluid become large near the critical point; this effect is manifested in critical opalescence. The usually adequate method of representing a single volume element of fluid by the grand canonical ensemble is invalid near the critical point as it predicts infinite fluctuations, contradicting experimental results. We have made a new calculation of the fluctuations treating the whole sample of fluid as divided into volume elements whose interactions are especially considered. The sample is represented by a grand canonical ensemble which is approximated (except very close to the critical point) by a multi-dimensional Gaussian distribution. The fluctuations in each volume element and their correlations are calculated and are always finite. The results are applied to the calculation of scattered light intensity leading to the formula of Ornstein and Zernike, with, however, a more adequate interpretation of the final expression. The relations of this calculation to previous work[1] and the generalization to other critical points and λ-points will be discussed.

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

[1] L. S. Ornstein and F. Zernike, Physik. Zeits. **27**, 761 (1926). See also M. v. Smoluchowski, Ann. de Physik **25**, 205 (1908).

L5. Approach to Spectral Equilibrium in the Penetration of X-Rays.* U. FANO and P. R. KARR, *National Bureau of Standards.*—In the process of Compton scattering

some of the scattered radiation is only infinitesimally softer than the incident radiation. Therefore, equilibrium between a primary beam and its secondaries is never attained in the course of penetration through a barrier. "Equilibrium" (implying a spectral distribution that does not vary with the depth of penetration) is, however, attained among the secondary components, except those extremely close to the high energy limit. Now, the spectral distribution right near the high energy limit is expressed at all depths by means of a confluent hypergeometric function, provided only that the absorption coefficient varies monotonically. This expression serves to bridge the spectral interval where equilibrium is not attained. From it one finds the asymptotic law of decrease at great depths of the intensity of all secondary components that have attained equilibrium among themselves: $\exp(-\mu(E_0)x)x^{K(E_0,E_0)}$. Here x is the depth of penetration, $\mu(E)$ the absorption coefficient at the energy E, E_0 the energy of the primary, $K(E, E')=\sigma(E, E')/(-d\sigma_{tot}(E)/dE)$, $\sigma(E, E')dE'$ the differential cross section for Compton scattering from the energy E to E', and $\sigma_{tot}(E)$ the total absorption cross section at the energy E. Representative values of K are:

E_0 (Mev):	0.5	1.2	2.5	5	10
$K(E_0, E_0)$:	4(Al)	2.2	1.4	1.4(Al)	1.4(Al)

* Research supported by Office of Naval Research grant.

L6. The Sensitivity of X-Ray Films in the 10-kv to 250-kv Range. HERMAN HOERLIN, *Ansco Research Laboratories.*—The spectral response of x-ray emulsions was determined as function of the number of absorbed quanta and also as function of the truly absorbed energy needed to produce a given optical density. Non Screen film requires 10^8 quanta/cm^2 at 1.27A and 10^7 quanta/cm^2 at 0.06A to develop a density of 1.5 above fog. When expressed in terms of truly absorbed energy (energy converted into electron energy), sensitivity increases with decreasing wave-length. These data, together with those of the range of electrons in silver bromide and of their energy loss per unit pathlength, permit the determination of the inherent sensitivity of the average grain, which for Non Screen is close to (2 kev)$^{-1}$. Hence, taking 7.6 ev as the energy required to form one ion pair in a silver halide,[1] 260 latent image silver atoms are needed to make the grain developable against 120 atoms for the same emulsion at 4250A. This relative inefficiency of x-ray exposures is believed to be due to formation of large amounts of internal latent image.

[1] J. P. Van Heerden, The Crystal Counter, Dissertation, Utrecht, 1945.

L7. Single Crystal *vs.* Double Crystal X-Ray Spectrometers. J. A. BEARDEN AND G. L. ROGOSA, *The Johns Hopkins University.*—Coster and DeLang[1] have constructed a Bragg focusing type of x-ray spectrometer of large dimensions and with it have made x-ray line widths and absorption measurements which they state are superior to similar measurements made with double crystal spectrometers. We have constructed a similar focusing spectrometer of even larger dimensions and have arranged a recording such that either the photographic or Geiger counter method could be used. The exploring slit used in front of the Geiger counter was 10^{-2} mm wide. The instrument has been tested by measuring the width of the copper $K\alpha_1$ line with different calcite crystals. The best result was obtained with a perfect calcite which was one of a pair that gave theoretical (1–1) widths on a double crystal spectrometer. The narrowest width obtained for the $K\alpha_1$ line was 44 seconds on the focusing spectrograph and 39.7 seconds on the double crystal spectrometer. This result, together with new absorption measurements made in this laboratory suggest that the resolving power of the focusing spectrometer has been considerably overestimated.

[1] D. Coster and H. DeLang, Physica 13, 379 (1947).

L8. L X-Ray Absorption Edges of Tantalum. G. L. ROGOSA AND H. GLASER, *The Johns Hopkins University.*—The L x-ray transitions involving the valence bands of Ta both in emission and absorption have been measured by means of a double crystal spectrometer with Geiger counter detection. The wave-lengths of the absorption edges and the widths of the L levels have been determined by fitting theoretical arc tangent curves to the experimental points according to the theory of Richtmyer, Barnes, and Ramberg.[1] An initial absorption due to the ejection of $2s$ electrons into the $5d$ and $6s$ bands having p character is clearly resolved for the L_I edge. The reality of this initial absorption and the width of the L_I level are in disagreement with the conclusions of Coster and DeLang[2] from their recent single crystal spectrographic measurements. There is good agreement in the appearance of the Ta L_{II} and Ta L_{III} edges as compared with those of WL_{II} and WL_{III} which have been discussed[3] in terms of the density of states in the valence bands.

[1] Richtmyer, Barnes, and Ramberg, Phys. Rev. 46, 843 (1934).
[2] D. Coster and H. DeLang, Physica 13, 385 (1947).
[3] J. A. Bearden and T. M. Snyder, Phys. Rev. 59, 162 (1941).

L9. The High Frequency Limit of the Continuous X-Ray Spectrum. G. SCHWARZ AND J. A. BEARDEN, *The Johns Hopkins University.*—An x-ray tube with a unipotential cathode has been developed for making a detailed study of the fine structure in the isochromats at the high frequency limit. The present measurements have been made at the wave-length of the copper $K\alpha_1$ line or a voltage of 8050. Targets of tungsten and tantalum exhibit similar sharp line structure near the high frequency edge, whereas with molybdenum and gold it is less pronounced and with copper this line seems to be practically missing. For tantalum the structure at 2.5°, 15°, and 30° is the same, which is contrary to the interpretation of the structure given by DuMond.[1] The necessity for applying the work function correction has been verified by the use of oxide cathodes. Subject to a final re-check of our three standard cells and the voltage divider resistance, the value of h/e is $1.3783\pm0.0001\times10^{-17}$ erg sec./e.s.u. This is in excellent agreement with our previous measurements[2] and definitely does not agree with the value computed from the inter-relationships of the fundamental constants.

[1] J. W. M. DuMond, Phys. Rev. 72, 276 (1947).
[2] J. A. Bearden and G. Schwarz, Phys. Rev. 74, 1209 (1948).

L10. Precision Measurement of the Wave-Length and Spectral Profile of the Annihilation Radiation from Cu^{64} with the Two-Meter Focusing Curved Crystal Spectrometer.* JESSE W. M. DUMOND, DAVID A. LIND AND BERNARD B. WATSON, *California Institute of Technology.*—The two-meter focusing curved crystal spectrometer has been used to make a direct precision wave-length measurement of the annihilation radiation from Cu^{64}. Using a 2.5-curie source of Cu^{64}, a sharp annihilation radiation line,

substantially symmetrical to within the precision of our observations, was obtained. The measured wave-length at the peak of this line was 0.024271±0.000010A which is in satisfactory agreement with the value 0.0242650 ±0.0000025A obtained by DuMond and Cohen for the Compton wave-length. The profile of the observed annihilation "line" is slightly broader than instrumental causes seem capable of accounting for. The residual "natural" profile, after abstraction of the instrumental broadening, is roughly estimated to have a half-width of 0.096 x.u. If this were ascribed to a Doppler effect of the motions of recombining pairs of moving negative and essentially stationary positive electrons, the velocities would correspond to electrons of only 16 ev, an order of energy which can hardly be associated with anything but the conduction electrons in copper. The 0.66-Mev positrons emitted by the Cu^{64} nuclei are so rapidly retarded by large parameter inelastic "collisions" with electrons as Heitler has shown, that less than two percent of them undergo annihilation before reaching thermal velocities. They then become virtually stationary targets for annihilation chiefly by conduction electrons and possibly M electrons.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

L11. A Precision Study of the Tungsten K Spectrum Using the Two-Meter Focusing Curved Crystal Spectrometer.* BERNARD B. WATSON,** WILLIAM J. WEST, DAVID A. LIND, AND JESSE W. M. DUMOND, *California Institute of Technology.*—Using the two-meter focusing curved crystal gamma-ray spectrometer, careful measurements were made of the wave-lengths of the K series lines and K absorption edge of tungsten for the dual purpose of establishing a precision linkage between wave-length measurements in the gamma- and x-ray regions and of improving our knowledge of the tungsten wave-lengths. The high precision, resolution, and luminosity of the instrument made possible the complete resolution of the β-doublet, the partial resolution of the γ-doublet, and the detection of a δ-line close to the absorption edge. Absolute determinations were made of the Bragg angles for Mo $K\alpha_1$ and W $K\alpha_1$ reflected from the (310) planes of quartz using a precision two-crystal spectrometer. These were undertaken (1) to standardize the tungsten K spectrum with higher accuracy in terms of the Siegbahn scale of x-ray wave-lengths and (2) to yield on this scale a precision determination of the grating constant of the quartz (310) planes. Adopting the value of 208.575±0.008 x.u. for the wave-length of the W $K\alpha_1$ line, the wave-lengths in x.u. of the K series lines (Sommerfeld notation) and K edge were found to be:

α_2	α_1	β_2	β_1	γ_2	γ_1	δ	Edge
213.387 ±0.010	208.575 ±0.008	184.772 ±0.020	183.967 ±0.020	179.212 ±0.020	179.038 ±0.020	178.052 ±0.020	177.947 ±0.020

* Work supported by contract with the Office of Naval Research.
** Now at Temple University, Philadelphia, Pennsylvania.

L12. Accurate Simple Recording Microphotometer. P. ROSENBLUM AND A. DE BRETTEVILLE, JR., *Signal Corps Engineering Laboratories.*—A microphotometer suitable for the study of x-ray diffraction film was designed and built at Squier Laboratory. This instrument may be of general interest since it is suitable for a wide range of film and glass plate photographs. The results obtained were satisfactory. Only essential components were used in order to facilitate manufacture in the laboratory shop. A simple optical system was used because of the large grain size of the film used in x-ray diffraction work, in contrast to fine grain optical spectroscopic plates. Thus it was possible to use a lower resolving power optical system. An electronic voltage recorder was used to amplify and record the signal from a photo-tube bridge circuit through an impedance matching cathode follower.

Meson Theory

M1. Symmetrical Meson Theory of Nuclear Forces. T. Y. WU AND H. M. FOLEY, *Columbia University.*—The static and the first order non-static nucleon potential on the basis of the Moller-Rosenfeld-Schwinger mixture of a vector meson of mass K_0 and a pseudoscalar meson of mass $315m_e$ is assumed. One relation among the coupling constants is postulated to remove the inadmissable singularities in the tensor force term. The coupling constants are then determined by means of the binding energy of the deuteron and the total cross section for slow neutron scattering. The potentials so determined are used to calculate the "effective range" r_0 for the triplet and the singlet states (proton-proton scattering), the quadrupole moment Q of the deuteron, and the cross section σ and $[\sigma(\pi)/\sigma(\pi/2)]$ for proton-neutron scattering at 100 Mev. The value $K_0=1.5\times315m_e$ while giving somewhat too low values for the r_0's yields entirely too small a Q and too large a ratio $\sigma(\pi)/\sigma(\pi/2)$; whereas the value $K_0=2\times315m_e$ while giving better values for Q and $\sigma(\pi)/\sigma(\pi/2)$ yields much too small values for the r_0's. It is concluded that this failure to account for both the high energy and the low energy scattering data seems characteristic of any potential having the exchange properties of the symmetrical meson theory.

M2. Correction to Nucleon Scattering from Virtual Meson Emission. NING HU, *Cornell University.*—The radiative coorection to the scattering of a nucleon by a given static meson field due to the virtual emission and reabsorption of mesons is calculated by the usual perturbation method. It is found that the radiative correction still diverges even after the relativistic mass effect (corresponding to terms $(4a, a', d, d', e, e')$ in Dancoff's calculation) has been subtracted. This is in contrast to the case of electrodynamics. For all types of coupling with any kind of mesons, the divergence is quadratic except the case (i) of pseudoscalar or scalar coupling with pseudoscalar or scalar mesons, where the divergence is logarithmic. These divergent terms can be interpreted as renormalization of *mesonic* charge, which is of different origin from that due to vacuum polarization. The same mesonic radiative correction to the scattering of a proton in an external electromagnetic field is also found to be divergent except for the case (i). These divergent terms must now be interpreted as renormalization or modification of the *electric* charge of the proton due to virtual mesons. This makes it difficult to understand why the electron, which has no direct interaction with mesons, should have the same electric charge as the proton. Further investigation is in progress to see whether the result is due to the inadequacy of the older non-covariant perturbation methods.

M3. The Interaction of Photon, Meson, and Nucleon Fields. GEORGE J. YEVICK, *Stevens Institite of Technology.*—

Following the method of Kanesawa and Tomonaga[1] who have worked the case out for meson-photon interaction, we have obtained the invariant interaction Hamiltonian for a photon-(charged scalar) meson-nucleon system with two types of coupling between the nucleon and meson field. The analysis for the coupling, depending on the derivative of meson field, produces two additional kinds of terms, an interaction connecting all three fields and one depending on the nucleon field alone. An insight into the nature of the interaction Hamiltonian is got by going from the Schrödinger picture (which is the starting point of Tomonaga's work) to the Heisenberg picture (starting point of Schwinger's new formalism) by a contact transformation and determining the contact transformation needed to go from the Heisenberg picture to the interaction representation. The nucleon-photon mass and polarization evaluations have been performed by Schwinger, meson-photon by Feynman and Pais, while the calculations for nucleon-meson interaction for scalar-type coupling are simple applications of Feynman's elegant prescription. We shall discuss the analysis (now under way) for derivative-type coupling using Feynman's method.

[1] Kanesawa and Tomonaga, *Prog. of Theo. Phys.* **3**, 1 (1948).

M4. Equivalence Theorems for Meson-Nucleon Coupling. K. M. CASE, *The Institute for Advanced Study.*—For some time[1,2] it has been known that to a certain approximation there exist relations between the different types of couplings of scalar and pseudoscalar meson fields with nucleons. Since these theorems obviously represent very important labor saving devices, an investigation was made of their precise statement and limits of validity. The modifications of these theorems when an external electromagnetic field is present were considered. For generality the Schwinger-Tomonaga many time formulation of meson theory was used. For the scalar theory the theorem may be stated as follows: To order g^2 the Hamiltonian describing mesons coupled with nucleons by means of both a vector and scalar interaction in the presence of an external electromagnetic field may be replaced by an equivalent Hamiltonian. This is one without any vector coupling plus an additional term of order eg^2. For the pseudoscalar case the theorem may be stated as showing the equivalence of the general Hamiltonian to one with a modified pseudoscalar coupling plus two additional terms. The significance of the additional terms will be discussed.

[1] E. C. Nelson, Phys. Rev. **60**, 830 (1941).
[2] F. J. Dyson, Phys. Rev. **73**, 929 (1948).

M5. On the Interaction of a Nucleon with a Pseudoscalar Meson Field. HERBERT GOLDSTEIN, *Harvard University,* AND HERMAN FESHBACH, *Massachusetts Institute of Technology.*—The recent reformulations of quantum electrodynamics have had remarkable success in explaining the finite radiative reactions observed in atomic spectroscopy. These successes suggest that a similar reformulation for meson fields might eliminate some of the difficulties of previous meson theories of nuclear forces. To explore this possibility a particularly simple model has been investigated by the methods of J. Schwinger.[1] The model was patterned closely after the atomic case; the electron moving around a center of force. Instead of a Coulomb potential the external field is a non-tensor spin-dependent potential. The role of the electromagnetic field is here taken by a neutral pseudoscalar meson field with a pseudoscalar coupling with the nucleon. The apparent infra-red catastrophe of the electromagnetic case does not occur here, because of the finite meson mass. Among the term generated are tensor-force potentials behaving as $e^{-\mu r}r^{-3}$ for large distances (starting from a Yukawa potential), but varying roughly as r^{-1} close to the center of force. The transition occurs in the neighborhood of $r=\hbar/Mc$.

[1] J. Schwinger, Phys. Rev. **73**, 416 (1948); **74**, 1439 (1948) and in press.

M6. On the Coupling of μ-mesons with Nucleons. J. TIOMNO AND JOHN A. WHEELER, *Palmer Physical Laboratory, Princeton University.*—The probability of the charge exchange reaction between a nucleus and a meson, previously captured in a K-orbit, was computed using the excitation probabilities referred to in the following abstract. Comparison with the experimental value for $Z\sim10$ gave for the coupling constant between *μ-mesons* and *nucleons* a value $\sim10^{-49}$ erg cm^3 in all three models used there. This value is of the same order as the coupling constant of the "in" principle quite independent interaction between *electrons* and *nucleons* determined from nuclear β-decay and also as that of *electrons* and *μ-mesons.* This unexpected agreement raises the possibility that there is a fundamental interaction between all elementary particles with $\frac{1}{2}$ spin which has in all cases the same strength. Of course the direct interaction of μ-mesons with nucleons could exist simultaneously with an indirect coupling of the same order—through a π-meson field—as would be implied by a π-meson of 10^{-8} sec. life which were responsible for nuclear forces.*

* Marty and Prentky, J. de Physique **9**, 147 (1948); J. Leite Lopes, Phys. Rev. (in press).

M7. On the Spin of π- and μ-Mesons. JOHN A. WHEELER AND J. TIOMNO.*—The possibility that π- and μ-mesons have spin $\frac{1}{2}$ has been investigated by a phenomenological treatment of the nuclear excitation resulting from meson capture. The basic reaction was taken as: negative meson plus proton→neutral meson (neutrino?) plus neutron. The Fermi model of the nucleus was used in the two extreme cases of nuclear radius small and large relative to the Compton wave-length of the meson. A Hartree model was also used for the case of μ-capture by O^{16}, as suggested by Christy. Results in all cases were qualitatively equivalent. Even for near zero mass of the neutral meson the nuclear excitation came out to be small. The maximum excitation energy was at most near $\frac{1}{5}$ of the rest mass of the negative meson. Thus very small and rare stars should be expected. This result agrees with experimental data for μ-meson capture but directly conflicts with the frequent and large stars produced by π-mesons. Thus the possibility of a spin $\frac{1}{2}$ is excluded for π-mesons and favored for μ-mesons.

* State Department Fellow of the University of São Paulo.

M8. The Absorption of Negative Pi-Mesons in Hydrogen.* A. S. WIGHTMAN, *Princeton University,* R. E. MARSHAK, *University of Rochester,* AND J. A. WHEELER, *Princeton University.*—The calculations reported here

show that an appreciable fraction of negative pi-mesons sent into liquid hydrogen reach inner orbits around the proton before decaying. Radiationless absorption of the meson by the proton to form a neutron is forbidden by energy and momentum considerations in contrast to the situation in all other nuclei. What reaction does occur depends on the nature of the meson and can be determined experimentally by a search for γ-rays and neutrons. If the negative pi-meson is a fermion, as seems very unlikely (see preceding abstract) then the absorption will give rise to a neutral fermion, a neutron of at most $\sim$10 Mev and no gamma-ray. If the meson is a boson, it may either be absorbed with the emission of a neutral boson which should decay into two photons of about 67 Mev each. Experiments on the capture of negative pi-mesons should therefore fix their boson or fermion character. Under favorable circumstances the strength of the coupling of pi-mesons to nucleons can also be determined.

* Work reported here and in the two previous abstracts supported by the Joint Program of the Office of Naval Research and Atomic Energy Commission.

M9. Production of π-Mesons in Nucleon-Nucleon Collisions.* L. L. FOLDY, *Case Institute of Technology* AND R. E. MARSHAK, *University of Rochester*.—The cross section for the production of π-mesons in nucleon-nucleon collisions is calculated at energies just above the threshold. The process is treated in analogy with photonic bremsstrahlung: the π-meson field is coupled to the nucleon and an empirical potential between the two nucleons ensures momentum and energy conservation. The nuclear potential is taken from the Berkeley experiments on neutron-proton scattering at 90 Mev. In our treatment the symmetric scalar theory yields zero-meson production cross section if the recoil of the nucleons is neglected. The symmetric pseudoscalar theory with pseudovector coupling leads to total cross sections of 0.05, 0.5, and 2 microbarns at 1.25, 1.5, 2.0 times the threshold energy, respectively, if the high energy scattering is fitted by a central Yukawa potential. The angular distribution is uniform in the center of mass system, and the ratios of charged and neutral mesons are essentially those expected from a weak coupling theory. The cross sections obtained are a thousand times smaller than the cross sections found by Morette and Peng[1] on the basis of a thoroughgoing field-theoretic treatment.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
[1] Morette and Peng, Proc. Roy. Irish Acad. **51A**, 217 (1948).

N1. The Performance of a Light Scattering Photometer for Determining High Molecular Weights. B. A. BRICE, *Eastern Regional Research Laboratory,** *Philadelphia*.—A photoelectric photometer designed for the measurement of absolute turbidity, dissymmetry, and depolarization of dilute solutions of high molecular weight materials is described. Improvements over an earlier model** include use of opal glass as a reference transmission diffusor, a multiplier photo-tube receiver, and compensation of most of the refraction effects. The working relationships leading to determination of absolute turbidity are developed, both for a "substitution" method and a "working standard" method. Sources of error encountered in earlier work and remedied include: serious deviations from the cosine law of emission for a reflecting diffusor of magnesium carbonate; dependence of response of photo-tube on plane of polarization of incident radiation; and refraction effects. Data illustrating the performance of the instrument include determination of Rayleigh's ratio and depolarization for benzene; molecular weights of sucrose octaacetate, lactoglobulin, serum albumin, and fractions of polystyrene. Agreement with other methods for these materials is in general within ± 5 percent.

* One of the Laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, United States Department of Agriculture.
** R. Speiser and B. A. Brice, J. Opt. Soc. Am. **34**, 364(A) (1946).

N2. Determination of Molecular Weights and Sizes by Absorption. W. M. CASHIN AND P. DEBYE.—The paper presents a convenient method for determining the weights and sizes of large molecules in solution. The method requires the measurement of the secondary absorption of polymer solutions at several concentrations and several wave-lengths, and also a knowledge of the change of refractive index of the solutions with concentration at the wave-lengths used. The conventional H^c/α *vs.* c plot for each wave-length is made, where

$$H=\frac{32\pi^3}{3}\left(\frac{\mu-\mu_0}{c}\right)^2\frac{\mu_0^2}{N\lambda^4}.$$

α is the secondary absorption (total turbidity) and c the concentration. When the molecules in solution are not small compared to the wave-length, the intercepts of the above plots will not be the same, and the equation for small molecules

$$H^c/\alpha=1/M \text{ does not hold.}$$

In such a case

$$H^c/\alpha=(1/M)\cdot(1/s),$$

where to a first approximation

$$1/s=1+AD^2(\mu_0^2/\lambda^2),$$

where D is a molecular linear dimension. If one plots the $(H^c/\alpha)_0$ intercepts against $(\mu_0/\lambda)^2$, a straight line is obtained (for highly cross-linked polymers), and the intercept at $(\mu_0/\lambda)^2=0$ of this latter plot is the correct $1/M$. If one selects as a model for the molecules in solution the homogeneous sphere, Debye has shown that the slope of the $(H^c/\alpha)_0$ *vs.* $(\mu_0/\lambda)^2$ plot is just equal to

$$6.056D^2/M$$

with D then the diameter of the homogeneous sphere. If the linear coiling model is used, the limiting slope is equal to $4.24R^2/M$, where R^2 is the square of the average distance from beginning to end of the chain.

N3. A Method of Measuring Molecular Weight Distribution Breadth. F. W. BILLMEYER, JR., AND W. H. STOCKMAYER, *E. I. duPont de Nemours Company, Inc.*—Based upon the suggestion of Spencer* a method for estimating the breadth of the molecular weight distribution of a high polymer has been devised: a polymer solution is divided into aliquots, and part of the polymer in each aliquot is precipitated with non-solvent so that the range from complete solution to complete precipitation is covered. The weight and (weight-average) molecular weight of each precipitate is measured. From these data the distribution breadth is estimated in terms of a parameter, H, representing the departure of the distribution from that of a single molecular species. In the theoretical section, H is related

to other parameters of distribution breadth, such as $\bar{M}w/\bar{M}n$, for some well-known analytical distribution functions. A number of experiments with polymethyl methacrylates are described and the results are discussed with reference to polymerization kinetics. Osmotic pressure and light scattering determinations have been made to evaluate directly $\bar{M}w/\bar{M}n$. The values compare favorably with $\bar{M}w/\bar{M}n$ estimated from H. Errors in both the theoretical and experimental treatments are discussed.

* R. S. Spencer, J. Polymer Science 3, 606 (1948).

N4. Soap Solutions.* P. DEBYE.—The light scattered by solutions of some cationic detergents has been investigated. The viscosities of these solutions have also been measured. Little difference in scattering or viscosity is observed between the solutions and the solvent until the critical concentration for micelle formation is reached. For higher concentrations both quantities increase considerably over those found for the solvent. The increase in turbidity has been used to calculate the molecular weights of the soap micelles in different solvents and under various conditions; the increase in the viscosity was used to find approximate values for the density of the soap micelle. The turbidities of solutions of lauryl trimethylammonium bromide in water-glycerine mixtures were measured. They were found to decrease when the percent glycerine in the solvent was increased and the micelles became smaller. When solutions of the same detergent were saturated with benzene they were found to be more turbid than before the addition of benzene. The amount solubilized was determined spectrophotometrically. Coupling this information with the molecular weights calculated from the turbidities it can be shown that the benzene makes up about one quarter of the micelle weight. Turbidity measurements at different temperatures indicate that as the temperature is increased the micelles become slightly smaller and the critical concentration increases.

* The experimental work was done by R. M. Hagen and E. W. Anacker. It was financed by the Office of Rubber Reserve, Reconstruction Finance Corporation, in connection with the Government's synthetic rubber program and by the Procter and Gamble Company.

N5. Scattering by Inhomogeneous Solids.* A. M. BUECHE AND P. DEBYE.—The scattering of light or x-rays by an inhomogeneous solid can be interpreted in terms of the magnitude of the average square of the fluctuations in refractive index or electron density and the sizes of the regions over which they occur. The intensity and angular distribution of the light scattered by "Lucite" and two glass samples have been investigated. The data have been interpreted by means of a new theory which enables one to find the above quantities. The intensity of blue light ($\lambda = 4358$A) scattered by "Lucite" was found to be high and strongly dependent on angle. The scattering at an angle of 6° from the direction of the primary beam was about 150 times more intense than at 90°, indicating large sizes for the inhomogeneities. The root mean square of the fluctuations in refractive index in "Lucite" was about 2×10^{-4}. Scattering data found using green light could be superimposed on that for blue light in a way depending on wave-length alone. This is evidence that we really are dealing with a diffraction phenomenon. Both the crown and the flint glass samples studied showed only a small angular dependence of scattering for blue light, indicating that the inhomogeneities were small in size. The root mean square of the refractive index fluctuations for the crown glass was approximately the same as for "Lucite."

* The work reported in this paper was done in connection with the Government Research Program on synthetic rubber under contract with the Office of Rubber Reserve, Reconstruction Finance Corporation.

N6. Determination of the Shape of Particles from Dityndallism. WILFRIED HELLER, *Wayne University.*—A conclusive determination of the shape of colloidal crystals or molecules is possible by studies of the conservative dichroism or of the dityndallism. In order to occur, these effects require a partial orientation of the respective particles by streaming, in an electric or a magnetic field. A determination of the basic shape (spheres, prolate or oblate spheroids) is possible without using the distribution function. By means of the latter, the three dimensions can be determined numerically and without difficulty, if all dimensions are small compared to the wave-length of light. The method is therefore particularly promising for numerical determinations of the three dimensions of protein molecules. It can also be anticipated that the method will allow a decision as to whether or not the statistical shape of polymer molecules varies with the solvent. The Langevin-Cotton relation makes it possible to decide as to whether or not the shape of non-rigid particles may change during the process of orientation, thus providing a quantitative tool for the study of possible hydrodynamic deformations of particles. An apparatus for the study of conservative dichroism and one for the study of dityndallism will be discussed, and a number of systematic preliminary data obtained with rigid colloidal particles will be presented.

N7. The Inter-Relationship of Some of the Hydrodynamic Properties of Flexible Molecules in Solution. JACOB RISEMAN, *Polytechnic Institute of Brooklyn.*—The viscosity, diffusion and sedimentation velocities of solutions of flexible molecules are intimately associated with the relative motion of the solvent in the vicinity of the segments of the chain. This motion is, in turn, to a large extent determined by the hydrodynamic interaction which occurs between the parts of the chain. Analogously the orienting effect of a velocity gradient depends upon the magnitude of the rotatory Brownian motion of the particle, and therefore on the rotatory diffusion constant of the particle. Since this latter quantity is influenced by the resistive forces of the fluid in which it is immersed, it follows that there should be a relationship between the rotatory diffusion constant and the above-mentioned properties. In particular, the rotatory diffusion constant is shown to be simply related to the intrinsic viscosity. Furthermore, data obtained from diffusion and sedimentation velocity measurements can also be used to calculate the rotatory diffusion constant. This, therefore, enables one to correlate viscosity, ultracentrifuge, and birefringence data, since from the latter the rotatory diffusion constant can be obtained. In addition, from such birefringence data one can obtain the size of the molecule, by comparing the experimentally obtained rotatory diffusion with that theoretically obtained.

Metals and Semi-Conductors; Cryogenics

O1. Determination of the Coefficient of Self-Diffusion without Radioactive Tracers. G. C. KUCZYNSKI, *Sylvania Electric Products, Inc.*—Fine silver wire was sintered to cylindrical blocks of the same metal. The analysis of the problem allowed an expression for the self-diffusion coefficient of silver in terms of the time and temperature of sintering and the breadth of the interface formed. The measurements yielded the values for self-diffusion coefficient D for silver summarized in the following equation: $D=1.2\times\exp(-45{,}000/RT)$ as against $D=0.89\exp(-45{,}900/RT)$ obtained by W. A. Johnson,* using radioactive tracer method.

* W. A. Johnson, Trans. A.I.M.E.E. 143, 107 (1941).

O2. Damping of Single Crystals of Lead and Copper.* J. W. MARX AND J. S. KOEHLER, *Carnegie Institute of Technology.*—Damping characteristics of single crystals of lead and copper were investigated by means of an impedance bridge, employing a composite piezoelectric oscillator, after the fashion described by T. A. Read. The specimens, made from 99.999 percent lead and copper, were measured when in longitudinal vibration at their resonant frequencies, which in all cases were about 37 kilocycles. Results noted were: (1) Discontinuities, possibly associated with slip, were observed when the acoustical impedance, or apparent a.c. resistance, was plotted against increasing strain amplitude. The discontinuities were observed only for lead specimens, never for copper, and they could not be reproduced by *decreasing* the strain amplitude from its maximum value. (2) The decrement of an impure lead crystal, one which contained 0.0015 percent bismuth as its major impurity, was compared with that of a specimen made from pure (99.999 percent) lead. At strain amplitudes in the neighborhood of 2×10^{-6}, the slope of the pure crystal was about six times as great as that of the impure crystal, with reference to the decrement *vs.* strain amplitude curves. (3) Single crystals of copper were obtained which, after eight hours annealing at 500°C, exhibited decrements of the order of 10^{-2} at strain amplitudes of 10^{-7}. This is about one hundred times as great as the decrement previously reported by other investigators for single crystals of commercial copper.

* This research was supported in part by the Office of Naval Research.

O3. Plastic Deformation of Filaments at Constant True Strain Rates. RICHARD LATORRE AND WALLER GEORGE, *Naval Research Laboratory.*—A new mechanical device will be described for straining metal and plastic filaments at coustant true strain rates from 10^{-5} to 1 per second. The force resisting such plastic deformation is measured by means of a suitable electromechanical pick-up and recorded on a high speed photoelectric recorder. Typical load *vs.* time curves will be presented for common metal and plastic wires. Rupture load measurements for small sample groups appear to yield average deviations from the mean of about ±4 percent. Data obtained at constant temperature and relative humidity for monofilaments of Type 300 high strength Nylon for an almost ten-thousand fold range of straining speeds indicates that the rupture strength of this material increases more rapidly with increasing strain rate than the strength of a steel over a comparable straining speed range as obtained by Zener,[1] using a different method. Further, the Nylon data indicate changes in the mode of variation of strength with strain rate which is a function of the relative humidity. For high humidity the strength increases more slowly, while for low humidity it increases more rapidly with straining speed.

[1] C. Zener and J. H. Hollomon, J. App. Phys. 15, 22 (1944)

O4. The Effect of Stress and Deformation on the Martensite Transformation.* ANDREW W. MCREYNOLDS, *University of Chicago.***—According to current theories, crystallographic transformations of the martensite type occur by a homogeneous lattice shear. Consequently, a mutual influence between transformation and shearing stress and strain would be expected near the transformation temperature. Such effects have been studied in Fe-Ni 71–29 alloy which transforms, *fcc* to *bcc*, beginning about −30°C (*Ms* point). In accord with prediction, deformation up to 50 percent induces transformation in amounts increasing with deformation. Maximum transformation is nearly 100 percent at −30°C, but decreases to zero at 50°C (*Md* point). Conversely, during transformation by cooling, plastic yield to very low stresses occurs in amounts increasing with degree of transformation. Plastic strain stabilizes the metal, however, against subsequent transformation by cooling. Contrary to expectation, as temperature decreases to the transformation point: (a) Young's modulus and rigidity modulus, measured statically and dynamically, remain constant through the transformation range. (b) Elastic limit increases then drops discontinuously at the *Ms* point, (c) The *Ms* temperature is independent of applied elastic stresses. These results are inconsistent with hypotheses that transformation occurs by homogeneous shear and represents an alternative mechanism of plastic yield, since such hypotheses would predict decreasing elastic moduli and elastic limits preceding instability at the transformation temperature.

* Supported in part by the Office of Naval Research.
** Now at Brookhaven National Laboratory, Upton, Long Island, New York.

O5. Ultrasonic Velocity of Longitudinal and Transverse Waves in Metallic Beryllium at Low Temperatures.* W. C. OVERTON, R. H. PRY, R. W. SCHMITT, AND C. F. SQUIRE, *Rice Institute.*—Ultrasonic waves at 10 megacycles per second have been pulsed, by means of quartz crystal transducers and familiar radar circuits, through solid beryllium metal from room temperature down to temperatures available with liquid helium. The sound pulse was reflected from the opposite face of the metal, and the return echos recorded with an AR-256*D oscilloscope (DuMont) so that velocity could be determined directly. The longitudinal waves have a velocity of about 12.5×10^3 meters per second at room temperature, and the velocity increases very slightly with lower temperatures. No deviation of velocity was detected in the region of the anomalous specific heat hump at 12°K. The transverse waves have a slower velocity of about 8.8×10^3 meters per second at room temperature, and the velocity increases slightly at lower temperatures. From the velocity data, and using the density of beryllium as 1.82 grams per cm^3, the adiabatic compressibility is 1.03×10^{-12} cm^2 per dyne, and the shear modulus is 1.43×10^{12} dynes per cm^2 at

temperature 273°K. Interference effects were observed in the multiple echo pattern. Results from echo ranging in pure metallic tin at very low temperatures will be discussed.

* This work was supported in part by a Navy contract.

O6. Electrical Properties of Highly Purified Tellurium.* VIRGIL E. BOTTOM, *Purdue University.*—By the use of multiple fractional distillation, tellurium of a purity higher than that hitherto reported has been prepared. The most nearly pure material thus far obtained has a Hall constant of +5000 and a resistivity of 5-ohm cm in the impurity range. The sign of the Hall constant is negative between the temperatures of +230°C and −40°C; outside of this range the sign is positive. In material of this degree of purity, the intrinsic range extends well below room temperature, and direct measurement of the intrinsic resistivity at 300°K gives about 0.6-ohm cm as measured on polycrystalline ingots. Single crystals have been prepared by the technique of Schmid and Wasserman.[1] In approximate agreement with their results, the resistivity is found to be greater in the direction perpendicular to the principal crystallographic axis than in the parallel direction. The ratio $\rho_\perp/\rho_{||}$ is found to be 1.9 ± 0.1. The Hall coefficient is not found to depend upon the direction of the current or magnetic field with respect to the crystallographic axis, in contrast with the results of Van Everdingen[2] on bismuth. When the degree of purity exceeds a certain minimum, double reversal of the sign of the Hall coefficient is observed. One reversal always occurs at a temperature of 230°C, while the temperature at which the other reversal occurs is lower and depends upon the impurity content.

* This work was assisted by a Signal Corps contract.
[1] Schmid and Wasserman, Zeits. f. Physik **46**, 653 (1927).
[2] E. Van Everdingen, Jr., Comm. from the Phys. Lab. of the Univ. of Leiden **6**, 61–72, Supplement 2, 1900–01, pp. 3–8.

O7. The Temperature Coefficient of Resistance of Sintered Semiconductors.* HENRY H. HAUSNER, *Sylvania Electric Products, Inc. and New York University.*—Semiconductors are generally characterized by their negative temperature coefficient of resistance. Sintered semiconductors consist of conducting and semiconducting or insulating components, and their temperature coefficients of resistance do not necessarily decrease with increasing temperature. Tests have shown that certain sintered mixtures of conducting and semiconducting components can be developed, the resistivities of which do not change at all with the temperature; other mixtures of this type are characterized by a positive temperature coefficient of resistance. Sintered materials are to be regarded as electrical networks, and the resistances between the particles are as important as the particle resistances themselves.[1] The temperature coefficient of these sintered materials depends, therefore, on the components, but also on the bond between the components. It is shown that the reduction of semiconducting oxides by metallic components affects widely the electrical properties. The degree of sintering determines not only the resistance but also the temperature coefficient of resistance.

* This work was done under contract with the War Department, Squier Signal Laboratories, Fort Monmouth, New Jersey.
[1] Henry H. Hausner, "Sintered semiconductors," Electronics (January 1948).

O8. The Effect of Surface States on the Temperature Variation of the Work Function of Semiconductors.* JORDAN J. MARKHAM,** *University of Pennsylvania.*—The effect of surface states on the temperature variation of the work function of semiconductors is considered. First, the variation of the electrochemical potential is given on the basis of an equation due to Fowler. An attempt is made to show at what temperature a semiconductor becomes intrinsic. Secondly, the temperature variation of the work function is considered for various densities of surface states and number of donator (or acceptor) levels. To carry this calculation through, a new expression, which is temperature dependent, is suggested for the number of electrons in the surface states. By using appropriate values obtained from experiments, one is able to explain Smith and Miller's[1] results.

* Assisted by the Navy.
** Now at Brown University.
[1] A. H. Smith and P. H. Miller, Jr., Phys. Rev. **73**, 1256 (1948).

O9. Electrical Properties of Cuprous Oxide Rectifier Cells Below Room Temperature. STEPHEN J. ANGELLO, *Westinghouse Research Laboratories.*—Measurements of boundary layer capacitance and resistance have been carried out upon cuprous oxide rectifiers in the temperature range 35° to −165°C. The purpose of these measurements was to test critically W. Schottky's[1] formula for the contact resistance at zero applied voltage. This formula predicts that the resistance in question increases exponentially with decreasing temperature. Some rectifier cells exhibit this behavior in the approximate range 35° to −10°C. In these cases it has been found possible to compute the contact resistance, and to obtain good agreement with measured values. In other cases (differences caused by different quench temperatures) deviation below the exponential relation occurs at temperatures above 25°C. Evidence will be presented to support the assertion that deviation from the exponential law is caused by a limiting boundary electron density of about $2\times10^6/\text{cm}^3$, below which the copper-cuprous oxide boundary cannot be depleted. The boundary layer thickness has been determined as a function of temperature from capacitance data. A rapid increase occurs below −100°C. This, coupled with a comparison between mean free path and boundary thickness, indicates that diffusion theory is not applicable below this temperature.

[1] W. Schottky, Zeits. f. Physik **118**, 539 (1942).

O10. The Viscosity of Mixtures of He_3 and He_4. H. WERGELAND AND D. TER HAAR, *Purdue University.*—The fact that He_3 atoms obey Fermi-Dirac statistics will have important consequences. Even if He_3 should show a λ-transition, it would not be superfluid: the kinetic viscosity[1] will not decrease appreciably with temperature, even if the dynamic viscosity[1] would be zero. The high value of the kinetic viscosity is due to the high average momentum of the He_3 atoms in the Fermi sea. It is possible to estimate the value of this viscosity due to this Fermi momentum, and the viscosity turns out to be much larger than the viscosity of the He_4 liquid. In this rough way, one can evaluate the change of viscosity due to an admixture of He_3 in He_4. The resulting increase of the viscosity of the liquid is given in the following table; this increase is in first approximation proportional to the concentration

of He_3:

T:	1.6°K	2.0°K	2.1°K	2.2°K	3°K
1% He_3	44%	10%	5.3%	0.5%	0.3%

[1] L. Tisza, Phys. Rev. **72**, 838 (1947).

O11. On the Thermodynamics of the Fountain Effect in Liquid Helium II.* R. J. HARRISON, *Research Laboratory of Electronics, M.I.T., Cambridge 39, Massachusetts.*—S. R. de Groot[1] has criticized the thermodynamic derivation[2] of the equation governing the thermomechanical effect in He II, on the grounds that irreversible effects have been disregarded. It may be shown, however, that the usual equation can be rigorously derived thermodynamically by adopting the method used by Boltzmann[3] in attempting to justify the Kelvin equations for thermoelectricity. Although the inequality Boltzmann derived was not strong enough for his purpose, the same inequality applied in a suitable manner to He II is sufficient to justify the "fountain effect" equation. Although de Groot's objections to the thermodynamic derivation would thus seem to have been answered, we have examined in some detail his use of Onsager's reciprocal relations as applied to phenomena in liquid helium. We have obtained explicit expressions for the values of the kinetic coefficients on the basis of the two fluid model. It has been found that irreversible effects are negligible within the range of validity of the assumptions underlying the Onsager relations.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.
[1] S. R. de Groot, Physica **13**, 555 (1947).
[2] H. London, Proc. Roy. Soc. **A171**, 484 (1939).
[3] L. Boltzmann, Ber. Wien. Akad. **96**, II, 1258 (1887).

O12. The General Electric Low Temperature Laboratory. Part I. The Building and General Facilities. M. D. FISKE, W. DESORBO, F. H. HORN, AND J. F. YOUNGBLOOD, *General Electric Research Laboratory.*—A new laboratory has been constructed for studies at very low temperatures as a part of the new facilities of the Research Laboratory at The Knolls, near Schenectady. A separate building houses laboratory space, a small shop, liquefaction plants of the regenerative Joule-Thomson type for both hydrogen and helium, and motor-generator sets for supplying direct current for magnetic work. The building, which is 71 feet by 62 feet over-all, contains 3320 square feet of floor space divided principally among two laboratories, compressor, liquefier, and motor-generator rooms and shop on the ground level. Separate space for gas holders, heating and ventilating equipment, and storage is provided on a mezzanine floor above the central corridor and shop. The extensive use of hydrogen dictated many of the features of the building. Electric equipment in liquefier, compressor, and gas holder rooms is explosion-proof. Ten air changes per hour are provided throughout the building. Interior walls are either reinforced concrete or heavy steel paneling, while 80 percent of the exterior walls is explosion-venting window area. Complete gas and electrical service, water, and drain are provided at all benches in the two laboratories. Photographs and drawings of the laboratory will be shown.

O13. The General Electric Low Temperature Laboratory. Part II. Liquefaction Cycles for Hydrogen and Helium. F. H. HORN, W. DESORBO, M. D. FISKE, AND J. F. YOUNGBLOOD, *General Electric Research Laboratory.*—The liquefaction cycles for hydrogen and helium, as installed in the Low Temperature Laboratory, will be briefly described. Both liquefiers employ the principle of regenerative Joule-Thomson cooling. The hydrogen liquefier has a design capacity of 25 liters per hour; the helium liquefier has a design capacity of 8 liters per hour. Designs have been based on liquefiers of these capacities in operation at other laboratories. The attention paid to safety and to simplicity of repair and operation in design, construction, and layout of the liquefiers and auxiliary equipment will be indicated.

O14. The General Electric Low Temperature Laboratory. Part III. d.c. Power Facilities. J. F. YOUNGBLOOD, W. DESORBO, M. D. FISKE, AND F. H. HORN, *General Electric Research Laboratory.*—In this new laboratory facilities have been included for supplying d.c. power to moderate size electromagnets. Two motor-generator sets, along with the primary control panel and the excitation equipment, are housed in a special room of the Laboratory. One set delivers 85 kw at 225 volts, the other 115 kw at 225 volts. They can be used separately or in parallel. A portable control panel makes possible the complete remote operation and control of the power sources at any location of experimental work. The electromagnets, in process of design, and the cooling system for them will be briefly discussed.

Miscellany in Electron Physics

PA1. Characteristics of Bridges between Electric Contacts. G. F. HULL, JR., M. H. COHEN AND R. W. TERHUNE, *Dartmouth College.**—Current-voltage characteristics of metallic bridges between Pt, Au, Pd, and Ir contacts have been obtained for bridges of the order of 10^{-3} cm in length and diameter, and these current-voltage characteristics are found to be nearly hyperbolic. Photomicrographs of the bridges show variation in bridge dimensions with bridge voltage E, which, when taken into account along with the absolute maximum temperature of the bridge $T_{max}=3200\ E$ given by contact theory, qualitatively accounts for the current-voltage characteristic. To check the above temperature equation, a micro-optical pyrometer was used, and this equation was found to hold within several percent.

Cathode-ray oscillograms of the voltage across separating contacts have been obtained for twenty different metals ranging from Sn to W. These oscillograms show a rise in voltage first to the melting point of the metal and a second rise to the boiling point. For ten of the metals investigated, the voltages at the melting and boiling points agree within a few percent with those predicted theoretically, while for the other ten, the discrepancy between theory and experiment is large.

* Assisted by the Office of Naval Research.

PA2. Theory and Application of the Variable Voltage Probe for Exploration of the Ionosphere.* A. REIFMAN AND W. G. DOW, *University of Michigan.*—A new method of studying the ionosphere has been developed which consists of using an isolated two-electrode system as an "ionosphere probe" on a high altitude rocket. By applying

a periodic sawtooth voltage to the electrodes and recording the resulting current, a series of volt-ampere characteristics are obtained for a wide range of altitudes in the ionosphere. A theory is established which predicts the form of such a characteristic in terms of the geometry of the collector, electron and ion energy distribution, electron and ion temperature, and concentration and relative rocket velocity. The method of interpreting the volt-ampere characteristic is discussed, and it is shown how the dependent variables can be evaluated. A few probe experiments were made on some V-2 firings but considerable difficulty was encountered in obtaining accurate data therefrom. However, a number of rough experimental results were obtained and showed good agreement with the calculated characteristic for a model ionosphere. The correlation between theory and experiment is to be considered tenative until more accurate results are obtained from near future experiments.

* This work was supported by the Air Materiel Command.

PA3. A Wide Range Capacitance-Conductance Bridge. ROBERT H. COLE AND PAUL M. GROSS, JR., *Brown University.*—The bridge to be described has been developed for reasonably accurate measurement by direct balance in the frequency range 50 c/sec. to 5 mc/sec., and over most of this range is essentially direct reading in capacitance and conductance with negligible unbalance from lead effects, guard circuits, and other residuals. The properties are realized by two circuits developed from designs by Young* and others. The first employs inductively coupled ratio arms to minimize effects of guard circuits and residuals; the second is a "conductance shifter" wye network with good high frequency properties and an essentially linear scale of conductance reading. Design considerations and limitations in use of these circuits are discussed, as are suitable test cells and results obtained.

* C. H. Young, Bell Lab. Record **24**, 433 (1946).

PA4. Activation Phenomena of Thoria Cathodes.* O. A. WEINREICH (Introduced by W. E. Danforth), *Bartol Research Foundation.*—Activation procedures include (a) flashing to high temperatures (up to 2500°C), (b) bombardment with a reverse electron current from a neighboring filament, (c) adsorption of vapor from a nearby active thoria cathode. The highest d.c. emission value obtainable seems to be about the same for all three methods and is approximately 1 amp./cm^2 at 1350°C Br. Numerical data regarding the three types of activation are included. It is shown that with reverse electron current the activation level will rise to a maximum and then decrease. Highly activated thoria cathodes are unstable. Deactivation is caused by residual gas and/or flow of emission current in the normal direction. Experiments are described in which different residual gases are used. Evaporation products from a nearby active thoria cathode were mentioned above as a source of activating material but will, however, cause deactivation if the cathode upon which they fall is at room temperature. The general pattern of activation phenomena with thoria in this temperature region suggests mechanisms similar to those proposed for BaO/SrO cathodes.

* Sponsored by U. S. Navy, Bureau of Ships, Contract NObs-34141.

PA5. Barium Fluoride as a Cold Cathode in an Argon Glow Discharge. HAROLD JACOBS, ARMAND P. LAROCQUE, AND ALFRED MAZZEI.—Additional work has been undertaken in relation to various barium compounds in glow discharge tubes. The barium fluoride cathode surfaces as well as other ionic compounds are shown to exhibit greater stability than the surfaces activated by evaporating barium metal on nickel electrodes. Some evidence is shown which indicates that during the bombardment of the cathode surfaces by positive ions, free barium has greater affinity for the barium fluoride surface than for the metallic surface. This may be the cause of greater stability of the barium fluoride cathode.

A series of voltage regulator tubes is proposed in which the cathodes are made of various fluoride compounds with the metallic element being varied and having the regulation voltage different for each fluoride, depending on the metallic constituent of the ionic crystal forming the cathode surface.*

* This work was undertaken in association with the Applied Physics Laboratory of the Johns Hopkins University contract sponsored by the Bureau of Ordnance, U. S. Navy.

PA6. Micro Analysis of Gas in Cathode Coating Assemblies. BERNARD WOLK AND HAROLD JACOBS. A study of gases evolved from oxide coated cathode assemblies was made during degassing and activation conditions. It was found, first, that the gases evolved from uncoated nickel cathode sleeves were qualitatively and quantitatively practically independent of the three different cleaning methods of factory processing commonly used, and, second, that hydrogen-fired cathodes liberated slightly larger quantities of hydrogen when heated in vacuum. In addition, the release of hydrogen from nickel cathodes was not instantaneous but was observed to continue even after 2½ hours of continued heating at 900°C Br. When a similar analysis was made of gases liberated from nickel sleeves coated with alkaline earth carbonates, the evolution of hydrogen was reduced considerably, but with a corresponding increase of CO indicating the reaction: $CO_2(g)$ (excess)$+H_2(g)=H_2O(g)+CO(g)$. The gas condition in the tubes during cathode degassing is shown to be related to the speed of exhaust. The lower speed of exhaust produces a condition leading to the right side of the equation, and a high exhaust speed produces conditions tending to retard the reaction to the right.

PA7. Secondary Emission From Barium Oxide as a Function of Temperature and Activation. GEORGE W. HEES AND HAROLD JACOBS.—Experimental secondary emission tubes were prepared in which the dynode consisted of cathode nickel coated with barium oxide. The secondary emission properties of these surfaces were studied in the range of 100 to 250 v with 50 microamps d.c. primary current. It was expected that the exponential temperature dependence of secondary emission from these materials would be found as pointed out by M. A. Pomerantz[1] and J. B. Johnson.[2] Instead it was found that only in some of the tubes was there any marked temperature dependence and in all of the tubes as activation and temperature treatment was increased, there appeared to be very little, if any, change in secondary emission with temperature. It was found that by the time the oxide coated cathode was fully activated as a thermionic

emitter that most of the temperature effects disappeared. The indications here are that some of the temperature dependence pointed out by Pomerantz and Johnson may be due to incomplete activation, pulsing techniques, or chemical preparation of surfaces.

[1] M. A. Pomerantz, Phys. Rev. **70**, 33 (1946).
[2] J. B. Johnson, Phys. Rev. **66**, 352 (1944); Phys. Rev. **69**, 693 (1946); Phys. Rev. **69**, 702 (1946).

Fluid Dynamics

PB1. On the Hydrodynamic Stability of Flame Fronts.[1] HARVEY EINBINDER, *Cornell Aeronautical Laboratory.*[2]—The hydrodynamic stability of a plane flame front is treated by discussing the behavior of a first-order infinitesmal disturbance of the main flow, in analogy with the well-known stability treatments of laminar parallel flows.[3] The fundamental differential equations are derived and the velocity and pressure perturbations found. A continuous main flow velocity distribution is unstable. Landau's work[4] on this problem, employing a discontinuous velocity distribution is discussed. It is shown that thermal processes must be included. To this end, the first-order perturbation equations, including thermal as well as hydrodynamical processes, are derived as the first step toward the solution of the stability problem for a plane flame front.

[1] This work was performed as a part of U. S. Navy Project Squid.
[2] Present address: Pupin Laboratories, Columbia University, New York, New York.
[3] C. C. Lin, Quart. App. Math. **3**, 117, 218 (1945); **3**, 277 (1946).
[4] L. Landau, Acta Physicochimica U.R.S.S. **19**, 77 (1944).

PB2. Cavity Pressure and Cavitation Number after Vertical Water-Entry of a Sphere.* ALBERT MAY, J. H. MCMILLEN, AND J. C. WOODHULL, *Naval Ordnance Laboratory.*—Using high speed motion pictures, measurements were made on cavities produced by the vertical water entry of ¼-, ½-, and 1-inch steel spheres at speeds between 22 and 131 ft./sec. For open cavities obtained when low pressure air is used above the water the cavity-wall motion is approximately horizontal, and the maximum diameters are roughly those to be expected if the hydrostatic head alone acted on the water. The reduced pressures in cavities which close at the water surface are found to hinder cavity expansion. Pressures in such cavities were found by comparing expansion times in open and closed cavities. When a half-inch sphere enters at 50 ft./sec., the average pressure during expansion is 4.5 to 7 percent below atmospheric for various atmospheric pressures. At 40 ft./sec. the drop is 25 percent less. The cavitation number is found to be 0.09 for a half-inch sphere entering from ordinary air at 50 ft./sec.

* Investigation sponsored by the Office of Naval Research.

PB3. Depolymerization by Ultrasonic Irradiation: The Role of Cavitation. ALFRED WEISSLER, *Naval Research Laboratory.*—Contrary to current belief,[1,2] cavitation is necessary for the depolymerizing effect of ultrasonic waves. This was demonstrated by irradiating two portions of a one percent polystyrene[3] solution in toluene for equal times with equal intensity. The first portion was given no special prior treatment, showed many cavitation bubbles during irradiation, and decreased in molecular weight to about one-tenth of the initial value. The second portion was thoroughly degassed first by boiling under vacuum, showed no cavitation bubbles during irradiation, and underwent no change in molecular weight. Oxidants known to be produced by irradiation of solutions containing dissolved oxygen or nitrogen cannot be responsible for the degradation, because substantially the same amount of depolymerization occurs even when helium is the only gas present. Molecular weights were measured by means of the intrinsic viscosity. Similar experiments with solutions of hydroxyethyl cellulose in water showed that, for this system also, cavitation is necessary for depolymerization. The opposite conclusion of earlier investigators[1] is attributed to their inadequate method for eliminating cavitation.

[1] Schmid and Rommel, Zeits. f. physik. Chemie **185A**, 130 (1939).
[2] H. Mark, J. Acoust. Soc. Am. **16**, 183 (1945).
[3] The polystyrene sample, together with molecular weight and related data, was obtained through the kindness of Dr. S. G. Weissberg of the National Bureau of Standards.

PB4. Gas Bubbles as Cavitation Nuclei.* F. G. BLAKE, JR., *Harvard University.*—Cavitation in the body of a liquid at points well removed from the vessel walls has been obtained by means of intense converging sound beams.[1] Measurements of the cavitation threshold sound pressure P_c (atmospheres, peak) have yielded the empirical formula $P_c=0.07(T_p-T)+1$. T is the temperature (centigrade) and T_p is the boiling point corresponding to the mean or hydrostatic pressure. The numerical constants are for conventionally "de-aerated" water. The "intrinsic pressure" of van der Waals law and thermal fluctuation nuclei both fail to explain the measurements by a wide margin. An interpretation consistent with these results and those of others is afforded by an assumption of stabilized submicroscopic gaseous nuclei, whose size varies with the hydrostatic pressure and dissolved gas content. Stabilization is apparently effected by Griffith-Joffé cracks in boundary walls or suspended dust particles.

* This work was supported in part by the Office of Naval Research.
[1] F. G. Blake, Jr., J. Acoust. Soc. Am. **20**, 223(A) and 590(A) (1948).

PB5. A Physical Optic Analysis of the Schlieren Method. H. JEROME SHAFER, *Princeton University.*—The conventional methods of analysis of the schlieren method lead to incomplete results regarding the relationship between the object under study and the observed image. In the present analysis the schlieren system is treated as a problem in diffraction along the lines of Linfoot.* The diffraction pattern in the focal plane of the objective, caused by the object under investigation, is calculated from Kirchoff's diffraction formulation. Calculated images for several simple objects are shown when the diffraction pattern is modified by the conventional knife edge, phase contrast, and dark field illumination. This analysis accounts for the halo surrounding images of opaque objects in schlieren systems. It also indicates that the sensitivity of a conventional schlieren system is independent of the focal length of the optics used for point source illumination. For light sources of finite size the sensitivity is determined by the relative sizes of the image of the source and of the Airy disk. The expressions for light intensity in the image plane are too complex to allow for quantitative evaluation of photographs.

* E. H. Linfoot, Proc. Roy. Soc. **186**, 72 (1946).

PB6. Influence of the Length of Wires on the Measurement of Turbulence with a Hot-Wire Anemometer. F. N. FRENKIEL, *Naval Ordnance Laboratory.*—The influence of the length of the wires on the measurements in a turbulent flow with a compensated hot-wire anemometer are considered. Correction factors by which the measured characteristics of turbulence should be multiplied to give the correct values are computed. The urgence of an accurate evaluation of these factors is emphasized, as it appears that inaccurate experimental data might lead to unwarranted theoretical conclusions. For some particular cases the influence of the length of the wire is found numerically. The case of wires of small but non-negligible lengths (compared to the microscale of turbulence) is also considered. The correction factors for the measured intensities of turbulence, correlation coefficients, scale and microscale of turbulence, etc., are then found.

PB7. Analytical Studies of the Mach-Zehnder Interferometer. ERNST H. WINKLER, *Naval Ordnance Laboratory.*—There are two current difficulties encountered in the use of the Mach-Zehnder interferometer. (1) The light intensity of available light sources which are sufficiently monochromatic is too low for the study of transient phenomena. (2) The field of view is too small. Since the light intensity of sufficient monochromatic light sources is restricted, the only way to solve the problem is to utilize the maximum possible light source extension. Though the field is not large enough, an increase in the field of view introduces restrictions in the size of the light source as a result of the increase in glass plate thickness, and to the effects of imperfections, and misalignments of the glass plates. Analytical studies have been made of the geometry of the arrangement, the position of the sharpest interference plane, the region of sufficiently sharp fringes, and the maximum extension of the light source. They are functions of the fringe number, fringe direction, the angle of incidence of the light rays, and the arrangements of the mirrors. The effects of the imperfections and misalignments of the glass plates have been investigated and possibilities of compensation of these effects considered. From this it follows that certain conditions have to be met to assure the reliability of the data obtained from fringe displacements.

PC1. Relationship between Gough-Joule Coefficients and Moduli of Vulcanized Rubbers. F. S. CONANT, G. L. HALL, AND G. R. THURMAN, *Firestone Tire and Rubber Company.*—The Gough-Joule coefficients (a) at constant stress and (b) at constant strain are defined, and methods of measurement of each on vulcanized rubbers are given. It is shown mathematically and experimentally that the ratio of (b) to (a) is equal to the "tangent" modulus. The quotient of the Gough-Joule coefficient at constant stress divided by the stress and the quotient of the Gough-Joule coefficient at constant strain divided by the strain are shown to be constants which are independent of the stress-strain-temperature conditions of the test. Experimental data are given for stocks based on Hevea, GR-S, Neoprene GN, Butyl rubber, and Butaprene.

PC2. Polymerization in the Solid State. E. MILLER, I. FANKUCHEN, AND H. MARK, *Polytechnic Institute of Brooklyn.*—Some substances can apparently polymerize while in the solid state. One such material has been studied in this laboratory in some detail. The melting point of ϵ-carbobenzoxy-α-carboxyl-l-lysine anyhdride stored in stoppered vials at room temperature for periods up to one year has been observed to rise considerably above that of the freshly prepared sample (m.p. 101°). Comparison of x-ray diffraction diagrams of fresh monomer, aged monomer, and bulk polymer indicate that the aged monomer samples suffered disorientation with distinct changes in the Bragg reflections, and the diagrams of the aged specimens appear to be similar to diagrams given by bulk polymer. Samples of freshly prepared monomer were heat-treated in the solid state at different temperatures below the melting point for periods up to one week. X-ray studies of these samples suggest that the threshold temperature for the disorientation process is about 70°C. The process appears to be complete in samples heat-treated at 85°C, since their x-ray diagrams resemble those of bulk polymer, and no further change is observed at higher temperatures.

PC3. Relations between the problems of rubber elasticity, phase-change, and ferromagnetism. E. GUTH, *Notre Dame University* AND H. M. JAMES, *Purdue University.*

PC4. Time and Stress Effects in the Behavior of Rubber at Low Temperature. J. R. BEATTY AND J. M. DAVIES, *B. F. Goodrich Research Center.*—The stiffening of rubber-like materials at low temperature involves several different phenomena, sometimes with their effects superimposed. One of these is crystallization. This is a rate process which is generally very fast at high stresses and very slow at zero stress. In these experiments at temperatures near −25°C and under a shear stress of about 148 p.s.i., the dynamic modulus of the rubber increased at a rate convenient to study. Correlation with x-ray data showed that crystallization was responsible for the increase in stiffness. The rate of change of stiffness increased rapidly with increase in applied stress, and there was no optimum temperature as has been found for unstressed rubber. The amount and kind of vulcanization influenced the stiffening, tighter cures giving smaller changes. Neoprene FR and polybutadiene, which ordinarily show little evidence of crystallization, showed very definite but small increases in stiffness. The results with GR-S were less definite, but in some cases there were definite changes. Mixing GR-S with natural rubber seems to limit the crystallization of the natural rubber rather effectively, but apparently Neoprene Fr does not mix intimately enough with natural rubber to affect the crystallization of the latter appreciably.

PC5. The Compatibility, Efficiency, and Permanence of Plasticizers. R. F. BOYER, *The Dow Chemical Company.*—This paper attempts to inter-relate three important aspects of plasticizer behavior: *compatibility*, or how much plasticizer can be added without causing phase separation; *efficiency*, or how much a given amount of plasticizer lowers the brittle temperature; and *permanence*, or how well a plasticizer is retained by the polymer on heat aging or solvent treatment. Compatibility is discussed in terms of the Flory-Huggins theory of the thermodynamics of

polymer solutions, which relates the activity of the plasticizer to its concentration in the polymer. Efficiency is measured by how the plasticizer lowers the melt viscosity of the polymer. An empirical relationship between efficiency and μ (the Huggins polymer-solvent interaction constant) is shown. Loss of plasticizer at elevated temperatures depends in part on the effective vapor pressure of the plasticizer, and in part on how rapidly diffusion of plasticizer from the interior of the sample replenishes that lost from the surface. From the fact that diffusion constant times viscosity is a constant, it is possible to correlate measured diffusion rates with plasticizer content and with plasticizer efficiency. A linear relationship is predicted and found experimentally between logarithm of the diffusion constant and the brittle temperature. In this sense, the more efficient a plasticizer is, the more rapidly it can diffuse out of the polymer and be lost.

PC6. Mechanical Properties of Polystyrene Films Cast from Solvents. E. MERZ, L. NIELSEN, AND R. BUCHDAHL, *Monsanto Chemical Company.*—Using a 2×2 block with replication design of experiment, the reproducibility of casting polystyrene films from methyl ethyl ketone and benzene was investigated. Various drying cycles were utilized to reduce the concentration of solvent so that there would be no effect on the mechanical properties. Tensile strength, creep at elevated temperatures, dynamic modulus, and damping capacity measurements were used as criteria of dryness. The instrument used to measure the dynamic elastic modulus and loss factor is described in some detail. The mechanical properties of "dry" benzene films differed from the properties of the "dry" MEK films. The change of the dynamic elastic modulus and loss factor near the so-called second-order transition point as a function of temperature and the effect of very small amounts of solvents on this transition region are discussed.

Cosmic Rays

Q1. Evidence of Low Energy Gamma-Rays (1–5 Mev) from Stopped Negative Mesons.* W. Y. CHANG, *Princeton University.*—Experiments** have been continued on the absorption of sea-level mesons by thin Al (0.002-inch), Fe (0.028-inch) and Pb (0.018-inch) foils. In each substance many pictures have been obtained, in which a particle identified as a meson stops at a foil but neither heavy charged particle nor decay electron is observed to emerge from the end. These stopped mesons are regarded as negatives, as a roughly equal number of decaying mesons has also been obtained from each element. The present results lead to the conclusion that no protons are emitted, at least in the case of Pb, when a negative μ-meson interacts with a nucleus. In Pb, 7 meson-oriented secondary electron tracks (two of them are pairs) have been obtained from 7 of the 27 stopped negative mesons. A similar track was found for Fe, and none for Al. The energies of these electrons are between one and five Mev. The chance that a stray secondary electron track may point accidently away from or toward the point where the meson disappears is estimated to be about 1 in 100. The occurrence frequency and energy of these electrons give good evidence that these meson-associated photons arise (1) outside the nucleus, owing to the meson transition between Bohr orbits as predicted by Wheeler's theory and (2) within the nucleus, caused by nuclear excitation as a consequence of a negative meson capture followed by a "neutral meson" or neutrino emission.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
** W. Y. Chang, Phys. Rev. **74**, 1236 (1948).

Q2. On the Range of the Decay Electrons of Cosmic-Ray Mesons. J. STEINBERGER, *University of Chicago.*—An experiment has been carried out both at Chicago and on Mt. Evans, Colorado, to determine the number of decay electrons, as well as the lifetime of the decay process, as a function of the thickness of a hydrocarbon absorber which the electrons must penetrate. The amount of material with high Z in the path of the electrons (counter walls) has been kept small, so that, for the energies involved, ionization is the chief means of energy loss. The resolution of the apparatus for the determination of energy has been calculated, taking the geometry, radiation, and scattering into account. About 8000 counts were obtained. The results indicate that the spectrum is either continuous from 0 to about 55 Mev, or consists of three or more discrete energies. The latter seems somewhat improbable, especially because no variation of lifetime with absorber thickness is observed. If one then assumes that the spectrum is continuous, it is possible to calculate its shape roughly. This will be presented. The average energy can be computed with greater accuracy and is ~32 Mev. The lifetime is observed to be 2.16 ± 0.08 sec.[1]

[1] This agrees with the value of Rossi and Nereson, Phys. Rev. **62**, 417 (1942).

Q3. The Disintegration of Mesons.* R. W. THOMPSON,** *Massachusetts Institute of Technology.*—The cloud-chamber experiment previously reported has been continued at Echo Lake, Colorado. A total of 14 measurable photographs, inclusive of sea-level results, has been obtained. Of these, one disintegration track indicates a momentum of 18 Mev/c, eleven show momenta between 36 and 48 Mev/c, and two show momenta of 53 and 61 Mev/c, respectively. The mean momentum is 42 Mev/c. Under the assumption that the disintegration particle is an electron and has a unique momentum of 42 Mev/c, the probability that one out of 14 electrons radiates more than half its energy in emerging from the absorber is about $\frac{1}{3}$. Although it is difficult to estimate the reliability of statistical arguments based on so few events, it should be noted that, according to Birge's criterion, the 14 observations are consistent with a unique momentum of 42 Mev/c. Conversely, under the assumption of a spectrum of momenta given by the statistical factor for the disintegration $\mu\rightarrow e+2\nu$ and the assumption that the apparatus discriminates completely against momenta less than 25 Mev/c, the probability of obtaining 11 out of 14 observations which are grouped in the stated range is estimated to be small.

* This work was supported in part by the Office of Naval Research.
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Q4. Nature of the Primary Cosmic Radiation as Revealed by Transition Effects in Lead and within the Atmosphere.* J. A. VAN ALLEN, L. W. FRASER, AND R. S.

OSTRANDER, *Applied Physics Laboratory, Johns Hopkins University.*—By means of equipment carried in rockets, through and above the atmosphere, data have been obtained (a) on transition effects produced by the primary cosmic radiation above the atmosphere in thicknesses of lead up to 275 g/cm², and (b) on the rate of production of multiple particle events in various thicknesses of lead as a function of atmospheric depth throughout the atmosphere. The transition data of (a), taken as a whole, cannot reasonably be attributed to electrons or gamma-rays; in particular, an upper limit of the combined flux of electrons and gamma-rays of energy exceeding 5×10^9 ev can be placed as not to exceed five percent of the primary flux. Three general hypotheses as to the nature of heavy particle reactions in lead will be discussed. The data of (b) show that the rate of multiple particle events under large thicknesses of lead increases monotonically with decreasing atmospheric depth throughout the atmosphere and can be satisfactorily described by a Gross transformation with $\mu=(200\ \text{g/cm}^2)^{-1}$. The rate of multiple particle events under small thicknesses of lead passes through a mild maximum at about 50 g/cm² atmospheric depth.

* Supported by Navy Bureau of Ordnance.

Q5. Heavily Ionizing Radiation at a 4300-Meter Altitude.* FRANK L. HEREFORD, *Bartol Research Foundation.*—The effective counting efficiency of a single low pressure Geiger counter (4 cm Hg of hydrogen) for the ionizing cosmic radiation penetrating various thicknesses of lead has been measured at a 4300-meter altitude. For thicknesses exceeding 100 g/cm² electrons are excluded, and from existing experimental results it is possible to determine the counting efficiency expected for mesotrons alone at that altitude. The observed excess in efficiency can then be interpreted as due to an N component which is more heavily ionizing than either μ- or π-mesotrons, *viz.*, protons and heavier nuclear particles. Assuming that only protons are present in this N component, their intensity relative to the total ionizing component penetrating various thicknesses of lead can be computed. On this basis the data indicate, for example, that 17 ± 5 percent of the hard component (radiation penetrating 167 g/cm²) consists of protons. The data also yield a rough absorption curve for this N component which can be fitted by $e^{-t/L}$ with $L=260\pm50$ g/cm². The close agreement with Bridge's[1] value of 280 ± 50 g/cm² for the radiation producing bursts under large thicknesses of lead at 4300 meters supports the view that the "burst primaries" are protons.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission. Field trip sponsored by National Geographic Society.
[1] Unpublished results; see B. Rossi, Rev. Mod. Phys. **12**, 562 (1948).

Q6. The Detection of Heavy Particles in the Primary Cosmic Radiation.* MARTIN A. POMERANTZ AND FRANK L. HEREFORD, *Bartol Research Foundation.*—Utilizing a new technique which renders feasible the selective detection of the charged components of cosmic radiation at very high altitudes, evidence has been obtained for the existence of heavy nuclei among the primaries, and a means has been afforded ultimately for resolving the various components throughout the atmosphere. The method employs G-M counters filled under conditions exploiting the dependence of the probability of discharge upon specific ionization.[1] The combination of such counters into a coincidence train and the establishment of a minimum range through interposed absorber result in a device capable of discriminating violently among different types of particle. Heavy particles were first detected during a free balloon ascent on July 11, 1947. Events ascribable to primaries of $Z\geq2$ were observed at altitudes exceeding 15 mm of Hg. More than 10 flights with telescopes having various characteristics and containing different absorbers have been conducted subsequently. Recent experiments have confirmed the original evidence for the presence of heavy particles, now well established,[2] and have revealed that the events observed here are not attributable to stars, bursts, air showers, etc.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
[1] W. E. Danforth and W. E. Ramsey, Phys. Rev. **49**, 854 (1936).
[2] P. Freier, E. J. Lofgren, E. P. Ney, F. Oppenheimer, H. L. Bradt, and B. Peters, Phys. Rev. **74**, 213 (1948).

Q7. Directional Intensity of Cosmic Rays at High Altitudes.* I. Instrumentation. W. G. STROUD, J. R. WINCKLER, AND J. SCHENCK, *Princeton University.*—In conjunction with a proposed study of the directional intensities of cosmic rays at high altitudes as a function of latitude, we have carried out a series of preliminary measurements.** The equipment was carried aloft by a balloon and remained at an altitude approaching 100,000 feet for 5 to 10 hours. The 15-channel frequency-modulated telemetering scheme will be discussed with respect to advantages and disadvantages. Some details of the counter geometry and other end instruments will be given. Shower protection was provided, and the results indicate few showers at high altitudes. The equipment was housed in a black-silver Cellophane greenhouse and complete with batteries for 12-hour operation weighed 75 pounds. Flights were made from Princeton, in Minnesota, and from aborad a ship at sea using various balloon structures. The type of data obtained by the equipment will be shown.

* Assisted by the Joint Program of the Atomic Energy Commission and the Office of Naval Research.
** See also Winckler, Stroud, and Schenck, Phys. Rev. **74**, 837 (1948).

Q8. Directional Intensity of Cosmic Rays at High Altitudes.* II. Interpretation. J. R. WINCKLER AND W. G. STROUD, *Princeton University.*—For analytical purposes the intensities observed at each zenith angle with various lead filters (see previous paper) have been plotted with the pressure height on a logarithmic scale. On this basis a shift of the pressure axes brings most of the zenith angle data with similar filters into agreement. The simplest explanation for this is the effect of the extra air path seen at low zenith angles, which is expressed by the relation $I(P,\theta)=I(P\sec\theta,0)$, where P is the atmospheric pressure and θ the zenith angle. The constant obtained by shifting the pressure axes agrees reasonably well with $\sec\theta$. A difference in curvature of the "hard" curves at 0° and 67½°, even when plotted as described, can be explained by meson decay, and an order-of-magnitude calculation gives 10^{-6} sec. for the mean life. The influence of the angular spread of secondary particles on the results of these experiments will be discussed in the light of a simple analysis. Direct evidence that the spread for the particles measured is not large is obtained from the low intensities observed at $\theta=90°$ at all pressures. The distribution of intensities in zenith and azimuth at the highest altitudes reached in

these experiments agrees with the assumption of a nearly isotropic primary flux at geomagnetic latitude 56°N.

* Assisted by the Joint Program of the Atomic Energy Commission and the Office of Naval Research.

Q9. The Latitude Effect at High Latitudes and High Altitudes.* W. F. G. SWANN, PETER A. MORRIS, AND DAVID SEYMOUR, *Bartol Research Foundation.*—Flights covering 141 hours have been made at 25,000 feet and 30,000 feet with the object of investigating the latitude effect in the vicinity of and above the knee of the curve. At 30,000 feet the curve continues to rise beyond the knee, affording a 10 percent increase for 10° increase of magnetic latitude. There is a statistical uncertainty of ±2.5 percent and some uncertainty depending upon general uncontrollable irregularities inherent in altitude fluctuations, barometer changes, and the like. However, the existence of a definite increase, which is absent at 25,000 feet, is considered established for 30,000 feet. It finds a ready explanation (and, indeed, as regards order of magnitude) in the phenomenon pointed out by Kupferberg and having to do with the variation of the altitude of mesotron production with latitude. The observations were made by Peter A. Morris and David Seymour, and the analysis of the same was carried out by Stephen H. Forbes, all under the general direction of the senior author.

* Supported by the Office of Naval Research, the Army Air Forces and the National Geographic Society.

Q10. Influence on the Cosmic-Ray Spectrum of Five Heavenly Bodies.* T. J. B. SHANLEY, E. O. KANE, J. A. WHEELER, *Princeton University.*—The low energy cut-off in the primary spectrum can be ascribed to a magnetic field of the sun. Primaries coming from infinity with $(2.32\times\mu_{sun})BV<(cp/e)<[(1+\sqrt{2})^2\times 2.32\times\mu_{sun}]BV$ can reach the earth within a restricted cone of directions allowed by the sun's field, about which the rotation of the earth's allowed cone leads us to expect a diurnal variation substantially greater than is actually observed. We have investigated an explanation for this inconsistency first suggested by Alfven that the earth's field scatters sufficient particles into bounded orbits in the sun's field to make the intensity outside the sun's allowed cone substantial. We determine an approximate scattering cross section for the earth's field and obtain absorption cross sections for the moon, sun, Venus, and Mars. Solution of the equilibrium equation yields an analytical expression for the relative intensity outside the sun's allowed cone. To simplify the calculations we assumed (1) a sun's field constant in time, and (2) a negligible effect from the magnetic moments of the moon and planets. Our results indicate a mean trapping time approximately 5000 years, and a small diurnal variation consistent with present scanty observations.

* Supported by Joint Program of Office of Naval Research and Atomic Energy Commission.

Q11. Detection of Cosmic-Ray Particles by Scintillation Counters.* GEORGE T. REYNOLDS, *Princeton University.*—Penetrating cosmic-ray particles have been detected by means of a scintillation counter consisting of polycrystalline sodium iodide.[1] The efficiency of the counter appears to be very high and may be limited only by the geometry of the available crystals. The shape of the pulses is limited in the present experiment by the characteristics of the amplifier, in this case yielding a rise time of 0.2 μsec. and a decay time of 5 μsec. In measuring the efficiency of the scintillation counter, the area occupied by the crystal is defined by a conventional Geiger counter telescope under 8 inches of lead. A coincidence in the telescope is made to sweep an oscilloscope. The signal from the crystal is amplified and delayed and put on the vertical plates of the oscilloscope. Experiments are also described in which two scintillation counters take the place of the Geiger counters. The pulse from one of these crystal counters is photographed on the sweep resulting from a coincidence between the two crystal counters.

* Supported by the Joint Program of Office of Naval Research and Atomic Energy Commission.
[1] R. Hofstadter, Phys. Rev. **74**, 100 (1948).

Molecular Structure

R1. Calculation of Molecular Force Constants. E. BRIGHT WILSON, JR., *Harvard University.*—A method of successive approximations has been devised which enables the calculation of N force constants from N vibration frequencies of a molecule or set of molecules. A preliminary approximate set of constants is inserted into the simultaneous equations which determine the amplitudes of vibration for a single fundamental mode of vibration of known frequency. One of these equations is set aside, and the remaining equations are solved for the amplitudes. If these amplitudes are inserted into the equation which was set aside, a linear, approximate relation between the force constants results. One such relation can be obtained from each of the N frequencies, so from their solution N force constants can be calculated. These may be used as an improved starting point and the process repeated until the results converge.

R2. Centrifugal Stretching in H_2O and D_2O. W. S. BENEDICT, *National Bureau of Standards.*—A general method has been developed for evaluating the effective reciprocal moments of inertia and centrifugal stretching coefficients of asymmetric-top molecules from empirical data (combination differences), and has been applied to various vibrational states of H_2O and D_2O. The method is based on the properties of the sums of the various elements of the symmetry-factored rotational energy matrices. The empirical data for the ground level of H_2O are known very accurately; for this level quite precise values have been obtained for the 7 first-order centrifugal stretching coefficients (those involving terms in P^4), as well as approximate values for most of the second-order coefficients (involving terms in P^6). The corresponding coefficients for upper vibrational levels of H_2O and for levels of D_2O are also obtained with fair accuracy. There is a marked dependence of the centrifugal stretching on the vibrational level; in particular, the coefficients involving rotation about the least axis of inertia increase very rapidly for higher values of the bending frequency ν_2. The empirical results show that second-order perturbation theory, while a useful first approximation, is inadequate to represent the rotational-vibrational interactions in the water molecule.

R3. Infra-Red Emission Spectra of Molecules.* N. GINSBURG, *Syracuse University.*—Spectra of various gases were

excited in a U-tube a.c. discharge tube at high current densities. Their emission in the infra-red was observed with a Perkin-Elmer spectrometer modified for this type of investigation. The wave-length of the observed emission bands (in microns) for the various gases is given in the following table:

CO_2	4.7	3.7	2.2	
N_2O	4.8	1.9		
H_2S	1.5	1.2	1.0	0.8
NH_3	4.9	1.2		
C_2H_6	4.6	3.75		

Some of the emission bands can be correlated with fundamental vibrational frequencies or their overtones. This is the case for the 4.7μ- and 2.2μ-band of CO_2, the 4.8μ-band of N_2O and the 4.9μ-band of NH_3. The emission region for H_2S corresponds with some combination bands, $\nu_1+3\nu_3$ and $3\nu_1+\nu_3$, but this seems a rather improbable identification. Similarly, the bands for ethane appear in a region where combination bands have been observed in absorption, but they are probably due to vibrations of fractions of the molecules dissociated by the discharge.

* The work described in this paper was carried out under Contract W-33-038 AC 14726 with the Air Materiel Command of the Air Force.

R4. Association Bands in the Ultraviolet Spectra of N—H···O Bridged Polymers.* GLADYS A. ANSLOW AND RUTH C. SHEA, *Smith College*.—Continuous ultraviolet absorption bands appear between 230–260 mμ in the spectra of molecules which are associated through N—H···O bridges, such as the amides, anilides, amino acids, and peptides. Absorption starts suddenly at frequencies which are mass dependent, obeying a relation similar to that established for end absorption in carboxylic acid dimers,[1] interpreted as rupture of both the bond and the bridge. Typical spectra will be exhibited for aqueous or alcohol solutions at various concentrations with different degrees of association. Spectra of highly monomeric solutions exhibit a weak band with onset near 330 mμ, resulting from unbridged NH absorption. Some specimens show absorption near 280 mμ. Interassociation is produced when heat-treated amide solutions are rapidly cooled in an ice bath. Slowly cooled solutions appear less closely associated. Strong interassociation bands appear in the spectra of the cyclic dipeptide, glycine anhydride, and of the Nylons formed from linear polyamides.

* This work was supported by the Office of Naval Research.
[1] Gladys A. Anslow, Phys. Rev. **61**, 547 (1942).

R5. The Stark Spectrum and Dipole Moment of HNCS. C. I. BEARD AND B. P. DAILEY.—The Stark effect on the rotational transition $J=1\rightarrow J=2$ of the slightly asymmetric rotor HNCS was measured using square wave modulation giving peak field values from 18 to 800 v/cm. The frequencies of the lines in the observed Stark spectrum were compared with differences in energy levels calculated for appropriate values of the field by the method of Golden and Wilson.[1] The experimental data are well fitted using a value of the dipole moment component along the axis of least moment of inertia of 1.72±.05 Debye units. A first-order and a second-order Stark component were observed for each of the transitions $1_{1,1;0}\rightarrow 2_{1,2;-1}$ and $1_{1,0;+1}\rightarrow 2_{1,1;0}$ and two second-order components for the transition $1_{0,1;-1}\rightarrow 2_{0,2;-2}$. The "center of gravity" of the first-order components of the former two transitions was found to shift in frequency by the amount predicted from the equations of Golden and Wilson. In addition, two first-order Stark components from rotational transitions forbidden at zero field, namely, $1_{1,1;0}\rightarrow 2_{1,1;0}$ and $1_{1,0;+1}\rightarrow 2_{1,2;-1}$, were observed. The frequencies and Stark effects of these lines were found to be simply related to those of the allowed transitions having first-order components.

[1] S. Golden and E. Bright Wilson, Jr., J. Chem. Phys. **16**, 669 (1948).

R6. O^{17} and S^{36} in the Rotational Spectrum of OCS.* C. H. TOWNES AND W. LOW, *Columbia University*.—A microwave spectroscope of the Stark modulation type has been attached to a recording ammeter so that a slow sweep and narrow band width can be used. This results in considerable reduction in noise, allowing detection in a 10-ft. wave guide of lines with absorption coefficients as small as 2×10^{-9} cm^{-1}, and thus making possible study of rotational lines of rare isotopes. Frequencies and relative intensities of the $O^{17}C^{12}S^{32}$ and $O^{16}C^{12}S^{36}$ $J=1\rightarrow2$ transitions were measured and the lines examined for hyperfine structure with the absorption cell at −78°C to enhance intensities. Abundance and mass of O^{17} determined from these measurements agree very well with accepted values. The mass difference $S^{36}-S^{34}$ obtained is 2.00055±0.0003 or $S^{36}=35.97834\pm0.0004$. Measured abundance of S^{36} is 0.0136±0.0010 percent, rather than 0.016 percent given by Nier,[1] who discovered S^{36}. No hyperfine structure was found, so that quadrupole coupling constants for both O^{17} and S^{36} are less than 5 mc. This is a good indication that the spin of S^{36} is zero, but does not allow a definite assignment of $\frac{1}{2}$ to the spin of O^{17} since its quadrupole coupling may be expected to be small.

* Work supported jointly by the Signal Corps and the Office of Naval Research.
[1] A. O. Nier, Phys. Rev. **53**, 282 (1938).

R7. Stark Effects in OCS.* R. G. SHULMAN AND C. H. TOWNES, *Columbia University*.—The dipole moments of OCS for several isotopic species and vibrational states have been determined from the Stark splitting of the $J=1\rightarrow2$ transition.[1] Three different wave guides were used to obtain the value of the $O^{16}C^{12}S^{32}$ moment as 0.711 ±0.004 Debye units. The $O^{16}C^{12}S^{34}$ and $O^{16}C^{13}S^{32}$ moments differ from this by less than 0.3 percent. The $O^{16}C^{12}S^{32}$ molecule in the excited bending mode ($v_2=1$) may be treated formally as a slightly asymmetric top which produces a pair of lines. Measurement of Stark effect for these lines give a dipole moment 1.4 percent less than for the ground state, or 0.701 Debye. Upon introduction of a Stark voltage two weak lines appear on either side of doublet $v_2=1$. With increasing voltage these lines move apart in frequency and increase in intensity, passing through a maximum intensity. They are explained as transitions involving the doublet levels which are forbidden in zero field, but allowed upon the introduction of a perturbing field. Measured frequencies and intensities agree very well with theoretical calculations based on this explanation.

* Work supported jointly by the Signal Corps and the Office of Naval Research.
[1] Cf. M. W. P. Strandberg, T. Wentink, Jr., and R. L. Kyhl, M.I.T. Research Laboratory of Electronics, Tech. Rpt. No. 59 (1948); T. W. Dakin, W. E. Good, and D. K. Coles, Phys. Rev. **70**, 560 (1946).

R8. Stark Effect in Symmetric Top Molecules with Nuclear Quadrupole Coupling.* W. LOW AND C. H. TOWNES, *Columbia University.*—Fano's treatment[1] of the diatomic molecule is extended to symmetric molecules with nuclear quadrupole interaction so that molecular dipole moments may be measured by Stark effect. For a molecule with only one nuclear quadrupole interaction the weak field formula is $\Delta W = -\mu[EMK/J(J+1)][F\cdot J/F(F+1)]$ plus second-order terms. The second-order terms have been obtained, but this weak field approximation is not useful for fields generally encountered in microwave spectroscopy. The intermediate field case requires solution of a secular determinant. Fortunately, for measurements of dipole moments the strongest and most widely split Stark component involves the maximum M. For a $J\rightarrow J+1$ transition and maximum M, the linear term is accurate for the lower state in intermediate fields and the upper state requires solution only of a second-order secular equation. The strong field cases have also been solved for either one or two quadrupole moments in the same molecule.

* Work supported jointly by the Signal Corps and the Office of Naval Research.
[1] U. Fano, J. Research Nat. Bur. of Stand. 40, 215 (1948).

R9. Torsion Vibrational States of CH_3CF_3.* B. P. DAILEY, H. MINDEN, AND R. G. SHULMAN. (Introduced by C. H. Townes.)—The $J=1\rightarrow J=2$ transition (first reported by Edgell and Roberts[1]) and the $J=2\rightarrow J=3$ transition have been observed for the symmetric rotor CH_3CF_3. Both transitions consisted of a series of three lines, about 40 mc apart, whose intensities decreased toward higher frequencies. All six lines exhibited the first- and second-order Stark effects characteristic of the symmetric top transitions. The similarity of the Stark splittings and the relative intensities of the Stark components for lines of the same series is explained if these transitions are due to excited vibrational states. From the relative intensities of the lines at 300°K and 195°K the separation of these vibrational levels was determined as 165 $cm^{-1}\pm 25$ cm^{-1}. For this molecule only the torsional vibration could be of this order of magnitude. Assuming a hindering potential of the form $V=(H/2)(1-\cos 3x)$, then[2] ν $cm^{-1}\cong 3(C_1C_2H/C)^{\frac{1}{2}}$. The barrier height, H, therefore is 1470+470 cal./mole. The previous value from entropy measurements was 3450 cal./mole,[3] calculated assuming the same barrier shape.

* Work supported jointly by the Signal Corps and Office of Naval Research.
[1] W. F. Edgell and A. Roberts, J. Chem. Phys. 16, 1002 (1948).
[2] J. S. Koehler and D. M. Dennison, Phys. Rev. 57, 1006 (1940).
[3] H. Russell, Jr., D. R. V. Golding, and D. M. Yost, J. Am. Chem. Soc. 66, 16 (1944).

R10. The Paschen-Back Effect in NH_3 and N_2O Microwave Spectra.* C. K. JEN, *Harvard University.*—The Paschen-Back effect in the $N^{14}H_3$ inversion spectrum and the $N^{14}N^{14}O$ $J=0\rightarrow 1$ rotational spectrum has been studied with a variable magnetic field up to 10,000 oersteds. The results for $N^{14}H_3$ yield a molecular g factor, g_{mole}, in good agreement with that deduced from the Zeeman effect.[1] Strong lines were observed wherever they obey the usual selection rules $\Delta M_J=0$, ± 1 and $\Delta M_I=0$. Much weaker lines were observed for the "forbidden" transitions, following the selection rules: $\Delta M_J=0$, $\Delta M_I=\pm 1$; $\Delta M_J=\pm 1$, $\Delta M_I=\mp 2$; and $\Delta M_J=\pm 2$, $\Delta M_I=\mp 1$. The existence of the "forbidden" lines, whose intensities continuously diminish with increasing field, indicates that the decoupling of nuclear spin and molecular rotation is not quite complete even in a field of 10,000 oersteds. Since the nuclear quadrupole moment couplings in N_2O are known to be very small, the Paschen-Back effect should be readily achievable in these fields. The experimental results to be reported in this paper for $N^{14}N^{14}O$ $J=0\rightarrow 1$ transition seem to indicate that the coupling of the two N^{14} nuclear spins and the molecular rotation is almost completely broken at H = 10,000 oersteds. A slight asymmetry of the Paschen-Back pattern is ascribed to the dependence of the quadrupole moment energy upon M_J^2 instead of M_J. A comparison of the theory with the observed pattern leads to a direct determination of the quadrupole moment coupling factors and the g_{mole} for $N^{14}N^{14}O$.

* This research is supported jointly by the Office of Naval Research and the Signal Corps.
[1] C. K. Jen, Phys. Rev. 74, 1396 (1948).

R11. Electron Diffraction by Gas Molecules—Results on the Structure of Ethyl Alcohol and Ethyl Mercaptan.—MARCEL ROUAULT AND GEORGES GALLAGHER, *Université de Montréal.*—An electron diffraction apparatus has been completed in this laboratory and a precise value of the wave-length of electron beam has been found by diffraction through a thin gold film. Diffraction on CCl_4 was done to insure accurate results. The structure of ethyl alcohol and ethyl mercaptan was determined by the visual method. For ethyl alcohol high contrast plates with varied exposure times were used to obtain results in better agreement with the theoretical curve for the first two maxima, and low contrast films were used for the other three maxima. If all the parameters in which there are hydrogen terms are included in the theoretical curve, the structure yields the following distances: C−C = 1.50A, C−O = 1.40A, C−H = 1.08A. Angle CCO = 109°28′. If the interaction between the hydrogen atoms grouped around the end carbon, and the oxygen atom, is neglected, it is found that, in order to obtain agreement between theoretical and experimental results, the angle CCO must be increased by appr 5 percent. The ethyl mercaptan yielded seven sharp maxima on low contrast film. The distances found were C−C = 1.50A, C−S = 1.80A.

R12. On the Isomerization of Hydrocarbons by Electron Impact. RICHARD E. HONIG, *Socony-Vacuum Research Laboratories.*—Electron impact in the mass spectrometer produces abundantly "forbidden" ions from branched hydrocarbons, such as $C_2H_5^+$ from $i-C_4H_{10}$. Two possible modes of rearrangement suggest themselves: A: $i-C_4H_{10}^+$ isomerizes to $n-C_4H_{10}^+$, yielding $C_2H_5^+$; B: $i-C_4H_{10}^+$ dissociates to $C_2H_4^+$ which combines with a H to form $C_2H_5^+$. Appearance potential data[1] favored mode A, yet mode B did not seem completely implausible. To obtain additional experimental evidence, the following molecules, tagged with 50 percent excess C^{13}, were studied: $(CH_3)_2CHC^{13}H_3$, $CH_3CH_2CH_2C^{13}H_3$, and $CH_3CH_2C^{13}H_2CH_3$. The $C_2H_5^+$ ions from end-tagged $i-C_4H_{10}$ should yield a 25 percent C^{13} excess for mode A, or a 16.7 percent excess for mode B. The observed excess of 24±1 percent clearly favors mode A. A comparison of $C_2H_5^+$ peak intensities from $i-C_4H_{10}$ and $n-C_4H_{10}$ indicates that a considerable portion of the $i-C_4H_{10}$ molecules isomerize

to $n-C_4H_{10}$ before dissociation. Smaller discrepancies between predicted and observed excess values for $C_3H_7^+$ and CH_3^+ formed from end-tagged $i-C_4H_{10}$ may be due to a C^{13} shift from end to center position, or to differences in $C^{12}-C^{12}$ and $C^{12}-C^{13}$ dissociation probabilities. Similar effects have been observed in the spectra of end- and center-tagged $n-C_4H_{10}$.

[1] D. P. Stevenson and J. A. Hipple, J. Am. Chem. Soc. **64**, 1588 (1942).

Spectra of Polymers

S1. Band Emission Spectra of Polymers. Effects of Curing Time. WM. W. A. JOHNSON, NATALIE S. JOHNSON AND DANIEL P. NORMAN, *New England Spectrochemical Laboratories.*—High polymers can be dissociated in a high current-density vacuum discharge to yield free radicals which radiate the characteristic band emission spectra of polyatomic radicals. We have found that the distribution and relative intensity of the spectra thus formed are a function of the nature of the original polymers and of the processes which they have undergone. Details of the apparatus are described elsewhere.[1] In this paper we discuss the application of this technique to a study fo the variations in polymers as a function of temperature and duration of cure. Special study has been made of the polymerization of melamine resins on cotton and of the polymerization of unsupported phenolic resins. This new technique offers a ready method for determining the degree of cure of an unknown sample and for the plant control of resins cure.

[1] Norman, Johnson, Johnson, American Dyestuff Reporter **37**, No. 26 (Dec. 27, 1948).

S2. A Low Temperature Infra-Red Transmission Cell.[1] H. O. MCMAHON, R. M. HAINER, AND GILBERT W. KING, *Arthur D. Little, Inc.*—A low temperature, all metal, infra-red transmission cell has been constructed to obtain absorption spectra at liquid helium temperatures of materials that are solid, liquid, or gas at room temperature. It is inserted in the light path of a Perkin-Elmer spectrometer without any modification of optics. Previously described low temperature cells employ the technique of reflection from a cold mirror, the data from which may involve important errors as a result of the change of reflection near strong absorptions. The present apparatus employs a cylindrical sample cell, 25 cc in volume, which is tapered to conform to the converging light path and in which a sample can be mounted. The sample cell is sealed by silver chloride windows at each end, the window material itself serving as a vacuum-tight gasket. The cell is charged with helium gas and is connected to an external pressure gauge by means of a capillary tube. This cell passes through a container which can be filled with liquid helium or any other refrigerant. The cell and liquid helium container are surrounded by a very high vacuum and by a radiation shield which can be cooled independently to the temperature of liquid air (or of solid oxygen if desired). Radiation enters and leaves the evacuated space through rocksalt windows. The helium gas surrounding the sample effectively removes the absorbed radiation energy and indicates the temperature.

[1] This work was supported by a grant from the American Cancer Society.

S3. Infra-Red Absorption Spectra of Some Polymers at Liquid Helium Temperatures. GILBERT W. KING, H. O. MCMAHON, AND R. M. HAINER, *Arthur D. Little, Inc.*—Infra-red absorption spectra of rubber, polythene, polystyrene, and polyvinyl chloride at 4°K have been obtained from 6 to 15μ. Films were mounted in a cell described elsewhere, and were in contact with helium gas at a few cm Hg pressure, which effectively removes absorbed radiant energy, keeping the sample very close to 4°K. The cell was inserted in the light path of a Perkin-Elmer model 12B spectrograph without disturbing the optics, of which the resolution was determined by calculation and confirmed by observation of gaseous spectra. Surprisingly small changes were observed in the spectra upon cooling. Some bands became slightly narrower, and thus became better resolved. Others became wider. A shift of a wave number or two occurred in the position of some peaks. In no polymer did any band disappear nor did new ones arise. The absence of marked changes cannot be attributed to any obvious defect in experimental technique. The spectra of crystalline materials changed under identical conditions. Reexamination of some of the spectra with slits definitely narrower than the bands showed no change in envelope. The widening of some bands on cooling cannot be attributed to insufficient resolution. Comparison of these results with those obtained for crystalline materials seems to show that the vibrational frequencies suffer perturbations of the order of several wave numbers in the variety of surroundings in these non-crystalline materials.

S4. The Infra-Red Absorption Spectrum of Cholesterol at Low Temperatures.[1] R. M. HAINER, GILBERT W. KING, AND H. O. MCMAHON, *Arthur D. Little, Inc.*—The infra-red spectrum at 80°K and 4°K and intermediate points was obtained of cholesterol, as a representative of an important class of biological materials of great clinical importance. On theoretical grounds it was expected that such spectra should become sharper, thus improving their value as a means of analysis and identification, and supplying additional information for the deduction of molecular structure. Thin samples of crystalline cholesterol triturated with mineral oil have been examined in a low temperature transmission cell in a Perkin-Elmer spectrometer in the region 6 to 15μ at 300°, 80°, 60° and 4°K. Relatively wide peaks at 300°K broke up into components at the low temperatures, and the general absorption between peaks became resolved into new ones. Particular attention was paid to the 12μ region with a slit width of 2.2 cm^{-1}. What appears in published data[2] as two absorption peaks at 800 and 840 cm^{-1}, with these narrower slits, shows up as the two given peaks with additional unresolved shoulders at 812, 830, and 848 cm^{-1}. At low temperatures the same region divides into ten resolved peaks, at 798, 803*, 808, 814, 820, 825, 830, 836, 844*, and 855 cm^{-1}, the strongest peaks being starred. The width of these peaks at 80°K is of the order of magnitude of the slit width, and considerably higher resolving power may be necessary to benefit from possible further changes on going to 4°K.

[1] This work was supported by a grant from the American Cancer Society. The material was kindly supplied by Lewis L. Engel, Collis P. Huntington Memorial Hospital, Boston, Massachusetts.

[2] W. S. Baird, O'Bryan, Ogden, and Lee, J. Opt. Soc. Am. **37**, 754 (1947).

Theoretical Physics

T1. Quantum Electrodynamics. FREDERIK J. BELINFANTE, *Purdue University.*—Electromagnetic fields can be regarded as fields of neutral vector mesons with negligible mass. By a canonical transformation, similar to Fermi's transformation in ordinary quantum electrodynamics, the Coulomb interaction is separated. In meson theory this does not eliminate the longitudinal meson field, but for vanishing meson mass the coupling between longitudinal mesons and matter disappears. In blackbody radiation, therefore, the longitudinal field is not in thermal equilibrium with the surrounding; also, any longitudinal mesons present would not be detected. Thus Planck's radiation law is ensured. By ordinary perturbation methods or by Møller's method, one finds for vanishing meson mass Møller's matrix element for electron scattering and Breit's expression for the electron interaction energy in atoms. The probability of emission of longitudinal quanta vanishes for vanishing meson mass. When the number of mesons is large and not exactly determined, the meson field acts for vanishing meson mass as a classical Maxwell field. Thus this meson field gives a complete description of electromagnetic phenomena, while the familiar difficulty with Lorentz' condition is avoided. Use of perturbation methods without preceding Fermi transformation, though not justifiable, sometimes yields correct results—similarly, Schwinger's method of canonical transformations.

T2. A Covariant Hamiltonian Formulation of Field Theory and the Transformation to the Interaction Representation. NORMAN M. KROLL, *The Institute for Advanced Study.*—The general Heisenberg-Pauli theory of field quantization can be written in manifestly covariant form by introducing a generalization of the Hamiltonian and the canonical momenta. Starting from a Lagrangian density $L(\psi_\rho, \partial\psi_\rho/\partial x_\mu)$, one defines canonical momenta $\pi_\rho = n_\mu \partial L/\partial[\partial\psi_\rho/\partial x_\mu]$ where n_μ is the normal to a space-like surface σ at the point x_μ, and a Hamiltonian $\mathfrak{H} = \int_\sigma H d\sigma$, where the Hamiltonian density H is defined in terms of the energy momentum tensor as $-n_\mu n_\nu T_{\mu\nu}$. $\mathfrak{H}$ is to be regarded as a function of ψ_ρ, π_ρ, and the tangential derivatives of ψ_ρ. Quantization according to Einstein-Bose or Fermi-Dirac statistics is accomplished by the introduction of the analogs of the conventional commutation or anticommutation laws. The generalization of the canonical equations which yields the correct equations of motion is then $\partial\psi_\rho/\partial n = \delta\mathfrak{H}/\delta\pi_\rho = -(1/\hbar)[\mathfrak{H}, \psi_\rho]$; $\partial\pi_\rho/\partial n = -(\delta\mathfrak{H}/\delta\psi_\rho) + k\pi_\rho = -(1/\hbar)[\mathfrak{H}, \pi_\rho] + k\pi_\rho$, where k is the mean curvature of the surface. Field variables transformed by a σ-dependent unitary transformation satisfy equations of motion modified only by the replacement of $\mathfrak{H}$ by $\mathfrak{H} - \hbar\int_\sigma (\delta U/\delta\sigma)U^{-1}d\sigma$. It follows that with H_0 being the interaction free Hamiltonian density, a U satisfying $\delta U/\delta\sigma = (1/\hbar)(H - H_0)U$ decouples the equations of motion, thus yielding the interaction representation for the field variables.

T3. On the Interaction of Charged Spin O Particles with the Electromagnetic Field. A. PAIS AND G. E. UHLENBECK, *The Institute for Advanced Study.*—The transition from the Schroedinger representation of a charged scalar field to its interaction representation in which arbitrary space-like surfaces replace the customary flat surface of constant time yields the generalized Tomonaga-Schwinger equation, $i\hbar c(\delta\Psi/\delta\sigma) = -n_\mu n_\nu T_{\mu\nu}\Psi$, where $T_{\mu\nu}$ is the interaction energy momentum tensor density and n_μ an arbitrary time-like vector. This equation has been proved to be integrable for the cases of spin 0, $\frac{1}{2}$, and 1. Physical statements derived from it should be properly covariant and gauge invariant and also independent of a particular choice of the n_μ. For the spin 0 case these three requirements have been verified to hold for: (a) the self-energy of the photon due to fluctuations of the charged scalar field; this energy can be considered to be zero by using methods much the same as those employed by Schwinger for the spin $\frac{1}{2}$ case; (b) the polarization of the vacuum due to an extraneous current J_μ; the induced current is $\delta J_\mu = -(\alpha/3\pi)\log(1/\gamma\epsilon) \cdot J_\mu - (\alpha/120\pi k_0^2)\Box J_\mu \cdots$, $\alpha = 1/137$, $\gamma = 1.781$, K_0 = inverse Compton wave-length; the first term, identical with the corresponding Dirac term, diverges in the limit $\epsilon \to 0$ and constitutes a charge renormalization; (c) the self-energy of a charged scalar particle; this can be written as $2m\delta m\psi + \psi$, where ψ is the scalar field wave function operator, m the mechanical, and δm the quadratically divergent electromagnetic mass. This form shows that the self-energy can be interpreted as a mass correction.

T4. An Alternative Subtraction Formalism for Quantum Electrodynamics. T. A. WELTON, *University of Pennsylvania.*—A convergent and consistent description of the interaction of electrons and photons can be developed by the procedure of modifying the usual equations of motion by the addition of two types of explicitly infinite subtraction terms. One type subtracts the classical action of an electron on itself, while the other type nullifies the charge and current induced in the vacuum by an electromagnetic field. The resulting equations of motion cannot be put into Hamiltonian form, but they do define an infinitesimal contact transformation whose generating function can be calculated to any desired order in the fine structure constant. This generating function can then be used in the same manner as the ordinary Hamiltonian. The resulting formalism has been applied to the case of two interacting scalar fields. The self-energy of a free particle is zero. The self-energy of a photon is finite and non-vanishing, but is unobservable, inasmuch as all levels of a given radiation oscillator are shifted equally. All reactive linear and nonlinear corrections to the electrodynamics of the vacuum vanish identically, but their resistive concomitants are unchanged. The Lamb shift arises entirely from the simply calculated fluctuation in position and spin orientation of an electron.

T5. The Theory of Positrons. R. P. FEYNMAN, *Cornell University.*—In quantum mechanics, the probability that an electron initially at a point P_1 will arrive later at P_2 is the square of a complex amplitude for this process. This amplitude can be represented as a sum of amplitudes, one for each available space-time path leading from P_1 to P_2.* This holds relativistically, provided one includes among the available world lines—those which can reverse themselves in the time direction. A path proceeding from P_1 to some point P_a at time t_a, from there to P_b, time $t_b < t_a$, and then to P_2, represents the alternative that a pair is created at P_b, the electron proceeding to P_2, while the positron proceeds to P_a where it annihilates the electron arriving there from P_1—paths for which time decreases as one proceeds along

the path represent positrons. If P_1 and P_2 lie at the same time, paths proceeding to the future from P_1 and turning back to P_2 give the probability that an electron at P_1 and a positron at P_2 will annihilate. The results agree with those of the theory of holes. The concept permits a considerable simplification of the analysis of problems in quantum electrodynamics.

* R. P. Feynman, Rev. Mod. Phys. **20**, 367 (1948).

T6. The Approach to Equilibrium in Ehrenfest's "Wind-Tree" Model. A. J. F. SIEGERT, *Northwestern University.*—We define $P(m_1, m_2, \cdots m_K/n_1, n_2, \cdots n_K; t)$ as the probability that n_i molecules move in direction i at time t, if m_i moved in direction i at time zero ($i=1, 2, \cdots K$; $m_i, n_i=0, 1, \cdots N$; $\Sigma_i m_i=\Sigma_i n_i=N$). The probability that a pair n_i, n_k changes to n_i-1, n_k+1 in a time element Δt is assumed to be $\alpha_{ki}n_i\Delta t$. The matrix α is assumed to be independent of the numbers n_i and symmetric (microscopic reversibility) and its diagonal elements are defined by $\Sigma_k \alpha_{ki}=0$. From the Smoluchowski equation we obtain a differential equation which yields for the generating function the result

$$\Sigma'_{n_1,n_2\cdots} P(m_1, m_2, \cdots m_K/n_1, n_2, \cdots n_K; t)\Pi_{i=1}^{K} u_i^{n_i} = \Pi_r [(u \exp \alpha t)_r]^{m_r},$$

where u is a one-row matrix with components u_i. Since the quadratic form with the matrix α can be written as $-\Sigma_{k<l}\alpha_{kl}(x_k-x_l)^2$, the largest eigenvalue is zero. The probabilities $P(m_1, \cdots/n_1, \cdots; t)$ approach $K^{-N}N!/\Pi_i n_i!$ as $t\to\infty$ if this eigenvalue is single. This is the case if there is for any pair k, m at least one sequence of nonvanishing elements $\alpha k k_1, \alpha k_1 k_2, \cdots \alpha k_n m$ of the matrix α.

T7. On Exact Solutions of the Dirac Equations. A. H. TAUB, *University of Illinois.*—In a previous paper* it was shown that solutions of the classical relativistic equations of motion for a charged particle in the field of a plane wave may be obtained in terms of a Lorentz transformation determined by the tensor describing the field. In this paper it is first shown that when plane wave solutions of the Dirac equations for a free particle are transformed by this Lorentz transformation, the exact solutions to the Dirac equation for an electron in the field of a plane wave found by Volkow** and Sengupta*** are obtained. In the second part of the paper, necessary and sufficient conditions in the external field are obtained in order that this method for solving the Dirac equations be applicable.

* A. H. Taub, Phys. Rev. **73**, 786–798 (1948).
** Volkow, Zeits. f. Physik **94**, 25 (1935).
*** Sengupta, Bull. Calcutta Math. Soc. **39**, 147 (1947).

T8. Relativistic Theory of Radiation Scattering. OTTO HALPERN, *University of Southern California,* AND HARVEY HALL, *Navy Department.*—The assumed[1] equivalence of the two forms of the theory (negative energy states free or occupied) holds for processes like Compton effect or bremsstrahlung, but not for coherent scattering or incoherent scattering by bound electrons. Matrix elements of transitions starting from occupied states of negative energy are not identical with matrix elements of transitions leading from bound states through intermediate unoccupied states of negative energy to final bound states. Judging by Waller's[1] calculations, agreement with experiment in the case of medium-hard x-rays can only be achieved if the negative energy states are unoccupied. We have calculated the coherent scattering of very hard radiation, obtaining for small angles the Thomson cross section with numerical factors differing for the two versions of the theory. The scattering by a bare nucleus[2] (or ion) has also been recalculated; the previously neglected[2] influence of intermediate bound states turns out to be of decisive importance.

[1] P. A. M. Dirac, Proc. Roy. Soc. **126**, 360 (1930); I. Waller, Zeits. f. Physik **61**, 837 (1930).
[2] N. Kemmer, Helv. Phys. Acta, 113 (1937); Achieser and Pomerantschuk, Physik. Zeits. d. Sowjetunion **11**, 478 (1937).

T9. A New Approximation Method in Scattering Phase Calculations. H. EKSTEIN, *Armour Research Foundation.*—The scattering of a particle by a center of force is described by a well-known three-dimensional integral equation in momentum space. This integral equation can be separated into one-dimensional integral equations which, in turn, can be reduced to purely real integral equations of the form

$$g_l(x)-2\pi P\int_0^\infty [y^2dy/(y^2-k_0^2)]g_l(y)K_l(x, y)=K_l(x, k_0),$$

where

$$K_l(x, y)=[-m/\pi\hbar^2(xy)^{\frac{1}{2}}]\int_0^\infty r\,V(r)J_{l+\frac{1}{2}}(rx)J_{l+\frac{1}{2}}(ry)dr$$

and where $V(r)$ is the potential, P stands for the Cauchy principal value, and the other symbols have the usual meaning. The phases are then given by

$$e^{2i\delta_l}=[1+i\pi^2k_0g_l(k_0)]/[1-i\pi^2k_0g_l(k_0)],$$

and $g_l(k_0)$ can be determined by iteration of the first equation.

T10. An Approach to Perturbation Theory by the Variation Iteration Method. W. KOHN, *Harvard University.*—In a perturbed Schroedinger equation one can regard the energy, E, as given and the parameter λ, multiplying the perturbing potential v, as unknown eigenvalue. By means of the Green function $G(x, x')=\Sigma_n(\varphi_n(x)\varphi_n(x'))/(E-E_n)$, where E_n and φ_n are the unperturbed eigenvalues and states, one can iterate trial functions according to the scheme $\psi_p(x)=\int G(x, x')v(x')\psi_{p-1}(x')dx'$. Successive approximations to λ are given by $\lambda^{(2p)}=\int\psi_{p-1}{}^*v\psi_{p-1}dx/\int\psi_{p-1}{}^*v\psi_p dx$ and $\lambda^{(2p+1)}=\int\psi_p{}^*v\psi_{p-1}dx/\int\psi_p{}^*v\psi_p dx$. (On replacing the E in the Green function by the preceding approximation, except in the term $n=k$, one can also solve directly for E in terms of λ.) For example, corresponding to second-order perturbation one obtains, when $v_{kk}\neq 0$,

$$\lambda_k^{(2)}=v_{kk}/\Sigma_n[1/(E-E_n)]|v_{nk}|^2.$$

In contrast to ordinary perturbation theory, this method converges for any given value of E. While no more complicated, it has in preliminary tests yielded better results.

T11. Interaction by Boundary Conditions. M. MOSHINSKY* AND E. P. WIGNER, *Princeton University.*—A system of two particles can be described in quantum mechanics by wave functions in eight-dimensional space. On a previous occasion, we attempted to introduce the equivalent of an interaction by postulating a singular behavior of the wave function at the coincidence of the two particles. At all other points in eight-dimensional space the wave function satisfies the two equations which are valid for the free particles. It has proved preferable to formulate the boundary condition in a form which is obviously relativistically

invariant, rather than to base the work on conservation theorems. Thus, for two Klein-Gordon particles of equal mass we can postulate that $(x^\lambda-y^\lambda)(\partial/\partial x^\lambda-\partial/\partial y^\lambda)\phi+2\phi=0$ wherever the coordinates x^λ, y^λ of the particles coincide. We found in all cases which we investigated that the singular wave function was not square integrable. However, our prescription yielded a unitary and symmetric collision matrix which even in relatively complicated cases, allowing, e.g., for the transmutation of the original pair of particles into a new pair, contained only very few arbitrary parameters.

* On leave from U.N.A. of Mexico.

T12. Geodesic Postulate and Field Equations in General Relativity. A. SCHILD AND L. INFELD, *University of Toronto.*—About ten years ago it was discovered[1] that Einstein's gravitational equations for empty space determine the motion of singularities of the field which represent mass particles; a first relativistic approximation for the equations of motion was obtained for quasistationary fields. The problem investigated here is the motion of a *test particle;* a natural approximation method presents itself, proceeding by powers of the mass. A solution $g_{\mu\nu}(x^\rho, m)$ of $R_{\mu\nu}=0$ is assumed, such that $g_{\mu\nu}(x^\rho, m)$ has a singularity of the type representing a mass particle along a world line L, but such that the "background field" $g_{\mu\nu}(x^\rho, 0)$ is regular on L. Neglecting m^2 and higher powers throughout, it can be shown that L is a *geodesic* of the space with metric $g_{\mu\nu}(x^\rho, 0)$. It is hoped that the calculations can be carried a step further and a term obtained in the equations of motion which represents a gravitational radiation reaction force proportional to m^2.

[1] A. Einstein, L. Infeld, and B. Hoffmann, Ann. Math. **39**, 65 (1938); **41**, 455 (1940).

Discharge in Gases; Microwave Apparatus

V1. Excitation and Damping of Plasma Oscillations. D. BOHM, *Princeton University,* AND E. P. GROSS, *Harvard University.*—The theory of oscillations of an unbounded plasma is extended to take into account the effects of collisions and special groups of particles having well defined ranges of velocities. It is found that as a result of collisions a wave tends to be damped in a time of the order of the mean time between collisions. If beams of sharply defined velocity or groups of particles far above mean thermal speeds are present, however, these produce a tendency toward instability so that small oscillations grow until limited by non-linear effects. It is found also that waves moving in the direction of decreasing plasma density show even stronger instability. In absence of plasma oscillations, any beam of well defined velocity tends to be scattered by the individual electrons, but when all the particles act in unison in the form of a plasma oscillation, the scattering can become much greater. Because of the instability of the plasma when special beams are present, the beams are scattered by the oscillations which they produce. It is suggested that this type of instability can explain the results of Langmuir. This type of instability may be responsible for radio noises received from the sun's atmosphere and from interstellar space.

V2. Medium-Like Behavior and Theory of Plasma Oscillations. E. P. GROSS, *Harvard University* AND D. BOHM, *Princeton University.*—A theory of oscillations of an unbounded plasma is developed, taking into account the effects of random thermal motions, but neglecting collisions. The first problem considered is that of finding the frequencies at which a plasma can undergo organized steady-state oscillations of small enough amplitude so that a linear approximation applies. The theory is then extended to describe the processes by which steady-state oscillations are set up. It is found that for a given wave-length a plasma can osciilate with arbitrary frequency, but that those frequencies not given by the steady-state dispersion relation describe motions in which, after some time, there is no contribution to macroscopic averages. In this way one can describe the manner in which the system develops organized medium-like behavior. The treatment is applied to large steady-state oscillations for which the equations are non-linear. One obtains solutions in which particles close to the wave velocity are trapped in the trough of the potential, oscillating back and forth about a mean velocity equal to that of the wave. One can also obtain non-linear traveling pulse solutions in which a group of particles moving as a pulse creates a reaction on the surrounding charge, which traps the particles and holds them together.

V3. Space-Charge Controlled Diffusion in Gaseous Discharges. T. HOLSTEIN, *Westinghouse Research Laboratories.*—Space-charge controlled diffusion of electrons and positive ions, of the type prevalent in d.c. positive columns and stationary microwave discharges, is usually analyzed in terms of Schottky's *ambipolar* diffusion theory.[1] In this theory the effect of space-charge fields is implicitly taken into account in the assumption of *quasineutrality*, i.e., the approximate equality of electron and ion densities. In the present paper, space-charge effects are treated explicitly by the use of Poisson's equation, in conjunction with the mobility-diffusion expressions for electron and ion currents. It is found that, at sufficiently high electron densities, the assumption of quasineutrality is valid except at the boundary, which is covered by a sheath of positive ions. For a plane parallel discharge region of width d, and for a ratio of electron to ion temperature, $T_e/T_p\gg 1$, the sheath thickness, $d_s\sim d(\pi kT_e/8N_e e^2 d^2)^{\frac{1}{2}}$, where N_e is the electron density at the center of the discharge region. The rate of electron diffusion to the boundary is larger than that predicted by Schottky's theory by a factor $(d/d-2d_s)^2$.

[1] See, for example, L. B. Loeb, *Fundamental Processes of Electrical Discharges in Gases* (John Wiley and Sons, Inc., New York, 1939), pp. 586–589, 594.

V4. Estimation of Hg-Type Arc Spot Temperature. JEROME ROTHSTEIN, *Evans Signal Laboratory, Belmar, New Jersey.*—Various methods of estimating "temperature" of Hg-type spots yield values from hundreds to thousands of degrees. This is not surprising because (a) spot conditions depart extremely from equilibrium, (b) different thermometers read differently for non-equilibrium conditions, (c) different estimates consider different observable quantities as thermometric—e.g., radiation, evaporation rate, and pressure at spot, thus using different thermometers, essentially. A recent theory[1] considers the spot as a microvolume where energy of organized motion of incident ions is progressively degraded by collisions with cathode atoms, electrons acquiring sufficient energy to

surmount the surface barrier. Current density, considered thermionic and thermometric, gives high temperature estimates, or rather high electron temperatures, part of the atomic motion still being organized. Vapor pressure, rate of evaporation, and submerged thermocouples, responding to randomized atomic velocities some distance from the ionic pumping action at the spot, give low estimates. Temperature in terms of average microvolume particle energy, random plus directed, and its radiation analog, optical pyrometry, yield high values. Pyrometric temperature depends on the filter used, the spectral distribution being entirely different from that of temperature radiation. The spectrum can be viewed as a perturbed recombination spectrum or as originating in transitions from excited electronic states of the liquid.

[1] J. Rothstein, Phys. Rev. **73**, 1214, **74**, 228 (1948).

V5. Microwave Gas Discharge Breakdown in Helium.* A. D. MacDonald and Sanborn C. Brown.—Breakdown electric fields in low pressure helium at high frequencies have been theoretically predicted and experimentally verified. The energy distribution of electrons is derived from the Boltzmann transport equation, taking into account all significant removal processes. The distribution function is expanded in spherical harmonics, and the resulting second-order linear differential equation is solved in terms of the confluent hypergeometric function. This distribution function combined with kinetic theory formulas permits calculation of the ionization rate and the electron diffusion coefficient. From these the high frequency ionization coefficient is determined. Through the diffusion equation this ionization coefficient is related to breakdown electric fields. Thus breakdown electric fields are predicted theoretically without using any gas discharge data other than experimental values of the excitation potential and collision cross section of helium. Breakdown electric fields are measured for helium in microwave cavities of various sizes with a large range of pressure. The theoretical electric fields, involving no adjustable parameters, are checked within the maximum experimental error of 6 percent.

* This work has been supported in part by the Signal Corps, the Air Matériel Command, and O.N.R.

V6. Formative Time Lags in Spark Breakdown. L. H. Fisher and B. Bederson, *New York University.*—Previous investigations of the formative time lag in spark breakdown have been carried out for the most part with an appreciable overvoltage. For the purpose of establishing a mechanism of sparking, experimental measurements of formative time lags in the neighborhood of the threshold are required. Experimental work is now in progress to determine the formative time lag for breakdown in air as a function of pressure and gap length at threshold. It is expected that one can discover from such experiments at what region of pressure and gap length a transition occurs from the Townsend to the streamer mechanism. Experimental results will be presented with tentative interpretation.

V7. Impulse Breakdown of Air in the 10^{-9} Sec. Range.* R. Fletcher, *Massachusetts Institute of Technology.*—The increased time resolution of the micro-oscillograph offers the possibility of recording the electric breakdown process to very short time intervals. A method has been developed for producing 10 to 30 kv impulses which rise to 8/10 of full value in 3×10^{-10} sec. Recording these impulses requires a voltage divider with uniform response from 100 to 10,000 mc/sec. No single divider has yet proven entirely satisfactory, but the information obtained from a combination of several indicates the successful elimination from the impulse of spurious oscillations which interfere with breakdown measurements. Preliminary measurements have been made on the impulse breakdown of air at atmospheric pressure, using gaps along the center conductor of a transmission line. The formative time lag of the atmospheric spark has been measured down to 6×10^{-10} sec. for fields of 120 kv/cm. There are indications that the formative lag itself is statistical for these shorter times. Sudden changes in the rate of rise of the current during breakdown require interpretation in terms of the spark mechanism.

* This work was supported jointly by the Navy Department (Office of Naval Research), the Army Signal Corps, and the Army Air Forces (Air Matériel Command).

V8. Pulsed Electron Beam for High Speed Photography.* L. B. Snoddy and J. W. Beams, *University of Virginia.*—A 400-megacycle reentrant cylindrical cavity oscillator is used for producing intense bursts of electrons lasting for the order of 10^{-8} sec. The cavity is pulsed with a 7C-22 twin triode oscillator and allowed to build up to maximum amplitude which gives an alternating potential of approximately 1.2 Mev across the space between the two reentrant arms or electrodes. A quenched vacuum spark is then produced by a transmission line arrangement on one of the electrodes.[1] This provides a copious supply of electrons which are accelerated across the space between the electrodes and emerge into the atmosphere through a thin window in the opposite electrode. The duration of the electron pulse depends upon the transmission line to the vacuum gap and the stored energy in the cavity. These short electron bursts have been used to make shadow photographs of rapidly moving objects such as a high speed mirror, ultracentrifuge, etc., as well as supersonic jets of CO_2 emerging into the air.

* This work was carried out under contract with the Bureau of Ordnance, U. S. Navy.
[1] L. B. Snoddy and J. W. Beams, Phys. Rev. **74**, 126 (1948).

V9. A Microwave Secondary Electron Multiplier. M. H. Greenblatt,* *University of Pennsylvania.***—The microwave secondary electron multiplier previously described[1] has been further investigated. Such a multiplier does not function satisfactorily as a linear photo-multiplier, and this fact has been qualitatively explained. This multiplier can be used as a detector of gamma-rays, in which case an electron ejected from the cavity wall by a gamma-ray can start an avalanche which heavily loads the cavity. External quenching in the form of a momentary decrease in power available to the cavity is employed. The pulses thus generated in a monitor loop are about 4 millivolts at the crystal rectifier and have a very short rise time (less than 10^{-7} sec.). Characteristics of such gamma-ray counting will be described. The use of this type of multiplier as a microwave power stabilizer will also be discussed.

* Now at the RCA Laboratories, Princeton, New Jersey.
** This work was assisted by the Navy Bureau of Ships.
[1] Presented at the Washington meeting of the A.P.S., May 1, 2, 3, 1947 (Paper C-7).

V10. A Microwave Electron Accelerator Using Two Resonant Cavities.* B. L. MILLER AND M. F. AMSTERDAM, *Bartol Research Foundation.*—Two cavities are powered by an HK7—10-cm magnetron to fields of the order of 150,000 volts per cm. The spacing of the cavities and phase of oscillation are fixed for additive acceleration of an electron beam entering at 8000 volts. Penetrating x-rays, coming from the screen on which the accelerated electrons impinge, have been detected. About 1 Mev is expected with this system; 2 Mev is planned by adding another cavity phased with a dielectric section in the main line.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

V11. Untuned Cavity Microwave Spectroscope Using Bolometer Detectors.* I. R. WEINGARTEN AND G. E. KIMBALL, *Columbia University.*—Lamb[1] has examined the possibility of obtaining microwave absorption data by measuring the decay time of pulsed radiation in an untuned cavity and shown that the principal objection to this method is the need for instantaneous space-averaging of the decaying energy. This difficulty has been overcome by using as detectors many long fine-wire bolometers connected in series and placed at random in the cavity. It is shown that exponential radiation transients can be measured if the thermal time constant of the bolometers is several hundred times the radiation decay time constant. This technique has been applied to measure directly the "Q" of an untuned cavity and thus the loss of radiation through apertures. Lamb's window formula has been verified using 10-, 20-, 35-, 50-, and 100-cm^2 openings, in cavities of 4.1 and 5.5×10^5-cm^3 value, and at wave-lengths of 1.05, 1.25 and 1.69 cm. It is also shown how a cavity's steady-state energy density can be averaged using bolometers instead of the slower thermocouples used by Becker and Autler. The use of a small cell in a large cavity to measure the microwave absorption of strongly absorbing or reactive materials has also been investigated.

* Work supported by the Signal Corps.
[1] W. E. Lamb, Jr., Phys. Rev. **70**, 308 (1946).

V12. Thermodynamics of a Thermomagnetic Generator. L. BRILLOUIN AND H. P. ISKENDERIAN, *Harvard University and Federal Telecommunication Laboratory.*—Proposals have been made (Edison, Tesla, Chilovsky) to use the properties of ferromagnetic substances near the Curie point for constructing thermomagnetic a.c. generators. Large flux variations could be induced in a coil and a.c. currents generated by heating above and cooling below the Curie point a ferromagnetic substance that is part of a magnetic circuit. A thermodynamical discussion shows that the efficiency should be about one-half of the efficiency of a Carnot cycle working between the same temperatures. A summary of these results will be presented along the lines of a paper recently published by the authors in Electrical Communications (**25**, 300 (1948)).

Anomalous Fine Structure; Nuclear Moments; Nuclear Magnetic Resonance; Emulsions in Nuclear Physics

W1. Anomalous Fine Structure in Singly Ionized Helium.* MIRIAM SKINNER AND W. E. LAMB, JR., *Columbia University.*—The displacement $2^2S_{\frac{1}{2}}-2^2P_{\frac{1}{2}}$ in singly ionized helium has been determined to be $14{,}100\pm300$ mc/sec. The method is analogous to that employed for hydrogen,[1] except that no beam of metastable ions is formed. Instead, helium atoms are bombarded by electrons of several hundred volts energy. In something less than one percent of the ionizing collisions, the remaining atomic electron is excited to the metastable $2^2S_{\frac{1}{2}}$ state of the ion. When the bombardment region is illuminated with microwave radiation of the proper frequency, transitions to $2^2P_{\frac{1}{2}}$ are induced, and the ultraviolet photons emitted in the subsequent decay to the ground state $1^2S_{\frac{1}{2}}$ are detected by a suitable photoelectric detector. Background effects due to metastable atoms and radiation from He I are reduced by the use of a collodion film filter. The shift predicted by Bethe[2] was about 13 times that for hydrogen. Using a recent value obtained for hydrogen, the shift in helium should be about 13,800 mc/sec. in very good agreement with the observations considering the uncertainty in the theoretical factor 13.

* Work supported jointly by the Signal Corps and the Office of Naval Research.
[1] W. E. Lamb and R. C. Retherford, Phys. Rev. **72**, 241 (1947).
[2] H. A. Bethe, Phys. Rev. **72**, 339 (1947).

W2. Shift of the $2^2S_{\frac{1}{2}}$ State in Hydrogen and Deuterium.* R. C. RETHERFORD AND W. E. LAMB, JR., *Columbia University.*—In a previous communication,[1] the shift of the $2^2S_{\frac{1}{2}}$ state of hydrogen was given as approximately 1000 mc (0.033 cm^{-1}). A new apparatus differing from the original one in details but not in principle has been built in order to improve the accuracy of the above result. The new apparatus provides greater intensity, a more homogeneous magnetic field, and a more accurate means of measuring the magnetic field. With these improvements, preliminary measurements of considerably increased accuracy have been made on both hydrogen and deuterium. In both cases the transitions observed were $2^2S_{\frac{1}{2}}$, $m=+\frac{1}{2}\rightarrow 2^2P_{\frac{1}{2}}$, $m=+\frac{1}{2}$ and $m=-\frac{1}{2}$. In the case of the latter transition for hydrogen the hyperfine structure is partially resolved, but not for deuterium because of the relatively smaller hyperfine splitting. There was no observable difference in the shift for hydrogen and deuterium, the average shift being 1062 mc in both cases with a tentative accuracy of ±5 mc. Further improvements in accuracy of observations are expected, and certain small corrections remain to be made.

* Work supported jointly by the Signal Corps and the Office of Naval Research.
[1] W. E. Lamb and R. C. Retherford, Phys. Rev. **72**, 241 (1947).

W3. Nuclear Moments of B^{10} and B^{11}. WALTER GORDY AND HAROLD RING, *Duke University,** and A. B. BURG, *University of Southern California.***—From microwave measurements on borine carbonyl the spin of B^{10} has been determined as 3 and that of B^{11} as $\frac{3}{2}$. These evaluations with the nuclear g factors 0.598 and 1.791 previously determined by Millman, Kusch, and Rabi[1] yield 1.794 and 2.686, respectively, for the nuclear magnetic moments of B^{10} and B^{11}. The quadrupole coupling, $eQ(\partial^2V/\partial z^2)$, in this molecule is 3.30 mc for B^{10} and 1.55 mc for B^{11}. From a consideration of the molecular structure of BH_3CO, also determined in this study, $\partial^2V/\partial z^2$ is evaluated approximately as 0.6×10^{15} e.s.u. Thus the signs of the nuclear quadrupole moments of

B^{10} and B^{11} are positive, and their magnitudes are $\sim 0.08 \times 10^{-24}$ cm^2 and $\sim 0.04 \times 10^{-24}$ cm^2, respectively.

* The work at this University was supported by a grant-in-aid from the Research Corporation.
** The work at this University was supported through a contract with the Office of Naval Research.
[1] S. Millman, P. Kusch, and I. I. Rabi, Phys. Rev. **56**, 165 (1939).

W4. Magnetic Resonance Frequencies for Several Nuclei.* F. BITTER, *Massachusetts Institute of Technology.*—The following ratios of magnetic resonance frequencies of the nuclei listed have been obtained, using two radio-frequency bridges operated at frequencies between 4 and 30 megacycles, in magnetic fields between 1 and 15 kilogauss. None of these values is in contradiction with previous measurements.

Nuclei compared	Observed frequency ratio
$_3Li^7/_1H^1$	0.388625 ±0.01%
$_5B^{10}/_5B^{11}$	0.33488 ±0.03%
$_5B^{11}/_1H^1$	0.32085 ±0.02%
$_{11}Na^{23}/_1H^1$	0.26450 ±0.01%
$_{13}Al^{27}/_1H^1$	0.26056 ±0.01%
$_{15}P^{31}/_1H^1$	0.40481 ±0.01%
$_{17}Cl^{35}/_{11}Na^{23}$	0.37051 ±0.03%
$_{29}Cu^{63}/_1H^1$	0.265056 ±0.02%
$_{29}Cu^{65}/_1H^1$	0.28391 ±0.02%
$_{35}Br^{81}/_1H^1$	0.27003 ±0.03%
$_{37}Rb^{85}/_{11}Na^{23}$	0.36512 ±0.03%
$_{37}Rb^{87}/_1H^1$	0.32718 ±0.02%
$_{55}Cs^{133}/_3Li^7$	0.33743 ±0.03%

* This research has been supported in part by the Signal Corps, the Air Matériel Command, and O.N.R.

W5. Fine Structure of the Proton Magnetic Resonance in $CuSO_4 \cdot 5H_2O$. N. BLOEMBERGEN, *Kamerlingh Onnes Laboratory, Leiden.* (Introduced by J. H. Van Vleck).—The magnetic resonance of protons in a single crystal of $CuSO_4 \cdot 5H_2O$ has been observed at 30.5 Mc/sec. between 300°K and 1°K. In spite of the large internal field from the Cu^{++} ions, the resonance line is only 14 oersted wide at room temperature. At 20°K the resonance is clearly split into several component lines. The pattern changes with the angle of the crystal axes and H_0, but for a given orientation the distance of each component from the undisplaced proton resonance occurring e.g., in paraffin, follows the same Curie-Weiss law as the static susceptibility. At 1.2°K the over-all splitting is over 400 oersted. The relaxation time T_1 is shorter than 0.01 sec. at all temperatures; the width of each component is determined by the neighboring protons. The Cu^{++} ions do not contribute to the width, as a consequence of the large exchange between them. But each Cu^{++} spin has a larger Boltzmann probability to be parallel than antiparallel to the external field H_0. So the constant field at the position of each proton in the unit cell is shifted by an amount which depends on the relative positions of H- and Cu-atoms and increases with decreasing temperature in the same way as the total static magnetization.

W6. A Pulse Method for Nuclear Magnetic Resonance.* HENRY C. TORREY, *Rutgers University.*—A new method for the observation of nuclear magnetic resonance has been developed with the following features. No applied modulation is used; radiofrequency power is applied in pulses; a modulation of the r-f voltage, produced by nuclear spin resonance, is detected and displayed on an oscilloscope. R-f power is often much larger than for conventional methods. The signal is larger because it is observed before saturation sets in. Noise is larger because of wider band-widths needed. Signal-to-noise is comparable to that of conventional methods using narrow band amplifiers. Some advantages of the pulse method are: More rapid search for unknown resonances because of wider band-widths; direct measurement of spin-lattice relaxation time by observation of build-up between pulses; direct measurement (by damping of signal) of spin-spin relaxation time T_2 even if the line width due to inhomogeneity is larger than that due to spin-spin relaxation. The last feature yields for glycerine at room temperature a preliminary value of $T_2 = 1.1 \times 10^{-2}$ sec., agreeing with the theory of Bloembergen, *et al.*[1]

* This work has been supported in part by the O.N.R. and the Atomic Energy Commission.
[1] N. Bloembergen, E. M. Purcell, and R. V. Pound, Phys. Rev. **73**, 679 (1948).

W7. A New Molecular Beam Magnetic Resonance Method. NORMAN F. RAMSEY, *Harvard University.*—Calculations have been made of the molecular beam magnetic resonance spectrum to be expected when the oscillating magnetic field is concentrated in two narrow regions at the beginning and end of the constant homogeneous magnetic field. These calculations show that such a distribution of the oscillating field intensity should produce narrower resonance minima both because of a theoretical reduction in half-value width to 0.6 times the conventional half-value width in a truly uniform magnetic field and because of the reduced dependence of the resonance width upon non-uniformities of the magnetic field. In the new method the magnetic field is effectively averaged over the path of the molecule. Since the averaging, however, is only along the path of each molecule, considerable uniformity must still be preserved over the beam height. Although secondary resonance minima are produced with the new method, these may be distinguished from the primary minimum due to the reduced intensities of the secondaries as a result of the velocity distribution of the molecules. A relative phase shift in the two oscillating fields by 90° produces a dispersion type curve whose steep slope at the Larmor frequency could be used to provide an even more precise means of measurement.

W8. The Magnetic Moment of the Proton. H. TAUB AND P. KUSCH, *Columbia University.*—The molecular beam magnetic resonance method has been employed to measure, in the same magnetic field, the frequency corresponding to a reorientation of the proton in NaOH and the frequency corresponding to a transition between certain of the h.f.s. energy levels of the ground states of both the atoms Cs^{133} and In^{115}. From these data are calculated the ratio of the g factor of the proton to the total electronic g factor with the result $g_H/g_J(Cs^{133}, {}^2S_{\frac{1}{2}}) = 15.1911 \times 10^{-4}$ and $g_H/g_J(In^{115}, {}^2P_{\frac{1}{2}}) = 45.6877 \times 10^{-4}$. The magnetic resonance method has also been applied to the determination of the ratios of the total electronic g_J's of the alkali atoms, and it is found that the g_J's of Li^6, Li^7, Na, and K^{39} are identical to within 1 part in 40,000 while $g_J(Cs^{133})/g_J(Na) = 1.000134$. From these results and from $g_J(Na)/g_J(In^{115}) = 3(1.00243)$, it is found that $g_H/g_J(Na) = 15.1923 \times 10^{-4}$ (from In^{115}) and $g_H/g_J(Na) = 15.1931 \times 10^{-4}$ (from Cs^{133}). We take $g_H/g_J(Na) = 15.1927 \times 10^{-4} \pm 0.005$ percent. The equivalence of the g_J values of Li, Na, and K is interpreted to mean that for these atoms $g_J = g_S$, the electron spin gyromagnetic ratio. Using $g_S = 2(1.00116)$, and making a small diamagnetic correction, it is found that $g_H = 30.4211 \times 10^{-4} \pm 0.005$ percent and $\mu_H = 15.2106 \times 10^{-4} \pm 0.005$ percent Bohr magnetons, in

which the assigned precision measure includes only the uncertainty in the ratio g_H/g_J(Na).

W9. Direct Photometry on Tracks in the Photographic Emulsion.* PIERRE DEMERS AND ROGER MATHIEU, *Université de Montréal.*—Rate of energy loss E may be studied by grain counting, or by the transmission $T=I/I_0$ of light through the track. Our installation measures directly T: Köhler lighting—objective×90, 1.3 n.a. apo—eyepiece ×12.5 comp.—tuning fork 500 c.p.s.—slit 0.1×1 to 10μ at the object—931A photo-multiplier—well stabilized HT—a.c. amplifier 1000 c.p.s.—Oscilloscope X and Y axes. Y varies with I, displacement of the track on the slit moves X. On the screen the absorption curve gives I, I_0, and W the width at half-reduction. Accuracy on I is near 1 percent. Typical results follow: in C_2 Ilford: α-rays: $T=0.54$; protons: 0.75, range R 1 cm air; with a strong development heavy meson: 0.69 ± 0.1, R 4 cm; light meson: $0.67\pm0.1R$ 4 cm.[1] Formula II:[2] p. 0.8 (R 1 cm); α-rays 0.70; fission fragments 0.44 to 0.61, $T=0.61-0.06\,R$ with a 5 percent difference at the beginning of heavy and light fragments in a pair confirming previous results.[3,4]—W is 0.3 to 0.45μ. —By this new method, objective measurements are possible; 1) on fading of the latent image 2) to identify tracks of cosmic and other origin.

* This work was rendered possible by a grant from the NRC, Canada.
[1] P. Demers and R. Fichaud, "A meson meson process," Acfas meeting 1948 progr. p. 6.
[2] P. Demers, Can. J. Res. **A25**, 223-251 (1947).
[3] P. Demers, Phys. Rev. **70**, 974-5 (1946).
[4] R. Sherr and R. Peterson, Rev. Sci. Inst. **18**, 567-75 (1947).

W10. A Photographic Emulsion Method of Measuring Relative Fission Cross Sections. MAURICE M. SHAPIRO, *Oak Ridge National Laboratory.*—A photographic plate method of measuring neutron fission cross sections, described by Borst and Floyd,[1] has been modified so as to obviate neutron flux measurements as well as corrections for detection efficiency. The sample under investigation is placed against an Eastman NTC photo-plate sensitive to fission fragments but insensitive to alpha-particles. A standard sample of known cross section is placed against another such plate. Then the two sample-photoplate pairs, in juxtaposition, are irradiated simultaneously in the same neutron flux. After development of the emulsions, fission-fragment tracks are counted microscopically over equivalent areas. The relative fission cross section is thus obtained. When the samples are both alpha-emitters or both beta-emitters of known half-lives, a *relative* determination of the quantity of each isotope suffices, thereby avoiding efficiency corrections in the assay. This method is especially applicable to rare substances, since only minute (microgram) quantities are required. Suitable modifications of this method lead to other applications, e.g., the assay of mixtures of isotopes and the identification of suspected isotopic contaminants.

[1] L. B. Borst and J. J. Floyd, Phys. Rev. **70**, 107(A) (1946).

W11. Sensitivity of Physically Developed Nuclear Emulsion Tracks to Specific Ionization.* N. W. CURTIS AND L. S. OSBORNE, *Massachusetts Institute of Technology.*—The physical development of a Ag-Br emulsion is dependent upon the volume density of latent image in the Ag-Br grains, and, thus, could be more sensitive to the specific ionization of particles passing through a nuclear emulsion than chemical development. Ninety micron Kodak NTB plates, exposed to a shielded Ra-Be fast neutron source to give knock-on protons, were developed: (1) using Odell's silver stock[1] at a dilution of 1 to 16, and (2) using D-19 Kodak developer. Since physical development results in a spread of Ag grain sizes, the two tracks were compared by a light densitometer measurement on the negatives of photomicrographs of these tracks. A plot of densitometer readings corrected for background versus specific ionization shows physical development to be more sensitive to specific ionization than chemical development over the track of a proton of 10 Mev, particularly at high specific ionization. In addition, densitometric measurements and grain counting for a chemically developed track were found to be equivalent.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
[1] Allan F. Odell, The New Photominiature, New Series No. 2, Old Series No. 207.

W12. Grain Density in Nuclear Tracks. M. BLAU, *Columbia University.*—Lattes, Occhialini, and Powell describe by an empirical law the relationship between the energy of heavy particles and the number of grains in corresponding tracks in photographic emulsions. Considering the importance of grain counts in tracks for the determination of particle mass, an attempt has been made to calculate this relationship assuming that the grain density is a function of the energy loss. In comparing the ionization phenomena in silver bromide grains with phenomena in highly ionized gaseous atmospheres or "strong electrolytes" the following equation has been deduced for the probability that a grain will be developed: $P=c(1-e)^{-b(dE/dR)^{\frac{1}{2}}}$, where dE/dR is the energy loss of the particle in the emulsion. The agreement between experimental data and calculated values and the meaning of the parameters b and c will be discussed. These parameters depend on the type of emulsion and condition of development. In connection with the above the grain density of beta-tracks in Eastman-Kodak emulsions will be discussed and development methods which give an increase in grain density described.

W13. The Statistical Distribution of Arc-Chord Differences in Scattered Particle Tracks.* W. T. SCOTT, *Brookhaven National Laboratory.*—The difference between total arc length and chord for scattered particle tracks in photographic emulsions has been proposed as a simple measure of the scattering.[1] We have calculated the distribution of these differences, neglecting energy loss, in order to investigate the validity of such measurements. Use is made of a diffusion equation for the correlated probability of arc-chord difference and net angular deflection as a function of track length. The result is a highly skewed curve, with the mean value about three times the most probable. The relative r.m.s. deviation σ is 0.89. Calculation has also been made of the distribution for the usual measure of scattering, involving the successive chord angles for N segments of track. For $N=9$, the distribution is nearly as broad as for the over-all arc-chord difference, but more symmetric; $\sigma=0.53$. The skewness of the first curve may be reduced by a change of independent variable. Report will

also be made of the distribution of differences between arc length and the projected length of the track on its original direction.

* Work done under the auspices of the Atomic Energy Commission, while the author was on summer leave from Smith College.
[1] S. A. Goudsmit and W. T. Scott, Phys. Rev. 74, 1537 (1948).

W14. Calibration of Photographic Emulsions for Low Energy Electrons.* L. CRANBERG** AND J. HALPERN, *University of Pennsylvania.*—Energy dependence of emulsion sensitivity to electrons has been studied for three different emulsions in the range of exposures in which the density-exposure relation is linear. The energy range from 5 to 45 kev was covered, using homogeneous electrons from an electron gun. Materials studied were no-screen x-ray film, Eastman Experimental Type K x-ray plates, and Ilford B-2 Nuclear Track Plates. All points of the energy spectrum were covered on a single plate or film sample to minimize the effect of variations in development. The results obtained are expressed in the form of curves of density per unit charge per unit area as a function of energy and are reproducible within 10 percent. Above about 10 kev the x-ray emulsions are more sensitive than the B-2 plates; below 10 kev the nuclear track plate is more sensitive. In the range of energy explored the sensitivity of x-ray film varied by a factor of 10^5. For the Nuclear Track Plates the factor was 15. At 25 kev the number of electrons per square mm required to give a density of 0.1 above background for x-ray film, Type K plate and B-2 plate is 3.6, 9.0, and 11×10^4, respectively.

* Supported in part by a joint program of the A.E.C. and O.N.R.
** A.E.C. Fellow.

Cosmic Rays; Stars, Bursts and Showers

X1. On the Star-Producing Radiation and the Absorption of the Nucleonic Component. G. BERNARDINI, *Columbia University.*—It appears very reasonable to assume that the stars (nuclear evaporations) in cosmic rays are mainly produced by the nucleonic component. Measurements taken under different materials demonstrate that the absorption law of the star-producing radiation is proportional to the geometrical cross section of the nucleus, but smaller by a factor of about 2.5. It is concluded, taking into account new results concerning hard showers, that the nucleonic component is absorbed with this law and some consequences of this fact are discussed.

X2. Studies of Cosmic-Ray Phenomena in Nuclear Research Emulsions. ADAIR MORRISON AND ERIC PICKUP, *National Research Council, Canada.*—A number of events produced by cosmic rays in nuclear research emulsions will be shown, and statistical data on the frequency of different kinds of stars will be given. The methods used in searching the emulsions, in identifying tracks, and in photomicrography will be described briefly. Data on uniformity of loading as deduced from plates which have been exposed to a uniform flux of slow neutrons will be presented.

X3. Some Cosmic Ray Events in Photographic Emulsions. ERIC PICKUP AND ADAIR MORRISON, *National Research Council, Canada.*—Ilford Nuclear Research emulsions have been exposed to cosmic radiation in aircraft on transatlantic flights. Emulsions with different types of loading were used, and meson events have been observed in plates loaded with boron, lithium and deuterium compounds. Such events include examples of ρ- and σ-mesons entering the emulsions and a π-μ-meson event and several instances of the ejection of mesons in cosmic stars. These mesons are ejected in stars with both few and many prongs, and there are one or two cases where the ejected meson appears to end in the emulsion without producing any observable disintegration. Occasionally, there is ejected also a heavier fragment which produces a small star; probably a case of direct nuclear collision. Also, in about 0.3 percent of the stars, including all cosmic events with two prongs or more, Li^8 nuclei, which show the characteristic hammer track at the end of the range, are observed to be emitted. One such fragment occurs in a 24-prong star.

X4. Lithium Borate-Loaded Emulsions as Neutron Detectors. HERMAN YAGODA AND NATHAN KAPLAN, *National Institutes of Health.*—The advantages of the high cross section of the $B^{10}(n, He^4)Li^7$ and the distinctive tracks originating from the $Li^6(n, H^3)He^4$ reaction can be combined by loading nuclear type emulsions with solutions of lithium borate. The preparation, stability and development of these emulsions for the detection of slow neutrons will be described. The medium also records characteristic stars originating from fast neutron interactions with B^{11} and B^{10} nuclei. Examples of $B^{11}(n, He^4)Li^8$ events recorded in lithium borate emulsions exposed to cosmic radiation at 90,000 ft. elevation will be discussed. Evaluation of the energy from the ranges of the alpha-particle and the Li^8 fragment (hammer track) show presence of neutrons with energies of 50 Mev.

X5. A Counter Controlled High Pressure Cloud Chamber. G. E. VALLEY AND J. A. VITALE, *M. I. T.*—A nine-inch cloud chamber will be described which operates at pressures up to 200 atmospheres. Built integrally with the cloud chamber is a magnet which produces a field of 8800 gauss, uniform to ±3 percent, for an expenditure of 43 k.w. The magnet coils can dissipate well in excess of 50 k.w. continuously. The cloud-chamber walls are relatively thin, and the instrument has been otherwise designed to facilitate its use in conjunction with Geiger counters. Stereoscopic photographs can be taken. The instrument is permanently mounted in a heavy trailer.

X6. High Altitude High Pressure Cloud-Chamber Pictures. C. P. LEAVITT, G. E. VALLEY, AND J. A. VITALE, *M.I.T.*—The instrument described in the previous abstract was operated at an altitude of 12,700 ft. (Mt. Evans, Colorado). Among the events recorded were twelve cases which can be identified, by range-scattering measurements, as mesons which stop in the gas (argon at 105 atmospheres). Of these, seven end in single-pronged "stars." The star prongs have apparent ranges of from 0.06 to 0.36 g/cm^2. There is considerable evidence that these mesons are locally produced. The remainder of the mesons simply end in the gas without producing any secondary particle, and it is not possible to state definitely whether they are locally produced. Photographs of mesons and of other phenomena will be shown.

X7. Nuclear Explosions in Photographic Emulsions Produced by Primary Cosmic Rays.[1] M. F. KAPLON, B. PETERS, AND H. L. BRADT, *University of Rochester.*—The size-frequency distribution and the energy spectrum of the fragments ejected in nuclear stars produced near the top of the atmosphere (95,000 feet$\sim$15 grams/cm^2) has been studied. At this high altitude the majority of the stars are produced by cosmic-ray primaries. The number of stars with more than 4 prongs is equal to 1200 stars per cm^3 and day for Ilford C_2 emulsions. The size-frequency distribution is markedly different from the one measured at mountain altitude, showing a much larger proportion of big stars. This is in agreement with the results of E. O. Salant, J. Hornbostel, E. M. Dollman.[2] The number of stars with more than N prongs is proportional to $\exp(-\gamma N)$ with $\gamma=0.26$. Tracks of primary helium nuclei have been observed and followed through several plates of a stack of the new Eastman NTB emulsions up to ranges of 60 g/cm^2 of glass. Their contribution to the production of nuclear explosions at 95,000 ft. will be discussed.

[1] Assisted by the Joint Program of the O.N.R. and A.E.C.
[2] E. O. Salant, J. Hornbostel, and E. M. Dollman, Phys. Rev. **74**, 694 (1948).

X8. Theoretical Remarks on Nuclear Disruptions by Primary Cosmic Rays.* S. A. WOUTHUYSEN, *University of Rochester.*—Recent investigation of primary cosmic rays, at 95,000 feet, by means of photographic plates, indicates that a large percentage of the "primary processes," to be expected in the emulsion is accompanied by large stars (average prong-number for stars with more than 2 prongs about 6—see abstract X7). At cosmic ray energies, a nucleus should be transparent, if only elastic nucleon-nucleon scattering occurs. However, at high energies, mesons are produced, so that the nucleon-collisions are predominantly inelastic. This allows for greater momentum transfers to the target nucleon. Assuming that above 600 Mev the collisions are completely inelastic, and elastic below, and taking for the inelastic cross-section a value derived from experiments on penetrating showers, a nuclear excitation curve was computed which shows preliminary agreement with the "number of stars versus prong number" curve up to prong numbers $\sim$15. The excitation by the simultaneously produced mesons was neglected as a first approximation. It seems likely that the larger stars (up to 5 percent of the total) are not produced by protons, but possibly by α-particles. About 5 percent α-particles would not disagree with the experimental star-curve.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

X9. Some Cloud Chamber Photographs Obtained with a High Pressure Cloud Chamber.—R. P. SHUTT, G. R. HOKE, W. A. TUTTLE, AND G. F. O'NEILL, *Brookhaven National Laboratory.*—In a high pressure cloud chamber described previously, approximately 1000 stereoscopic pictures have been obtained at sea level. A few events that may be of interest are to be discussed. The cloud chamber was filled with argon at a pressure of 140 atmospheres, and a magnetic field of 4000 gauss was applied. Several negatively charged mesons appeared to stop in the gas of the cloud chamber without another particle appearing, while a few positive mesons seemed to decay into electrons in accordance with now well-accepted experimental results of others. Furthermore, pictures of two small stars originating in the gas and containing two and three prongs, respectively, were obtained. The prongs show an average range of 1 cm in the gas at high pressure. Finally, a star containing seven prongs originating at a point in the gas was photographed. The shortest of these tracks can be seen to end inside the cloud chamber. From the small amount of scattering and the large density of ionization, it can be identified as a proton with fair certainty. Its initial energy would amount to about 70 Mev. There is another proton of comparable energy. The remaining five tracks are also straight and only lightly ionized. One can estimate that the total energy involved in the star is at least of the order of 10^9 ev. In none of these cases is a particle visible that could have produced a star. We therefore assume that a fast neutron was responsible for these nuclear collisions.

* Research carried out at Brookhaven National Laboratory under the auspices of the Atomic Energy Commission.

X10. Observations at Sea Level with a Self-Controlled Cloud Chamber.* MARTIN J. COHEN, *Princeton University.*—A self-controlled cloud chamber has been operated for a sensitive time of 150 hours. The preliminary results obtained demonstrate the advantages of this device in experiments involving cloud-chamber studies of heavily ionizing events. During this time 649 frames were exposed. The following heavily ionizing (ionization equivalent of a 6-Mev alpha-particle or greater) events were observed at sea level. Six 2-pronged stars, one each of a 3-, 4-, and 7-branched star. Six hundred frames contained alpha particles. Forty frames were blank, of which 15 were due to unknown causes. A 6-Mev alpha, or greater, is thus obtained about once every 15 minutes. In a series of 200 frames taken with random expansion, only one sharp alpha-track was observed. Fifteen other frames had alpha-tracks in various states of diffusion. The cloud chamber is of conventional design using a rubber diaphragm. Dehydrated isoamyl alcohol and commercial tank argon (99.6 percent pure) form the gas mixture. Gum rubber, silk velvet, apiezon wax, glass and brass are exposed to this atmosphere. The oxygen and water given off by these materials cause the electron collection efficiency of the pulse ionization chamber component of the device to be reduced to about one-half in 5 days. The chamber is completely refilled about once a week. This procedure takes about one hour including slow expansion of the cloud chamber to clear it for observation of tracks.

* Assisted by the Joint Program of the Atomic Energy Commission and the Office of Naval Research.

X11. Ionization Bursts as a Function of Chamber Area. C. G. MONTGOMERY AND D. D. MONTGOMERY, *Yale University.**—Bursts of ionization were observed in cylindrical chambers of various sizes at Climax, Colorado, elevation 11,500 ft. Bursts were recorded by two methods: (1) pulse amplifiers and counting circuits were employed for the small bursts whose rate of occurrence exceeded about 10 per hour, (2) electrometer tubes actuating galvanometers with photographic recording for the large bursts of small frequency. In this way it was possible to measure bursts both larger and smaller than the ionization produced by alpha-particles from the chamber walls. The rates found covered a range of more than a factor of 10^5. Observations

by the two methods with independent absolute calibrations agreed well. The chamber dimensions were approximately (diameter and length) 2 by 8 in., 3 by 10 in. and 4 by 16 in. Bursts caused by extensive air showers should occur at the rate characteristic of the showers and have a magnitude corresponding to the number of rays passing through the chamber and hence proportional to the area. Bursts of local origin, such as nuclear disintegrations or small showers, should occur at a rate proportional to the area of the chamber. It is thus possible to distinguish between the two mechanisms. Most of the small bursts appear to be of local origin, in agreement with our previous results.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

X12. Narrow Air Showers. JOHN PAO-NGO WEI, *Yale University.**—The abnormal rise for small separations of the decoherence curve of cosmic-ray air showers as measured by a pair of Geiger-counter telescopes has been interpreted by Alichanian *et al.*§ as a new kind of air shower which they call narrow showers. Data taken at sea level and at 1640 m and 3500 m above sea level are in agreement with this interpretation rather than the hypothesis that they are stars or cores of large air showers. The spread of large air showers increases with altitude but the opposite seems to be true for the narrow showers. These showers have very low particle densities and are hard. Absorption by matter is mass proportional.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
§ Alichanian and Alexandrian, J. Phys. USSR 10, 296 (1946).

X13. Cloud-Chamber Observations of Penetrating Showers in Lead at 3020 Meters.* WILLIAM B. FRETTER, *University of California, Berkeley.*—A counter-controlled cloud chamber containing sixteen ½-inch thick lead plates has been operated at an altitude of 3020 meters to detect the production of penetrating particles in lead. 167 penetrating showers were observed, 101 of which were "local" penetrating showers, the others being components of extensive electron showers. In the local showers, 25 successive events were observed. A mean free path for production of penetrating particles in lead can be calculated from observations of the distances between successive events and consideration of the probabilities of observation of different types of events. The mean free path as calculated from the observations at 3020 meters was 81 g/cm² of lead. Multiplicities of production and angular distribution of particles were also observed. The large number of penetrating showers observed as components of extensive electron showers indicates the importance of nuclear events in the large showers. Among the 2700 pictures taken of electron showers, 23 photographs were obtained which could be interpreted as showing production of penetrating particles in high energy electron showers.

* Assisted by the Joint Program of the O.N.R. and A.E.C.

Y1. Infra-Red Studies of Neoprene. M. B. HALL AND W. E. MOCHEL, *duPont.*—Infra-red absorption spectra of amorphous and crystalline Neoprene in the wave-length range 2–23 microns have been studied. Spectra of bromoprene and other reference compounds, the dichroism of stretched samples, and the spectral changes accompanying crystallization have been used to characterize the bands and to "assign" most of the strong bands to vibrations of more or less limited regions of the molecule. Spectral changes, some very pronounced, accompany crystallization of the polymer either in the unstretched state or following stretching. Perceptible spectral changes were found to occur for some twelve hours following stretching of Neoprene GN, a type which tends to crystallize slowly. These spectral changes, particularly the surprising appearance of strong absorption bands when the polymer crystallizes, are of interest because of their relation to order in the polymer and also because of their bearing on general infra-red applications, particularly quantitative analysis of polymer films.

Y2. X-Ray Diffraction Studies on the Stretching and Relaxation of Polyethylene. ALEXANDER BROWN, *Carbide and Carbon Chemicals Corporation.*—When polyethylene is stretched at 96°C, the orientation of the crystallites changes smoothly from a random configuration to a highly preferred one. This preferred orientation is "normal," and has the long chain axes of the crystallites parallel to the stretching direction. However, when stretching is carried out at room temperature a different preferred orientation occurs at intermediate degrees of stretch. This preferred orientation is "abnormal," and in it the long chain axes of the crystallites are inclined at almost right angles (72°) to the stretching direction. As stretching proceeds past this intermediate extension range, the preferred orientation gradually changes to the "normal" one. This same "abnormal" preferred orientation exists in the region of the "neck" in necked down polyethylene. When highly stretched polyethylene is relaxed by heating, the disorientation of the crystallites in the "normal" preferred orientation does not occur in a gradual and random manner. Instead of the preferred orientation remaining constant and the distribution about it merely becoming broader, the preferred orientation itself changes.

Y3. Macromolecular Nomenclature. M. L. HUGGINS, *Eastman Kodak Research Laboratory.*—A report on nomenclature in the field of macromolecules has been prepared by the National Research Council Committee on Macromolecules for submission to the corresponding commission of the International Union of Chemistry. This report will be outlined, and parts related especially to high polymer physics will be presented in detail, with the object of evoking discussion, criticism, and suggestions for revision before final adoption.

Y4. Equilibria in the Dyeing of Nylon with Acid Dyes. W. R. REMINGTON AND E. K. GLADDING, *duPont.*—A mechanism for the acid-dyeing of wool, proposed by Gilbert and Rideal, postulates that (1) amino and carboxyl end groups ionize within the fiber to produce carboxylate ions ($-COO^-$) and alkyl ammonium ions ($-NH_3^+$) and (2) dye uptake by the fiber consists of combination of dye anions with the $-NH_3^+$ groups and hydrogen ions with the $-COO^-$ groups. Gilbert and Rideal's equation has been modified to allow for the excess of carboxyl over amino end groups in Nylon and rearranged so that the data could be tested by means of a linear plot. The latter has permitted an estimate of the number of amino end

groups present in the fiber. Nylon staple was equilibrated with aqueous buffers of varying *p*H and dye concentration, and the distribution of dye between the fiber and the bath was determined. The data were found to be in accord with the suggested mechanism for both single dyes and mixtures of two dyes. Equilibrium constants were determined with a probable error of 12 percent, and amino end groups were determined to within about 5 percent. The loss in tensile strength of Nylon dyed under excessively severe conditions was shown to be caused by hydrolysis of amide linkages.

Y5. Pyrolysis of Hydrocarbon Polymers. S. L. MADORSKY, S. STRAUS, DOROTHY THOMPSON, AND LAURA WILLIAMSON, *National Bureau of Standards.*—Samples (25–50 mg) of hydrocarbon polymers, such as polystyrene, polyisoprene, polyisobutene, polyethylene, polybutadiene, and GR-S, were pyrolyzed in a high vacuum at 350 to 450°C, in a specially designed apparatus. Pyrolysis resulted in a mixture of paraffins, monoolefins, diolefins, etc., varying in molecular weight from 16 to about 1000. The mixture was separated into a gaseous liquid intermediate and wax-like fractions. Mass spectrometer analysis of the gaseous fraction showed it to consist in all cases of a small amount of methane. Similar analysis of the liquid fraction gave a spectrum characteristic for each polymer investigated. This spectrum can be used to identify the polymer or to determine its purity. Because the mass spectrometer at the present stage of development is not capable of analyzing organic compounds over 100–150 molecular weight, the intermediate and wax-like fractions were not analyzed. A molecular weight determination, by the freezing point lowering method, of the wax-like fractions gave values varying from 264 in the case of polystyrene to 775 in the case of polybutadiene.

[1] S. L. Madorsky and S. Straus. J. Research Nat. Bur. Stand. **40**, 417 (1948); see also, Ind. Eng. Chem. **40**, 848 (1948).
[2] S. L. Madorsky, S. Straus, Dorothy Thompson, and Laura Williamson. In preparation for publication in J. Research Nat. Bur. Stand.

Y6. Mass Spectrometric Study of Copolymer Pyrolyses. L. A. WALL, *National Bureau of Standards.*—When copolymers are made from a monomer of the type CH_2CHX or CH_2CX_2 (A) and a monomer of the type CHXCHX or $CH_2CXCHCH_2$ (B), the pyrolytic yield of monomer A, (Y_{AC}), from a copolymer of any composition made at low conversion can be estimated from the relationship

$$Y_{AC} = Y_{A_p}(A/A + r_B B)[1 + (B/2r_A A)\ln(B/r_A A + B)],$$

where Y_{A_p} is the yield from the polymer of A alone, A and B are concentrations of monomers used in preparing the copolymer, r_A is the ratio of rate constants for the propagation steps of A-type radicals in copolymerization, and r_B is similarly defined. The chief assumptions involved are: (1) Equality of all bonds making up the chain in all sequences of A units and (2) side reactions dependent only on the nature of A. Pyrolyses of 0.001-gram samples of styrene-butadiene and styrene-isoprene copolymers were carried out in small tubes adapted to allow complete expansion of all volatile products into the mass spectrometer. Plots of the mass 104 peak heights of monomeric styrene are in agreement with the above relationship.

Y7. Dilatometric Studies of High Polymers I. Second-Order Transition Temperature. HARRY J. KOLB AND EMMETTE F. IZARD, *duPont.*—By means of a density balance, the relationship between intrinsic viscosity and dilatometric properties is established for polyethylene terephthalate. The most pronounced property change associated with increasing intrinsic viscosity was observed to be the second-order transition temperature. The relationship between crystallinity and dilatometric properties is presented for 3 aromatic polyesters. In every case, increased crystallinity in the polymers is associated with higher second-order transition temperatures, larger transition range, higher density, and lower volume coefficients of expansion. Second-order transition temperature, densities at 0°C, and volume coefficients of expansion are presented for a number of polyesters and vinyl polymers to illustrate the effects of chemical structure as well as physical state on these dilatometric properties. Illustration of the effect of copolymerization on second-order transition temperatures is made with a copolyester system.

Y8. Dilatometric Studies of High Polymers II. Crystallization of Aromatic Polyesters. HARRY J. KOLB AND EMMETTE F. IZARD, *duPont.*—By means of both a density balance and gradient tube, experimental density data are obtained to illustrate the thermal crystallization behavior of 3 aromatic polyesters at temperatures from 90°C to 150°C. The data are discussed with reference to both amount and rate of crystallization, and density curves are presented to show qualitative similarity between kinetics of polymer crystallization and the kinetics of chemical reactions. From the experimental data, a temperature, for convenience labeled the minimum crystallization temperature, is described and is shown to be 30° to 50° above the second-order transition temperature for the polyesters. In addition to thermal crystallization, data are presented to show that immersion media may initiate crystallization below the minimum temperature associated with thermal crystallization of polymers. Liquids used as immersion media for polyethylene terephthalate were water, methyl alcohol, acetone, benzene, nitromethane, and nitric acid. The last four liquids initiate crystallization of the polymer at room temperature.

Papers Not Classed Elsewhere

Z1. A Theoretical Study of a Proposed High Intensity Molecular Beam Source. JERRY GREY AND ARTHUR KANTROWITZ, *Cornell University.*—In a standard molecular beam source the maximum attainable intensity in the collimated beam is limited first by the effusion rate through the first slit, which must be made sufficiently narrow to attain free molecule flow, and second by unfavorable geometrical factors encountered in selecting a collimated beam from random initial velocities. This paper will propose that the first slit be placed in the flow from a miniature high velocity nozzle coaxial with the final beam. The nozzle converts part ($\sim\frac{3}{4}$ for a Mach number of 4 in the design for air to be presented) of the random translational and internal energy of the oven gas into directed mass motion. The mass motion provides an initial rough collimation which improves both the effusion rate and the geometrical factors, indicating a considerable possible beam intensification (by a factor of $\sim$75 in the sample design). This proposed source requires the following: first, a greatly

increased gas supply (~0.1 g/sec.), second, a condenser or pump (~1 HP) to maintain the nozzle flow, and, finally, the nozzle and a "streamlined" first slit.

Z2. Formation of Metastable H Atoms by Electron Bombardment of H_2.* W. E. LAMB, JR. AND R. C. RETHERFORD, *Columbia University.*—One would expect that H_2 could be dissociated by electron bombardment into two H atoms, one in the ground state and one in the metastable state $2^2S_{\frac{1}{2}}$. This should be energetically possible at an energy $10.20+D_0$ volts, where D_0 is the dissociation energy of the molecule. With the accepted value $D_0=4.478$ volts, the threshold would be 14.68 volts. On the basis of the available potential energy curves for the excited electronic states of H_2 and the Franck-Condon principle, one would expect the dissociation at this energy to be quite improbable, and possibly to appear only when the bombarding energy were raised to reach one of the repulsive states giving fast metastable plus normal atoms. This would require at least 17 volts. Actually, using the apparatus designed for hydrogen fine structure observations, we have measured an excitation curve for the production of H ($2^2S_{\frac{1}{2}}$) with a threshold at 14.66 ± 0.10 volts. The yield is quite comparable to that obtained using the atomic hydrogen oven, although the signal-background ratio is less favorable. A similar "violation" of the Franck-Condon principle was found by Bleakney in 1930 in the formation of hydrogen ions at 18.0 ± 0.2 volts (expected threshold $13.60+4.48=18.08$ volts).

* Work supported jointly by the Signal Corps and the Office of Naval Research.

Z3. Loss of Ions in Magnetic Analyzer as Affected by Initial Kinetic Energy. R. M. REESE AND J. A. HIPPLE, *National Bureau of Standards.*—In the conventional magnetic analyzer there is no focusing in the direction of the magnetic field. Washburn and Berry[1] have pointed out that this causes a discrimination in addition to that at the source between the various ionic fragments arising from the dissociation of molecules by electron impact; for instance, CH_3^+ formed from the butanes has sufficient initial kinetic energy that most of these ions that enter the analyzer do not pass through the exit slit because they have drifted too far in the direction of the magnetic field at the usual values of the ion accelerating voltage. They have studied this effect, by measuring the increase in ion current as the accelerating voltage is increased. This effect may be studied in a different manner by using the electrodes in the analyzer of the mass spectrometer manufactured by Consolidated Engineering Company to deflect the ions in the direction of the magnetic field. The curve for CH_3^+, as expected, has a very broad maximum compared with that for the parent ion $C_4H_{10}^+$. The experimentally determined peak shapes may be used as a measure of the kinetic energy of the fragments and general agreement with existing information on these energies is obtained.

[1] H. W. Washburn and C. E. Berry, Phys. Rev. **70**, 559(L) (1946).

Z4. Double Charged Ion Spectra in Mass Spectra of Hydrocarbons. FRED L. MOHLER, EVELYN G. BLOOM, E. J. WELLS, JR., J. H. LENGEL, AND C. EDWARD WISE, *National Bureau of Standards.*—We have made a compilation of all doubly charged ions observed in the mass spectra of 148 hydrocarbons using an ionizing voltage of 70 volts. The compilation is based on mass spectra obtained with a Consolidated mass spectrometer and published in the API catalog of mass spectral data. In hydrocarbons with 3, 4, or 5 carbon atoms, the most probable double ionization process involves the loss of all but two or three H atoms without breaking carbon bonds. Unsaturated molecules give larger doubly charged ion peaks than saturated molecules. Ions with an even number of H atoms tend to be more abundant than those with an odd number. In saturated hydrocarbons with six or more carbon atoms, double ionization with breaking of carbon bonds is most probable, but in benzenes and highly unsaturated molecules double ionization without loss of carbon atoms is probable. These heavier molecules show distinctive differences depending on molecular structure. The ratio of ion current at 70 volts to that at 50 volts ionizing voltage is an indication of the appearance potential of the ion. It increases as the number of H atoms removed increases, and the results indicate that H atoms are removed in pairs to give H_2.

Z5. Separation of Argon 36 by Thermal Diffusion. JAMES O. BUCHANAN,* *Yale University.*—The performance of a multistage metal thermal diffusion isotope separation unit has been investigated as specifically applied to the concentration of the light argon isotope of mass 36. The unit was a modified version of one used for the concentration of carbon 13[1] with an additional hot wire glass wall column as the final stage. Since tank argon was used, a purification process was necessary to remove the nitrogen impurity. Discontinuous operation, with the first column acting as a scrubber, was maintained for 336 hours. The average rate of flow of gas into the unit operating at atmospheric pressure was 188 $cm^3\ hr^{-1}$. At this time the separation factor had reached 104 and the end volume (225 cm^3 effective) contained 27.9 percent argon 36. The performance of the unit appeared to be in agreement with the theoretical expectations.[2] A stepwise increase in the concentration with time[3] was evidence of an unbalance in the transport of the light isotope for the different columns.

* Now at West Virginia University.
[1] H. L. Schultz and W. W. Watson, Phys. Rev. **58**, 1047 (1940).
[2] R. C. Jones and W. H. Furry, Rev. Mod. Phys. **18**, 151 (1946).
[3] S. B. Welles, Phys. Rev. **69**, 586 (1946).

Z6. He^3 and the Origin of Terrestrial Helium. P. MORRISON AND D. B. BEARD, *Cornell University.*—A wholly radiogenic source for the earth's helium has long been plausible on geochemical and astrophysical grounds. We have calculated the expected isotopic abundance ratio, R=atoms He^3/atoms He^4, assuming radiogeneration of all present helium by specific nuclear processes. Other processes considered were negligible. For helium from various sources we obtain:

(a) Atmospheric helium: $R\sim10^{-6}$. He^4 is released by rock weathering; He^3 is a product of cosmic-ray star processes in the upper fifth of the atmosphere.

(b) Gas-well helium: $R\sim2\cdot10^{-7}$. He^4 is the decay product of Th and U in their general dilute distribution through igneous rock; He^3, the delayed product of the reaction $Li^6(n,\alpha)H^3$, with the neutron source just that provided by the (α, n) reactions of the natural alphas on the major rock constituents.

(c) Helium from radioactive minerals: $R \sim 10^{-8}$. Here R is much reduced from the similar case (b), because the heavy element content of these minerals lowers the (α, n) yield and introduces competing neutron capture processes. All these calculated ratios agree with the measured values of Aldrich and Nier.[1]

We conclude: (1) all helium present is radiogenic; (2) the He rich gases of the SW United States must be due to unusual collection of gases from normal rock, not to special concentrations of radioactive elements. Other noble gases are now under study.

[1] Aldrich and Nier, Phys. Rev. **74**, 1225(A) (1948) and private communication.

Z7. Remarks on the Evolution of the Expanding Universe.* R. A. ALPHER AND R. C. HERMAN, *Applied Physics Laboratory, The Johns Hopkins University.*—Recently, Gamow[1] has discussed the problem of the evolution of the universe with particular reference to the formation of galaxies. We have reformulated this problem in order to avoid certain difficulties. The relativistic energy equation for the general non-static universe has been integrated and interpreted with the aid of knowledge of the physical conditions required by the neutron-capture theory of element formation.[2] The time dependences of proper distance, matter density, radiation density, and temperature are found. These relationships are employed according to a suggestion by Gamow[1] to determine the mean galactic diameter and mass as $\sim 2\times 10^{8}$ light years and $\sim 4\times 10^{7}$ sun masses, respectively.

* This work was supported by the Navy Bureau of Ordnance.
[1] G. Gamow, Phys. Rev. **70**, 572 (1946); G. Gamow, Nature **62**, 680 (1948).
[2] R. A. Alpher and R. C. Herman, Phys. Rev. **74**, 1737 (1948).

Z8. Ozonosphere Temperatures from Ground Stations. ARTHUR ADEL, *Arizona State College.*—A further application has been made of the author's method for ascertaining ozonosphere temperatures from near-simultaneous observations of atmospheric emission and absorption at 9.6 microns.[1] The experiment, under the joint auspices of Air Materiel Command and the University of Michigan, was in force at Holloman Air Force Base at Alamogordo, New Mexico, from late March, 1948, until mid-July, 1948. Data collected during this period have yielded ozonosphere temperatures for some fifty days (sun as source) and several nights (moon as source). The temperatures for both day and night are found to lie chiefly within an interval extending several degrees on each side of forty degrees below zero, centigrade. A discussion of the sensitivity of the method reveals that a one percent change in the absolute temperature of the ozonosphere corresponds to a six percent change in the radiation intensity of the layer at 9.6 microns. This emphasizes the importance of the experiment, so far as the energy (weather) relationship between ozonosphere and troposphere is concerned, since it measures the radiation intensity of the ozonosphere directly.

[1] Arthur Adel, Astrophys. J. **105**, 406 (1947).

Z9. On the Origin of Solar Radio Noise. ANDREW V. HAEFF, *Naval Research Laboratory.*—The observed anomalous radio frequency radiations from the sun are associated with sun spot activity and are believed to be generated within intermingling streams of charged particles issuing from active areas of the sun. Such streams have the property of greatly amplifying initial space-charge fluctuations over a range of frequencies determined by the density and velocity distribution of particles in the stream. The theory[1,2] of generation of radio energy resulting from space-charge interaction between streams of charged particles is reviewed and applied to the solution of the solar radio noise problem. From estimates of average density and velocity distribution of solar particles, the frequency of the most intense radiation (30 to 60 megacycles) and the absolute value of radiation intensity at the surface of the earth (7 to 2)$\times 10^{-22}$[watt/(cm^2/cycle/s)] are computed and found to agree well with measurements.[3] The most probable spectral distribution of the anomalous solar radiation is derived in the form

$$E/E_m = (\lambda/\lambda_m)^2 \exp[2(1-(\lambda/\lambda_m))],$$

where E_m is the maximum intensity corresponding to the wave-length λ_m.

[1] Andrew V. Haeff, "Space-charge wave amplification effects," Phys. Rev. **74**, 1532 (1948).
[2] Andrew V. Haeff, *The Electron Wave Tube—A Novel Method of Generation and Amplification of Microwave Energy* (Naval Research Laboratory Report No. R-3306, June 24, 1948). (To be published in the January issue of Proc. I.R.E.)
[3] E. V. Appleton and J. S. Hey, "Solar radio noise," Phil. Mag. **37**, 73–84 (1946).

Z10. Mechanisms of Charge Generation in Thunderclouds.* SEVILLE CHAPMAN, *Cornell Aeronautical Laboratory.*—Simpson's breaking drop theory of thundercloud electrification based on the generation of 1.6×10^{-12} coulomb per drop with negative electrification only in the air is quantitatively inadequate and yields a cloud of the wrong polarity. Wilson's induction theory makes no use of the typical thundercloud updraft, and is quantitatively inadequate since insufficient ionization exists in the atmosphere. New experiments on water drops breaking in air under conditions more closely resembling thundercloud conditions indicate approximately 20×10^{-12} coulomb of both positive and negative electrification appear in the air per broken drop. If this charge is separated by the Wilson mechanism, reasonable frequency of lightning flashes can be accounted for. Freely falling natural snow striking snow typically leaves the snow positively charged 1×10^{-12} coulomb per impacting flake, with negative charge in the air. Radiosondes modified to measure electric field show that the main thundercloud charge centers (positive above) are higher in elevation than the freezing isotherm.[1]

* This work was done at Stanford University and was sponsored by the Office of Naval Research.
[1] Compare Workman, Reynolds, Holzer, and Pelsor, Bull. Am. Phys. Soc. **23**, No. 7, 28 (1948); Physical Review **74**, 709 (1948); and National Advisory Committee for Aeronautics Technical Note 864.

Z11. Analog Computers for Functions of Many Variables.* EUGENE W. PIKE AND THOMAS R. SILVERBERG, *Raytheon Manufacturing Company.**—Practical devices analogous to cams, representing in the relationship of physical quantities arbitrary functions of five or more independent variables, can be designed systematically by expanding the given function into a sum of products of functions of the variables singly. The expansions used are

(a) the analysis of variance form (given in statistical texts),

$$F(x_1, \cdots, x_n) = F_1(x_1) + \cdots + F_n(x_n) + F_{12}(x_1, x_2) + \cdots F_{123}(x_1, x_2, x_3) + \cdots$$

and so on, plus a residual, after any stage, which is a least square, and

(b) an obvious iterative procedure provides functions $f_j(x_j)$, etc., in

$$F(x_1 \cdots, x_n) = \prod_{j=1}^{n} f_j(x_j) + \prod_{k=1}^{n} g_k(x_k) + \cdots + \text{Residual},$$

such that the residual is a least square. The functions of single variables can be represented by cams or potentiometers; multiplication and addition use standard devices.

* This work supported by the Air Materiel Command.

Z12. A Theory of Equivalent Linearization for Non-Linear Oscillatory Systems with Large Non-Linearity. AUTHOR UNKNOWN.—This paper introduces a method, based partially on existing non-linear theory and partially on experimental results, for transforming a non-linear oscillatory system into an equivalent linear one, regardless of the amount of non-linearity in the restoring force of the original system. Thus a system represented by the equation,

$$m(\partial^2 \mathbf{x}/\partial t^2) + \beta(\partial \mathbf{x}/\partial t) + f(x) = P_0 \sin \omega t,$$

in which the non-linearity is introduced in $f(x)$, can now be represented by the equation,

$$m(\partial^2 \mathbf{x}/\partial t^2) + \beta(\partial \mathbf{x}/\partial t) + k_e x = P_0 \sin \omega t,$$

in which $k_e x$ represents an equivalent restoring force which can be utilized regardless of the amount of non-linearity in $f(x)$. Existing methods of equivalent linearization require the original system to be quasilinear.

Z13. On the Hydrogen Spectrum. GERTRUDE SCHWARZMANN.—Interpretation of emission and absorption of light quanta by the atoms as wave phenomena allow, on one hand, of selecting—as innermost hydrogen orbit described by the interacting satellite electron—the one wherein the electron spins twice per revolution in preference to the Mercurial one, and of introducing, on the other hand, the concept of the "satellite photons" revolving 137 times about the hydrogen nucleus while spinning once about their axis, or, rather, that of the "satellite light waves" revolving about the hydrogen nucleus in circular orbits with radii r the 860th part of their wave-lengths λ. Among these orbits, those described by the shortest wave in each series of the hydrogen spectrum, their radii twice those of Bohr's original circular orbits, are simultaneous stationary orbits of satellite electron and "satellite photon" having equal kinetic energies. From the viewpoint of this and previously presented papers,* the existence of an absorption spectrum is prerequisite to, not a consequence of, the interaction between satellite electron and light, and the difference in scale between the two natural constants, $2e^2/c$ and $2\hbar$, originates in the ratio λ/r.

* A.P.R. **72**, pp. 154, 536, 744; **73**, pp. 1273, 1274.

Z14. Further Experimental Proofs of the Existence of Single Magnetic Poles. FELIX EHRENHAFT, *University of Vienna.*—The author stated in 1930, and repeatedly confirmed by experiments later on, the fact that particles carrying single magnetic poles do exist.* P. A. M. Dirac advanced the idea of magnetic poles from a quantum-mechanical point of view in 1931 and completed this concept quite recently,** assuming that high energies are necessary for their separation. My experiments gave no evidence that high energies would be necessary for this purpose. E.g., J. A. Schedling*** repeated at my institute, by means of smallest magnetic field strengths, Oersted's experiment using iron particles suspended in gases, having six degrees of freedom. These particles circulate clockwise and counterclockwise simultaneously around the wire, through which a constant electric current is flowing, reversing the direction of movements with the reversal of the current. Therefore, the particles carry an excess of magnetic charge, north or south. The magnetic charges measured amount to 10^{-8} to 10^{-12} m.st.u. Recently**** the author, R. F. K. Herzog, and co-workers found that radiation of RaE when exposed to the action of a longitudinal homogeneous magnetic field penetrates much thicker layers of aluminium than without a magnetic field. We are dealing in this case plausibly with particles of higher energies carrying single magnetic poles.

* Comptes Rendus, 190, 263 (1930); Physik. Zeits. **31**, 481 (1930); cf. Phys. Rev. **68**, 105 (1945); **70**, 114 (1946). J. Franklin Inst. 233, 235 (1942); Comptes Rendus 225, 926 (1947).
** Proc. Roy. Soc. **A133**, 60 (1931); Phys. Rev. **74**, 817 (1948).
*** Comptes Rendus 227, 470 (1948).
**** Comptes Rendus 626 (1948).

Z15. On the Mechanism of Conductivity of Electricity According to Modern Physical Theories. OLEG YADOFF, *Columbia University.*—The electromagnetic theory of Maxwell and the electronic theory of Lorentz which supplemented the former one rendered great services to the physicists and permitted the explanation of a great number of phenomena, but they have their limitations and in due time met great difficulties. The author intends to show the physical character of electric current according to quantum theory and the theory of new wave mechanics. Introducing the idea of interactions, the author distinguishes two phases which are quite different and shows the existence of a definite value of the time necessary for the formation or suppression of current. The interaction of the electronic waves and of the atomic structure of the conductor has been explained physically for normal conditions as well as for conditions of superconductivity. The different aspect of the phenomenon is explained mathematically by borrowing from the theory of diffusion of a particle by an atom. The propagation of electronic waves (electric current) is presented under a new aspect. The cases of elastic and rigid shocks of electronic waves' electrons against the oscillating atoms of thermic waves are presented in accordance with this new theory.

SUPPLEMENTARY PROGRAMME

SP1. On the Positive Excess of the Penetrating Component in Cosmic Rays. G. BERNARDINI, *Columbia University.**—Old and new results on the positive excess of the hard (mesonic) component demonstrate that the positive excess decreases when the energy of particles increases. This conclusion is discussed in connection with the production of mesons in high atmosphere.

* To be given after Session X if the Chairman rules that time permits.

SP2. The Application of Jacobians to Statistical Thermodynamics. Part I. The Explicit Calculation of Thermodynamic Functions. HARVEY EINBINDER, *Columbia University.**—The Jacobian method developed by Shaw[1] for calculating thermodynamic derivatives is extended to provide a ready means for finding any partial second derivative in terms of two sets of reference derivatives based on the independent variables (V, T) and (P, T), respectively. A simplified and enlarged table of second order Jacobians is given in terms of these reference sets. Methods are developed for explicitly obtaining the reference Jacobians in the cases of greatest importance in statistical thermodynamics, i.e. from the Helmholtz function, the internal energy, the partition function, and the caloric equation $PV=sE$. Thus, any first or second partial derivative can be found as an explicit function of (V, T). The reference J's are given for the polyatomic ideal and van der Waals gases, black body radiation, the general (relativistic and non-relativistic) quantum, degenerate Bose-Einstein and Fermi-Dirac gases. Their great usefulness is illustrated. Finally, the application of these methods in the development and evaluation of semi-empirical theories of thermodynamic systems, particularly liquids and gases, is noted.

* To be given after Session T if the Chairman rules that time permits.
[1] A. N. Shaw, Phil. Trans. Roy. Soc. **A234**, 299 (1935).

SP3. The Application of Jacobians to Statistical Thermodynamics. Part II. The Theory of Thermodynamic Fluctuations. HARVEY EINBINDER, *Columbia University.**—The work done by earlier investigators in the theory of thermodynamic fluctuations, inaugurated by Einstein and Smoluchowski, is reviewed and clarified. The methods developed in Part I find a ready application. With their aid a number of interesting and important relations between the second moments of different fluctuating thermodynamic variables are found. All the second moments and correlation coefficients of such variables have been expressed in terms of the reference Jacobians (cf. Part I), so that they can be calculated explicitly for any system whose reference J's are known. The ease and generality of the method is illustrated using the ideal polyatomic gas. The thermodynamic fluctuations in degenerate systems is also treated with the aid of Jacobians. While the theory developed is limited to systems obeying classical statistics, its extension to quantum statistics is noted.

* To be given after Session T if the Chairman rules that time permits.

SP4. Effect of Tension upon the Electrical Resistivity of Metals and Alloys. G. C. KUCZYNSKI, *Sylvania Electric Products, Inc.**—The change of the electrical resistivity with elongation at constant temperature was investigated in the case of Cu, Ni, Al, Pt, Fe, Co, Mo, Ta, W, Sn, Bi, some Cu-Ni and Bi-Pb, Bi-Sn and Bi-Se alloys. It was found that with the exception of Bi, Ni and some of their alloys there is a small increase of resistivity with tension. Bi and Ni decrease their resistivity appreciably with elastic elongation although each for different reasons. Most of the results are explained by the simple free electron theory of metals.

* To be given after Session O if the Chairman rules that time permits.

SP5. The Properties at Very High Altitudes of Comsic Radiation at Large Zenith Angles, and Verification of a Consequence of Liouville's Theorem.* MARTIN A. POMERANTZ,** *Bartol Research Foundation.*—In a series of free balloon ascents, the altitude-dependence of the unidirectional cosmic-ray intensity at large zenith angles has been investigated with standard instruments of the type utilized previously[1] for observations in the vertical direction. Thus far, 11 flights with quadruple-coincidence counter trains inclined at 90° and 60° from the vertical, containing interposed absorbers up to 7.5 cm of Pb, have been conducted. Measurements at smaller zenith angles are still in progress.

The important observations regarding the magnitude of the horizontal intensity obtained with telescopes containing no interposed absorber during the National Geographic Society-AAF Stratosphere flights[2] have been confirmed, and extended to higher altitudes. Intensity *vs.* altitude curves appear to converge at the "top of the atmosphere" toward the same primary intensity characteristic of the vertically-incident radiation. This provides direct experimental verification for the directional isotropy, formerly perforce assumed in analyses of the geomagnetic effects,[3] which had been predicted as a fundamental consequence of the applicability of Liouville's theorem to this problem.[2]

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
** To be given after Session Q if the Chairman rules that time permits.
[1] M. A. Pomerantz, Phys. Rev. **75**, in press.
[2] G. Lemaitre and M. S. Vallarta, Phys. Rev. **43**, 87 (1933), W. F. G. Swann, Phys. Rev. **44**, 224 (1933).

SP6. Cathode Vapor, the Discontinuous Glow-Arc Transition, and Arc Stability. JEROME ROTHSTEIN, *Evans Signal Laboratory.**—Experiments of Plesse and Hofert show that the discontinuous glow-arc transition (DGA) is facilitated by vapor in the cathode region, that normal evaporation is inadequate for supplying vapor where the cathode is its source, and that the probability of a DGA on superimposing a large current pulse on a glow increases with increasing pulse magnitude and rate of rise. This agrees with a recent suggested mechanism of cathode spot emission according to which ionic bombardment of the cathode spot creates a microvolume into which current flows by ordinary conduction and from which it flows thermionically. Added vapor near the cathode means more ions (created by electron impact) to bombard the cathode, resulting in more electrons and sputtered or "evaporated" atoms from the cathode, hence still more vapor, etc.,

culminating in arc microvolume conditions. Added energy input, e.g., by current pulses, acts similarly, but if insufficient in amount or supplied too slowly to overcome dissipating effects, e.g., heat conduction, a DGA is not obtained. Anomalies earlier reported, cold C & W arcs and arc instability with pure electrodes in pure rare gases also seem to be explained by the theory; cathode vapor liberated by chemical reaction or by surface bombardment facilitates a DGA or stabilizes an arc otherwise extinguishing for lack of it.

* To be given after Session V if the Chairman rules that time permits.

SP7. Cathode Vapor and Anchoring of the Cathode Spot. JEROME ROTHSTEIN, *Evans Signal Laboratory.**—General features of the anchoring of the Hg cathode spot[1] receive a natural interpretation according to the author's theory of arc spot emission. When anchored, the spot can be maintained by virtue of the vapor blasted off the surface of the wet metal anchor by ion bombardment. Anchoring being preferred to mobility would follow if the critical rate of energy input to maintain an arc spot is less for a surface layer than for bulk liquid. This seems likely as energy inter-change between spot microvolume and anchor would be governed by a kind of accommodation coefficient doubtless smaller than that governing energy transfer from spot to rest of liquid. Anchor erosion, akin to sputtering, would be expected to be less for the more refractory metals. Anchoring would be poor if surface not wet by Hg. Heating the anchor would tend to drive off the surface layer and free the spot. A junction well wet by a large current should permit a spot carrying a comparatively small current to wander over the wet surface. The slight tendency to anchor before the metal is wet may be explained by reflection of spot vapor by the projecting anchor giving a slight increase in local vapor density. This type of anchoring would also occur with insulators.

* To be given after Session V if the Chairman rules that time permits.
[1] L. Tonks, Physics **6**, 294 (1935); N. Warmolz, Physica **7**, 209 (1940).

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