Proceedings of the American Physical Society

MINUTES OF THE MEETING AT NEW YORK, FEBRUARY 2–4, 1950

THE 297th meeting of the American Physical Society, being the 1950 Annual Meeting, was held in New York City on February 2, 3, and 4, 1950. (Last year's Annual Meeting was designated as the 1948 Annual Meeting, for the sake of continuity with the times when the Annual Meetings were held just before New Year's day; we now break that continuity.) Measured by registration, this was the largest meeting in the history of the Society; we had never had so many as 2000 registrants before, this time we had 2070. Measured by number of papers it was slightly smaller than the corresponding meeting of the previous year (231 ten-minute papers). The congestion also seemed to have slackened, and it is possible that we had a lesser attendance but a still lesser proportion of non-registrants. Anyway, it was a very big meeting! Five simultaneous sessions were the order of each day.

The Local Committee at Columbia University performed its huge task with its customary extraordinary competence (the two adjectives seem to contradict one another, but both are right). The Secretary would like to exhibit to the entire Society the eleven-page compendium of instructions drawn up by this Committee, with assignments of room supervisors, slide operators, and lights' operators to every one of the twenty-nine sessions, plus other assignments to lobby, registration desk, and placement register. All of this immeasurably complicated business was under the direction of W. W. Havens, Jr., and among his principal assistants were A. M. Sachs and Irving Resnick. The American Institute of Physics provided the staff at the registration desk. Services were also rendered, by persons unknown to this office, to the Division of Electron Physics at its meeting at Washington Square College of New York University, and to the Division of High-Polymer Physics at its meetings at the Polytechnic Institute of Brooklyn.

Eight invited papers—among which I include the Retiring Presidential Address of F. W. Loomis and the after-dinner speech of F. Seitz—appeared on the general programme: their titles are listed hereinafter. It is understood that the speeches of Loomis and Seitz are to be published in the *Bulletin of the Atomic Scientists*. In addition, nuclear physics benefited by a Symposium on Nuclear Shell Structure, the authors and the titles being listed on a following page.

Each of our four Divisions presented a half-day Symposium; half a day to each Division is the maximum time now allowed for Divisional sessions of invited papers at Columbia University, for a reason which needs no statement. The givers and the titles of the papers in these Symposia are listed hereinafter. In addition, the Division of Electron Physics held a two-day meeting (on January 31 and February 1) at Washington Square College of New York University; and the Division of High-Polymer Physics held sessions at the Polytechnic Institute of Brooklyn on February 2 and 4. By recent action of the Council, these "separate" meetings of the Divisions—"separate" meaning here that they do not encroach on the space placed at the disposal of the Society by Columbia University—are liberated from certain of the constraints imposed by necessity on the general meetings of the Society. At separate meetings, the Divisions may allow more than ten minutes for the presentation of a "contributed paper," without forfeiting the right to have the abstracts of such papers printed in *The Physical Review*. The abstracts of the papers presented at Washington Square and at Brooklyn are therefore printed at the end of these Minutes, following upon the abstracts of the ten-minute papers offered at the general meeting.

The banquet of the American Physical Society and of the American Association of Physics Teachers was held on Friday evening February 3, those present numbering 328. The after-dinner speech, already mentioned in these pages, was given by F. Seitz: its title was "Physicists in the Cold War."

At the Business Meeting of the Society, held on the Friday morning with the customary slim attendance, the Tellers of Election reported (by letter) that I. I. Rabi had been elected President of the Society for 1950; C. C. Lauritsen had been elected Vice-President; K. K. Darrow, G. B. Pegram and J. T. Tate had been re-elected Secretary, Treasurer, and Managing Editor, respectively; Harvey Brooks, R. F. Christy, and Bruno Rossi had been elected to the Board of Editors; H. A. Bethe had been elected to the Council. It was necessary to hold a run-off election to fill the second vacancy of the Council: this resulted in the election of J. W. Beams. The Secretary reported that the membership of the Society was 9000: this obviously rounded figure represents the best estimate that can be made, in view of such facts as the failure of certain recently elected members to qualify thus far and the presence in our files of the names of numerous members who have not responded to notices sent to their latest known addresses. This

figure also includes our 113 Japanese members, from most of whom no word has been received since before the war.

The Council met on February first. It elected to Membership 217 candidates and to Fellowship 102 candidates, whose names are printed hereinafter. The remarkably great number of elections to Fellowship results from a systematic effort, undertaken by several special committees and finally by the Council as a whole, to comb the Membership List for cases of members worthy of Fellowship whose friends had overlooked the duty of sponsoring them. This job is not yet completed.

Authorization was granted by the Council for the establishment of a Division of Chemical Physics in the American Physical Society: an organizing committee headed by R. S. Mulliken is preparing the plans.

Elected to Fellowship: Raymond V. Adams, Julius Ashkin, Yardley Beers, Persa Raymond Bell, Jr., G. Bernardini, Garrett Birkhoff, John Blatt, Marietta Blau, David Bohm, Hugh Bradner, Helmut L. Bradt, R. Robert Brattain, R. G. Breckenridge, Giuseppe Cocconi, Marcello Conversi, Robert Cornog, Dale R. Corson, Ernest D. Courant, Dean B. Cowie, Eugene C. Crittenden, Jr., Baldwin R. Curtis, G. C. Danielson, Leo P. Delsasso, Howard D. Doolittle, Harold E. Edgerton, N. E. Edlefsen, Leonard Eisenbud, W. C. Elmore, C. T. Elvey, Richard M. Emberson, Peter P. Ewald, Carl F. Eyring, Leslie L. Foldy, Stanley P. Frankel, William B. Fretter, David H. Frisch, Erwin R. Gaerttner, Serge Golian, G. K. Green, Earle C. Gregg, Jr., Kenneth Greisen, Benno Gutenberg, Harvey Hall, David Halliday, Bernard Hamermesh, Wayne E. Hazen, A. Carl Helmholz, Arthur Hemmendinger, Frank L. Hereford, Jr., W. A. Higinbotham, Robert Hofstadter, Leopold Infeld, J. M. Jauch, Joseph Kaplan, Thomas J. Killian, Arthur F. Kip, J. B. Horner Kuper, Robert V. Langmuir, Willard F. Libby, E. J. Lofgren, Emmeth A. Luebke, C. E. Mandeville, Marvin M. Mann, Joseph E. Mayer, Ralph L. McCreary, Ralph E. Meagher, Donald H. Menzel, David Middleton, Philip Morrison, Seth H. Neddermeyer, Leonard O. Olsen, Frank Oppenheimer, A. Pais, Wolfgang K. H. Panofsky, R. Pepinsky, Bernard Peters, Oreste Piccioni, John R. Platt, E. H. Plesset, Bruno Pontecorvo, R. V. Pound, Wilson M. Powell, D. A. Quarles, Simon Ramo, William Rarita, Victor H. Regener, Robert Curtis Retherford, Howard L. Schultz, Erwin F. Schrader, Charles S. Smith, Jr., Hartland S. Snyder, Arthur K. Solomon, H. Guyford Stever, James A. Van Allen, Arthur H. Warner, Wallace Waterfall, Albert Wattenberg, P. R. Weiss, Gregor Wentzel, G. C. Wick, Volney C. Wilson, and Harold A. Zahl.

Elected to Membership: Louis K. Acheson, Jr., John E. Ainsworth, Jr., Alfred H. Aitken, William Parker Alford, Simonne Allard, Raymond A. Allen, Robert C. Allen, Hugo Atterling, Theodore Auerbach, William Thomas August, Robert Palmer Auty, Robert A. Bailey, Donald H. Baird, Roger E. Batzel, Walter C. Beckham, John K. Beling, Warren Lee Bendel, John A. Berberet, Conrad Heinrich Biber, Brebis Bleaney, Hans Boemmel, Aage Niels Bohr, Harry M. Bowman, James N. Bradford, Stanley Breen, *James J. Brophy, Albert R. Brosi, Russell B. Bryan, Frank P. Buff, Mario Bunge, Geoffrey R. Burbidge, Edward Burke, Richard L. Burling, Sidney M. Cadwell, Robert Calfee, Ray N. Cauble, Zenobius V. Chraplyvy, Feng Kan Chuang, Herbert Mottram Clark, Joseph D. Clement, Hans O. Cohn, James A. Coleman, John Convey, Robert L. Cooper, Malcolm Correll, Robert Cortell, Franklyn G. Creese, Robert W. Crews, Marshall F. Crouch, Harold Ormand Curtis, Melvin Cutler, Rob Roy Cyr, Paul M. Dandurand, Philip N. Daykin, George Dean, Robert J. Debs, Owen P. Dickson, Mary I. Donnelly, Cecil Eugene Duncan, Brian B. Dunne, Jr., James Durlacher, William Eiselstein, Tilden Euster, Henriette Faraggi, Giuseppe Romolo Fidecaro, Manus R. Foster, Francis L. Friedman, Robert M. Fristrom, Solomon Frost, Jack N. Gadel, Avery M. Gage, Aaron I. Galonsky, Gerald R. Garrison, Richard Lawrence Garwin, Robert K. Golden, Jacobo M. Goldschvartz, Martin Goldstein, Bernard Gregory, Carl Greifinger, Maurice Griffel, Peter H. Haas, Uri Haber-Schaim, Kenneth George Halvorsen, John N. Harris, Melvin A. Harrison, Roger Hayward, Bertram Heil, Edward J. Hennelly, Gerhart R. Hennig, John M. Hood, Jr., Henry John Hrostowski, Ming-kuei Hu, Craig C. Hudson, James N. P. Hume, Charles Harve Humphrey, Vincent Jaccarino, Ralph A. Jack, Moses Gamzen Jacobson, Joseph Jaffe, Frank E. Jaumot, Jr., James Farris Jenkins, Jr., Horace R. Johnson, John C. Johnson, Rosalie Joseph, Hellmut J. Juretschke, George T. Kallman, Stanley L. Kameny, Lien-Pei Kao, Glenn Keister, William E. Keller, Paul R. Kintzinger, Terje Kjeldaas, Jr., Alfred Kleider, Melvin Klerer, A. Morris Koblenz, Boris V. Korvin-Kroukovsky, Valdemar Kowalowski, Bernard A. Kulp, Walter C. Lamphier, Henry L. Laquer, Eugene J. Lauer, James M. LeBlanc, Irwin L. Lebow, Theodore E. LeLoup, Andrew Lenard, David Lichtman, Robert Loyd Lillestrand, John Linsley, William H. Louisell, David Lupfer, William Van Rensselaer Malkus, Lawrence James Marks, Charles Martin, H. C. Martin, Daniel L. Massignon, Joseph W. Mather, Jacob Mazur, Aubrey L. McLellen, Jr., Gordon McClure, Robert L. McCormack, John L. McLucas, Robert Charles Miller, R. Douglas Moffat, Harold J. Morowitz, Giacomo Morpurgo, Paul L. Morrison, Jr., John H. Muller, William W. Mullins, John P. Neissel, E. A. Nesbitt, George Nestor, James Blakey Newman, Velmo Lee Norris, G. P. S. Occhialini, Jay Orear, Lorne A. Page, Carolyn Parker, Sidney Passman, Jane Shera Pease, Willis B. Person, William Peters, Arthur V. Phelps, Lucy W. Pickett, George R. Pitnam, Jr., Spencer L. Plehaty, David Polur, S. James Press, *Giampietro Puppi, Martin G. Redlich, Richard S. Rettie, Shepard Roberts, Thomas E. Roberts, Jr., Charles Rubinstein, Wyman C. Rutledge, Harold Salwen, Harold Samelson, Albert J. Saur, Abraham Savitzky, Milton Schach, Robert A. Schluter, Lawrence A. Schmid, Harry J. Schulte, Jr., Dr. Paul Schulz, Merrill B. Scott, Ganapathy Shrikantia, Paul H. Sidles, Albert Silverman, Richard C. Sirrine, Edward Cutrer Smith, Michel Soutif, Wallace P. Spaulding, Fred N. Spiess, Ralph Henry Stahl, Jorge P. Staricco, Alonzo E. Stoddard, Jr., Don R. Swanson, John C. Swartz, Theos Jardin Thompson, Sam B. Treiman, Lucio Vallese, Juanita Hubbard Wagner, Nathan S. Wall, Peter P. Wegener, David B. Wehmeyer, Jose F. Westerkamp, John A. Wethington, Jr., George W. Wheeler, Alan Whittaker, Armin T. Wiebke, Anthony J. Wilk, Arthur H. Williams, Joel Q. Williams, Allan N. Wilson, Shi-Shu Wu, Kenneth Yass, Frink Mansfield Young, and Robert Gaines Young.

* One sponsor only.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Invited Papers on the General Programme

Neutron evaporations produced by cosmic rays. G. BERNARDINI, *Columbia University.*

Physical viewpoints in quantum electrodynamics. R. P. FEYNMAN, *Cornell University.*

Neutron mirrors. D. J. HUGHES, *Brookhaven National Laboratory.*

Can physics serve two masters? F. W. LOOMIS, *University of Illinois.*

Recent developments in quantized field theories. W. PAULI, JR., *Eidgenossische Technische Hochschule and Institute for Advanced Study.*

Physicists in the cold war. F. SEITZ, *University of Illinois.*

Turbulence and the evolution of spiral nebulae. C. F. VON WEISZAECKER, *University of Chicago.*

Recent investigations on the shapes of beta-ray spectra. C. S. WU, *Columbia University.*

Symposium on Nuclear Shell Structure

W. D. HARKINS, *University of Chicago.*
V. F. WEISSKOPF, *M. I. T.*
MARIA GOEPPERT-MAYER, *Argonne National Laboratory.*
L. W. NORDHEIM, *Duke University.*
EUGENE FEENBERG, *Washington University.*

Symposium of the Division of Electron Physics

Imprisonment of resonance ratiation in mercury vapor. A. O. MCCOUBREY, D. ALPERT, AND T. HOLSTEIN, *Westinghouse.*

Recent work on the ratio of the magnetic moments of electron and proton, and related atomic constants. E. M. PURCELL, *Harvard University.*

Scintillation counters and photo-multipliers. G. A. MORTON, *RCA Laboratories.*

Photo-conductivity and optical absorption in BaO crystals. WINFIELD W. TYLER, *Cornell University.*

Symposium of the Division of Solid-State Physics

Behavior and properties of grain boundaries. R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*

Energy bands and electron mobilities in non-polar crystals. J. BARDEEN, *Bell Telephone Laboratories.*

The shape of absorption lines in dielectrics. H. FROEHLICH, *University of Liverpool.*

Symposium of the Division of High-Polymer Physics

Mechanism of plastic flow in single crystals. F. SEITZ, *University of Illinois.*

Structure and physical properties of crystalline polymers. H. LEADERMAN, *National Bureau of Standards.*

Rheological properties of glass. W. A. WEYL, *Pennsylvania State College.*

Internal friction in solids. C. ZENER, *University of Chicago.*

Static and dynamic viscosities of amorphous polymers. A. V. TOBOLSKY, *Princeton University.*

Discussion. Led by M. L. HUGGINS, *Eastman Kodak Company.*

Symposium of the Division of Fluid Dynamics

Stability theory of viscous flows. C. C. LIN, *M. I. T.*

Transonic flow. W. R. SEARS, *Cornell University.*

Development of supersonic airfoil theory. J. C. EVVARD, *Lewis Flight Propulsion Laboratory.*

Symposium on Dielectrics of the American Institute of Electrical Engineers

Dielectrics in Electrical Engineering. A. VON HIPPEL, *M. I. T.*

Structure and Polarization of Atoms and Molecules. J. C. SLATER, *M. I. T.*

Relaxation Phenomena in Liquids and Solids. C. P. SMYTH, *Princeton University.*

Modern Plastics. H. MARK AND T. ALFREY, *Polytechnic Institute of Brooklyn.*

Conduction Phenomena in Gases. J. P. MOLNAR, *Bell Telephone Laboratories.*

Conduction in Liquids and Plastics. R. M. FUOSS, *Yale University.*

Fluorescence and Phosphorescence. P. PRINGSHEIM, *Argonne National Laboratory.*

Crystals

A1. The Status of the Measurement of the Properties of Some Piezoelectric Crystals.* KARL S. VAN DYKE, *Wesleyan University.*—Comparison is made of static and resonator methods for determining piezoelectric constants and of the values of the constants of KDA (potassium dihydrogen arsentae, tetragonal) and of EDT (ethylene diamine *d*-tartrate, monoclinic) by the two methods. Measurements by Niemiec and by Officer** on KDA are cited, and measurements by Niemiec on EDT compared with values given by Jaffe, by Mason, and by Bechmann and Lynch. The latter authors appear not to have been aware of an unpublished revision of his values by Mason to which attention was called by Jaffe, and of the limited circulation of these values in A Handbook of Piezoelectric Data† in which the revised values were used through Mason's courtesy. Niemiec's measurements now in progress confirm the values for EDT used in the Handbook as fairly representative. Success of the resonator method, even for the piezoelectric constants of thickness-shear plates, is demonstrated when adequate attention is given to the distribution of strain in a given mode of vibration.

* Work supported by U. S. Army Signal Corps.
** C. B. Officer, Thesis, "Piezoelectric Properties of Potassium Dihydrogen Arsenate," Wesleyan University, June, 1948. Not published.
† K. S. Van Dyke, Parts II of Fifth and of Sixth Semi-Annual Reports to Signal Corps (January 21, 1948 and July 28, 1948) under the above mentioned contract.

A2. Anelastic Effects in Ionic Crystals. R. G. BRECKENRIDGE AND A. L. WARD, *National Bureau of Standards.*—The internal friction in single crystals of NaCl, LiF, and K Br has been studied by observations of the decay of free torsional oscillation of a composite piezoelectric resonator consisting of a *Y*-cut quartz bar with the crystal cemented to one end. The *Q* of the resonator is calculated from the logarithmic decrement of the decay curves. Plots of *Q* as a function of temperature for the composite resonator show three minima not found for the quartz alone. These increases in the loss are attributed to relaxation processes in the ionic crystal. The activation energies for the processes have been determined. A tentative identification of the loss mechanisms may be made for the two processes of lower energy because of the good agreement found with previously reported values for the activation energy for self diffusion in NaCl[1] and for reorienting pairs of vacancies through cation migration[2] in all three cases. It is suggested that the process of highest energy may be the reorientation of pairs through anion migration.

[1] D. Mapother and R. J. Maurer, Phys. Rev. **73**, 1260 (1948).
[2] R. G. Breckenridge, J. Chem. Phys. **16**, 959 (1948).

A3. Anelasticity of Quartz Crystals. RICHARD K. COOK AND ROBERT G. BRECKENRIDGE, *National Bureau of Standards.*—By means of the piezoelectric effect, measurements have been made of the variation with temperature of (1) the *Q* of a bar executing free torsional oscillations, and (2) the equivalent series resistance of bars driven at their fundamental longitudinal frequencies. For each of the three bars studied, it was

found that the internal dissipation had a maximum value at a temperature between room temperature and the inversion temperature of 573°C. Measurements of the equivalent series resistance as a function of frequency were made in order to decide whether or not the dissipation had an Arrhenius-type variation with temperature. The origin of the dissipation is uncertain. For two of the bars, the maximum dissipation increased after the bars were heated to temperatures a little below inversion. In these cases, the dissipation is probably due to twinning. For another bar, however, the dissipation was not significantly changed by heating to temperatures near inversion, and hence it is surmised that the bar had some sort of a lattice imperfection.

A4. Vibrations of a Circular Crystalline Plate.* SHEPARD BARTNOFF, CHARLES R. MINGINS, AND JOSEPH F. CLAYTON, *Tufts College.*—In an effort to obtain expressions which fit the situation more satisfactorily than existing relations, the problem of a vibrating crystal has been attacked by tensor methods. Cylindrical coordinates are set up appropriate for the analysis of the vibrations of a circular Y'-cut quartz plate. The matrices transforming from rectangular coordinates to the new coordinates are evaluated and tensor methods, using these matrices, are applied to express the piezoelectric equations, the piezoelectric constants, and the elastic constants in the new system. For a given applied electric field, the strains, expressed in terms of contravariant displacements, are used in the piezoelectric equations to describe the stresses in terms of these displacements. The resulting stress expressions are substituted into the equations relating the stresses to the contravariant force components. There then result three equations involving the three contravariant displacements and their derivatives. The general motion of any point of the crystal is given by that solution of these three equations which satisfies boundary conditions. The boundary conditions are evaluated for a circular crystal clamped at its circumference.

* This work is sponsored by the Frequency Control Branch of the Signal Corps.

A5. Intense Multiple Reflection of Electrons. L. G. SCHULZ, *University of Chicago.*—When thin films of alkali halides are formed by evaporation on mica substrates the atoms in a (111) plane of the crystals in the deposit tend to match the hexagonal atomic network in the cleavage surface of the substrate. Electron diffraction patterns taken by reflection from films containing crystals in twinned relationship were found to contain strong "extra spots." These spots are attributed to intense multiple reflection involving successive diffraction by crystals of both orientations. Extra spots can be used to give information on the structure of the sample, such as crystal size and perfection of orientation. In addition, multiple reflection can be employed in the study of very thin films which fail to give good diffraction patterns by direct methods. For convenience, a systematic procedure was developed for predicting the position and approximate intensity of extra spots. A consequence of multiple reflection is a shifting of the relative intensities of all diffraction spots which enhances the weak reflections at the expense of stronger ones. This could account for some of the reported anomalies in intensity given by electron diffraction.

A6. Oriented Overgrowth of Alkali Halides on Ag, Bi, Sb, and Fe. GERALD W. JOHNSON, *Brookhaven National Laboratory.**—Royer[1] gave as one condition for the occurrence of oriented overgrowth that the substances have the same type of binding. While the orientation of evaporated metallic films by cleaved ionic crystals is well known, there have been few reports of epitaxy of ionic crystals crystallized from solution on metals. Recently here several cases of this type of epitaxy have been found. Sodium chloride was completely oriented on silver films having {100} and {111} planes exposed. NaCl, KCl, and RbCl all were oriented on the {111} plane of Bi, while only NaCl was oriented by the {111} of Sb. On polycrystalline Ag, Bi, and Sb sodium chloride crystals were oriented by almost every grain. On polycrystalline Fe only CsCl was oriented and only for particular orientations of the Fe grains. From the number of cases of epitaxy noted here for polycrystalline aggregates clearly closeness of fit of lattice cannot be a strict criterion for oriented growth. The requirement that the type of binding of the two structures be the same must be relaxed. On polycrystalline substrates growth across boundaries often occurred without modification which suggested that the orientations are determined in the nucleation stage.

* Work performed under the auspices of the AEC.
[1] L. Royer, Bull. Soc. Franc. Mineral. 51, 7 (1928).

A7. Studies of Gas Adsorption on the (100) Face of a Copper Crystal by Low Speed Electron Diffraction.* ROBERT E. SCHLIER AND H. E. FARNSWORTH, *Brown University.*—The diffraction tube permits a wide variation of temperature of the crystal during observations. For a well-outgassed crystal part of the surface is covered with a monolayer of a double-spaced face-centered structure, the gas atoms being located directly above the copper atoms. A small part of the surface is covered with a single-spaced simple-cubic structure. When the pressure in the tube is increased for ten-minute intervals at room temperature, no adsorption of air, nitrogen, or CO_2 takes place until a critical pressure is reached. At this pressure adsorption occurs in a single-spaced simple-cubic structure and the double-spaced face-centered structure is no longer observed. The critical pressures are: 0.5μ for air, 10μ for N_2, and 1μ for CO_2. At the temperature of dry ice there is no critical pressure but adsorption is observed at a pressure as low as 0.001μ for all three gases. For air and nitrogen the adsorption occurs gradually in the same structure as is observed at room temperature. However, at the lower temperature, CO_2 does not adsorb in the single-spaced simple-cubic structure or any other structure which has been found.

* Assisted by ONR and Research Corporation of New York.

A8. The Photoelectric Work Function of a Silver Film on the (100) Face of a Silver Crystal.* EDWARD KELLY, H. E. FARNSWORTH, AND EDWARD N. CLARKE,** *Brown University.*—Doubly distilled silver is deposited by evaporation onto the (100) face of a silver crystal which has been outgassing in a high vacuum. The work function after deposition of the film is approximately 0.1 ev less than that of the crystal before deposit. Subsequent low temperature heating of the crystal and film at a temperature of 35° to 40°C causes the work function to increase to approximately its original value. These results are consistent with the view that the work function of a microcrystalline film is less than that of the bulk metal support and is a function of the type of support. Measurements are in progress with a low speed electron diffraction arrangement in the phototube to follow any changes in structure which occur.

* Assisted by ONR and Research Corporation of New York.
** Socony Vacuum predoctoral fellow.

A9. An Explanation for "Extra Levels" in Rare Earth Crystal Spectra. HARVEY WINSTON, *University of California, Berkeley.*—A consideration of just the unit cell has been shown sufficient to give vibrational selection rules in crystals; this turns out to be true also for electronic spectra in many cases. Bethe's classification of electronic levels in the site is a first step in obtaining the unit cell classification. It is shown that the number of crystalline levels arising from a free ion level J is not limited to $2J+1$. The results of Freed and Weissman on the visible spectrum of EuF_3 led them to assign J values of 0,

2, and 3 to the upper levels; the present treatment indicates that 0, 1, and 2 are possible, in accord with other work. These ideas also make plausible the observed doubling of lines in many rare earth salts, the "hyperfine structure" of Hellwege. The method is general; the ultraviolet spectrum of crystalline benzene can be explained by it. Experiments in progress are designed to compare the predicted and observed polarization properties.

A10. Structure and Growth Mechanism of Photolytic Silver in Silver Bromide. CHESTER R. BERRY AND ROBERT L. GRIFFITH, *Eastman Kodak Company.*—An investigation has been made by x-ray and electron diffraction of single crystals of pure silver bromide during the process of photolytic decomposition induced by irradiating the crystals with light from a mercury vapor lamp. The orientation of the silver determined from the x-ray diffraction patterns is quite different from the orientations determined from the electron diffraction patterns. It has been found that these differences are not due to any production of silver by the x-ray or electron beams, but correspond to differences in the silver orientations in the body and near the surface of the silver bromide crystals. Two different mechanisms of silver separation in the two regions of the crystals appear to account for the observed silver orientations. In the interior, the silver separation seems to depend on the existence of dislocations and the motion of cations, but near the surface it depends on the production of *F*-centers during the escape of bromine and on the subsequent aggregation of these *F*-centers, as described by Mitchell.[1]

[1] J. W. Mitchell, Phil. Mag. **40**, 249 (1949).

A11. Crystal Strain Energy in Solid Solutions. ROBERT L. SCOTT, *University of California, Los Angeles.*—Non-zero heats of formation of solid solutions result partially (for ionic crystals, almost entirely) from strain energy arising when particles of different sizes are built into a single lattice. A more general treatment than those of previous authors expresses the lattice energy as a sum of pair potentials $\epsilon(r-r_0)$ expanded about r_0, the interatomic distance corresponding to minimum energy. The leading term in each of these series (aside from ϵ_0) is $B(r-r_0)^2$; B can be deduced theoretically or calculated from compressibilities. By neglecting all but nearest neighbor interactions (except for coulomb terms) and by minimizing the energy with respect to the single parameter r, expressions for the strain energy and for the deviation from Vegard's law are obtained, the leading terms of which depend solely upon the B's, the concentrations, and the square of the difference of the lattice parameters. This strain energy is critical in determining solubilities and in depressing melting points of solid solutions. At room temperature a difference in lattice parameters of more than 4 percent for ionic crystals, 8 percent for molecular crystals, and 14 percent for metals precludes complete miscibility. Calculations indicate that inaccuracies resulting from the approximations of a single interatomic distance are significant.

A12. A Neutron Diffraction Study of Vitreous Silica. I. W. RUDERMAN, *Columbia University.*—The neutron transmission of a 9.59 g/cm² disk of transparent vitreous silica was obtained with the Columbia neutron velocity spectrometer at neutron wave-lengths up to 6.3A. Well-defined diffraction peaks were found at wave-lengths corresponding to interplanar spacings of 0.7, 1.1, 1.7, 1.9, 2.2, and 2.7A. Other peaks, which were not as well resolved, were also found. The peak at 1.1A is the most prominent. Previous careful x-ray studies by Warren[1] on vitreous silica have shown only a broad peak at 4.2A and three weak and poorly resolved peaks corresponding to shorter spacings. Front and back reflection x-ray photographs of samples cut from the specimen used for the neutron study showed only the well-known diffuse pattern. The relation of these results to the current theories of the amorphous state will be discussed.

[1] Warren, Krutter, and Morningstar, J. Am. Ceram. Soc., **19**, 202 (1936).

A13. Lattice Constants of Zinc Oxide. J. MCGANNON, R. HELLER, AND A. H. WEBER, *Saint Louis University.*—Since ZnO is a useful material for calibration of electron wavelengths in electron diffraction studies, a precision determination of the crystallographic cell edge a and the axial ratio c/a of powdered ZnO (Analytic Reagent), hexagonal structure, has been made by x-ray diffraction employing the Debye-Scherrer powder technique. A cylindrical (diam., 0.025 in.; length, 0.5 in.) specimen was used in a cylindrical camera of radius 57.296 mm and exposed to CuK radiation from a Picker x-ray unit for three hours. The resulting data was analyzed by the Cohen analytical method[1] which corrects for errors usually present. Values of Cu wave-lengths were taken as $\lambda K\alpha_1 = 1.54050$A and $\lambda K\alpha_2 = 1.54434$A.[2] Radii of Debye-Scherrer rings were measured to five significant figures and $\sin\theta$ was interpolated accurately from eight-place trigonometric tables.[3] Data from at least 25 films each containing 14 measurable lines in the back-reflection region will be presented. The precision and consistency of the results will be discussed.

[1] M. Cohen, Rev. Sci. Inst. **6**, 68 (1935).
[2] E. A. Wood, Phys. Rev. **72**, 430 (1947).
[3] *Tables of Sines and Cosines for Radian Arguments*, Fed. Works Proj. Ad., New York City (1940).

Beta-Emitters from Neutron to Neodymium

C1. Radioactive Decay of the Neutron. A. H. SNELL, F. PLEASONTON, AND R. V. MCCORD, *Oak Ridge National Laboratory.*—Coincidences have been observed between discharges in a beta-proportional counter placed near a neutron beam from the Oak Ridge Reactor and pulses from an electron multiplier placed approximately opposite the counter. A transverse electric field accelerates positive particles appearing in this region of the beam through 8 kv and focuses them upon the first plate of the multiplier. The coincidences depend upon the presence of this field. They do not appear when (1) the beam is interrupted by a boron or a cadmium shutter, and (2) the reactor is off and the detectors are actuated by Co^{60} gamma-rays. The coincidence rate is not increased (1) if H_2 gas is introduced into the tank; or (2) the apparatus is surrounded by Cd (thereby increasing the local neutron captures by a large factor). Thus the coincidences are associated with positive particles and slow neutrons, and not with gamma-rays. A slight delay in the counter channel is necessary to reveal them, time-of-flight considerations accordingly show that the particles are of roughly protonic mass. These observations are interpreted as showing that the events are beta-proton coincidences associated with neutron decay. The derived half-life lies in the range 10 to 30 minutes as previously reported.

C2. The Beta-Spectrum of He^6. VICTOR PEREZ-MENDEZ AND HAROLD BROWN, *Columbia University.*—The β-spectrum of He^6 has been observed in a semi-circular focusing spectrometer modified so as to permit study of a gaseous source. The He^6 is produced by the (n, α) reaction on finely divided beryllium powder in an internal cyclotron probe, using the fast neutrons produced by bombarding a beryllium plate with the deuterons from the 36″ Columbia cyclotron. The He^6 was pumped to the spectrometer using He^4 as a carrier gas. The equivalent thickness of the source was 0.1 mg/cm², and the thickness of the window separating it from the spectrometer was 1.8 mg/cm². The radius of curvature of the spectrometer was 13.6 cm, and the resolution employed about 5 percent. The spectrum obtained shows the allowed shape down to about 200 kev. Its end-point is established as (3.21 ± 0.015) Mev, which gives He^6 an $ft_{\frac{1}{2}}$ value of about 570.

C3. Beta-Spectrum of Be^{10}. L. FELDMAN AND C. S. WU, *Columbia University.*—In a Letter to the Editor,[1] we concluded that the β-ray spectrum of Be^{10} may well be a D_2 spectrum as predicted theoretically by Marshak.[2] Subsequent investigations in various laboratories[3] have substantiated this conclusion. Recently we received an electro-magnetically enriched Be^{10} source[4] through the Isotope Division of the Atomic Energy Commission. The average BeO source thickness used in this investigation was around 0.3–0.4 mg/cm², deposited on a thin formvar-polystyrene film (0.1 mg/cm²). The high transmission solenoid spectrometer (~8 percent transmission and 8 percent resolution) was used with thin Nylon window counter (0.6 mg/cm²) requiring no window correction on the measured data above 100 kev. Preliminary investigations of the β-spectrum of the enriched Be^{10} thus obtained follows a D_2 forbidden spectrum closely for three quarters of the whole spectrum. The upper energy limit is again 555±5 kev. The good agreement between the experimentally observed and the theoretically predicted Be^{10} spectrum is a good test of the present theory of β-decay.

[1] C. S. Wu and L. Feldman, Phys. Rev. **76**, 698 (1949).
[2] R. E. Marshak, Phys. Rev. **75**, 513 (1949).
[3] Fulbright and Milton, Phys. Rev. **76**, 1271 (1949); R. P. Bell group, private communication; D. J. Hughes group, private communication.
[4] Produced by Carbide and Carbon Chemical Corp., Y-12 Research Lab., Oak Ridge, Tennessee.

C4. The β-Spectrum of Be^{10}. D. E. ALBURGER, *Brookhaven National Laboratory,** AND D. J. HUGHES** AND C. EGGLER, *Argonne National Laboratory.*—The beta-ray spectrum of Be^{10} has been measured using a lens spectrometer. The source was formed by neutron irradiation of Be in the Hanford pile followed by careful chemical purification. 1200-fold electromagnetic enrichment to 0.3 percent Be^{10} was then performed at Oak Ridge under the direction of C. P. Keim. Enriched BeO was finally deposited in suspension over an area 1.5 cm in diameter on a 0.08 mg/cm² Nylon backing. Effects of the 0.4 mg/cm² source thickness and 17 percent resolution used because of the low Be^{10} activity were investigated by separate experiments on the Na^{22} positron spectrum which has about the same end point. Thin sources of Na^{22} run under the same conditions and corrected for resolution and 0.5 mg/cm² counter window thickness showed accurate linearity of the Kurie plot down to 100 kev. Sources ~0.4 mg/cm² of Na^{22} mixed in inert BeO gave linear Kurie plots down to 170 kev. The Kurie plot of Be^{10} with additional correction by Marshak's D_2 factor is linear from the 560±5 kev end point down to about 180 kev and has deviations below that point similar to the thick Na^{22} source results. This indicates that the Be^{10} beta-ray distribution follows the theoretical D_2 shape at least down to 100 kev.

* Research carried out under contract with the AEC.
** Now at Brookhaven National Laboratory.

C5. Beta-Spectrum of Na^{22}. P. A. MACKLIN, L. J. LIDOFSKY, AND C. S. WU, *Columbia University.*—Na^{22} is a positron emitter with a fairly long half-life. From its ft value, it is classified as twice forbidden. Its β-spectrum was investigated by the M.I.T. group[1] and appeared to be allowed from upper energy limit down to 220 kev. Below 220 kev there were no published results on its distribution. Recently the Na^{22} spectrum was reinvestigated in our solenoidal spectrometer (8 percent transmission and 4 percent resolution). The source, whose average thickness was less than 50 μg/cm², was mounted on a 10 μg/cm² backing. The Fermi plot appeared linear from the upper energy limit of 542±5 kev down to around 25 kev. The deviation below 25 kev could be very well accounted for by the source thickness and local variations in the source thickness. The upper energy limit was consistent for several runs with different resolution widths, but is considerably lower than the previously reported value of 575 kev.[1] Compton electrons from the annihilation radiation and from the 1.3 Mev γ-rays were also investigated.

[1] Good, Peaslee, and Deutsch, Phys. Rev. **69**, 313 (1946).

C6. Beta-Spectrum of S^{35}. LEONARD GROSS*,** AND DONALD R. HAMILTON, *Princeton University.****—A new type of electrostatic beta-ray spectrograph has been constructed for the measurement of low energy spectra. This electrostatic spectrograph is in the form of a hemisphere in which electrons move radially outward in the direction of a retarding electric field. The prime advantage of this apparatus lies in the high resolving power obtainable, accompanying sufficient intensity to permit the replacement of conventional GM counter detection in favor of d.c. current detection. The beta-spectrum of S^{35} in the region below 30 kilovolts has been investigated. The S^{35} spectrum shape was found to be in agreement with the predictions of the Fermi theory even in this extremely low energy region. With a source less than 0.5 microgram/cm² thick (chiefly calcium sulfate) on a 3.1 microgram/cm² collodion backing, the Fermi plot was a straight line down to 6 kev. The deviation below 6 kev is attributed to backscattering and absorption in the source and backing.

* This work was performed under the tenure of an AEC predoctora fellowship.
** Presently at Hughes Aircraft Co., Culver City, California.
***Supported in part by the ONR.

C7. Disintegration of Zinc 65 by Positron Emission.* RUTH A. COHN AND J. D. KURBATOV, *The Ohio State University.*—Previously it has been reported that 2.2 percent of zinc 65 decays by emission of 320 kev positrons to the ground state of copper 65.[1] In the present study of Zn^{65}, evidence was obtained for the existence of converted photons of ~210 kev in coincidence with 320 kev positrons. The coincidences were obtained: (1) for positrons and gamma-rays of ~210 kev, (2) for positrons and electrons of ~200 kev, (3) for ~210 kev gamma-rays and annihilation radiation. The conversion ratio N_e/N_γ was estimated from coincidence measurements to be ~0.1. Independently, the presence of electrons of ~200 kev was verified by observations in a cloud chamber. It is concluded that Zn^{65} decays by positron emission to an excited state of Cu^{65} which is about 210 kev above the ground state.

* Assisted by a grant of The Graduate School of The Ohio State University.
[1] W. M. Good and W. C. Peacock, Phys. Rev. **69**, 680 (1946).

C8. Bromine 80 and Its Isomers. I. J. LIDOFSKY, P. A. MACKLIN, AND C. S. WU, *Columbia University.*—Br^{80}, a classic case in the history of isomerism,[1] emits two soft gamma-rays of energies 49 and 37 kev. The 49 kev is probably completely internally converted[2] and is assigned as magnetic octupole radiation because of the half-life and the ratio of K to L internal conversion coefficients as determined by the absorption method.[3] We have recently investigated the internal conversion electron lines and the continuous spectra of Br^{80} and Br^{82} in the Columbia solenoidal spectrometer. The energy found for the two gamma-rays is 36.3 kev and 48.1 kev. From the conversion coefficients obtained, we substantiate the assignment of the 48.1 kev gamma-ray as magnetic octupole but strongly suggest that the 36.3 kev gamma-ray is electric dipole. The upper energy limit of the Br^{80} spectrum is 1.99 ±0.01 Mev while exhibiting the allowed shape.

[1] Segrè and Helmholz, Rev. Mod. Phys. **21**, 291 (1949).
[2] Grindberg and Roussinow, Phys. Rev. **58**, 181 (1940).
[3] Berthelot, Ann. de physique **19**, 219 (1944).

C9. Radioactive Y^{87} and Sr^{87}. B. E. ROBERTSON, W. E. SCOTT, AND M. L. POOL, *The Ohio State University.*—The activities of the Y^{87} isomer have been investigated by cyclotron bombardments of strontium targets electromagnetically enriched in the various strontium isotopes. The 14-hour and 3.3-day activities previously ascribed to Y^{87} have been produced by alpha-bombardment of an enriched Sr^{84} sample, confirming this mass assignment as the result of the reaction $Sr^{84}(\alpha, p)Y^{87}$.

In agreement with previous reports that the 3.3-day activity decays by K-capture to 2.7-hour Sr^{87}, a Sr $K\alpha$ x-ray line has been obtained on a curved-crystal spectrograph film exposed to samples of the 3.3-day yttrium. In addition to the well-known 0.37 Mev gamma-ray of the 2.7-hour strontium, a higher energy gamma-ray of 0.5 Mev energy has been found to be associated with this activity as shown by a β-ray spectrogram of its conversion electrons and lead absorption measurements. The characteristic radiations of the 14-hour yttrium activity are observed to be 1.1 Mev positrons associated with K-capture decay to 2.7-hour Sr^{87}. A small amount of 0.7 Mev positron activity is found associated with the 3.3-day activity. It is concluded that the 14-hour and 3.3-day activities of Y^{87} decay independently to 2.7-hour Sr^{87} and that the 14-hour activity has the higher energy level of this isomeric pair.

C10. Disintegration of Cesium 131 and Metastable State of Xenon 131.* LIN-SHENG CHENG AND J. D. KURBATOV, *The Ohio State University.*—The metastable state of Xe^{131} has been observed by several authors[1,2] in disintegration studies of I^{131}. In the present work, this excited state of Xe^{131} was identified as a product of disintegration of Cs^{131}, the latter being produced by radioactive Ba^{131}. Cs^{131} of very high specific activity was separated from Ba^{131} without carrier. It was established that Cs^{131} decays mainly by orbital electron capture to the ground state of Xe^{131} and by a small fraction to the excited state of Xe^{131}. The metastable state of Xe^{131} was identified by converted 163 kev photons and by $T_{\frac{1}{2}}$ equal to $11\frac{1}{2}$ days. The conversion ratio N_K/N_L was found experimentally to be 4.5. Independently, conversion coefficients of the 163 kev photon of Xe^{131*} were calculated for different changes in angular momentum of electric and magnetic 2^l-pole radiations. The closest agreement between experimental data and the calculations was obtained for a magnetic radiation with a change in angular momentum equal to four and $N\beta_K{}^l+N\beta_L{}^l/N_\gamma = 19.5$. $T_{\frac{1}{2}}$ of Xe^{131*} was measured using separated Xe gas.

* Assisted by a grant of the Alumni Development Fund of The Ohio State University.
[1] Brosi, DeWitt, and Zeldes, Phys. Rev. 75, 1615 (1949).
[2] J. M. Cork, Phys. Rev. 75, 1621 (1949).

C11. Radiations from the 33-Hour Cerium (143).* E. SHAPIRO AND C. E. MANDEVILLE, *Bartol Research Foundation.*—The 33-hour activity was induced in CeO_2 irradiated by slow neutrons in the Oak Ridge pile. In order to study Ce^{143} free of its 13-day praseodymium daughter element, chemical separations were carried out repeatedly during the course of the investigation. The beta-rays were found to have a maximum energy of about 1.1 Mev. Three gamma-ray components were found in lead absorption curves having energies of 0.87 Mev, 0.20 Mev, and 40 kev. All of these gamma-rays were observed to decay with the 33-hour period. A coincidence absorption curve gave 0.89 Mev as the maximum gamma-ray energy. The beta-gamma coincidence rate seemed also to decay with the 33-hour period and was within relatively poor statistical accuracy, independent of the beta-ray energy. The magnitude of the beta-gamma coincidence rate showed that on the average, each beta-ray is accompanied by 0.18 Mev of gamma-ray energy. Very few beta-rays are coupled with the hard gamma-ray of energy 0.89 Mev.

* Assisted by the Joint Program of the ONR and the AEC.

C12. Some Characteristics of the 11-Day Neodymium.* C. E. MANDEVILLE, *Bartol Research Foundation.*—The 11-day activity of Nd^{147} was induced in pure Nd_2O_3 irradiated by slow neutrons in the Oak Ridge pile. Two beta-ray groups, having end points at 0.17 Mev and 0.78 Mev and an intensity ratio of 1:2, were resolved by aluminum absorption, and a lead absorption curve of the quantum radiations showed that two gamma-rays are present, having energies of 35 kev and 0.58 Mev. The softer gamma-ray is about fourttieen mes more intense than the harder one at 0.58 Mev. The beta-gamma-coincidence rate of Nd^{147} was observed to decrease from an extrapolated value of 0.21×10^{-3} coincidence per beta-ray at zero absorber thickness to 0.13×10^{-3} coincidence per beta-ray at an aluminum absorber thickness of 25 mg/cm², remaining constant thereafter. These data show that both beta-ray groups are coupled with gamma-radiation. No beta-beta-coincidences were observed in the decay of Nd^{147}.

* Assisted by the Joint Program of the ONR and the AEC

Mesons, Cosmic-Ray Stars, and Bursts

D1. The Detection of Photo-Mesons and the Relative Cross Section of Carbon and Hydrogen for their Production. J. STEINBERGER AND A. S. BISHOP, *University of California, Berkeley.*—The positive mesons produced in the photon beam of the synchrotron are detected in scintillation counters by means of the delayed coincidence technique. A meson is counted if it stops in the last crystal of a telescope and if its decay electron is detected in the same crystal at a time coincident with one of several delayed gates started by the original meson pulse. The relative counting rates in the delay channels measure the half-life of the μ-meson, providing a test on the reliability of the method. The $\pi^+\rightarrow\mu^+$ decay, which precedes the $\mu^+\rightarrow e^+$ decay, is not resolved in this apparatus. In a first application of this method we have measured the relative cross section for the production of photomesons in carbon and in hydrogen at 90° in the laboratory system as a function of the meson range. The hydrogen results are obtained from a carbon-paraffin difference. The photons have a bremsstrahlung energy spectrum with a maximum of about 300 Mev. About 4000 counts were obtained with a $\mu\rightarrow e$ lifetime of 2.1 ± 0.1 μsec. The total cross section at 90° *per proton* is greater for hydrogen than for carbon.

D2. Magnetic Deflection of Cosmic-Ray Mesons Using Nuclear Plates.* IAN BARBOUR,** *University of Chicago.*—A method has been described[1] in which the mass and charge sign of mesons are investigated by exposing two nuclear plates with an air gap separating their parallel emulsion surfaces in a perpendicular magnetic field; the radius of magnetic curvature of the trajectory in the air gap can be computed from the orientation of the tracks left by a given particle in the two emulsions. Preliminary results reported[2] have been extended by a flight for 6 hours at 90,000 ft., using our 65-lb. permanent magnet, field strength 12,800 gauss. Analysis of tracks has been completed, the charge signs determined, and values for the mass computed for each case. Probable errors will be discussed, and the best mass value for each type of meson determined by a least-squares fit of curves of constant mass on a range-curvature plot.

* Assisted by the Joint Program of the ONR and the AEC.
** Now at Kalamazoo College, Kalamazoo, Michigan.
[1] C. F. Powell, Nature 161, 473 (1948); I. Barbour, Phys. Rev. 74, 507 (1948).
[2] I. Barbour, Phys. Rev. 76, 320 (1949).

D3. Semi-Automatic Device for Analyzing Events in Nuclear Emulsions. ROBERT RUDIN, MARIETTA BLAU, AND SEYMOUR LINDENBAUM, *Columbia University.*—The apparatus is built around a microscope with a motor-driven stage, moved by selsynmotors either in the X or Y direction, or by a steering device in any desired direction, at variable speed. The track is observed through an eyepiece and simultaneously projected onto a small slot before a photo-multiplier, the output of which is recorded on a chart moving with a speed equal to 2000 times the stage speed. On the same chart, the vertical component of motion (the magnified manual focusing movement of the observer) and the angular direction of stage travel are recorded. If only the geometric properties of the track are

wanted (scattering or angular relationship of tracks in stars), the X-Y-steering is used and 3 coordinates of a series of points are recorded simultaneously and used for calculations. In cases where the accumulation of grains is too heavy to be analyzed (heavy tracks, dense shower cores), direct photometric comparison of track against background is used. Technical details and measuring results are given.

D4. Investigation of Cosmic-Ray Stars and Slow Protons with a Silver Chloride Crystal. FREDERICK C. BROWN AND J. C. STREET,* *Harvard University.*—A disk of silver chloride six cm in diameter and one cm thick was cut from a crystal grown from the melt. It was operated as an ionization detector well below saturation where it has been shown that the height of conduction pulses is very nearly proportional to the energy released over a wide range of energy. Pulse distributions at elevation 11,200 feet and at sea level were recorded for two types of events: (1) a simple recording of pulses from the crystal above a discriminator setting of 900μ volts ~30 Mev, (2) a similar recording but a counter telescope required the presence of a single ionizing particle above the crystal of energy sufficient to penetrate one cm of lead. Additional counters indicated that in about ten percent of the events of type (2) a single particle is present below ten cm of lead under the crystal. Analysis shows that protons stopping in and just below the crystal, as well as stars, contribute to the rates up to ~60 Mev, whereas larger pulses are due mainly to stars. With certain assumptions it is possible to calculate the relative production of stars by protons and neutrons. The variation of rates with altitude will be discussed.

* Assisted by the Joint Program of the ONR and the AEC.

D5. Disintegration of Nuclei by π^- Mesons.* W. CHESTON AND L. GOLDFARB, *University of Rochester.*—Kodak nuclear emulsions were exposed to the π-meson beam of the 130-in. Rochester cyclotron by S. W. Barnes. The energy spectrum of protons emitted in the disintegration of the nuclei which absorbed the π^- mesons was obtained by determining the specific energy loss and/or residual range of these protons. The former was obtained by measuring the grain densities of meson and proton tracks of known residual range. 10±2 percent of the mesons give rise to protons with energies $\geqslant$30 Mev.[1] One of the emitted protons was found to have an energy greater than 100 Mev. 35 percent of the mesons stop without producing stars; 45 percent of these give rise to recoil of the absorbing nucleus. The proton energy spectrum, star size distribution, and nuclear recoils will be discussed; comparisons will be made with the results of other observers[2] and with theory.[3] To date, 429 meson events have been investigated; this work is being extended.

* This work was assisted by the Joint Program of the ONR and the AEC.
[1] This is four times the number observed by Adelman (Abstract for Stanford Meeting of the Am. Phys. Soc.).
[2] D. H. Perkins, Phil. Mag. No. 305, June, 1949.
[3] S. Tamor, Phys. Rev. 77, 42 (1950).

D6. Cosmic-Ray Phenomena in Extremely Thick Emulsions.[1] PIERRE DEMERS, *Université de Montréal.*—Baseless sheets 150μ thick of author's emulsion No. 2 modified,[2] have been prepared, stacked together forming a continuously sensitive homogeneous mass. Sheets are separated for processing and examination. Such stacks 4 to 12 mm thick (*6.4 to 19.2* m *air*), were irradiated 2 hours at 25–35-km altitude on 14 VII 49. Some advantages follow: homogeneous medium; identity, energy and history of all tracks single or in stars. The complete tracks for 10–14 branched stars have been followed in 4–6 sheets, sometimes a second star is formed in another sheet at the end of a long branch. δ-rays along α-tracks 15 mv and more are visible thanks to sensitivity, and very small size of the grains, which also reveals the existence of two branched stars made of a long track (α, p, μ) and a very short recoil, making up 10–20 percent of all stars; these stars may be expected to be more abundant at lower levels. A grant from NRC is gratefully acknowledged.

[1] Ann. Acfas (19) (to be published).
[2] Science 110, 380 (1949).

D7. The Dependance of High Altitude Star and Meson Production Rates on Absorbers. MARIETTA BLAU, JOHN NAFE, AND HERBERT BRAMSON, *Columbia University.*—Photographic emulsions (mainly Ilford C_2 emulsions, 200 microns) shielded with lead and copper have been exposed for 3 hours at an altitude of 93,000 feet in Minnesota ($\lambda = 55°$N) in order to investigate the effect of absorbing material upon the rate of star and meson production. The plates were placed horizontally in cut out sections of truncated pyramids of copper and lead so that the absorber thicknesses were 11.3, 22.6 g/cm^2 in the case of copper and 11.3, 22.6, and 33.9 g/cm^2 in the case of lead. Furthermore one set of horizontal plates were placed in about 4 cm distance of the copper pyramid resting on a vertically placed box of plates. Comparing star and meson production in the different sets, distinct transition effects have been observed. The result will be discussed and compared with those of other authors.

D8. Statistical Considerations Concerning the Mass of the μ-Meson. O. HALPERN AND H. HALL, *University of Southern California.*—Recent cloud-chamber observations[1] of 75μ-meson decay processes gave a wide energy distribution of the decay-electrons; the authors[1] inferred from their data a value of 217±4 electron masses for the mass of the μ-meson assuming the other decay products to be neutrinos. In this determination the mass of the μ-meson was taken to be twice the maximum observed electron-energy. A more accurate evaluation assuming various distribution functions[2] for the energy spectrum of the decay electron leads to an increase in the value for the mass of the μ-meson of about 2½ percent. If the electron-spectrum should approach its maximum value with zero slope, an assumption which is made unlikely by the data published, then the statistical correction would become very much larger.

[1] Leighton, Anderson, and Seriff, Phys. Rev. 75, 1432 (1949).
[2] Cf., e.g., J. Tiomno, Phys. Rev. 76, 856 (1949).

D9. On the Nuclear Collision Path Length for π-Mesons. W. E. HAZEN, *University of Michigan.*—If the nuclear collision cross section for high-energy π-mesons is about the geometrical cross section, we should expect a difference between the μ-meson and the π-meson spectra above 10^{11} ev. Greisen[1] has suggested that the underground depth-intensity data are most readily explained in terms of competition between $\pi-\mu$-decay and π-nuclear collisions. Another consequence of the proposed decay-collision competition is a variation in the μ-meson spectrum with zenith angle and a consequent dependence of underground intensity (below some critical depth) not only on earth absorber thickness but also on zenith angle. The earth absorber thickness at which a zenith-angle dependence first appears determines the energy where nuclear collisions compete with decay in the upper atmosphere. Thence, we could proceed to calculate unambiguously the collision path length. Existing data show that the underground intensity depends only on the thickness of earth absorber to thicknesses of 1100-m w.e. Therefore, nuclear collisions do not compete with decay for π-meson energies $<3.5\times10^{11}$ ev and the nuclear-collision path length for high energy π-mesons is greater than 150 g/cm^2 of air.

[1] K. Greisen, Phys. Rev. 73, 521 (1948).

D10. Properties of Cosmic Rays under 1100 Ft. of Earth. C. A. RANDALL, *University of Michigan.*—In a salt mine at 707-m water equivalent the angular distributions and absolute

vertical intensities of the hard component and of combined soft and hard have been determined from G-M counter measurements. Absorption curves in Pb and C were obtained. The ratio of soft to hard component was measured; its dependence upon angular distribution and upon the least energy which can penetrate the counters and absorber was taken into account. A range-energy relation for mesons of energy up to 5×10^3 Bev was calculated; this was done by using average meson energy loss due to ionization calculated by Halpern and Hall, calculating average meson energy loss due to radiative collisions from the Christy and Kasaka bremsstrahlung cross sections, and normalizing to Smith's calculations at 100 Mev. By means of this range-energy relation the meson energy spectrum in the mine was deduced. The spectrum was used to calculate soft-to-hard ratio and to estimate a tentative extension of the meson spectrum at sea-level to 5×10^3 Bev. Results are consistent with the assumptions: that only μ-mesons carry cosmic-ray energy to 707-m w.e., and that the soft component consists of electron and photon secondaries, existing in their familiar cascade symbiotic relation, and arising from knock-on and bremsstrahlung processes.

D11. A Fluctuation of the Nuclear Disintegration Rate in Photographic Emulsions Exposed in the Stratosphere Following a Solar Flare.* J. J. LORD AND MARCEL SCHEIN, *University of Chicago.*—Photographic plates exposed at 95,000 ft. in the stratosphere by free balloons approximately 22 hours following the large solar flare of May 10, 1949,[1] showed an increase of approximately 50 percent in the rate of production of stars having less than 10 prongs. The frequency of occurrence of heavy nuclei during the balloon flight on May 10th and during a flight on the night of November 30th will be discussed.

* Assisted by the Joint Program of the ONR and the AEC.
[1] A. H. Shapley and R. M. Davis, Jr., Science **110**, 159 (1949).

D12. Large Cosmic-Ray Bursts under Thick Absorbers at 11,500 Feet Elevation.* THOMAS G. STINCHCOMB, *University of Chicago.*—Using a Carnegie model C meter, experiments on bursts of more than 200 particles under a minimum spherical absorber of 122 g/cm² lead have been carried out at Climax, Colorado. Counters to detect air showers energetic enough to penetrate this minimum absorber indicate that only 3 percent of these bursts are in coincidence with such air showers. For bursts of more than 2000 particles the percentage is 13 percent. Subtracting these bursts due to air showers, one finds a power law for the integral frequency *versus* size distribution with an exponent 1.99 ± 0.09 having no variation with burst size detectable within error indicated. Additional large spherical absorbers of 181 g/cm² lead and 135 g/cm² iron indicate that the mean free paths of this burst producing radiation are 440 ± 65 g/cm² lead and 220 ± 25 g/cm² iron. Varying the area covered by an additional plane absorber of 129 g/cm² iron above the minimum spherical lead absorber indicates that within experimental error of 6 percent no radiation enters at zenith angles larger than 35 degrees. If this radiation were nucleonic in origin with a mean free path in air of 140 g/cm², one would expect 24 percent of the radiation at zenith angles more than 35 degrees.

* Assisted by the Joint Program of the ONR and the AEC.

D13. Cosmic-Ray Bursts at High Altitudes.* G. N. WHYTE, *Princeton University.*—A series of thin-walled, spherical ionization chambers of the type developed by Coor[1] have been flown to altitudes exceeding 90,000 ft. at geomagnetic latitudes 0°, 29°, and 35°. The frequency of cosmic-ray bursts due to the formation of more than 10^5 ion pairs in the chamber has been recorded as a function of altitude at these latitudes. Preliminary considerations indicate that the effects of primary and secondary rays in producing bursts can be separated. The interpretation of the altitude dependence of the burst rate will be discussed in terms of the primary flux of heavy nuclei and protons and the multiplication of the proton and neutron components by nuclear disruptions.

* Assisted by the Joint Program of the ONR and the AEC.
[1] Thomas Coor, Princeton University thesis (1948).

Theoretical Physics, I

E1. "Bremsstrahlung" in High Energy Nucleon-Nucleon Collisions. ALBERT SIMON, *University of Rochester.*—The "bremsstrahlung" accompanying high energy nucleon-nucleon collisions has been calculated by Ashkin and Marshak[1] in analogy with coulombic bremsstrahlung. This approach, using an empirically determined nuclear potential, necessarily omits the "exchange" terms which arise in the appropriate third-order field-theoretic calculation. The phenomenological treatment also predicts a photon spectrum of the form $(E_0-k)^{\frac{1}{2}}(dk/k)$, where E_0 and k are the energies of the nucleon and photon, respectively, in the cm system. We have calculated nucleonic bremsstrahlung in a field-theoretic way using scalar theory with scalar coupling and pseudoscalar theory with pseudoscalar coupling. The results for the spectra, making the same approximation as in (1), are: $\sigma_s(k)dk\sim(E_0-k)^{\frac{1}{2}}(dk/k)$; $\sigma_p(k)dk\sim(E_0-k)^{\frac{1}{2}}kdk$. It also turns out that the "exchange" terms are larger than the "ordinary" terms. In particular, for $E_0=125$ Mev, the "exchange" terms contribute 1–2 times as much as the "ordinary" terms (over the range $k=E_0/2$ to E_0) for both scalar and pseudoscalar theories. The bearing of these results on the Berkeley experiments[2] will be discussed. This work was assisted by the Joint Program of ONR and AEC.

[1] J. Ashkin and R. E. Marshak, Phys. Rev. **76**, 58 (1949).
[2] Bjorklund, Moyer, and York, Phys. Rev. (in press).

E2. Deuteron Photo-Effect at High Energies. L. I. SCHIFF, *Stanford University.*—The results described at the Stanford meeting of the American Physical Society (December, 1949, Abstract B8) are being applied to the computation of the cross section for photoelectric disintegration of the deuteron by high energy gamma-rays. The object of the calculation is to provide a basis for distinguishing between the two forms of neutron-proton interaction (Yukawa and exponential) that appear to be most successful in explaining the high energy neutron-proton scattering.[1] These interactions are closely simulated by potentials for which the ground-state deuteron wave function can be found in a convenient analytic form. Electric quadrupole as well as electric dipole transitions are considered, as are the effects of nucleon interaction on the final states.

[1] R. S. Christian and E. W. Hart (private communication).

E3. Multiple Scattering in an Infinite Medium. H. W. LEWIS, *University of California, Berkeley.*—The integro-differential diffusion equation which describes the multiple scattering of a particle in an infinite medium is studied without the usual small angle approximation. The angular distribution irrespective of position is found exactly as a series of Legendre polynomials, and as a function of track length, taking into account energy loss. This series converges slowly when small angle scattering is important, in which case the solution recently obtained by Snyder and Scott is applicable, but converges rapidly otherwise. Exact closed expressions are also derived for the moments of the longitudinal and radial distributions, and for various correlation functions of position and direction of the scattered particle.

E4. Phase Shifts in *p-d* Scattering and Exchange Forces. J. L. GAMMEL, *Cornell University.*—Verde[1] gives rigorous integral formulas for the phase shifts (δ's) in *n-d* scattering. In this paper his method is extended to *p-d* scattering. Tensor forces are neglected, which is satisfactory below 10 Mev with the

usual tensor forces.[2] It is found that the Coulomb barrier decreases the p-d δ's compared to the n-d δ's by a factor which is about 0.8, but which depends on L and the energy. The integral formulas are used to formulate a Born approximation for the P and D δ's. Calculation with a nuclear potential $(W+BP_\sigma+HP_\tau-MP_x)U(r)$ where P_σ, P_τ, and P_x are spin, charge, and space exchange operators, respectively, taken with the experimental[3] δ's shows that B and H must be small, in agreement with the high energy scattering data. The results are remarkably independent of W and M, however. An interpretation of the observed P and D phases is given.

[1] Mario Verde, Helv. Phys. Acta 22, 339 (1949).
[2] Roy Thomas, Phys. Rev. 76, 1002 (1949).
[3] Sherr, Blair, Kratz, Bailey, and Taschek, Phys. Rev. 72, 662 (1947); C. L. Critchfield, Phys. Rev. 73, 1 (1948).

E5. Some Calculations Concerning Neutron-Proton Scattering with Tensor Forces.* L. Biedenharn and J. M. Blatt, *M. I. T.*—The Schwinger variational method gives an expansion of $k\cot\delta$ in terms of the energy,[1,2] which is general enough to include the presence of tensor forces. Previous analysis of the available scattering data[2] has been made on the assumption that tensor force effects are negligible. We have obtained values of the first three terms of the above expansion for the square well and Yukawa well shapes, for relevant ranges and depths, consistent with a binding energy of 2.237 Mev, a quadrupole moment of 2.73×10^{-27} cm^2 and a "percentage D-state" of 2–6 percent. The tensor force is found to cause no significant change in the results given in reference (2).

* This work has been supported in part by the ONR and the AEC.
[1] J. M. Blatt, Phys. Rev. 74, 92 (1948).
[2] J. M. Blatt and J. D. Jackson, Phys. Rev. 76, 18 (1949).

E6. The Range of Tensor Forces and the Theory of H^3.* Robert L. Pease and Herman Feshbach, *M. I. T.*—The theoretical evaluation of the binding of H^3 is very sensitive to the range of tensor forces. We have calculated this binding energy for the potential

$$V(r_{12})=-[(1-g/2+(g/2)\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)V_c f(r_{12}/r_c)+S_{12}V_T f(r_{12}/r_t)].$$

For f we have employed the Yukawa well: the range of central forces r_c was chosen to equal that obtained from proton-proton scattering; the range of tensor forces r_t was varied. The other constants were determined from two-body data. A variational method was employed in which the S state and the three possible D states were included. It was found that all of the D states made important contributions. The ratio of the tensor to central range is close to 1.4. The corresponding equivalent triplet range for n-p scattering is 1.74×10^{-13} cm, in excellent agreement with the most recent determinations.[1]

* Supported in part by the ONR and the AEC.
[1] Hughes, Ringo, and Burgy (in press).

E7. On the Phenomenological Theory of Exchange Moments. R. K. Osborn and L. L. Foldy, *Case Institute of Technology.*—As first pointed out by Siegert, the existence of exchange forces in nuclei implies the existence of accompanying exchange currents. Sachs has calculated an expression for these, by making the Hamiltonian containing exchange potentials gauge invariant, and applied it to the calculations of exchange magnetic moments in H^3 and He^3. The Hamiltonian obtained by Sachs is not the most general admissible one. More generally the exchange current density is found to depend on a vector function whose irrotational part is completely determined by gauge invariance but whose solenoidal part is arbitrary except for the requirements (following from conditions of translational invariance and symmetry in all nucleons on the Hamiltonian) that it be translationally invariant and antisymmetric under the exchange of the spin and space coordinates of each pair of nucleons. In the resultant exchange moments, the irrotational part leads to the same expression as obtained by Sachs, while the solenoidal term contribution contains the spin operators of the nucleons in particular combinations together with arbitrary functions of the nucleon separation. Villars' exchange moment expression, as obtained from meson theory, is included as a special case and hence the exchange contributions to the moments of H^3 and He^3 are explicable on a phenomenological basis, contrary to the results obtained in Sach's special case. This work has been supported by the AEC.

E8. The Cross Section of $(n, 2n)$ Reactions Near the Threshold.* George Snow, *Brookhaven National Laboratory.*—The energy dependence of the cross section of $(n, 2n)$ reactions near the threshold is derived using the nuclear dispersion theory formalism.[1] Configuration space is divided into three regions: An internal region, corresponding to the compound nucleus, an intermediate region, in which one neutron and the remaining nucleus are sufficiently far apart so that their nuclear interaction vanishes, and an external region, in which two neutrons do not interact with the residual nucleus. Boundary conditions are derived for the stationary wave function in the external region. An approximation to these boundary conditions allows the determination of the external region wave function, whose asymptotic form yields the result $\sigma(n, 2n)\cong(E-E_t)^2$, where E is the incident neutron energy in the center of mass system, and E_t is the $(n, 2n)$ threshold energy. The neutron-neutron interaction in the external region does not alter the energy dependence of $\sigma(n, 2n)$ near the threshold. This derivation is valid for an energy range too small to allow comparison between theory and experiment. A crude perturbation theory argument yields the same result for $\sigma(n, 2n)$.

* Research carried out at Brookhaven National Laboratory, under the auspices of the AEC.
[1] E. P. Wigner and L. Eisenbud, Phys. Rev. 72, 29 (1947).

E9. Variational Methods and Cross-Section Theorem for Non-Conservative Collisions. Melvin Lax, *Syracuse University.*—Recent applications of variational methods to transition problems have been generalized to include the possibility of absorption (capture). Let ϕ_a and ψ_a be the unperturbed and perturbed states and V be the interaction potential inducing transitions. The exact transition probability from state ϕ_a to state ϕ_b may be obtained by replacing the Born approximation matrix element $(\phi_b, V\phi_a)$ by $T_{ba}=(\phi_b, V\psi_a)$. A variational expression is found for the transition amplitude, T_{ba}, in terms of ψ_b, ψ_a and corresponding solutions of a suitable adjoint equation. The latter must be introduced because of the non-hermitian nature of the operators involved in an absorption problem. Collisions induced by hermitian operators obey the known theorem that the total cross section is proportional to the imaginary part of T_{aa}, the scattering amplitude in the forward direction. This theorem, equivalent to the unitary nature of the Heisenberg S matrix, expresses the conservation of probability. (If only one form of particle is involved, the conservation of particles.) For non-conservative collisions we show that the cross-section theorem remains valid providing the total cross section is now interpreted to include the capture cross section. A check on the accuracy of the variational method is given in an adjoining abstract by A. Levitas.

E10. Statistical Theory and the Angular Distribution of Nuclear Reactions. L. Wolfenstein, *Carnegie Institute of Technology.*—Nuclear reactions involving high energy particles are commonly treated on the assumption that a compound nucleus is formed in which the original projectile loses its identity. It should not be expected, however, that the resultant angular distribution is isotropic. Conservation principles require that the angular momentum of the compound nucleus be polarized, because of the polarization of the incident

orbital angular momentum. This polarization displays itself partly in the polarization of the outgoing nuclei at certain angles and partly as an anisotropy in their angular distribution. As a simple example, a single outgoing neutron group from a collision of two spin zero particles is considered. It is assumed that many compound nuclear states are involved and that the transition probabilities to the final states can be determined from statistical concepts. If orbital angular momenta up to $4\hbar$ are effective and if the residual nucleus has a spin $\frac{1}{2}$ the forward intensity is calculated to be five times that at 90°. The angular distribution is characteristically symmetrical about 90°. For larger residual nuclear spins the distribution is more isotropic. Applications to (α, n) and (d, n) reactions will be discussed.

Cosmic Rays

G1. On the Extraordinary Increase of Cosmic-Ray Intensity on November 19, 1949. SCOTT E. FORBUSH, *Carnegie Institution of Washington*, AND THOMAS B. STINCHCOMB AND MARCEL SCHEIN, *University of Chicago*.—Beginning about $10^h 45^m$ GMT on November 19, 1949, there occurred the largest increase in cosmic-ray intensity yet observed. By 11^h GMT the ionization at sea level under 12 cm Pb was 43 percent above normal at Cheltenham (geomagnetic latitude $\Phi = 50°$N) and at Godhaven ($\Phi = 80°$N). At Huancayo ($\Phi = 0°$, elevation 11,000 ft.) no increase was detected. At Climax (elevation 11,500 ft.) the ionization under similar shielding increased to about 180 percent above normal in 15 min. and remained at least 100 percent above normal for about an hour, decreasing exponential-wise to near normal in about seven hours. The absolute magnitude of the increase at Climax was about ten times greater than at Cheltenham. This large increase with altitude appears to rule out mesons or soft component, leaving relatively low energy protons, or neutrons, or possibly some unknown radiation, to account for the effect.

G2. On a Difference-Equation Method for Solving Diffusion Equations in Cosmic-Ray Shower Theory and Similar Problems. W. T. SCOTT, *Smith College*.—The equations dealt with may be written $\partial F/\partial t - \beta \partial F/\partial E = L_E F(E, t)$, where L_E is a linear, integral operator involving cross sections for elementary physical processes, and β is a constant. The method requires that these cross sections be homogeneous functions of the energy, as in the case of high energy cascades. Hence, a combined Laplace-Mellin transform can be usefully employed: $g(p, s) = \int_0^\infty e^{-st} dt \int_0^\infty (E/\beta)^p F(E, t) dE$. Applying these transforms to the original equation, we obtain a difference equation for g: $pg(p-1, s) + V_s(p) g(p) = \varphi(p)$, where $\varphi(p)$ is the Mellin transform of the initial condition. Using the behavior of g as $p \to \infty$, the difference equation may be solved by iteration. The resulting infinite series may be written as a contour integral through the use of an infinite product representation of the nth term, that can be generalized for non-integral values of n.[1] The final result is an exact solution of the original equation, satisfying the boundary conditions exactly, in the form of a triple complex integral. Suitable evaluations by use of the calculus of residues, combined with the saddle-point method, lead to numerical results.[2]

[1] First obtained by H. S. Snyder, Phys. Rev. **75**, 906 (1949).
[2] H. S. Snyder, Phys. Rev. **76**, 1563 (1949).

G3. A Hodoscope Study of Local Cosmic-Ray Showers. K. SITTE, *Syracuse University*.—The collision mean free path of charged particles which produce penetrating showers in lead has been measured with a more rigid selection of the penetrating events than that used in similar experiments of other authors. The results prove a dependence of the collision cross section on the total shower energy: The mean free path is (162 ± 10) g/cm² for showers of 200 g/cm² minimum penetration, and (196 ± 13) g/cm² for showers of 100 g/cm² minimum penetration. The vertical intensity of the charged shower-producing radiation at 3260 m altitude is $(1.6 \pm 0.3) \times 10^{-5}$ cm^{-2} sec.$^{-1}$ sterad.$^{-1}$. This is only one-tenth of the intensity one would expect from the observed primary proton flux and the absorption coefficient of fast nucleons in air, and indicates the predominance of "soft" nuclear collisions for low energy primaries.—Local soft showers originated by ordinary μ-mesons in lead were observed, and the electronic nature of the shower particles established. They occur in about one of 10^5 traversals of a μ-meson.

G4. Cosmic-Ray Showers Observed in a Cloud Chamber Triggered by Neutron Coincidences.* E. C. FOWLER AND J. C. STREET, *Harvard University* AND W. B. FOWLER AND R. D. SARD, *Washington University*.—The 565 accepted sets of photographs[1] have been examined for cosmic-ray showers. As expected from the results of V. Cocconi-Tongiorgi,[2] there are many photographs showing air showers and penetrating showers. There are 124 expansions showing nuclear interactions or electromagnetic cascade showers or mixed showers, as defined below. Of these, 62 are nuclear interactions, defined as events with at least three tracks having a point in common, and with at least one dense track or alternatively three penetrating tracks. Of these, five appear to be nuclear cascades, i.e., there are two nuclear interactions in the chamber. In some of the 62 cases, an outgoing particle can be identified as a slow meson. There are 47 electronic showers, defined as events with five or more bundles of three or more rays each between the two bottom Pb plates and containing no detectable heavily ionizing or penetrating particles. Some of these appear to be of very high energy. There are 15 mixed showers, containing recognizable electrons and heavily ionizing or penetrating particles. Examples illustrating these events will be discussed.

* This work was supported by the Joint Program of the ONR and the AEC.
[1] See the abstract G5, "Stopped cosmic-ray particles observed in a cloud chamber triggered by neutron coincidences," by Fowler, Fowler, Sard, and Street.
[2] V. Cocconi-Tongiorgi, Phys. Rev. **73**, 923 (1948); Cocconi, Cocconi-Tongiorgi, and Greisen, Phys. Rev. **74**, 1867 (1948).

G5. Stopped Cosmic-Ray Particles Observed in a Cloud Chamber Triggered by Neutron Coincidences.* W. B. FOWLER AND R. D. SARD, *Washington University*, AND E. C. FOWLER AND J. C. STREET, *Harvard University*.—To examine further the coincidences between neutrons and charged particles,[1] we have used them to trigger the cloud chamber[2] containing three Pb plates (approximately 10 g cm^{-2} each), seven Al foils and one graphite plate (2.0 g cm^{-2}). The chamber was beneath fourfold G-M tube telescopes[2] (no Pb) and above an anti-coincidence tray on a paraffin block containing BF_3 counters. A telescope-neutron coincidence triggered the chamber, anti-coincidences being indicated. Locale: Climax (3400 m). The 565 accepted sets of photographs have been examined for stoppings of particles entering the chamber with minimum ionization. There are, respectively, seven and 14 cases of stoppings in the two bottom Pb plates; of the 14 at least three show the increased ionization expected for a meson stopped in the upper part of the plate. In addition, we note seven cases of increased ionization on leaving the bottom plate, which could be mesons stopped immediately below. Two possible interpretations of the stoppings—negative μ-mesons stopped by ionization loss, and minimum ionization protons producing stars of which only one particle, heavily ionizing, emerges,—will be discussed.

* Work supported by the Joint Program of the ONR and AEC.
[1] Sard, Ittner, Conforto, and Crouch, Phys. Rev. **74**, 97 (1948); Sard, Conforto, and Crouch, Phys. Rev. **76**, 1134 (1949).
[2] Cool, Fowler, Street, Fowler, and Sard, Phys. Rev. **75**, 1275 (1949); Cool, thesis, Harvard University (1949); E. C. Fowler, thesis, Harvard University (1949).

G6. Relativistic Showers in Nuclear Emulsions (I).* L. S. OSBORNE, B. T. FELD, AND I. L. LEBOW, *M. I. T.*—We have examined NTB3 nuclear emulsions, exposed in balloon flights to about 90,000 ft. at various latitudes, and analyzed 15 high energy stars characterized by the emission of collimated groups of minimum ionizing particles (average, ten per event). These events also show a less collimated component of near-relativistic particles (energies between 0.1 and 0.5 mc^2) as well as heavy tracks (below 0.1 mc^2). Eight stars have a minimum track opposite the shower, presumably a relativistic proton. The angular distribution of all tracks was measured with respect to the "shower axis," defined as the geometric axis of the shower of minimum ionization tracks. The heavy particle distribution is spherically symmetric. Comparing the minimum charge carried by these "boiled off" particles, the stars separate into two groups: five with minimum charge between two and five and ten between 15 and 40. The groups are interpreted as disintegrations of light (C, N, O) and heavy (Ag, Br) nuclei, respectively. Coulomb scattering measurements on eight near-minimum tracks identified one meson and seven protons. The angular dispersion and the average multiplicity of both minimum and near-minimum tracks are less for events involving light nuclei than for the heavy.

* Assisted by the Joint Program of the ONR and AEC. Plates courtesy of Brookhaven National Laboratory.

G7. Relativistic Showers in Nuclear Emulsions (II).* B. T. FELD, I. L. LEBOW, AND L. S. OSBORNE, *M. I. T.*—Using the data from the previous abstract, identification of the near-minimum tracks as protons and the excess of tracks over nuclear charge in the stars imply that the minimum ionization tracks are predominantly mesons. Plotting the average angular dispersion, $\bar{\psi}$, *vs.* the multiplicity, N, of these tracks, for each event, the light nucleus collisions lie significantly below those for the heavy nuclei; $\bar{\psi}$ decreases with N in both cases. We have calculated $\bar{\psi}$ for a single, meson producing nucleon-nucleon collision assuming various energy spectra, angular distributions, and multiplicities of mesons in the center-of-mass system. Comparison with the experimental points shows possible agreement for the light nuclei but definite disagreement for the heavy nuclei under any reasonable assumptions. The above, plus the multiplicity of near-relativistic protons, strongly suggests that meson production in a nucleus is by a cascade process, with relatively low multiplicity in each nucleon-nucleon encounter. The decrease of the ratio of minimum (meson) to near-minimum (proton) tracks from light to heavy nuclei suggests that sharing of the incident energy is sufficiently rapid to decrease the meson production efficiency when the thickness of nuclear material traversed is doubled from light to heavy nuclei.

* Assisted by the Joint Program of the ONR and AEC.

G8. Directional and Latitude Survey of Cosmic Rays at 95,000 Feet. I. Experimental Procedure.* T. STIX, K. DWIGHT, R. SABIN, AND J. R. WINCKLER, *Princeton University.*—A total of 17 Skyhook balloon flights were made at geomagnetic latitudes 0°, 20°, 30°, and 40° to determine the directional distribution of cosmic-ray intensity at 95,000 feet. The principal measuring instrument was a Geiger tube telescope of three trays, each 10×10 in., with 50-in. separation between top and bottom tray. A 3-cm Pb filter was placed just above the bottom tray for most flights. An electric motor drove the telescope in azimuth and periodically varied the zenith position. The counting rate and orientation of the telescope and the atmospheric pressure were radio-telemetered continuously to the ship. A description of the apparatus and the methods of standardization, as well as the advantages and limitations of the experiment, will be presented. The work took place during July and August of 1949 aboard the USS Norton Sound on a cruise from Port Hueneme, California, to Jarvis Island and return.

* Assisted by the Joint Program of the ONR and AEC.

G9. Directional and Latitude Survey of Cosmic Rays at 95,000 Feet. II. Interpretation of Vertical Flux Data. K. DWIGHT, R. SABIN, T. STIX, AND J. R. WINCKLER, *Princeton University.*—The vertical flux of ionizing particles was measured at 15 g/cm² atmospheric depth at 0°, 20°, 30°, and 40° geomagnetic latitude and previously at 52° and 56°. These data are in satisfactory agreement with rocket experiments and other balloon measurements, and are interpreted using the vertical cut-off energy at each latitude. Assuming a *number* spectrum of the type $N(E)=CE^{-\gamma}$ for the primary radiation, preliminary fitting shows that γ varies with energy but has an average value of about 1.8. N is the number of particles of the energy E contained in unit energy interval. This gives for the *energy* spectrum, $N(E)E$ an exponent $\gamma-1=0.8$ instead of the value 1.8 which is often assumed for this spectrum. The vertical flux of ionizing particles at 0° latitude at 15 g/cm² atmospheric depth is considerably higher than the primary flux estimated from the atmospheric depth-ionization measurements.

* Assisted by the Joint Program of the ONR and AEC.

G10. Directional and Latitude Survey of Cosmic Rays at 95,000 Feet. III. Interpretation of Azimuthal and Zenithal Data.* J. R. WINCKLER,** K. DWIGHT, R. SABIN, AND T. STIX, *Princeton University.*—The azimuthal distribution was measured at zentih angles of 20°, 40°, and 60° at geomagnetic latitudes of 0°, 20°, and 40°N at atmospheric depths of about 20 g/cm². The E-W asymmetry was also studied as a function of depth between 20 and 200 g/cm² with and without a 3-cm Pb shield. These measurements show that the E-W difference is roughly constant far into the atmosphere, but the percent asymmetry decreases with increasing depth. A large E-W effect is observed even in the total radiation between 20 and 200 g/cm², at the peak of the total intensity curve. The percent asymmetry to be expected for all positive primaries may be predicted from the latitude variation of the vertical flux. The observed E-W asymmetries are all smaller than predicted. This difference will be discussed in terms of negative primaries, direct atmospheric effects, and secondary particles moving outside the atmosphere.

* Assisted by the Joint Program of the ONR and AEC.
** Now at University of Minnesota.

G11. Matters Pertaining to the Magnetic Deviation of Cosmic-Ray Particles in the Atmosphere.* W. F. G. SWANN, *Bartol Research Foundation.*—The possibility of a telescope recording from below requires consideration in the case of low energy rays at high altitudes. Any ray traveling vertically upward and coming originally from above must have passed through a condition in which it was horizontal. Taking into account absorption, it is possible to show that any proton entering a telescope vertically from below at 100,000 ft. would have its horizontal portion more than 3.8×10^6 cm below the telescope. For alpha-particles, the distance is greater, so that, both for protons and α-particles, there would be no room between the earth's surface and the telescope to describe the orbit. For mesotrons, the distance would be less than 100,000 ft. However, mean life considerations demand that, regardless of the nature of energy loss, the fraction of any group of mesotrons which could survive long enough to turn through a right angle is $e^{-12.4}$. The numerical integrations involved in the problem have been carried out by Mr. Stephen S. Forbes under the writer's direction.

* Assisted by the Joint Program of the ONR and AEC.

G12. The Increase in the Primary Cosmic-Ray Intensity at High Latitudes, and the Non-Existence of a Detectable Permanent Solar Magnetic Field.* MARTIN A. POMERANTZ, *Bartol Research Foundation.*—The primary cosmic-ray intensity at Churchill, Man. ($\lambda=69°$N) has been compared directly with that at Swarthmore, Pa. ($\lambda=52°$N). The measurements, obtained with identical vertical quadruple-coincidence counter trains, have revealed an increase at the more northern station caused by the presence in the primary radiation of particles having energies below that which would have been permitted had the sun's magnetic field been effective to the extent previously assumed. The ratio of intensities is $I_T(0,69°)/I_T(0,52°)=1.46$. *Intensity vs. altitude* curves were obtained with several different thicknesses of absorber interposed in the counter trains. There is no indication of any diurnal variation which could be in conformity with the existence of a permanent dipole-moment at the sun. The differential energy distribution at the low energy end of the primary cosmic-ray spectrum cannot be evaluated exactly because of absorption considerations, but it is doubtful that the exponent in an inverse power-law representation is as large as has usually been assumed. It is concluded that the sun possesses no detectable permanent magnetic field and, on the basis of the present experiments, an upper limit of 0.6×10^{33} gauss-cm^3, as compared with the previously quoted value of 10^{34} gauss-cm^3, may be assigned as a maximum possible value of the dipole-moment.

* Assisted by the Joint Program of the ONR and AEC. Field expedition sponsored by National Geographic Society.

G13. Measurement of the Cosmic-Ray Intensity as a Function of Altitude at a Geomagnetic Latitude of 28 Degrees.* M. L. VIDALE AND MARCEL SCHEIN, *University of Chicago.*—Through the courtesy of the ONR a counter experiment was carried out at 28° geomagnetic latitude with balloons launched from the aircraft carrier, Palau. Measurements were made on the soft and hard component using a fourfold coincidence arrangement with 0 and 12 cm Pb. The hard component showed a maximum at 6 cm Hg pressure. The maximum in the soft component occurred at a pressure of 10 cm Hg. The latitude effect of the hard component was observed to be 300 percent at 92,000 ft. elevation above sea level. This value is in agreement with measurements made on the latitude effect of large nuclear disintegrations initiated by primaries. The frequency of multiple coincidences detected under 12 cm Pb did not show any increase from 10 cm Hg to 1.2 cm Hg, in contrast to similar measurements at a geomagnetic latitude of 51° were an increase by a factor of two has been found.[1] Possible explanations of this effect will be discussed.

* Assisted by the Joint Program of the ONR and AEC.
[1] Schein, Yngve, and Bowen (unpublished results).

G14. Measurements on the Latitude Effect of the Neutron Component of Cosmic Radiation at High Altitudes.* LUKE C. L. YUAN,** *Princeton University.*—Measurements on the intensity distribution of slow neutrons in the free atmosphere using balloon-borne equipment similar to those used in previous experiments[1] were made at the equator and at 27°N geomagnetic latitude. Two proportional counters filled with enriched boron trifluoride (96 percent B^{10}) at a pressure of 50 cm Hg were employed. One counter was shielded with 0.030-in. cadmium and the other counter was shielded in tin of the same thickness for the compensation of possible effects caused by stars produced in the cadmium shield. The high voltage system for the counters were pressurized to prevent any effect caused by corona discharge at the high voltage terminals which might appear as neutron counts.

The balloon-borne equipment ascended to an altitude of 92,000 ft. at the equator. The results obtained show a maximum in the intensity distribution as a function of altitude in a manner similar to that[1] obtained at Princeton, New Jersey (geomagnetic latitude 51° 46'N). An absorption depth $\lambda=225$ g/cm^2 was obtained in agreement with our previous measurements[2] made on a B-29 airplane at lower altitudes.

* Assisted by the Joint Program of the AEC and ONR.
** Now at Brookhaven National Laboratory, Upton, Long Island, New York.
[1] Luke C. L. Yuan, Phys. Rev. **74**, 504 (1948); Luke C. L. Yuan (to be published shortly).
[2] Luke C. L. Yuan, Phys. Rev. **76**, 1267 (1949); Luke C. L. Yuan, Phys. Rev. **76**, 1268 (1949).

Beta-Emitters; Nuclear Scattering

H1. Radiation from Au^{197*}(7×10^{-9} sec.).** F. K. MCGOWAN, *Oak Ridge National Laboratory.*—Using a delayed coincidence scintillation spectrometer both the radiation announcing the formation of the isomeric state in $Au^{197*}(7\pm1)\times10^{-9}$ sec.[1] and the radiation resulting from its decay have been measured. Huber *et al.*[2] have observed that four percent of the disintegrations of Hg^{197}(23 hr) lead to a 7.5-sec. isomeric state in Au^{197} and 96 percent of the disintegrations are followed by γ-ray transitions corresponding to 135 and 165 kev which are strongly converted. With the delayed coincidence scintillation spectrometer K and L conversion electrons of the 135 kev transition appeared in the spectrum of the delayed radiation. The ratio N_K/N_L is $\lesssim1$. The K and L conversion electrons corresponding to the 165 kev transition, which announces the formation of the short-lived isomeric state, were observed. In this case $N_K/N_L\sim0.1$.

** This document is based on work performed for the AEC at Oak Ridge National Laboratory.
[1] F. K. McGowan, Phys. Rev. **77**, 138 (1950).
[2] Huber, Steffen, and Humbel, Helv. Phys. Acta **21**, 192 (1948).

H2. A Delayed Coincidence Measurement of $Hg^{203,205}$. DANIEL BINDER, *Yale University.**—An attempt has been made to measure the half-life of the γ-ray level in the beta-gamma cascade emission from $Hg^{203,205}$ by a delayed coincidence measurement. A proportional counter is used as the beta-ray detector and a 931A photo-multiplier with an anthracene crystal as the gamma-detector. A symmetrical resolution curve with a half-width of 7×10^{-8} sec. was obtained by sending beta-rays from P^{32} through the proportional counter into the photo-multiplier. The coincidence *versus* delay curve obtained with $Hg^{203,205}$ placed between the detectors is also symmetrical. An upper limit for the half-life may be determined by using theoretical expressions for the curves and finding what value of the half-life produces a distinct asymmetry. By this method an upper limit of 2×10^{-8} sec. was obtained. Further investigations of γ-ray levels are in progress.

* Assisted by the Joint Program of the ONR and the AEC.

H3. Low Energy Photons from Radioactive Nuclei.* GERTRUDE SCHARFF-GOLDHABER,** E. DER MATEOSIAN, M. MCKEOWN AND A. W. SUNYAR, *Brookhaven National Laboratory.*—Low energy photons have been observed for a number of radioactive nuclei with the help of an argon filled proportional counter. Results have been obtained as shown in Table I. The 24-kev electrons reported by Teillac[1] for Pa^{231} and interpreted as L-electrons of a 44-kev transition are reinterpreted as M-electrons of the 27-kev transition. Although no unconverted γ-rays could be detected from U^{234}, comparison with other α-emitters indicates that the L-radiation is caused by a

TABLE I.

	Sm^{151} (a)	Tb^{161}(?) (b)	Pa^{231} (c)	U^{234} (d)
Energy of γ-rays in kev.	21	26	27	—
X-rays observed	L	K, L	L	L

(a) Separated from fission products by Glendenin and Marinsky.
(b) Produced by slow neutron bombardment of Gd in Oak Ridge.
(c) Prepared by M. Studier, Argonne National Laboratory.
(d) Isotopically enriched at Y-12, Oak Ridge.

highly converted nuclear transition following at least one quarter of the α-transitions, rather than by excitation of the electronic shell by the α-rays as suggested by Macklin and Knight.[2]

* Research carried out at Brookhaven National Laboratory under the auspices of the AEC.
** On leave from the University of Illinois.
[1] J. Teillac, C. R. **229**, 650 (1949).
[2] R. L. Macklin and G. B. Knight, Phys. Rev. **72**, 435 (1947).

H4. Isomerism in Pb^{204} and Radiations of Bi^{204} and Bi^{206}. A. W. SUNYAR, D. E. ALBURGER, G. FRIEDLANDER, M. GOLDHABER,* AND G. SCHARFF-GOLDHABER,* *Brookhaven National Laboratory.***—The even-even isomer Pb^{204} (68 min.) is found to decay in two steps. A 905-kev γ-ray ($\sim$10 percent internally converted, K/L ratio $\sim$1.5) is followed by a 374-kev γ-ray ($\sim$5 percent internally converted, K/L ratio $\sim$2) with a half-life of 3×10^{-7} sec. The results can be interpreted by assuming that a transition of multipole order 6 is followed by one of multipole order 3. This requires a spin between 7 and 9 units for the upper metastable state of remarkably high excitation energy (1279 kev). The Pb^{204} was separated from its parent, Bi^{204} (12 hours), which was produced by deuteron bombardment of lead in the MIT cyclotron. The internal conversion electrons were studied in a lens spectrograph. Bi^{204} studied in equilibrium with its daughter, showed additional lines corresponding to a 217-kev transition. Weaker lines might have been masked because of the presence of Bi^{206} (6.4 days) which shows an extraordinary number of lines corresponding to the following γ-ray energies: 182, 234, 260, 341, 396, 470, 505, 536, 590, 803, 880, 889, 1020, 1097, 1720 kev.

* On leave from the University of Illinois.
** Under the auspices of the AEC.

H5. Photo-Neutron Production.* E. DER MATEOSIAN AND M. GOLDHABER,** *Brookhaven National Laboratory.*—Because of the incomplete state of our knowledge of gamma-rays of sufficient energy to disintegrate Be or D we have recently begun a systematic search for such gamma-ray emitters. The photo-neutrons are slowed down in paraffin and detected by $B^{10}F_3$ counters. The sensitivity of the arrangement is such that one microcurie Ra inside Be produces 35 counts per minute, above a background of 10 counts per minute. With this sensitivity the difficulty lies not in the detection of weak gamma-ray branches (of the order of 10^{-6} or less) but rather in the exclusion of photo-neutron producing impurities. Two new cases were established: Ag^{110} (225 days) and Bi^{206} (6.4 days) which produce photo-neutrons in Be but not in D_2O. For approximately equal γ-intensities measured by an air ion chamber shielded with $\frac{1}{4}$-inch lead, the neutron counting rate was 1/2000 for Ag^{110}, and $\frac{1}{3}$ for Bi^{206} in comparison with $Ra-\gamma-Be$. The energy of the gamma-rays responsible is not yet known for Ag^{110}, but from Bi^{206} a 1.72 gamma-ray has been observed in a lens spectrometer to which the photo-neutrons can be ascribed (see preceding abstract).

* Research carried out under the auspices of the AEC.
** On leave from the University of Illinois.

H6. Proton-Proton Scattering at 340 Mev. C. WIEGAND AND O. CHAMBERLAIN, *University of California.*—We have measured proton-proton scattering at 340 Mev using the externally deflected beam of the 184-inch Berkeley cyclotron. Two coincidence counter methods are employed to detect the scattered protons from a polyethylene target: (a) a telescope of three proportional counters in line and very similar to that used for neutron-proton scattering,[1] (b) a telescope of two small proportional counters to count one scattered proton and a larger proportional counter at approximately 90° to count the other scattered proton. The larger counter is moved close enough to the target to count every proton whose counterpart reaches the small counter telescope. At the present time method (b) gives cross sections about 15 percent lower than method (a). Backgrounds are taken by substituting equivalent carbon targets for the polyethylene. The proton beam current is measured by an ionization chamber which has been calibrated against a Faraday cup. The average results are: $d\sigma/d\Omega$ in 10^{-27} cm^2 sterad^{-1} at 90°, 5.5±0.6; 62°, 5.4±0.6; 41°, 5.6±0.8; where angles and cross sections are in the center of mass system. These cross sections are about twice the theoretical maximum for pure s-scattering.

[1] Hadley, Kelly, Leith, Segrè, Wiegand, and York, Phys. Rev. **75**, 351 (1949). Fig. 2.

H7. Magnetic Deflection Method for Observing Proton-Proton Scattering at 250 Mev.* O. A. TOWLER, JR. AND C. L. OXLEY, *University of Rochester.*—The magnetic field of the University of Rochester 130-in. synchro-cyclotron has been used to deflect the protons scattered by polyethylene and carbon targets. The scattered protons strike photographic plates which are placed along a nearly radial probe. The probe, lying just above the lower pole, is shielded from particles traveling in the general direction of the circulating beam by 2 to 4 inches of copper. At a given position along the probe the protons from p-p scattering arrive in a nearly collimated group which corresponds to a well-defined angle of p-p scattering. With the present apparatus such groups of proton tracks have been observed corresponding to scattering angles ranging from 50° to 80° (laboratory). If the number of protons counted in the plates is plotted against the entrance angle, a much lower and broader peak is observed from a carbon target than is observed from the hydrogen in the polyethylene target. From the measurement of the C^{11} beta-activity of the target it is expected that cross sections can be obtained relative to the $C^{12}(p, pn)C^{11}$ cross section.

* Assisted by the Joint Program of the AEC and ONR.

H8. Scattering of 4.5 and 5.5 Mev Neutrons by Deuterons.* E. WANTUCH, *Brookhaven National Laboratory.*—Atmospheric pressure deuterium gas was bombarded with neutrons from the $D(d, n)He^3$ reaction. Incident deuterons were accelerated in the Van de Graaff Generator at the Department of Terrestrial Magnetism. Recoil deuterons (but not disintegration protons) were measured with thin window twofold coincidence proportional counters of 1 microsecond resolving time. Table I shows preliminary results. Background was at most $\frac{1}{3}$ of total counts. The counting errors are ±10 percent, due mostly to uncertainties in monitoring. On the basis of Hunter and Richards' yield values[1] for the D-D reaction, the differential scattering cross section at 0° (in the center-of-mass system) was determined to be 0.25±0.10 barn per steradian. The results are compared with the theory of Buckingham and Massey.[2]

TABLE I.

Scattering angles in lab. system / Neutron energy, Mev	0°	10°	20°	30°
	Net number of coincidences			
5.5±0.1	2300	2400	1200	400
4.5±0.2	2300	2000	1200	—

* Research carried out under the auspices of the AEC.
[1] G. T. Hunter and H. T. Richards, Phys. Rev. **76**, 1445 (1949).
[2] R. Buckingham and H. Massey, Proc. Roy. Soc. **A179**, 123 (1941).

H9. High Energy Electron-Proton Scattering. M. N. ROSENBLUTH AND L. I. SCHIFF, *Stanford.*—In connection with the pending completion of the Stanford linear electron accelerator it has been thought worth while to estimate as accurately as possible the results to be expected from high energy

electron-proton scattering. As corrections to the usual Mott scattering formula we have considered: (a) recoil and magnetic moment of the proton treating it as a Dirac particle of finite mass and having an anomalous Pauli magnetic moment; (b) Spreading of charge and magnetic moment due to the virtual meson cloud; (c) Radiative corrections to scattering as calculated by Schwinger. Calculation (a) has been carried out in a relativistically invariant way; (b) has been done by assuming that the proton charge and magnetic moment are spread over a meson Compton wave-length part of the time. At relatively low energies (100 Mev) and small angles the important contributions are from radiative corrections and proton recoil. At high energies and large angles the other effects are of comparable importance. The meson cloud also has been treated in a relativistically invariant way. Numerical values of these corrections will be presented.

Miscellany in Electrical Physics

HA1. Efficiency of the Thermoelectric Process. G. PRESTON BURNS, *Mary Washington College of the University of Virginia.*—Formulas for the efficiency of the thermoelectric process have been derived for the following cases: (1) External load is different from the internal resistance of the couple. (2) Couple delivers maximum power. (3) Efficiency of the couple is maximum. The maximum efficiency of the process is given by

$$\text{efficiency}=\frac{e^2(T_h-T_c)}{e^2T_h+8\rho k+4(\rho k)^{\frac{1}{2}}(e^2T_h+4\rho k)^{\frac{1}{2}}},$$

where e is the thermoelectric power of the couple, T_h the temperature of the hot junction, T_c the temperature of the cold junction, ρ the specific electrical resistance and k the specific heat conductivity of the elements. If both elements of the couple are made to satisfy the Wiedemann-Franz-Lorenz relation and the temperatures of the junctions are 27°C and 427°C, respectively, then for maximum efficiency the external load is 3.91 times the internal resistance of the couple. For $e=1000$ microvolts per degree centigrade this yields an efficiency of 33.9 percent.

HA2. Effective Reduction of Scattering of Electron Beams in Tissue by Means of a Magnetic Field. W. H. BOSTICK, *Tufts College.*—The root-mean-square scattering for 20-Mev and 50-Mev electrons incident on tissue has been calculated, layer by layer, with the use of the expression for the mean-square scattering angle $\bar{\theta}_i^2=(K/E_i)^2l_i$, where E_i is the average energy in Mev of the electron in the layer, $K=21$ Mev, l_i is the thickness of layer number i in radiation units, and where the angle $(\bar{\theta}_i^2)^{\frac{1}{2}}$ is required to be small. The total mean-square scattering angle for n layers is then

$$\bar{\theta}^2=(\bar{\theta}_1^2+\bar{\theta}_2^2+\cdots\bar{\theta}_n^2).$$

The calculated root-mean-square trajectories in tissue show that electrons are, on the average, scattered far away from their original target. The results of approximate calculations on the effect of a magnetic field parallel to the electron beam indicate that this departure from the intended target can be markedly reduced with a magnetic field of 10,000 oersteds.

HA3. Multiple Scattering Effects in the Measurement of Maximum Electron Ranges. FRANK L. HEREFORD, *University of Virginia.*—Recent data concerning the practical maximum range of monoenergetic electrons (3 Mev$<E<$12 Mev) in aluminum[1] yield values which fall below a computed curve[2] normalized to agree with previous data in the region of lower energy ($E<3$ Mev). It is normally assumed that the practical maximum range, R_p, as well as the absolute maximum range,[3] R_0, is determined by a small number of the incident electrons which do not experience appreciable scattering in the absorber. Hence, the thickness of the absorber is assumed equivalent to the actual trajectories. While this is valid for those electrons determining R_0, it cannot be absolutely valid for those determining R_p which are stopped within a smaller thickness as a result of multiple scattering in the absorber. Such a scattering effect can be accounted for by means of a semi-empirical correction to the computed lengths of trajectory to give corresponding absorber thicknesses, R_p. The values so computed agree well with the experimental values in both aluminum[1] and copper (data to be published).

[1] F. L. Hereford and C. P. Swann, Phys. Rev. **76**, 570 (1949).
[2] W. A. Fowler, C. C. Lauritsen, and T. Lauritsen, Rev. Mod. Phys. **20**, 237 (1948).
[3] As defined by E. Bleuler and W. Zunti, Helv. Phys. Acta. **19**, 376 (1946).

HA4. Percent Beta-Ray Transmission through Thin Windows. EDWARD STURCKEN, ROBERT HELLER, AND ALFRED H. WEBER, *St. Louis University.*—The percent transmission (I/I_0) of monoenergetic electrons in the range 16–32 kilovolts was measured for thin Nylon films (0.02 mg/cm² to 0.1 mg/cm²). The monoenergetic beam was obtained from an electron diffraction camera. The beam was incident on a Scheelite crystal counter employing a 1P21 photomultiplier tube. Thin windows were inserted in front of the crystal counter by means of an "O" ring sealed probe. Ten second counting periods were used. The average value of I_0 was controlled to give a probable error in counting of less than 0.2 percent. Thin Nylon films (0.05 mg/cm²) gave percent transmissions varying from 10 percent at 16 kilovolts to 70 percent at 32 kilovolts. Slides will be presented showing the percent transmission as a function of electron energy (16–32 kv) for thin films of Formvar, mica and Nylon.

HA5. Radiation Characteristics of a Turnstile Antenna in a Cylindrical Shield.* DAVID S. SAXON,** ALFREDO BAÑOS, JR.,** *University of California, Los Angeles,* AND LOUIS L. BAILIN, *National Bureau of Standards.*—Radiation characteristics have been established for a turnstile antenna in a cylindrical shield. This antenna consists of perpendicularly crossed wires driven by a sinusoidal current distribution, harmonic in time, and differing in phase by 90° between members of the cross. The shield is assumed to be a perfectly conducting cylindrical can open at one end and its diameter is taken to be of the order of a fraction of the driving wavelength. The axis of the shield is perpendicular to the plane of the antenna, passing through its center. The excitation of an infinitely long circular wave-guide by the above current distribution is considered first and conditions under which only the dominant (TE_{11}) mode is important are determined. The essential radiation problem can then be regarded as one in which a semi-infinite circular guide, excited by a TE_{11} mode, radiates into free space. This problem has been formally solved by Levine and Schwinger[1] and using their results, values of the reflection coefficient and gain function have been computed by the National Bureau of Standards, Institute for Numerical Analysis, University of California, Los Angeles. The results of this theory are compared with experiment and with the Kirchhoff method.

* Supported in part by the ONR.
** Consultant for the National Bureau of Standards.
[1] To be published soon. The authors express their appreciation for the private communication of these results.

HA6. On the Radiation Patterns of Dielectric Rods of Circular Cross-Section.* C. W. HORTON, F. C. KARAL, AND C. M. MCKINNEY, *University of Texas.*—A systematic study is being made of the radiation patterns of untapered dielectric rods of circular cross section for different modes of excitation, diameters, and lengths. Theoretical patterns are calculated from equivalent electric and magnetic currents.[1] These surface currents are evaluated by assuming, as a first approximation, that the fields in the dielectric radiator are the same as those in an infinitely long dielectric guide. The resulting theoretical pattern has three parameters; the length, diameter, and the

wave-length of the guided wave. In a careful study of the $TM_{0,1}$ mode in a sequence of five rods of diameter 0.87λ and lengths 2λ to 10λ, it is found that excellent agreement between theory and experiment is obtained if one uses 65 percent of the diameter of the rod for the diameter of the radiating surface. Thus in this series one can correct for the effect of the termination of the rod by using an equivalent rod of the same length but of smaller diameter but whose dielectric constant is such that the wave-length of the guided wave is unchanged.

* The work described in this paper was done at the Defense Research Laboratory under the sponsorship of the Bureau of Ordnance, Navy Department.

[1] See R. B. Watson and C. W. Horton, J. App. Phys. **19**, 661–70 (1948).

HA7. The Analog Solution of Simultaneous Partial Differential Equations by Means of Passive and Active Electrical Networks. JAMES H. GREEN, JR., AND VICTOR B. COREY, *Fredric Flader, Inc.*—A general method of obtaining the analog solution of simultaneous partial differential equations by means of iterative electrical networks is developed. The basic theory depends upon developing a formal analogy between the finite difference form of the equations to be solved and the equations describing the distribution of potential in an electrical network. Application of the theory results in the solution of certain simultaneous groups by the use of passive networks containing such circuit elements as resistors, capacitors and inductors, and of more complex groups by means of active networks containing amplifiers. Illustrations are provided in which the general method is applied to the design of practical simulators, and equations are derived which relate specific values of circuit components to the coefficients contained in the equations to be solved. The theory is extended to cover groups of "n" simultaneous partial differential equations. Experimental results obtained on a one-dimensional simulator are found to compare, within expected experimental error, with the exact solutions of the simulated equations for certain cases where the analytical solutions may be obtained.

Theoretical Physics, II

J1. Dependence of Fermi $|M|^2f$ on Z for Certain Isotopic Numbers. D. N. KUNDU AND M. L. POOL, *The Ohio State University.*—The logarithm of the half-life t of radioactive odd A nuclei is approximately a linear function of Z for a constant value of $A-2Z=I$. Both odd and even Z $(0<Z\leqslant 60)$ have been examined for $I=-1$ to 21 for nuclei on the positron-emitting side of the valley of stability. Abrupt departure from linear dependence sets in as t approaches infinity. Within the range of validity of this linear relationship $\log t=-\alpha Z+\delta$, it follows that $|M|^2f=Ae^{0.434\alpha Z}$, where $|M|=|\int\cdots|$ is the nuclear matrix and f the usual integral Fermi function.[1] The constant α has approximately the same value 0.35 for all values of I except for $I=-1$ when $\alpha=0.13$. A may be estimated from the straight lines plotted. Though in general both $|M|$ and f may individually be complicated functions of Z, the product $|M|^2f$ has a simple exponential dependence. The curves also help predict the half-lives of probable isotopes for given Z and I. The change in the value of α may be related to the fact that one group has neutron excess and the other, neutron deficiency. The case of decay by K-capture with its different form for f is evidenced by a change in the value of δ.

[1] E. J. Konopinski, Rev. Mod. Phys. **15**, 209 (1943).

J2. On the Nuclear Quadrupole Moment of Li^7. R. D. PRESENT, *University of Tennessee* AND E. FEENBERG, *Washington University.*—Recent measurements unexpectedly determine the sign of the moment as positive.[1] The estimated magnitude is uncertain because of lack of resolution in the experimental line and the uncertain value of the electric field gradient. Assuming the ground state to be $1s^42p^3\,{}^2P_{3/2}$ the calculated moment is -6 in units of $\langle r^2\rangle_{2p}/25$. Configuration interaction modifies this result if the ground state eigenfunction contains an admixture of P state functions belonging to low odd-parity configurations.[2] In the "equal-forces" approximation, which we use throughout, all components of the ground state function are characterized by a definite symmetry[3] corresponding to the partition [3] or supermultiplet $(\frac{1}{2},\frac{1}{2},-\frac{1}{2})$. A variational calculation of the moment has been made taking into account the symmetrized P state functions arising from $1s^42p^23p$ (two) and $1s^42p^24f$ (one). Oscillator eigenfunctions were used to obtain ratios of $\langle r^2\rangle$. The maximum value of the moment is 2.32 in the above units. Calculations with P states from the remaining low configurations $1s^32s2p^3$ and $1s^32p^33d$ are incomplete; however these can only increase the maximum above 2.32. We conclude that a positive quadrupole moment is not inconsistent with a pure P ground state for Li^7.

[1] P. Kusch, Phys. Rev. **76**, 138 (1949).
[2] The magnetic moment is unaffected by an admixture of P states.
[3] The configuration $1s^42p^3$ gives no D states of this symmetry.

J3. Space Exchange Magnetic Moments in Light Nuclei.* L. SPRUCH, *M. I. T.*—The calculations were based on Sachs'[1] phenomenological theory and on the independent particle model. Spin exchange moments were not included. Uncertainties in the form, strength, and range of the neutron-proton interaction, in the fractional part of the interaction which is of an exchange nature, and in the shell dimensions, cause the calculated values to be uncertain by a factor of about 5. For L-S coupling, the values found for Li^7, Be^9, B^{11}, C^{13}, N^{15}, and in the $3d$ shell for ^{2}D states, for Ne^{21}, Na^{23}, Cl^{37}, and K^{39} were -0.04, -0.01, 0.1, 0.05, 0.1, -0.4, -0.1, 0.4, and 0.4 nuclear Bohr magnetons, respectively. For $j-j$ coupling, the values for B^{11} $(^2p_{3/2})^{-1}$ and $C^{13}(^2p_{1/2})$ were 0.2 and -0.09; N^{15} and K^{39} had the same values as above. Since spin exchange moments were not included, no agreement with experiment was expected; the values are nevertheless large enough for some nuclei to be quite significant. Heavier nuclei will probably tend to have larger space exchange moments.

* AEC postdoctoral fellow.

[1] R. G. Sachs, Phys. Rev. **74**, 433 (1948).

J4. The Monte-Carlo Method in Quantum Mechanics. GILBERT W. KING, *Arthur D. Little, Inc., and M. I. T.*—If one averages over a time of appropriate length the lowest stationary state $\psi_0(\xi)$ can be found by repeated applications of the Hamiltonian on an arbitrary state. This may be done by the transformation $t=iht$ on the time-dependent Schroedinger equation, to get Ulam's form $\partial u/\partial t=\Delta^2u-Vu$, where $u=\psi(\xi)e^{-\lambda t}$ in time reaches the configuration $\psi_0(\xi)$, the amplitudes decaying with a logarithmic decrement equal to the lowest energy. A solution of this "diffusion" equation can be found by a stochastic process, the points in ξ, t space moving $\Delta\xi$ in time Δt by a random process, and increasing in weight at each step by $e^{-V\Delta t}$. If all possible random walks were to be taken, the final distribution would be precisely that obtained by iterative methods of solving the corresponding difference equation. If the step function, $x_n=n\Delta x$ be replaced by orthogonal functions, the diffusion process occurs in a Hilbert space, and if all random walks were to be taken the process becomes that of iterating the Heisenberg matrix on an arbitrary vector. Excited states can be obtained by imposing nodes where "particles" become annihilated. The method will be illustrated by the harmonic oscillator and particle in a box.

J5. On the Probability Distribution of Recurrence Times. A. J. F. SIEGERT, *Northwestern University.*—Recurrence time probabilities are mentioned in various fields of physics and it seemed of interest to find a simple case for which an exact solution for the recurrence time probability could be found.

Markoffian random functions are known to be unsuitable, but we could solve the problem for the stationary Markoffian random-process with continuous time.† Let $p_{ik}(t-t_0)$ be the conditional probability that a system which was in state i at time t_0 is in state k at t, $\rho_i(t)dt$ the probability that a system returns to i for the first time at a time between t and $t+dt$ after leaving, and τ_i the mean persistence time, and $\rho_i^*(\lambda)$ and $p_{ik}^*(\lambda)$ the Laplace transforms of these functions, then $\rho_i^*(\lambda)=1-\lambda\tau_i\{[\lambda p_{ii}^*(\lambda)]^{-1}-1\}$. The obvious relation between mean persistence time, mean recurrence time, and probability of state i can be verified by expansion to first order in λ.

† For discrete Markoffian Processes cf. M. Kac, Am. Math. Monthly **54**, 369 (1947).

J6. Relativistic Kepler Problem. M. H. JOHNSON AND B. A. LIPPMANN, *Naval Research Laboratory.*—Besides the usual integrals of motion, **M** and j (in Dirac's notation) the relativistic equations for a charge in a Coulomb field admit

$$A=\boldsymbol{\sigma}\cdot\mathbf{r}r^{-1}-i(\hbar c/e^2)(mc^2)^{-1}j\rho_1(H-mc^2\rho_3)$$

as another integral of motion. Since A and j anticommute, the pairs of states with the same $|j|$ are degenerate. Thus the existence of A establishes the "accidental" degeneracy in the relativistic Kepler problem just as the existence of the axial vector establishes the degeneracy with respect to l in the corresponding non-relativistic problem.

J7. Accelerated and Rotating Coordinate Systems. H. C. CORBEN, *Carnegie Institute of Technology.**—The use of conformal transformations to relate mutually accelerated coordinate systems possesses the disadvantage that rotating systems, and hence the Thomas precession effect, cannot be easily included in the scheme. However, rotating and accelerated observers may be discussed simultaneously by considering the transformation $x^*=Sx$. Here x denotes the $(\mathbf{r}, ict)$ coordinates relative to an inertial observer O of an event on the space-time path of a particle P^*; $x^*(\equiv\mathbf{r}^*, ict^*)$ denotes the coordinates of the event relative to another observer O^*, and S is an orthogonal operator which is a function of the interval s along the path of P^* in system O. If $\Omega=S'\dot{S}$ ($'$ = transpose, $\cdot=d/ds$) then Ω is antisymmetrical, and writing $c\Omega_{jk}=\epsilon_{jkl}\omega_l$, $c^2\Omega_{j4}=if_j$ ($j, k, l=1, 2, 3$) then, when P^* is fixed relative to O^*, f_j and ω_j may be regarded as the relativistic acceleration and angular velocity of P^* relative to O. The velocity of light is invariant for these transformations. This offers a relatively simple method of describing kinematical composition laws for acceleration and angular velocity in relativity theory.

* Supported in part by ONR contract.

J8. The Hamiltonian of Einstein's Theory of Gravitation with Electromagnetic Field.* PETER G. BERGMANN, ROBERT PENFIELD, RALPH SCHILLER, AND HENRY ZATZKIS, *Syracuse University.*—After the development of the general canonical formalism of covariant field theories,[1] we have constructed the Hamiltonian density corresponding to the general theory of relativity with electromagnetic terms. It turns out that the simplest possible Hamiltonian is quadratic in the momentum densities canonically conjugate to the gravitational and electromagnetic potentials and linear in the momentum densities conjugate to the coordinates, which represent energy and linear momentum densities. In their canonical form, the field equations are first-order differential equations, solved with respect to the (time) derivatives. To test the power of the new formalism, we have examined the motions of field singularities. While our results agree with those of the Einstein-Infeld-Hoffmann theory, we can develop rigorous expressions for the particle accelerations in any given situation; integration of the equations of motion would, of course, also require expansions.

* Supported by ONR.
[1] Bergmann and Brunings, Rev. Mod. Phys. 21, 480 (1940).

J9. Covariant Spinor Theory.* JACK HELLER, *Polytechnic Institute of Brooklyn,* AND PETER G. BERGMANN, *Syracuse University.*—The laws of nature appear to possess both general covariance and spin properties. We have therefore developed further the formalism proposed by Schrödinger, Schouten, and others, in which the spin transformations are independent of the coordinate transformations. The basic (Dirac) spin matrices are determined by equations involving only Kronecker symbols on the right, and by the requirement that they are self-adjoint with respect to an invariant indefinite Hermitian form. The ordinary metric tensor is then formed from the Dirac matrices algebraically. The spinor connections are determined only partly by the condition that the covariant derivatives of the Dirac matrices vanish. There results a "spin curvature tensor" and a corresponding scalar, but the latter turns out to equal Riemann's curvature scalar. Thus, the most obvious variational principle not involving electromagnetic cross terms merely yields Einstein's equations of gravitation. We are now examining the effects of quantization.

* Supported in part by ONR.

J10. On the Quantization of Einstein's Gravitational Field Equations. A. SCHILD AND F. A. E. PIRANI, *Carnegie Institute of Technology.*—The following points illustrate the method: (1) By splitting off a divergence term, the usual Lagrangian $(-g)^{\frac{1}{2}}R$ of gravitational theory is replaced by a first order differential expression. (2) Weiss'[1] method of quantization of field theories characterized by first order Lagrangians, can be carried out in a non-metrical "amorphous" space. The gravitational equations may be regarded as differential equations for the field variables $g_{\mu\nu}$ in an amorphous space and the quantization procedure can be applied to them. (3) The gravitational field equations are written in Hamiltonian form, the Hamiltonian being a function of coordinates, momenta and velocities. Point (2) above was first stated by Bergmann and Brunings.[2] The Hamiltonian (3) is obtained, using a method developed by Dirac[3] for Lorentz invariant theories.

[1] Proc. Roy. Soc. **A169**, 102 (1938).
[2] Rev. Mod. Phys. 21, 480 (1949).
[3] Mimeographed lecture notes, Second Seminar, Canadian Mathematical Congress, August 1949.

J11. Approximate Solutions of the Field Equations in Einstein's Generalized Theory of Gravitation. HANS FREISTADT, *University of North Carolina.*—Quasi-static solutions of the field equations of Einstein's "Generalized Theory of Gravitation,"[1] in which matter is represented by singularities are investigated by means of an expansion in powers of small parameters. The difficulty of expressing the Γ in terms of the g is overcome by an expansion in which the Γ at each order of the approximation are expressed in terms of the Γ of lower order and the g. In lieu of the anti-symmetric field Eqs. (15) of reference 1, the more stringent equations $R_{ik}=0$ are used, which were privately communicated to the author by Professor Einstein. The Lienard-Wiechert fields satisfy these equations (uniquely if one excludes magnetic poles) up to the order investigated so far, which is the second.

[1] Rev. Mod. Phys. 20, 35 (1948).

Miscellany in Nuclear Physics

L1. High Intensity Ion Source for Cyclotrons. R. S. LIVINGSTON, R. J. JONES, AND R. E. WRIGHT, *Carbide and Carbon Chemicals Corporation.*—The characteristics of a hot-cathode arc-type ion source have been determined with d.c. applied potentials. More than one half of the atoms in the hydrogen gas fed into the source are converted to ions. The ratios of H^+, H_2^+, and H_3^+ have been measured mass spectrographically. Protons account for 85 percent of all ions formed when the source is adjusted to optimize this quantity. Ion current is

an increasing function of applied potential, as expected, with currents above 10^5 μa observed at 10 kv. The performance of this source has also been studied in a small cyclotron, in which protons were accelerated up to 2 Mev with applied *rf* potentials of 10–20 kv peak. The attenuation of circulating ion current with radius, was measured by means of a movable probe. The dimensions of the arc chamber have been chosen to avoid interception of ions on their first revolution. The source may be of particular interest for machines where only small dee voltages are available. This is based on work performed under contract with the AEC.

L2. Asymmetry of Nuclear Fission. DAVID L. HILL, *Vanderbilt University.*—The asymmetry of nuclear fission is related to the dynamics of the liquid drop model in terms of a treatment developed in collaboration with Professor John A. Wheeler. Certain conjectures are discussed along with their testing by means of extensive numerical calculations executed, as an endowed problem, on the IBM SSEC. Successive computed nuclear shapes are shown to illustrate how the irreducible zero-point asymmetric surface oscillations persist in the elongating form to cause an unequal mass division. Results are given both for uranium and for that element of high atomic number for which the conventional dumbbell shape of unstable equilibrium degenerates into a sphere.

L3. Range of α-Particles in Water and Ice. H. G. DE CARVALHO,* *National Institutes of Health.*—The range of α-particles in water is an important constant for evaluating the biological effects of densely ionizing radiations on tissue. The early measurements on the range of 5 to 8 Mev α-particles in water made with the aid of scintillation screens are about 30 percent low when compared with ranges computed from stopping power laws. To determine the nature of the discrepancy the range of α-particles in water and ice have been measured by means of nuclear emulsions sensitive to residual alpha-energies of about 0.2 Mev. Specially prepared radiocolloid aggregates of polonium and radium sulfate served as micropoint sources, suspended in either water or ice in direct contact with the emulsion. Preliminary measurements show a range in water of 39 microns for RaF, 67 for RaC′, and ranges of 42 and 73 microns respectively in ice. These values are in closer agreement with the Bragg law than the scintillation measurements, and exhibit only a 1 to 4 percent departure from ranges computed by modern stopping power theory. This method of range measurement is of general applicability to liquids that do not destroy emulsion sensitivity and to highly active alpha-emitters capable of radiocolloid aggregation.

* Public Health Service Research Fellow of the Experimental Biology and Medicine Institute on leave of absence from Laboratorio da Producao Mineral, Brasil.

L4. Ratio of N^{15}/N^{14} in Gases Occluded in Radioactive Minerals. HERMAN YAGODA AND WILLIAM C. WHITE, *National Institutes of Health.*—In a study of the occluded gases in radioactive minerals by means of the mass-spectrometer, the isotopic ratio of N^{15} to N^{14} was found to be invariably higher than in samples of atmospheric air or in nitrogen isolated from nitrogenous compounds. For primary uranium and thorium minerals studied the N^{15} content varied between 0.532 to 0.614 atom percent, as compared with the normal abundance of 0.376. The abundance of N^{15} increases progressively with the geological age of the specimen over a range of (50 to 1000)10^6 years. Different specimens of pitchblende of the same Pb/U age exhibit closely agreeing N^{15}/N^{14} ratios, suggesting a new age indicator. The nitrogen ratio is independent of the chemical composition and the uranium content of the host mineral. Thus samarskite (11.3 percent U_3O_8) and uraninite (91 percent U_3O_8) both from the same region, 250×10^6 years old, show a N^{15} abundance of 0.549 ± 0.015 and 0.546 ± 0.009, respectively. Attempts at measuring the N^{15}/N^{14} ratio in old non-radioactive minerals have failed owing to insufficient occluded gas for analysis. The available data suggests that the nitrogen may have been a component of the minerals at the time of their formation, and that the N^{15}/N^{14} ratio increased as a result of the more rapid diffusion of the lighter isotope. Alternative hypothesis based on nuclear reactions will be discussed.

L5. Packing Fractions of Fe^{56}, Ni^{58}, and Ni^{60}.* HENRY E. DUCKWORTH AND HOWARD A. JOHNSON, *Wesleyan University.*—A large Dempster-type double-focusing mass spectrograph has been used to photograph the doublets Si^{28}-$Fe^{56}/2$, Si^{29}-$Ni^{58}/2$, and Si^{30}-$Ni^{60}/2$. The ions were obtained from a high frequency discharge between a silicon electrode and one of stainless steel, containing about 10 percent nickel. Exposure times of 30–40 seconds were adequate for the first doublet while exposure of 3–5 minutes were needed for the other two. The separations Si^{28}-Si^{29} and Si^{29}-Si^{30}, assumed to be integral, provided suitable mass scales. The following packing fraction differences were found: Si^{28}-Fe^{56}, $\Delta f=(3.32\pm0.02)\times10^{-4}$ from five photographs; Si^{29}-Ni^{58}, $\Delta f=(3.07\pm0.03)\times10^{-4}$ from five photographs; Si^{30}-Ni^{60}, $\Delta f=(2.90\pm0.01)\times10^{-4}$ from eight photographs. The probable errors are based on the internal consistency of the data. No experiments were done to determine the effect of pressure on the doublet spacing, but all exposures were taken with the pressure less than 5×10^{-6} mm in the analyzing region. Assuming the packing fractions $Si^{28}=-(4.8\pm0.07)\times10^{-4}$, $Si^{29}=-(4.6\pm0.07)\times10^{-4}$ and $Si^{30}=-(5.6\pm0.10)\times10^{-4}$, as given by H. A. Bethe and R. F. Christy, one can calculate $Fe^{56}=-(8.1\pm0.08)\times10^{-4}$, $Ni^{58}=-(7.9\pm0.08)\times10^{-4}$ and $Ni^{60}=-(8.7\pm0.10)\times10^{-4}$. Typical doublets will be shown and the agreement between these values and other recently reported ones will be discussed.

* This work was supported by the AEC.

L6. Co-60 γ-Ray Penetration through Large Masses of Water. GLADYS R. WHITE,* *National Bureau of Standards* (Introduced by U. Fano).—An experiment was conducted in a 60-foot water tank at the Naval Gun Factory in effectively spherical geometry. Two Co-60 sources of 0.34 and 4.9 curies were used. Dosage was measured at distances from 30 to 180 cm (corresponding to a maximum attenuation of the primary radiation by a factor of $e^{-11.4}=1.1\times10^{-5}$) using sealed Kelley-Koett ionization chambers of the pen type. At short distances the results matched those obtained at M.I.T.[1] The dosage decreases with distance less rapidly than according to an $\exp(-\mu r)/r^2$ law owing to the building up of secondary radiation. The "build-up factor" increases a little faster than linearly. Its largest observed value was approximately 23. The experimental data will be compared with current theoretical predictions.[2]

* Supported by the ONR.
[1] Levin, Weil, and Goodman, M. I. T. Tech Rep. 22, June 15, 1949.
[2] Fano, Hurwitz, and Spencer, Phys. Rev. Feb. 1, 1950.

L7. Integral Relationships between Atomic and Nuclear Quantities. ENOS E. WITMER, *University of Pennsylvania.*—In 1946 the writer[1] stated that hc/e^2 is very probably *exactly* 861. The most recent values of α are consistent with this idea. Integer 861 is $\frac{1}{2}\times42\times41$. This suggests that 42 is an important number, possibly related to the fact that space is three-dimensional. We now note that the binding energy of the deuteron is $4M_p/41^2$ or 2232 kev in excellent agreement with the recent measurements. M_p is the proton mass. The recent accurate determinations of e/m indicate that M_p/m is close to 1836, and we believe it is *exactly* 1836. Using the values of R_∞, N, and c given by Birge in 1945 and these two integral relationships involving 861 and 1836, we can calculate the fundamental atomic constants very accurately. Also it seems probable that the nuclear magnetic moments are in accord

with these ideas about the importance of integers; see Abstract No. SP1 and note the remarkable agreement of the calculated value of the magnetic moment of the proton in Bohr units with the experimental values. Our value of e is $(4.80290\pm0.00020)\times10^{-10}$ e.s.u., and of e/m is $(1.758972\pm0.000073)\times10^{7}$ e.m.u. g^{-1}.

[1] Proc. Nat. Acad. Sci. **32**, 283, 1946.

Discharge in Gases; Mass Spectrometry

M1. A "High Vacuum" Cold Cathode Gaseous Discharge. I. R. SENITZKY, *Signal Corps Engineering Laboratories and Columbia University.*—By suitably combining low d.c. and low r-f voltage, and a magnetic field perpendicular to both electric fields, a cold cathode gaseous discharge is produced at extremely low pressures. In a specially built magnetron, with pressure less than 10^{-7} mm and with a cold uncoated Nickel cathode, a typical situation is the following: 40 volts on anode, 10 microwatts of 3.4 cm r-f power flowing into magnetron, and a magnetic field near 3100 gauss, produce 1.5×10^{-8} ampere direct anode current. Dependence of anode current on magnetic field, r-f power, d.c. voltage, and pressure, is shown. Anode current flows only if magnetic field is within a critical range near cyclotron value, and exhibits one or more maxima within this range. Lower limits exist for d.c. voltage (around 18 volts) and r-f power, below which there is no self-sustained discharge. Anode current increases with r-f power if d.c. voltage is below about 400 volts. Above this voltage, r-f power loses control, and discharge characteristics change. A simple theory is presented, showing that, if electrons leave cathode with zero velocity, a combination of d.c. and non-uniform tangential r-f fields at the cathode is necessary for self-sustained discharge.

M2. Holes and Retrograde Arc Spot Motion in a Magnetic Field. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—If cathode spot current density is 10^{5} amp./cm^2 with a sixth ionic, 10^{23} ions arrive per cm^2 per sec. With spot surface atomic density 10^{16}/cm^2, the area occupied by a surface atom emits five electrons and collects one ion every 10^{-7} second on the average. Ions transport both vacant energy levels to the electronic configuration and energy to maintain spot excitation (high electron "temperature"). A fraction of the current in the spot must thus consist of holes which increases with hole lifetime. It is proposed that as in the anomalous Hall effect the holes are deflected in the "wrong" (retrograde) direction, nascent electron emission following the effectively positive holes, whence ions later formed by collision outside the spot return bringing holes and excitation to a region shifted in the retrograde direction. At high pressure photons could contribute substantially to spot excitation without hole generation whence reversal of motion as observed. Increased magnetic field gives larger hole deflection and so greater retrograde velocity and higher reversing pressure as observed. Very large increases slow down and then reverse the motion possibly because the pre-annihilation trajectory doubles back on itself, hole effects thereby progressively cancelling out.

M3. Role of Cathode Temperature in a Glow Discharge. HAROLD JACOBS AND JACK MARTIN, *Evans Signal Laboratory.*—Experiments were conducted to study the properties of a glow discharge tube* utilizing an oxide coated cathode and argon gas. The sparking potential was found to decrease with increasing cathode temperature (300°K–750°K). However, the regulation voltage showed a slight rise, as the temperature of the cathode was increased in this range. The current density decreased in the same interval. The effect is attributed to metastable states of the gas.

* Acknowledgment should be made to Mr. K. M. McLaughlin, of RCA, Harrison, New Jersey, for suggestions in the design of the experimental tubes.

M4. Further Measurements of Formative Time Lags of Spark Breakdown in Air.* L. H. FISHER AND B. BEDERSON, *New York University.*—Previously[1] reported measurements of the formative time lags of spark breakdown in a plane parallel gap in air have been extended with an improved power supply. With the new circuit, the delays can be measured extremely close to the threshold voltage for breakdown. The new measurements have been carried out as a function of pressure, plate distance, and over-voltage. The formative time lags very close to threshold have been found to be of the order of 100 microseconds and longer. These lags are at least ten times as long as those we have previously reported. Varying the approach voltage by as much as 4 kv does not affect the results appreciably. The number of initiating electrons at the cathode has been varied by a factor of ten and this again does not materially alter the results.

* Supported by the ONR and the Research Corporation.
[1] L. H. Fisher and B. Bederson, Phys. Rev. **75**, 1615 (1949).

M5. Interpretation of Formative Time Lags of Spark Breakdown in Air at Low Overvoltages.* B. BEDERSON AND L. H. FISHER, *New York University.*—An attempt has been made to account for the long formative time lags observed in the passage of an electric spark in air in a plane parallel gap by (1) secondary emission by positive ions at the cathode, and (2) by the enhancement of field intensified ionization due to field distortion.[1] For mechanism (1) an equation for electron and positive ion charge densities as a function of position, time, and overvoltage is developed (no field distortion), and it is assumed that the time for a spark to form is the time for the positive ion density to reach a critical value at the anode. It is then assumed breakdown could proceed by the streamer mechanism. It is shown that mechanism (1) is not in accordance with the experimental data as regards the variation of the time lags with pressure, plate distance, and overvoltage. For mechanism (2), the positive ions created by the primary electron avalanches produce a locally strengthened field upon approaching the cathode, thus magnifying Townsend's first coefficient in that region. Thus an effective secondary mechanism is produced. The transient equation for the growth of the current by mechanism (2) is more in accordance with the experimental facts. The role of photo-ionization in mechanism (2) will be discussed qualitatively.

* Supported by the ONR and the Research Corporation.
[1] See, for example, Varney, White, Loeb, and Posin, Phys. Rev. **48**, 818 (1935).

M6. Electron Density and Spectroscopic Measurements in Metal Vapor Afterglows. P. DANDURAND AND R. B. HOLT, *Harvard University.*—Measurements have been made of the rate of electron density decay following the removal of the excitation for pulsed microwave (3000 mc/sec.) discharges through cesium and mercury vapor. Following S. C. Brown's technique, the shift of the resonant frequency of a microwave cavity due to the presence of the electrons was observed as a function of time. Simultaneous observations of the emission spectrum of the discharge plasma were made by means (1) of a high speed mechanical shutter (resolving time 2 microseconds) plus a high intensity spectrograph and (2) of a pulsed photo-multiplier equipped with various optical filters. As might be expected, electron density and light intensity measurements indicated an exponential decay at low pressures (below 0.2 mm) in both cases. The data allow the calculation of ambipolar diffusion coefficients according to the usual theory. Interpretation of electron density data in metal vapors at high pressures is complicated by the fact that the expected collision frequency is of the same order of magnitude as the frequency of the search signal. This effect has been investigated theoretically and experimentally. The light intensity measurements, since they are independent of electrical

properties, give a check on the electron density measurements in this range.

M7. Temperature Variation of Mass Spectra of Hydrocarbons. ROBERT M. REESE, VERNON H. DIBELER, AND FRED L. MOHLER, *National Bureau of Standards.*—Intensity distribution in mass spectra of hydrocarbons is known to depend markedly on the temperature of the ionization chamber.[1] We have observed ion current per unit pressure and relative intensity in the temperature range 50° to 300°C for selected mass peaks in the spectra of paraffins, olefins, acetylenes, and cyclics. Data were obtained with a Consolidated mass spectrometer equipped for temperature control of the ionization chamber by taking measurements as the temperature increased from room temperature to 300°C. The pattern coefficient (ratio of a mass peak to the maximum peak in the spectrum) for the molecule ion in general decreases rapidly with increasing temperature and the change for most other peaks is small or zero. The pattern coefficient for the molecule ion of *n*-butane decreases from 20 percent at 100°C to 10 percent at 300°C, for *n*-hexane it changes from 32 percent to 13 percent, for 2,3-dimethylbutane it changes from 10 percent to 2.9 percent and for 2,5-dimethylhexane it changes from 15 percent to 2.4 percent. The change is less for unsaturated hydrocarbons and cyclics. Results will be presented in tables of percent change per degree at 250°C.

[1] C. E. Berry, J. Chem. Phys. **17**, 1164 (1949).

M8. The Non-Magnetic Radio Frequency Mass Spectrometer. WILLARD H. BENNETT, *National Bureau of Standards.*—The non-magnetic radio frequency mass spectrometer has been developed and refined considerably beyond the form described previously.[1] A three-stage form of this instrument has been developed which eliminates all harmonics, and by so doing attains much greater sensitivity. The instrument has advantages in ordinary gas analysis because of its simplicity. It has advantages in studies of solids because it uses no slits and all the ions coming from a solid surface are used in the analysis. The instrument can be used in the analysis of the ions present in gaseous discharges because no strong magnetic field is needed for the operation of the instrument. The results of some measurements will be presented which demonstrate the great flexibility and sensitivity using both positive and negative ions, for determining the ions arising either at a solid surface or in the vapor phase, and in distinguishing between the points of origin of each mass component.

[1] Willard H. Bennett, Phys. Rev. **74**, 1222A (1948).

M9. The Omegatron. J. A. HIPPLE, H. SOMMER, AND H. A. THOMAS, *National Bureau of Standards.*—The recently reported[1] method of measuring the mass-to-charge ratio of ions by measuring their cyclotron resonance frequency in a magnetic field will be discussed. With the first model a resolution of 1 part in 5000 has been attained for N_2^+ and 1 part in 10,000 for H^+—these figures being based on the width of the peak at the base. A field of approximately 5000 gauss was used and the ions at resonance are accelerated until they attain an orbit radius of 0.9 cm before striking the ion collector. The effect on resolution and intensity of adjustment of the various parameters will be described. A revised model which will be located in a more uniform magnetic field is nearing completion and the initial performance characteristics of this model will be presented.

[1] Hipple, Sommer, and Thomas, Phys. Rev. **76**, 1877 (1949).

M10. Total Ionization of Hydrocarbons from Mass Spectral Data. FRED L. MOHLER AND STAFF OF MASS SPECTROMETRY SECTION, *National Bureau of Standards.*—Mass spectral data[1] are commonly presented in terms of the intensity of each peak relative to the maximum peak and the sensitivity (current per unit pressure in the gas reservoir) for the maximum peak. The sensitivity for mass 43 of *n*-butane is also given and the ratio of the sum of the mass peaks times sensitivity for the compound to the corresponding product for *n*-butane gives the total ionization relative to *n*-butane. A diaphragm type of micromanometer in which small displacements are measured electrically has for the first time made it possible to measure sensitivity of the heavier hydrocarbons with reliability. It is found that the total ionization of isomers is nearly equal or at least falls in a narrow range. Thus, for the 35 nonames the mean value of total ionization is 1.94 ± 0.13 relative to *n*-butane; for 18 octanes, 1.79 ± 0.06; for 17 C_8H_{16} cyclics, 1.57 ± 0.06; for 9 heptanes, 1.69 ± 0.05, for 5 hexanes, 1.54 ± 0.06; for 14 hexenes, 1.46 ± 0.05; 6 pentenes and 11 C_5H_8 isomers both give 1.03 ± 0.04.

[1] Catalog of Mass Spectral Data API Research Project 44.

M11. Ionization Potentials of some Molecules Commonly Used in Counters. RAYMOND KAUFMAN, *New York University.*—Ionization potentials of some molecules were determined experimentally by the electron bombardment method. Electrons were accelerated between a cathode and grid and retarded between the grid and a plate. The electron current stream was measured with a high sensitivity galvanometer in conjunction with a d.c. amplifier. By plotting curves of grid potential *versus* plate current when the gas was present in the tube, it was possible to determine by the drop in current when ionization took place. In order to calibrate the equipment, some gases whose ionization potentials are known were measured along with the unknowns. The following ionization potentials were observed: Neon 20.8 volts; methane 15.2; ethyl acetate 9.5; ammonia 10.1; argon 15.4; boron trifluoride 10.25. Butane showed a curve with a break at 10.4 and propane at 11.0 but the interpretation of this is probably complicated by dissociation phenomena.

Acoustics; Atmospheric Physics; Astrophysics

N1. Analysis of Multiple Echo Effect Arising from the Release of a Stored Wave Train. LOUIS GOLD, *University of Colorado.*—A generalized theoretical treatment is presented of a problem which has direct application to the phenomenon of multiple echo patterns as employed for propagational studies of high frequency sound waves in various media. An analysis is made of the functional dependence of the number of observable echoes in terms of a prescribed threshold sensitivity db^* of a detecting device, and the storage medium parameters, which are the effective absorption coefficient α and the boundary reflection coefficient R. The equation derived is

$$N=\left(\frac{db^*}{10}+\log\frac{R}{1-R}\right)\Big/\left(\log R-\frac{2\alpha d}{2.303}\right),$$

where d is the length of the storage system. This relation has values $Ropt$ for which N is a maximum, and it is shown that $N_{max}=1/1-Ropt$. The solutions for N_{max} are actually difficult to express explicitly since $Ropt$ must be evaluated from the condition for a maximum

$$\frac{Ropt}{1-Ropt}\log Ropt+\log(1-Ropt)-\frac{\alpha d\log e}{1-Ropt}=db^*/10.$$

N2. On the Non-Specular Reflection of Sound. VICTOR TWERSKY, *New York University.*—The non-specular reflection of plane waves of sound by various rigid, non-absorbant, nonporous surfaces composed of either semicylindrical or hemispherical bosses (protuberances) on an infinite plane has been analyzed. Exact solutions for the problem of the single

boss and a plane wave at arbitrary angle of incidence have been derived through consideration of a cylinder or sphere and two simultaneously incident "image waves." Finite patterned distributions of such bosses were then treated and the far-field solutions obtained subject to the restriction that the secondary excitations be neglected. (The equivalent problems for cylinders and spheres were also considered as well as the second-order solution which takes into account interactions of nearest neighbors.) These solutions were found to contain the characteristic Fraunhofer terms for a grating or lattice. The asymptotic solutions for the single bosses ($Kr \gg 1$, $Ka < 1$) were then extended to consider finite and infinite uniform random distributions. The solutions for the finite distributions were found to contain the characteristic Fraunhofer terms for similarly shaped apertures. The solutions for the infinite distributions were found to be remarkably similar when expressed in terms of the volumetric departure from the plane per cm² of distribution.

N3. Analysis of Acoustic Scattering by Variational Methods. ALFRED LEVITAS, *Syracuse University.*—The variational methods discussed in a previous abstract by Melvin Lax have been applied to the scattering and absorption of sound by a strip of absorbing material placed on a hard wall. These results have been compared with an exact calculation by Pellam[1] and the results are accurate to within 1.5 percent. This problem differs from most scattering problems in that the perturbation exists solely on the surface. An integral equation is obtained for the surface pressure. This integral equation is used to construct a variational principle for the scattering amplitude. The scattering cross section is obtained by integrating the absolute square of the scattering amplitude over all directions. The total cross section is proportional to the scattering amplitude in the forward direction and therefore available variationally. Because the scattering surface is infinite, the forward direction is the direction of specular reflection. Maximum absorption per unit panel width is shown to occur when the panel-width is zero. Maximum scattering per unit panel width is shown to occur when the ratio of panel width to wave-length is approximately two to three.

[1] J. R. Pellam, J. Acous. Soc. Am. 11, 396 (1940).

N4. The Pressure at Which a Rarefaction Wave Initiates Cavitation in Sea Water.* A. B. ARONS, *Woods Hole Oceanographic Institution and Stevens Institute of Technology.*—Measurements at various ranges of the amplitude of the surface reflection of the shock wave produced by an underwater explosion provide evidence to support the view that the rarefaction wave causes bulk cavitation in sea water at positive absolute pressures of about 8 lb./in.². This would imply that, under these circumstances, the cavitation bubbles are formed by the evolution of dissolved gases rather than by the tensile "fracture" of the liquid, and that the pressure within the cavitation bubbles is therefore considerably higher than the vapor pressure of water at the temperature of the experiment.

* Work supported by the Navy Department, Bureau of Ordnance.

N5. Refraction Effect in Interferometry of Boundary Layer of Supersonic Flow along Flat Plate.* G. P. WACHTELL, *Princeton University.*—Large density gradients, as in the boundary layer of the supersonic flow along a flat plate, cause curving of the light rays used in interferometry. This curving produces an error in interferometric evaluation of the gas density. Taking into account the optical system between boundary layer and photographic plate,** it is found that the error depends on h, the distance of the focal plane from the channel exit window, and vanishes, in first approximation, when h is one-third of the distance, D, between channel windows. The thickness, t, of the exit window and higher order terms depending on higher powers of D and higher derivatives of density may produce an appreciable error even when $h = D/3$. In the Palmer Laboratory wind-tunnel, however, where $D = 3$ in., $t = 1$ in., the error for density gradient $< 3 \times 10^{-3}$ g cm^{-4}, and second derivative $< 2 \times 10^{-1}$ g cm^{-5}, is negligible when $h = D/3$.

* Performed under a contract with the ONR.
** D. Bershader and G. P. Wachtell, Phys. Rev. 76, 880 (1949).

N6. Abnormally Low Molecular Rotation and Upper Atmosphere Temperatures. LEWIS M. BRANSCOMB, *Harvard University.*—Rotational profiles of night sky band spectra have been interpreted as indicating consistently lower upper atmosphere temperatures than are obtained from almost every other source of information. This apparent inconsistency may be removed if we assume the night sky bands are excited by electron impact, for all the conditions will then be fulfilled for the occurrence of abnormally low rotation in the excited molecules, as predicted by Oldenberg.[1] An experiment is described which verifies this prediction. For gas temperatures from 400 to 670°K rotational temperatures from the second negative bands of O_2^+ were found by two methods of analysis to be in qualitative agreement with the predicted relation $T_{rot} = T_{trans}\, B'/B''$, where B'/B'' is the ratio of the inertias in the initial and final states of the excitation process. The upper atmosphere temperature problem is discussed in the light of these results, with special reference to temperature measurements from night sky and auroral spectra. The effect of this change in inertia on the excitation of the Schumann-Runge bands of O_2 and the identification of these bands in the night sky is also discussed.

[1] O. Oldenberg, Phys. Rev. 46, 210 (1934).

N7. The Distribution of Atomic and Molecular Oxygen in the Upper Atmosphere. H. E. MOSES* AND TA-YOU WU,** *Columbia University.*—Theoretical calculations are carried out to determine the distribution of atomic and molecular oxygen and the temperature in the region of 100–125 km. It is assumed that solar radiation is responsible for photodissociation of molecular oxygen and (as justified from theoretical considerations) that the recombination of the atoms by twobody radiative processes is much more probable than by threebody collisions. From the conditions for a steady state, which are that for any given volume (a) the number of dissociations equals the number of recombinations and (b) in these processes the energy of radiation which is absorbed equals that of the radiation which is emitted, together with an appropriate form of the barometric equation, one can calculate the number density of molecular oxygen, the number density of atomic oxygen, and the temperature, all as functions of height, provided that the temperature and temperature gradient are known at one height. The results of the calculations indicate that dissociation is not complete until around 200 km and that the maximum number density of atomic oxygen (which occurs at about 100 km) is about 10^{11}/cm³ and is thus considerably less than that estimated by previous workers.

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** Present address: National Research Council of Canada, Ottawa.

N8. High Dispersion Studies of the Solar Spectrum.* ROBERT M. CHAPMAN, JOHN H. SHAW, AND DUDLEY WILLIAMS, *The Ohio State University.*—A high dispersion, Pfund-type prism-grating spectrograph has been used to re-examine the solar spectrum in the region between the visible and 6μ. Several thousand absorption lines, some of solar and some of terrestrial origin have been observed. Curves showing telluric absorption bands due to O_2, CO_2, CO, N_2O, and HDO will be exhibited. The CO absorption has been observed on

numerous occasions and hence CO must be regarded as a "permanent" constituent of the atmosphere in this locality. The bands due to N_2O and HDO are well resolved into rotational lines. The possibility of the existence of other atmospheric constituents will be discussed.

* This work was done under Contract between The Ohio State University Research Foundation and Watson Laboratories of the Air Materiel Command, Red Bank, New Jersey.

N9. Radiation Equilibrium in the Stratosphere.* GILBERT N. PLASS AND JOHN STRONG, *The Johns Hopkins University.*—The outward radiation emitted from the stratosphere by the 15μ CO_2 and O_3 bands is less than 260 microcalories/cm² sec. The radiation absorbed in the stratosphere by the O_3 band at 9.6μ from the blackbody radiation from the earth's surface, minus the O_3 emission, is about 120 microcalories/cm² sec. The ozone in the stratosphere also absorbs ultraviolet radiation from the sun. These three effects together with the losses from 50μ H_2O band give the main contribution to the heat balance in the stratosphere. The heat loss from the 15μ CO_2 band has been calculated assuming that the line width is given by the Lorentz pressure broadening formula and is directly proportional to the pressure. The calculation and results will be described. It is found that the radiation from a given optical thickness of emitting gas is *independent* of its height, giving a strong differential cooling of the lower layers. An equilibrium characterized by constant temperature at all heights is possible by balancing the radition lost by the 15μ bands against that absorbed by the ozone. The above ideas help to understand the discontinuity in temperature lapse rate at the tropopause and the discrepancy between experimental and theoretical lapse rate in the tropopause.

* This work was supported in part by the ONR.

N10. On the History of the Noble Gases. P. MORRISON, *Cornell University.*—Recent work on cosmic isotope abundance gives fairly reliable fractionation factors f for the noble gases, where f is the ratio of the observed terrestrial abundance to the interpolated cosmic abundance for a given gas. The course of the f curve as a function of atomic weight shows a very steep dependence of f on A for the light gases, but not for the heavy ones. If diffusion of positive-energy molecules out of an attracting gravitational field is the main mechanism for noble-gas loss, this implies two main stages of assembly for the planetary material. All gases were lost in the first stage at a rather low temperature from a very diffuse mass; in the second stage temperature and gravitational acceleration both increase markedly. Limits can be given for the temperature and density variations in time. The implications of such data for the present theories of planetary formation are examined. Some extension is made to compound-forming elements and to other planetary bodies. The large terrestrial excess of A^{40} is supplied by the K-capture of potassium. The conditions imposed by this process upon the early history of the earth's crust are considered for a range of values of the not-very-well-known branching ratio.

N11. The Temperature in an Accreting Planet. A. E. BENFIELD, *Harvard University.*—The temperature of a planet growing by accretion rises as a result of the gravitational field in and near it. At first, when the gravitational field is small, the temperature is low. Later, the temperature at the *surface* of the planet becomes high, due to the kinetic energy of the incoming accreting material, as has already been shown.[1-3] During its growth a temperature increase in the *interior*, however, also takes place, due to its compression by the accumulating overyling material. A calculation based on thermodynamics, using the computations of astrophysicists and information about the properties of matter at high pressures, indicates a temperature not exceeding 2000°C at the center of a planet, having the size of the earth, due to the effect of compression alone.[3] This does not seem high enough to ensure melting, but other factors will contribute toward raising the temperature. A considerable uncertainty exists in these calculations due to our ignorance of the behavior of materials at pressures as high as 3×10^6 atmospheres.

[1] D. ter Haar and H. Wergeland, Kgl. Norske Vid. Sels. Forhandlinger Bd. 20, No. 14, 52 (1948).
[2] F. Hoyle, M.N.R.A.S. **106**, No. 5, 406 (1946).
[3] A. E. Benfield (in press).

Semi-Conductors

OA1. Nucleon-Bombarded Silicon. K. LARK-HOROVITZ, M. BECKER, R. E. DAVIS, AND H. Y. FAN, *Purdue University.*—The resistivity of P and N type silicon increases under nucleon bombardment.[1] Low resistivity silicon (~.03 ohm-cm) was investigated before and after intensive neutron irradiation in the Oak Ridge reactor.** The resistivity increased to over 10,000 ohm-cm. Heat treatment cycles of irradiated silicon show a resistivity *vs.* temperature curve with a slope indicating deep-lying impurity levels in the forbidden band (>0.7 to 0.8 ev). The transmissivity increases at $\lambda>2\mu$ after irradiation. There is a strong absorption band around 1.6μ (0.7 ev), barely detectable in unbombarded material. This confirms the interpretation of the electrical measurements and is confirmed also by a greater absorption of the bombarded material near the band edge, due to the production of a greatly increased number of absorbing centers effective at $\lambda<2\mu$.

* Supported in part by a Signal Corps contract.
** We are indebted to J. C. Pigg (O.R.N.L.) for these exposures in the reactor.
[1] K. Lark-Horovitz *et al.*, Phys. Rev. **73**, 1256 (1948); **76**, 442 (1949).

OA2. Impedance Characteristics of Grain Boundaries in High Resistivity *N* Type Germanium.* N. H. ODELL AND H. Y. FAN, *Purdue University.*—The d.c. electrical properties of these barriers are discussed in the accompanying paper by Taylor and Fan. Impedance characteristics have been measured** as functions of frequency and temperature. The voltage applied to the barrier was kept small compared with kT. Measurements were made between 400 kilocycles and 4 megacycles. It was observed that barrier capacity computed from impedance measurements is independent of frequency at temperatures below 0° centigrade. At higher temperatures, the capacity is observed to decrease as signal frequency increases. For small applied voltages, the barrier impedance should be independent of frequency if the current across the barrier is carried by electrons, the sample being N type. This agrees with measurements below 0° centigrade. With increasing temperature, the share of the current at the barrier carried by holes increases. It can be shown that barrier impedance of hole current should show frequency dependence. For the sample used, this seems to be the case above 0° centigrade. It was also observed that barrier capacity decreases with decreasing temperature.

* This work was assisted by Signal Corps contract.
** We wish to thank Professor R. P. Siskind, E. E. Department, for discussions and experimental facilities.

OA3. Efficiency of γ-Counters. R. J. HART, K. RUSSELL, AND R. M. STEFFEN, *Purdue University.**—The local efficiency of cylindrical γ-counters with Bi-cathode was measured with a well-collimated γ-beam of different energy. The intensity of the γ-beam was calibrated with an anthracene scintillation counter. The amount of radiation absorbed in the anthracene was detected with an efficiency of (96±6) percent. It has been

shown that the local efficiency $\epsilon(x, y)$ of the Bi counter (x = distance of the incident beam from counter-axis, y = distance from middle section of the counter) varies considerably; $\epsilon(0, y)$ being much smaller than $\epsilon(r, y)$ (r = inside radius of counter). The γ-efficiency for cylindrical counters $\epsilon(x, 0)$ can be calculated approximately as $\epsilon(x, 0) = \mu[\{(r+d)^2 - x^2\}^{\frac{1}{2}} - [(r^2 - x^2)]^{\frac{1}{2}}\}$; μ, coefficient of γ-absorption in Bi, d, the effective thickness of the Bi-cathode. The agreement with the measured values of $\epsilon(x, 0)$, corrected for the finite width of the γ-beam is good. The calculated average efficiency $\bar{\epsilon} = (2/rL) \int_0^r \int_0^{L/2} \epsilon(x, y)\, dx\, dy$ (L: length of counter), also agrees well with $\bar{\epsilon}$ obtained by coincidence measurements.

* Supported by contract with ONR.

OA4. Temperature Dependence of Photovoltaic Effects on *P-N* Barriers in Germanium.* H. Y. FAN AND M. BECKER, *Purdue University.*—Photo-voltaic effects on germanium *P-N* barriers produced by deuteron bombardment are investigated from room temperature to −190°C. Monochromatic light of different wave-lengths is used. For all wave-lengths used, from 0.9μ to 1.9μ, the photo-voltage increased greatly with decreasing temperature: about 5 times from 20°C to 0°C and about 80 times from 0°C to −70°C. With light pulses rising to full intensity in 15μ sec. and taking the same time to fall off, no time lag in the rise and fall of photo-voltage can be observed both at 20°C and at 0°C. At −70°C delays in build up and falling off is observed, with a time constant ~130 μsec. The shape of photo-voltage pulses seems to be independent of the wave-length of the light, although at the short wave-lengths used the light is absorbed in a very thin layer, whereas light of 1.8μ produces excitation throughout the thickness of the sample.[1]

* Work assisted by Signal Corps contract.
[1] M. Becker and H. Y. Fan, Phys. Rev. **76**, 1530 (1949).

OA5. D.C. Characteristics of High Resistance Barriers at Crystal Boundaries in Germanium.* W. E. TAYLOR AND H. Y. FAN, *Purdue University.*—Grain boundaries in high resistivity *N* type germanium are often found to have a high resistance to the passage of current in either direction. The current-voltage characteristic in both directions resembles the back characteristic of the germanium rectifier. Similar results were observed by Benzer[1] with a mechanical germanium-germanium point contact. The high resistance of grain boundaries can be removed by nucleon bombardment to *P* type; by converting the material back to *N* type by heat treatment the original condition can be restored.[2] Pearson also has reported the removal of such high resistance regions by heat treatment methods. The high resistance can be explained by natural barriers on both sides of the grain boundary resulting from localized energy states within the energy gap. For applied voltages smaller than kT the current is given by $i = ATe - e\varphi/kT$ Vap, where $e\varphi$ is the energy difference between the top of the barrier and the Fermi level. Measured values of $lu(kT)$ in the range from 20°C to −50°C give a straight line with a slope corresponding to about 0.5 ev for the value of φ.

* Assisted by a Signal Corps contract.
[1] S. Benzer, "Ge-ge contacts," Progress Report, Department of Physics, Purdue University, November, 1946.
[2] Lark-Horovitz and Davis, "Bombardment of semiconductors by nucleons," Progress Report, Department of Physics, Purdue University, January, 1948.

OA6. Resistivity of Semiconductors Containing both Acceptor and Donator Impurity Levels.* C. S. HUNG AND V. A. JOHNSON, *Purdue University.*—The Hall coefficient and resistivity have been measured as functions of temperature down to about 10°K for a number of germanium samples. For samples of intermediate purity, the mobility behavior indicates that the resistivity below 100°K is almost entirely due to scattering of carriers by impurity ions. As the temperature decreases to very low values, the resistivity becomes increasingly greater than the value calculated from the Conwell-Weisskopf formula[1] on the assumption that all impurity ions have the same sign and thus that their number is given directly by the Hall coefficient. However, the formula predicts the observed resistivity satisfactorily on the assumption that both acceptor and donator impurity atoms are present in the material. For example, in *N*-type material, N_p acceptor impurity atoms would take up an equal number of electrons from donator atoms, thus producing N_p negative impurity ions and N_p positive ions in addition to the n positive ions corresponding to n conduction electrons. The scattering of carriers is due to the $n+2N_p$ impurity ions rather than to the n ions whose presence is indicated by the Hall coefficient.

* Work assisted by Signal Corps contract.
[1] E. Conwell and V. F. Weisskopf, Phys. Rev. **69**, 258 (1946).

Biophysics and High-Polymer Physics

OB1. A Large Water-Prism Monochromator. R. B. SETLOW AND D. J. FLUKE,* *Yale University.***—The determination of the action spectrum of protein molecules, viruses, and bacteria quite often requires the use of high intensity ultraviolet light. The investigation of possible fine-structure in the action spectrum also demands that the monochromator used to isolate a given wave-length interval be capable of passing a 30A band when using slits of the order of one millimeter wide. The limitation on the slit width is set by the use of capillary-arc light sources of about this width.[1] A monochromator satisfying these conditions will be described in detail. The focussing elements are spherical aluminized-mirrors of 25 cm diameter and 50 cm focal length. The dispersing element is a 60° water prism with quartz side-faces. The use of water as the prism material gives adequate dispersion and negligible absorption down to 2000A. Wave-length variation is obtained by rotation of the prism about a vertical axis. The monochromator is comparatively inexpensive.

* U. S. Public Health Fellow.
** Assisted by AEC.
[1] R. M. Hoffmann and F. Daniels, J. Am. Chem. Soc. **54**, 4226 (1932).

OB2. An Apparatus for Ultraviolet Irradiation of Viruses at the Temperature of Liquid Hydrogen. DONALD J. FLUKE,* *Yale University.***—A technique for monochromatic ultraviolet irradiation of viruses at liquid air and liquid hydrogen temperatures has been worked out. The viruses are deposited in small areas of dried film on aluminum foil covering a cylindrical brass flask containing the refrigerant. The upper section of the flask is a stainless steel tube of considerably smaller diameter, working through a Wilson seal in the top plate of an outer vacuum envelope. A quartz window in one side of the outer envelope permits the ultraviolet beam from a monochromator to be directed upon the several areas on the inner flask, the Wilson seal affording change of specimens. A radiation shield cooled by liquid air effectively surrounds the inner flask. The top plate joins the rest of the outer envelope by a gasket seal, so that the inner flask and its shield can be withdrawn for deposition and recovery of the specimens.

* U. S. Public Health Research Fellow.
** Assisted by the AEC.

OB3. Cyclotron Bombardment of Enzymes and Viruses. ERNEST POLLARD AND F. FORRO, JR.,* *Yale University.***—A technique for deuteron and alpha-particle bombardment of dry enzymes and viruses has been developed. The basic requirement is a beam which is somewhat defocussed so that it is uniform across an area of about $\frac{3}{4}$ inch. This is achieved by a deflecting magnet and a long evacuated tube so that irradiation takes place two meters from the magnet. The dry specimens are introduced on coverslips placed on a copper disk which prevents undue temperature rise. Exposure is by

means of an electrically operated shutter. The beam is measured both on the entire bombardment chamber and also by a Faraday cup. The ionization density of the beam can be varied by means of foils placed over the exit port for the beam. The inactivation cross section so obtained correlates with molecular dimensions and offers promise as a method of measuring the internal structure of viruses.

* Public Health Research Fellow.
** Assisted by the AEC.

OB4. Double Crystal and Slit Methods in Small Angle X-Ray Scattering.* PAUL KAESBERG, W. W. BEEMAN, AND H. N. RITLAND, *University of Wisconsin.*—An angular resolution of about 10 seconds of arc is obtainable in small angle scattering experiments using a calcite double crystal spectrometer in the parallel position and Cu K_α radiation. However, the rather large wing background at large angles makes the detection of radiation from weakly scattering materials difficult. Of the order of 10^6 counts per second are detected with a stationary, water cooled copper target and parallel crystals. Wing backgrounds do not fall much below 10^2 counts per second. Wing heights may be considerably reduced by the addition of a third calcite crystal placed parallel to the second crystal and rotated with it. With this modification the double crystal spectrometer is a useful instrument for most scattering experiments in which extremely high resolution is desired. However, it is inferior to a slit system and Geiger counter arrangement when lesser resolution but high sensitivity are required. A slit instrument with an angular resolution of 4 or 5 minutes of arc provides an effective incident flux of more than 10^6 counts per second while wing intensities may be as low as 1 count per second.

* Supported by the ONR and the Wisconsin Alumni Research Foundation.

OB5. The Shapes and Hydrations of Several Protein Molecules in Solution.* W. W. BEEMAN, PAUL KAESBERG, AND H. N. RITLAND, *University of Wisconsin.*—Using the slit collimator and Geiger counter described in the previous abstract, the radii of gyration of several protein molecules in dilute aqueous solution have been determined from the angular distribution of the small angle x-ray scattering. Asymmetry factors can be calculated with the help of the known molecular volumes. Hydrations may also be estimated from the asymmetries and the frictional ratios. The molecules to be discussed are lysozyme, $R=16.0$A; β-lactoglobulin, $R=24.6$A; ovalbumin, $R=24.0$A; bovine hemoglobin, $R=23.9$A; bovine serum albumin, $R=26.6$A; and human γ_2-globulin, $R=37.0$A. Some possibilities and limitations of the method will be pointed out.

* Supported by the ONR and the Wisconsin Alumni Research Foundation.

OB6. Statistical Theory of Volume Effect in a Long Chain Molecule. CHAN-MOU TCHEN, *National Bureau of Standards.*—The purpose of this paper is to find the non-Gaussian distribution function of the distance between the endpoints of a material flexible chain, by eliminating certain configurations containing overlaps of volume. To this aim, first a continuous Markoff's probability function is calculated in order to study the interaction between an arbitrary pair of points on the chain, for a given distance r between the endpoints. Second, we consider the cross-interaction acting upon a given pair of points by the presence of other close points. Such cross-interactions are manifested in the entanglements of the loop or loops which have to be formed in order to have a close approach between the given pair of points. The *mechanism of entanglements of loops* is studied by investigating a new probability function called "*cross-interaction probability*" which is a more general one than the Markoff's probability function. It is found that a loop containing a large number of links will have a large number of configurations, and hence will have more chances to escape any entanglement than shorter loops. The ratio of the non-Gaussian distribution for the chain with volume effect to the Gaussian distribution for the chain without volume effect is found to be constant $\exp(-v^*)$, where: $v^*=C_2(n)^{\frac{1}{2}}\exp(-z^2)$, $z^2=(3/2)(r^2/nb^2)$ with $n=$number of links, $C_2=(b_1/b)^3$, $b=$length of one link, and $b_1=$a critical distance of interaction. From the above non-Gaussian distribution function, the most probable values of the square distance between the endpoints has been calculated: the ratio of this value in a chain with volume effect to the same value in an ideal chain without volume effect is found equal to $1+C_2(n)^{\frac{1}{2}}e^{-1}$ for small values of the parameter $C_2(n)^{\frac{1}{2}}$, and equal to $\ln[C_2(n)^{\frac{1}{2}}]$ for large values of the parameter.

OB7. Plasticity and Elasticity: Some Fundamental Concepts. M. L. HUGGINS, *Eastman Kodak Company.*—Viscosity in simple liquids and plastic flow and elasticity in metals and in high polymers are discussed with the aid of energy diagrams for simplified models. The essential requirement for long-range elasticity is the possibility of reversible shifts of parts of the molecules, relative to neighboring molecules. For high elasticity without plastic flow, some part of every molecule must be permanently prevented from moving, relative to some part of an adjacent molecule, either by forces too strong to be broken in the time available by the temperature motions, aided by the applied stress, or by the cooperative action of several (or many) weak forces. Under certain conditions, several small energy humps are equivalent to a single large one. Oriented and crystalline regions can thus act effectively as cross-links. Plastic flow occurs if some molecules are not locked at any point with adjacent ones.

OB8. Infra-Red Spectra of Some Fibrous Protein in Polarized Radiation. MARTIN GOLDSTEIN AND RALPH S. HALFORD, *Columbia University.*—Infra-red spectra in polarized radiation have been obtained for representative members of the three classes of fibrous proteins. The region from 3 to 6 microns was studied with a CaF_2 prism, that from 6 to 14 microns with a rocksalt prism. A silver chloride polarizer was used throughout. The observations could be made with the electric vector of the incident radiation either perpendicular to the fiber axis, or parallel to it. Both β-keratins, such as fibroin and feather keratin, and collagens, from a number of mammalian sources, show differences between spectra taken in these two ways that are consistent with an extended or nearly extended polypeptide chain structure. α-keratins including myosin and porcupine quill show only small effects of a different sort. The effects in α-keratins do not lend themselves readily to interpretation, but some deductions as to the orientation of certain chemical bonds in the structure can be made.

Reactions of Transmutation

P1. Angular Distribution of the Alpha-Particles from the $Li^7(p, \alpha)\alpha$ Reaction.* F. L. TALBOTT AND A. BUSALA, *Catholic University of America.*—The angular distribution of alpha-particles from the reaction Li^7 (p, α) α has been investigated from 0.5 to 1.4 Mev in steps of 0.1 Mev. A photographic emulsion technique was used which permits counts to be made at many angles. As many as 15 angles were counted in some instances. Most calculations are based on the counting of over 20,000 alpha-tracks. Several sets of such calculations have been averaged at each energy. The curves show clearly the presence of a $\cos^4\theta$ term as indicated by Heydenburg *et al.*[1] and the coefficients of $\cos^2\theta$ and $\cos^4\theta$ are in good agreement with their values where the two experiments overlap in the region above 1.0 Mev.

* This work was supported in part by the ONR.
[1] Heydenburg, Hudson, Inglis, and Whitehead, Phys. Rev. 73, 241 (1948).

P2. Neutrons from the Disintegration of Beryllium by Deuterons.* W. D. WHITEHEAD AND C. E. MANDEVILLE, *Bartol Research Foundation.*—Ilford C_2 emulsions, making an angle of zero degrees with the incident beam, were irradiated by neutrons from the reaction $Be^9(D, n)B^{10}$ when a beryllium target of thickness 100 Kev was bombarded by deuterons of energy 1.62 Mev supplied by the Bartol Van de Graaff generator. Groups of recoil protons were observed corresponding to Q-values of (-0.74), 0.73, 2.19, 3.70, and 4.39 Mev, indicating excitation levels in B^{10} at 0.69, 2.20, 3.66, and 5.13 Mev with a probable error of 0.10 Mev or less. The group of negative Q-value did not appear for a bombarding energy of 1.20 Mev, because the low energy neutrons did not record against the general background of the plates. In a separate experiment at 1.62 Mev, the recoil protons of $C^{12}(D, n)N^{13}$ were shown to have a range twice as great as that of the negative Q group. The group of negative Q constitutes 20 percent of the total thin target yield at 1.62 Mev deuteron energy, agreeing in energy and intensity with the analysis of counter data given by the Rice group.[1]

* Assisted by the Joint Program of the ONR and the AEC.
[1] Evans, Malich, and Risser, Phys. Rev. **75**, 1161 (1949).

P3. Proton Groups from the Deuteron Bombardment of Boron. W. O. BATESON, *Yale University.**—A preliminary investigation of the proton groups emitted at 90° when separated B^{10} [1] is bombarded by 3.8 Mev deuterons from the Yale cyclotron has been made. Groups with 147.2, 105.0, 67.0, 58.5, 35.1, 26.3 and 19.2 cm of air equivalent range were found, corresponding to Q values of 9.18 ± 0.06, 7.03 ± 0.06, 4.70 ± 0.06, 4.15 ± 0.10, 2.26 ± 0.06, 1.36 ± 0.10 and 0.70 ± 0.10 Mev. The fourth, sixth, and seventh of these are new, the other four values being in reasonable agreement with previous work.[2] Bombardment of ordinary boron has revealed no additional groups due to $B^{11}(d, p)B^{12}$, but these may be masked by the very prolific groups at 19 and 26 cms from $B^{10}(d, p)B^{11}$.

* Assisted by the ONR and the AEC.
[1] 96 percent B^{10} was obtained from Oak Ridge.
[2] J. D. Cockcroft and W. B. Lewis, Proc. Roy. Soc. **154**, 246 (1936). Pollard, Davidson, and Schultz, Phys. Rev. **57**, 1117 (1940).

P4. Deuteron Bombardment of C^{14}.* EMMETT L. HUDSPETH AND CHARLES P. SWANN, *Bartol Research Foundation.*—A target of 400 $\mu g/cm^2$ of $BaCO_3$ (containing approximately 40 percent C^{14} and obtained from Oak Ridge) has been bombarded by deuterons. Neutrons were recorded on photographic plates while bombarding at 1.26 Mev. Groups of proton recoils consistent with the formation of N^{15} in its known[1] excited states were observed. The most intense groups correspond to Q-values of 8.0 and 2.6 Mev. The cross section for this reaction is somewhat greater than for the $C^{12}(d, n)$reaction at the same bombarding voltage. Deuteron bombardment of C^{14} yields high energy beta-rays, which we ascribe to the decay of B^{12}. An absorption curve in aluminum is apparently identical with that obtained from B^{12} as formed in $B^{11}(d, p)$. The $C^{14}(d, \alpha)B^{12}$ reaction is a strong source of beta-rays at 750 Kev; the yield increases rapidly with bombarding voltage. Limits on bombarding voltage prevent formation of C^{15}. Coincidence absorption of the Compton recoils produced by gamma-rays emitted during bombardment indicates a strong gamma-ray of energy about 5 Mev (in addition to others of lower intensity), consistent with the nature of the neutron spectrum.

* Assisted by the Joint Program of the ONR and the AEC.
[1] W. F. Hornyak and T. Lauritsen, Rev. Mod. Phys. **20**, 217 (1948) have summarized the relevant data.

P5. Evidence for the Reactions $N^{14}(\gamma, \alpha)B^{10}$ and $O^{16}(\gamma, \alpha)C^{12}$. A. G. W. CAMERON AND C. H. MILLAR, *Chalk River Laboratory.*—An Ilford type E1, 100 micron, nuclear research emulsion was exposed under paraffin and cadmium to 200 r of γ-radiation from the 24 Mev betatron at the University of Saskatchewan. A modified Van der Grinten grain gradation development[1] of the plate minimized γ-ray fogging and suppressed proton tracks. Many 3- and some 4-pronged α-particle stars were found due to the photo-disintegration of C^{12} and O^{16} respectively; and among many single α-particle tracks, due presumably to photo-alpha reactions in Ag and Br, were several each associated with a short heavy recoil track at the origin. These last were interpreted as photo-alpha reactions in light nuclei. With the range-energy relation in functional form and the average effective charge of the recoiling nucleus assumed as approximately 60 percent of the nuclear charge, these examples can be unambiguously allocated to one or the other of the reactions $N^{14}(\gamma, \alpha)B^{10}$ and $O^{16}(\gamma, \alpha)C^{12}$. In addition, range-energy curves for B^{10} and C^{12} in type E1 emulsion have been obtained for the region 1–5 Mev. Agreement with measurements[2] of C^{12} in gases is satisfactory.

[1] H. Yagoda, *Radioactive Measurements with Nuclear Emulsions* (John Wiley and Sons, Inc., New York, 1949), p. 62.
[2] G. A. Wrenshall, Phys. Rev. **57**, 1095 (1940).

P6. Energy Levels in N^{15}.* R. MALM AND W. W. BUECHNER, *M. I. T.*—The proton groups from N^{14} targets bombarded with 1.5-Mev deuterons have been studied using semicircular magnetic analysis. Preliminary Q-values found for the observed groups are 8.61, 3.32, and 3.29 Mev. With lesser resolution, the latter two groups appear as a single peak and probably correspond to the group previously reported as having a Q-value of 3.18 Mev. The present work indicates the existence of energy levels in N^{15} at 5.29 and 5.32 Mev.

* This work has been assisted by the Joint Program of the ONR and the AEC.

P7. Energy Levels of the F^{20} Nucleus from the $F^{19}(d, p)F^{20}$ Reaction. R. C. ALLEN AND WALDO RALL, *Yale University.**—Lead fluoride, evaporated on a gold foil, was bombarded by 3.9-Mev cyclotron deuterons. Protons were detected at 90° with respect to the deuteron beam by means of a highly biased proportional counter. Aluminum absorption techniques gave proton groups of extrapolated range 68.2, 58.5, 53.8, 49.4, 41.3, 34.0, 30.2, 24.3, and 19.0 equivalent air (cm). These ranges correspond to energy levels of 0.0 ($Q_0=4.29$ Mev), 0.64, 0.98, 1.31, 1.95, 2.57, 2.90, 3.49, and 4.07 Mev, respectively. Probable errors on all but the highest level are within 0.08 Mev, that of the last level being 0.20 Mev. The levels are in good agreement with the 0.7-, 1.0-, 1.35-, and 1.9-Mev levels found earlier by Bower and Burcham[1] using lower beam energies. The levels appear to be integral multiples of a unit energy of 320 Kev. In terms of this unit the levels exist at 2, 3, 4, 6, 8, 9, 11, and 13, all agreeing well within the probable errors.

* Assisted by the ONR and the AEC.
[1] Bower and Burcham, Proc. Roy. Soc. **173**, 379 (1939).

P8. Excitation Curve for Protons in the Reaction $F^{19}(d, p)F^{20}$.* S. C. SNOWDON, *Bartol Research Foundation.*—The excitation curve for the total yield of the reaction $F^{19}+H^2\rightarrow F^{20}+H^1$ has been studied by measuring the β-ray yield from the reaction $F^{20}\rightarrow Ne^{20}+\beta-$. In order to annul the effect of fluctuations in the beam current, $I(\tau)$, it was necessary to construct a special integrator which measures $\int_0^t I(\tau)e^{-\lambda(t-\tau)}d\tau$, where λ is the disintegration constant for the β-decay. Preliminary results indicate a smooth rise in the yield curve from 0.7 Mev to 1.8 Mev.

* Assisted by the Joint Program of the ONR and the AEC.

P9. Alpha-Particles from $F^{19}(p, \alpha)O^{16}$.* E. N. STRAIT, D. M. VAN PATTER, AND W. W. BUECHNER, *Massachusetts Institute of Technology.*—The alpha-particle groups from thin

targets containing fluorine bombarded by protons have been analyzed at 90 degrees using a 180-degree focusing annular magnet. The proton incident energy is measured by analyzing the elastically scattered protons from a thin Formvar target. All energy measurements are determined using polonium alpha-particles as standard. The Q-values for the alpha-particles going to O^{16} in the ground state and first excited state for gamma-radiation have been measured as $Q_0=8.068$ and $Q_1=1.969$ Mev. These values are in good agreement with the recent measurements of Chao, Tollestrup, Fowler, and Lauritsen[1] who find $Q_0=8.101\pm0.030$ and $Q_1=1.977\pm0.008$ Mev. The relative intensities of the alpha-groups corresponding to the formation of O^{16} in the pair level and the ground state are being investigated at proton energies between 1.1 and 1.4 Mev at reported pair resonances.[2]

* This work has been assisted by the Joint Program of the ONR and the AEC.
[1] Chao, Tollestrup, Fowler, and Lauritsen (private communication).
[2] Bennett, Bonner, Mandeville, and Watt, Phys. Rev. **70**, 882 (1946).

P10. d-p Reactions with Separated Neon Isotopes.* A. ZUCKER AND W. W. WATSON, *Yale University.*—With neon gas enriched 93 percent Ne^{22} or to 99 percent Ne^{20} we confirm the observations of Elder, Motz, and Davison,[1] who used less well-separated isotopes, on the $Ne^{20}(d, p)Ne^{21}$ and Ne^{22}(d, p)Ne^{23} reactions. Aided by the enrichment factor of 3 for Ne^{21} in the "heavy" neon, we find a new long-range proton group assigned to Ne^{21}(d, p)Ne^{22} with a Q of 7.00 ± 0.10 Mev for the reaction. Consideration of these and other reactions involving the neon isotopes and neighboring elements shows that the mass of Ne^{21} is 21.00062 ± 0.00010, and that the new proton group indicates an excited state at 1.37 Mev in the Ne^{22} nucleus. The mass of Ne^{23} obtained by us agrees just within the limits of error with that obtained from the reaction $Ne^{23}(\beta^-)Na^{23}$. The latter gives the mass of Ne^{23} as 23.00160 ± 0.00040.

* Assisted by the AEC.
[1] Elder, Motz, and Davison, Phys. Rev. **71**, 917L (1947).

P11. Neutrons from Deuterons on Magnesium (25).* C. P. SWANN, C. E. MANDEVILLE, AND W. D. WHITEHEAD, *Bartol Research Foundation.*—Isotopic Mg^{25}, obtained from the Y-12 plant, Carbide and Carbon Chemicals Corporation, Oak Ridge, was irradiated by deuterons of energy 1.47 Mev, supplied by the Bartol Van de Graaff generator. Recoil protons, knocked on in the forward direction by the emitted neutrons, were observed in Ilford C_2 emulsions located 10 cm from the target at angles of zero and ninety degrees with the incident beam. At both angles, four groups of neutrons were noted having Q-values of 0.45, 1.95, 3.58, and 5.58 Mev, indicating nuclear energy levels in Al^{26} at 2.00, 3.63, and 5.13 Mev. The probable error in the location of the levels is estimated as 0.10 Mev. The mass of Al^{26} is calculated to be $(25.9935\pm9.0\times10^{-4})$ mu. Measurements concerning neutron spectra resulting from the reactions Mg^{24}(D, n)Al^{25} and Mg^{26}(D, n)Al^{27} are in progress.

* Assisted by the Joint Program of the ONR and the AEC.

P12. Proton Groups from the Deuteron Bombardment of Aluminum, Sodium, and Manganese. W. D. WHITEHEAD* AND N. P. HEYDENBURG, *University of Virginia and Carnegie Institution of Washington.*—Thin targets of sodium, aluminum, and manganese were bombarded with deuterons from the large statitron at the Department of Terrestrial Magnetism, and the protons were observed at 90° to the beam with an argon filled proportional counter. The counter was biased to count protons at the end of their range and the ranges of the groups were measured in air and aluminum. Proton groups due to oxygen and carbon were found with all targets.

Element	Bombarding energy	Average Q
Na	2.0, 2.5, 3.0	4.77, 4.23, 3.45, 2.94, 2.22, 1.33, .96, .78, .50, .12
Al	3.0	5.72, 4.71, 4.35, 4.07, 3.49, 3.05, 2.69, 2.39, 2.08, 1.59, .94, .70, .46, .04
Mn	3.0	5.01, 3.47, 3.13, 2.85, .48, .13, −.19

* AEC Predoctoral Fellow, now at Bartol Research Foundation.

P13. Proton-Gamma-Ray Coincidence Study of the Energy Level Scheme of Si30. H. H. LANDON, *Yale University.**—The energy level scheme of Si30 was studied by means of a proton-gamma-ray coincidence technique using the $Al^{27}(\alpha, p)$ reaction. The protons were observed at 90° with respect to the incident alpha particle beam. Preliminary Q values estimations were made by examining the proton group structure and the following results obtained. $Q_1=2.4$, $Q_2=0.0$, $Q_3=-1.3$, $Q_4=-2.6\pm0.2$ Mev. The gamma-rays giving coincidences with protons from the first and second excited states were studied by measuring the absorption coefficients in copper. Preliminary estimates strongly suggest that a hard and soft component exist indicating that the gamma-ray from the second excited state comes from a transition directly to the ground state.

* Assisted by the ONR.

P14. Excitation Function of $Ta^{181}(d, p)Ta^{182}$.* KUAN-HAN SUN, F. A. PECJAK, R. A. CHARPIE, J. F. NECHAJ, *Westinghouse Research Laboratories and the University of Pittsburgh.*—The excitation function of $Ta^{181}(d, p)Ta^{182}$ up to 15.0 Mev deuteron energy was measured by the stack foil (10 mg/cm²) technique. The half-life (115 days) and the energy of the two β-groups (0.52 and 1.1 Mev) observed were in agreement with the literature data. The reaction Al^{27}(d, pα)Na^{24}, previously studied by Clarke,[1] was used for monitoring the deuteron beam by placing an Al-foil (2 mg/cm²) in front of the Ta-stack. The relative yields are 1.00, 1.08, 0.96, 0.54, 0.18, 0.01, and 0.00 for deuteron energies of 15.0, 13.5, 12.0, 10.5, 9.0, 7.5 and 6.0 Mev, respectively. The ratio of the cross section at 15 Mev for the Ta- and Al-reactions was found to be 35. This yields an absolute cross section of 0.89 barn for the Ta-reaction using the corresponding cross section of the Al.[1] A thick target yield curve was also obtained. At 15.0 Mev the yield was 0.97 rd/μah of the deuterons.

* Assisted by the Joint Program of the AEC and the ONR.
[1] E. T. Clarke, Phys. Rev. **71**, 187 (1947).

P15. Spectrum of Neutrons from Ta(dn). R. A. PECK, JR., *Brown University.**—Neutron energies from this reaction have been studied using recoil proton tracks in Eastman NTB emulsions. 14 Mev deuterons from the Massachusetts Institute of Technology cyclotron were used to bombard a 1 mil tantalum foil. The exposed plates were processed and examined, following a conventional microphotographic procedure.[1] The spectrum (2 Mev and above) shows a strong preference for the lowest neutron energies. The expected maximum energy is approximately 16 Mev, but to date none greater than 14.5 Mev has been observed. Some evidence of group structure appears in most of the spectrum (below 12 Mev), but the yield is so far insufficient to show structure at higher energies (lower excitation of the product W^{183} nucleus). When the data are plotted in the form log(N/E) *vs.* E breaks appear in the slope. The nuclear temperature[2] obtained from the slopes of this line is approximately 0.7 Mev,

changing to 1.3 Mev above 4.7 Mev and to 3.6 Mev above 7.1 Mev.

* Exposures were made at the Massachusetts Institute of Technology, with the support of the ONR.
[1] R. A. Peck, Jr., Phys. Rev. **76**, 1279 (1949).
[2] V. F. Weisskopf, Phys. Rev. **52**, 295 (1937).

Nuclear Magnetic Resonance; Molecular Hyperfine Structure

Q1. The Absolute Value of the Gyromagnetic Ratio of the Proton. R. L. DRISCOLL, H. A. THOMAS, AND J. A. HIPPLE, *National Bureau of Standards.*—Since our previous report on this work,[1] a careful study of the sources of error has continued. The measurements have been repeated with symmetrical shims instead of the unsymmetrical ones previously used. The magnetic field distribution was checked immediately before and after each run. The main contributing error had been caused by the asymmetry of the copper wire employed in the construction of the precision rectangular coil for measuring the magnetic field. The uncertainty due to this cause has been greatly reduced by measuring this wire after dismantling the rectangular coil. These studies and others which will be described indicate that the accuracy will be much higher than previously reported. Consequently, there will be less uncertainty in the values of e/m of the electron and of the Faraday.

[1] H. A. Thomas, R. L. Driscoll, and J. A. Hipple, Phys. Rev. **75**, 902 (1949).

Q2. The Internal Diamagnetic Field Correction in Precision Measurements of the Proton Magnetic Moment. NORMAN F. RAMSEY, *Harvard University.*—In recent high precision experiments involving the proton magnetic moment, the internal diamagnetic field correction to the measurement has become an important limitation to the precision of the result. This correction arises from the fact that the protons being measured are contained in a molecule, such as H_2, whose electrons to some extent magnetically shield the nucleus. An exact theoretical evaluation of this correction for molecules has been impossible because one important term in the correction is extremely difficult to evaluate. In the present paper it is pointed out that this difficult term is directly related to the spin-rotational interaction constant of the molecule, which has been experimentally measured in certain cases, notably H_2. With the notation characteristic of the subject the diamagnetic correction is

$$\frac{H'(0)}{H}=-\frac{e^2}{3mc^2}\int\frac{|\Psi|^2}{r}d\tau+\frac{1}{6}\alpha^2\frac{a_0a^2}{(\mu_0m/M)}\left\{\frac{2Z(\mu_0m/M)}{a^3}-\frac{\mu}{M}H_p\right\}.$$

The first term has been evaluated from Nordsieck wave functions by Anderson to be -3.24×10^{-5}, and the second can be determined from the experiments of Kellogg, Rabi, Ramsey, and Zacharias with the result that $[H'(0)]/H=[-3.2_4+0.53]\times10^{-5}=2.7_1\times10^{-5}$.

Q3. Regulation of Large Electromagnets Using Proton Resonance. H. A. THOMAS, *National Bureau of Standards.*—Our experience in regulating electromagnets by means of nuclear resonance, first suggested by Bloch,[1] has shown that field stability of the order of a few parts per million may be obtained. The resonance absorption signal from a proton sample may be fed into a power amplifier which may be used to regulate the field directly by means of auxiliary coils on the magnet or by driving the field of the exciter for the main generator. Large magnets having time constants of the order of 5 seconds or larger introduce more difficult problems in hunting that require special attention. The two systems of regulation mentioned above and the necessary anti-hunt methods will be discussed and performance data given for a 1-ton magnet and a 36-ton magnet.

[1] F. Bloch, Phys. Rev. **70**, 460 (1946).

Q4. Nuclear Spin Relaxation in KH_2PO_4, KH_2AsO_4, $NH_4H_2PO_4$, and $NH_4H_2AsO_4$. ROGER NEWMAN AND EDWARD M. PURCELL, *Harvard University.*—Studies have been made of the proton magnetic resonance absorption at 30 Mc in KH_2PO_4, KH_2AsO_4, $NH_4H_2PO_4$ and $NH_4H_2AsO_4$ from liquid air temperature to room temperature. Both line shapes and relaxation times have been measured. The potassium salts, which undergo ferroelectric transitions,[1] show closely similar magnetic resonance properties. Their relaxation times show relatively small variation in the temperature interval studied. The characteristic times derived therefrom do not obey any simple exponential law in the reciprocal temperoture. In the ammonium salts, which have para-electric properties,[1] there are two minima in the relaxation time *vs.* temperature curves, one minimum corresponding to a temperature where the acid hydrogens are the most effective relaxation agent and the other to a temperature where the ammonium hydrogens are most effective. The line shape is also of a composite character. This is most clearly shown below 100°K where the absorption lines appear to be superpositions of the broad NH_4 line for which NH_4Cl is typical, and the narrow line found in KH_2PO_4 or KH_2AsO_4.

[1] G. Busch, Helv. Physica Acta **11**, 269 (1938).

Q5. Factors Influencing the Positions of Nuclear Magnetic Resonances.* W. C. DICKINSON, *M. I. T.*—It has been found that the shift of a nuclear magnetic resonance on addition of paramagnetic ions is a function of the resonating nucleus and the chemical compound in which it is contained. Shifts can be either positive or negative, both for a spherical and transverse cylindrical sample shape. The magnitude of this paramagnetic shift is sometimes sufficient to affect the results of a high precision measurement when paramagnetic ions are added to shorten the thermal relaxation time. In the course of this investigation it was discovered that the position of the fluorine resonance is dependent on the chemical compound containing the fluorine atom. Such shifts never have been observed or predicted previously for liquids. The largest separation between resonances observed to date is (1.05 ± 0.03) gauss in a field ≈7000 gauss for the fluorine resonances in BeF_2 and $C_2F_3Cl_3$, the latter one coming at the lower applied field. Nuclear resonance shifts in metals,[1] interpreted as being due to the conduction electrons, are larger by about an order of magnitude.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and the ONR.
[1] W. D. Knight, Phys. Rev. **76**, 1259 (1949).

Q6. Nuclear Magnetic Moment of S^{33}.* C. K. JEN, *Harvard University.*—An attempt has been made to determine the nuclear magnetic moment of S^{33} from the Zeeman effect of an OCS^{33} ($J=1\rightarrow2$) rotational line in the microwave range.[1] The OCS^{33} molecule was present in the carbonyl-sulfide sample in its natural isotopic abundance of about 0.7 percent. The nuclear magnetic moment is calculated from the observed Zeeman data on the basis of an IJ coupling between the nuclear spin and molecular rotation, using the known spin value $I(S^{33})=3/2$.[1] The molecular g-factor for OCS^{33} (0.026 in nuclear units), used in the calculations, is deduced from the data on the Zeeman splitting of the $J=1\rightarrow2$ rotational lines of OCS^{32} and OCS^{34}. The present estimate of the nuclear moment is considered rather crude, chiefly due to low line intensities and insufficient resolution. A provisional estimate gives $|\mu(S^{33})|=0.9$ n.m. The sign of the moment, while seemingly positive, has not been established. This result is within

the Schmidt limits and is in general agreement with the "one-particle" picture for the nuclear shell structure.[2,3]

* Supported by Navy, Signal Corps and Air Force under ONR contract.
[1] C. H. Townes and S. Geschwind, Phys. Rev. **74**, 626 (1948).
[2] E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949).
[3] L. W. Nordheim, Phys. Rev. **75**, 1894 (1949).

Q7. Radio Frequency Spectrum of $TlCl^{35}$. C. A. Lee, R. O. Carlson, B. P. Fabricand, and I. I. Rabi, *Columbia University.*—The radiofrequency spectrum of $TlCl^{35}$ has been investigated by the molecular beam electrical resonance method.[1,2] The quadrupole interaction constant, due to the Cl^{35} nucleus for the first rotational state and zeroth vibrational state, has the value $eqQ=-15.79$ mc/sec. (± 0.04 mc). There is an increase of about $\frac{1}{2}$ percent of this interaction for the first vibrational state. In the above notation $q=(\partial^2 V)/(\partial Z^2)$.[3] This coupling constant is approximately fifty times that of chlorine in KCl and 1/7 that for atomic chlorine. Further details of this spectrum will be discussed.

[1] H. K. Hughes, Phys. Rev. **72**, 614 (1947).
[2] J. W. Trischka, Phys. Rev. **74**, 718 (1948).
[3] J. Bardeen and C. H. Townes, Phys. Rev. **73**, 97 (1948).

Q8. Molecular Beam Spectrum of $TlCl^{35}$ and $TlCl^{37}$ at Zero Fields. H. Zeiger, D. Bolef, and I. I. Rabi, *Columbia University.*—The zero-field spectrum of $TlCl^{35}$ and $TlCl^{37}$ has been observed using the molecular beam magnetic resonance method.[1] Two of the observed lines can be attributed to the quadrupole interactions of Cl^{35} and Cl^{37}. Each of these lines is in turn split by an $\bar{I}\cdot\bar{J}$ interaction due to chlorine. The quadrupole interactions are $eqQ_{35}=15.84\pm 0.10$ mc and $eqQ_{37}=12.48\pm 0.10$ mc, where $q=(d^2V)/(dz^2)$.[2] The ratio $Q_{35}/Q_{37}=1.27$, which agrees with the value of 1.28 obtained by atomic beam methods.[3] The splitting due to the $\bar{I}\cdot\bar{J}$ interaction can be expressed as that due to an equivalent magnetic field at the chlorine nucleus. The magnetic field per rotational quantum number, H', has the value $H'=3.4$ gauss for Cl^{35} and $H'=3.2$ gauss for Cl^{37}. The line shape is due to the $\bar{I}\cdot\bar{J}$ interaction and the variation of eqQ with rotational and vibrational state.

[1] W. A. Nierenberg and N. F. Ramsey, Phys. Rev. **72**, 1075 (1947).
[2] J. Bardeen and C. H. Townes, Phys. Rev. **73**, 97 (1948).
[3] Davis, Jr., Feld, Zabel, and Zacharias, Phys. Rev. **76**, 1076 (1949).

Q9. Resonant Modulation, A New Technique in Radio Spectroscopy.* S. H. Autler and C. H. Townes, *Columbia University.*—Splitting of a microwave absorption line has been observed upon application of a weak oscillating electric field whose frequency is such that it induces transitions between either the initial or final energy level of the line and some other level of the molecule. Consider three levels a, b, and c of a molecule. Suppose ν_{ac} ($\nu_{ac}=(E_c-E_a)/h$) lies in the microwave region while ν_{ab} is much smaller, say 40 megacycles. Assume $a\rightarrow c$ and $a\rightarrow b$ are allowed transitions. If an r-f field is applied across the wave guide in which the microwave absorption line, ν_{ac}, is being observed, the line splits into two components when the r-f field is made resonant with ν_{ab}. The amount of splitting depends upon the intensity of the r-f field; and the relative intensity of the two components into which the line splits depends sensitively on the deviation from the resonant frequency. This effect has been observed on the l-type doublet of OCS and the hyperfine structure of AsF_3. A theory has been developed which agrees closely with the observations although there are small unexplained discrepancies. It is hoped that use of resonant modulation will allow somethat improved accuracy in measuring fine and hyperfine structure.

* Work supported jointly by the Signal Corps and the ONR.

Q10. Magnetic Electron Spin—Nuclear Spin Interaction In the Rotational Spectrum of NO_2.* K. B. McAfee, Jr., *Harvard University.*—The microwave spectrum of NO_2—a slightly symmetric top molecule whose ground state is a doublet with spin momentum 1/2—has been studied by means of a Stark-effect spectrograph. The observed spectrum consists of six absorption lines of average and equal intensity extending over a range of approximately 85 mc at 26,600 mc and several other very weak lines. Identification of the rotational transition as $J=6_{06;-6}\leftrightarrow 5_{15;-4}$ was made possible by means of Zeeman-effect measurements. The observed hyperfine structure is ascribed to the magnetic spin-spin interaction of the resultant electron spin with the nitrogen nucleus, and the interaction of the electron spin with molecular rotation. The spin-spin interaction energy for symmetric top molecules given by Van Vleck is:

$$W_{I_s}=-\frac{1}{5}g_I\beta_I\beta\frac{\bar{1}}{r^3}\left[1-\frac{3K^2}{J(J+1)}\right]\left[\frac{F(F+1)-J(J+1)-3/4}{2}\right]\times\left[\frac{G(G+1)-F(F+1)-I(I+1)}{2F(F+1)}\right],$$

where r is the radius of the free spin and $S=1/2$; $G=F+I,\cdots[F-I]$. Application of the above to NO_2 yields agreement to ± 2 mc, while the magnetic coupling constant represented by the multiplicative factor is determined to be 206 ± 10 mc.

* This work supported in part by the ONR.

Q11. Microwave Magnetic Resonance Spectra of NO. Robert Beringer and J. G. Castle, Jr., *Yale University.**—The magnetic resonance absorption of gaseous nitric oxide occurs as a symmetric nine-line spectrum arranged in three triplets. The separation of the triplets arises from perturbations of nearby molecular levels. The separation of 30 Mc/sec. within each triplet arises from the magnetic interaction of the nuclear magnetic moment of N^{14} and the molecular magnetic moment. This interpretation is supported by the line intensities and the absolute value of the triplet spacings which have been calculated by H. Margenau and A. F. Henry. The absolute intensity of the spectrum has been measured and compared with theory. A method for obtaining the line widths from the dependence of the observed shapes on the modulation amplitude will be discussed. The line widths are closely the same for the nine lines and are proportional to the gas pressure near 1 mm Hg.

* Assisted by the ONR.

Ferroelectricity, Ferromagnetism, Cryogenics

R1. Preliminary Results with Macrocrystals of Ferroelectric Barium Titanate. A. deBretteville, Jr. and G. Katz, *Signal Corps Engineering Laboratories.*—Crystal rods of barium titanate 17.5 mm in diameter by 23 mm in length have been grown by Mr. Harold D. Williams of the Harshaw Chemical Company. X-ray reflections using monochromatic radiation were made of the 100 plane on a 3 mm thick wafer cut at an orientation of 45° to the long axis of the rod. This orientation was initially obtained by cleavage. Evidence of twinning was shown by the two clearly separated spacings of the c and a axes ($c-a$ approximately 0.04A) in the fourth order. Gold electrodes were sputtered on the wafer and a field of 16,800 volts/cm was applied for less than one second. Re-examination with the x-ray spectrometer showed almost complete orientation along the polar c axis. A permanent piezoelectric effect as well as a permanent charge was observed with a vacuum tube voltmeter. From knowledge of the orientation of the crystal in the rod, a 110 cut was made and subsequently verified by x-ray reflection. This sample was made from material supplied by the Titanium Division, National Lead Company. In general, the crystals are not homogeneous in orientation throughout but large enough

areas are available to enable physical measurements to be made.

R2. The Behavior of $BaTiO_3$ Crystals under Hydrostatic Pressure.* W. J. MERZ, *M. I. T.*—The effect of hydrostatic pressures (up to 5000 atmos.) on the Curie point and on the transition near 0°C was determined by measuring the dielectric constant as a function of temperature and pressure. It was found that the Curie point shifts to lower temperatures with increasing pressures. The shift is linear at least up to about 2500 atmos., with a gradient of ca. $dT/dp = -5.8\times10^{-3}$ °C/atmos. With the help of Ehrenfest's formula for second-order transitions one can calculate the change of the specific heat and of the compressibility at the Curie point. The specific heat change is in good agreement with direct measurements. With the knowledge of the compressibility and of the expansion coefficient, it is possible to calculate the Curie temperature as a function of the lattice constant. These results are in a good agreement with the relation between Curie point and lattice constant obtained from mixed crystals of $BaTiO_3$ and $SrTiO_3$. The characteristic of dielectric constant *vs.* temperature retains its general shape except for a slight increase in the peak value. For the transition point near 0°C we find a similar shift to lower temperatures, but at about 1500 atmos. the trend reverses and the transition temperature increases with increasing pressure.

* Sponsored by the ONR, the Army Signal Corps, and the Air Force.

R3. The Electro-Mechanical Coupling of $BaTiO_3$ Single-Domain Crystals.* M. E. CASPARI, *M. I. T.*—The d_{31} piezoelectric coefficient of $BaTiO_3$ single-domain crystals was investigated from room temperature to above the Curie point by measuring the strain component along the *a*-axis developed by d.c. electric fields applied along the *c*-axis. Hysteresis effects were observed, compelling one to distinguish between true piezo effects and effects produced by the orientation of domains. Prepolarization tends to minimize such domain effects and makes the remaining hysteresis curves reproducible. Thus good estimates of the d_{31} coefficient can be made. The domain effects can be saturated at very high field strengths, but thermal expansion due to the finite resistivity of the crystal makes measurements at such high field strengths inaccurate. At room temperature the coefficient is about twice as large as the d_{36} coefficient of KH_2PO_4 at the same temperature. Near the Curie point the effect was found to be many times larger. Although the crystal structure above the Curie point has a center of symmetry and is thus not piezoelectric, this large effect was found to persist above the Curie point at high fields, but decreased steadily. This is assumed to be due to the fact that a tetragonal crystal structure is induced by large fields above the Curie point.

* Sponsored by the ONR, the Army Signal Corps, and the Air Force.

R4. A Simple Model for Ferroelectricity. P. W. ANDERSON, *Bell Telephone Laboratories.*—A simple theoretical model for substances showing ferroelectric behavior is being investigated. An assembly of slightly anharmonic oscillators, with potential for each oscillator of the type $V=[(sx^2)/2]+[(px^4)/2]$ $p \ll s^2$ is assumed to interact according to the Lorentz force. Curves of polarization *vs.* local field F are derived and combined with the Lorentz local field to give curves for saturation polarization, dielectric constant ϵ, etc. The slope of the $1/\epsilon$ *vs.* T curve about the Curie point for $BaTiO_3$, and of the saturation polarization *vs.* T for relatively low temperatures (20–100°C) are not inconsistent with reasonable values for p; however, the transition at the Curie point appears to be much more rapid than can be accounted for by this theory, and to have unexplained accompanying effects. It is suggested that this is due to fluctuations, and some ideas on fluctuations are outlined.

R5. On the Triangular Ising Net. G. H. WANNIER, *Bell Telephone Laboratories.*—Kaufman[1] introduced a systematic method for evaluating the partition function of certain cooperative assemblies. When we apply it to the triangular Ising net we get essentially new results if the coupling is antiferromagnetic. Results on the triangular net have been published,[2] but they apply only to ferromagnetism. The calculations cover both types of coupling and show (a) that the antiferromagnetic binding energy is only 1/3 of the corresponding ferromagnetic one; (b) that the system has a finite entropy at absolute zero which equals 0.3383R; (c) that the system is disordered at all temperatures and has no Curie point. The calculation throws some light on the behavior of actual antiferromagnets which often have elementary magnets in a face centered cubic arrangement. In making such comparisons one must keep in mind (a) the sharp distinction for antiferromagnets between an Ising interaction and exchange coupling,[3] (b) the possibility of next nearest neighbor interaction through superexchange.[4]

[1] Bruria Kaufman, Phys. Rev. **76**, 1232 (1949).
[2] G. H. Wannier, Rev. Mod. Phys. **17**, 50 (1945).
[3] Lamek Hulthen, Arkiv. f. Math., Astr. o. Fys. **26A** (1938).
[4] P. W. Anderson (to be published).

R6. Interaction between Paramagnetic Ions in Crystals.* NORMAN ELLIOTT, *Brookhaven.*—The magnetic susceptibilities of manganous fluoride and solid solutions of manganous and zinc fluorides obey the Weiss-Curie law over a wide temperature range. The paramagnetic Curie temperature is found to be linearly dependent on the manganous ion concentration. The results will be discussed in relation to the Heisenberg exchange interaction.

* Work done under the auspices of the AEC.

R7. Memory in Simple Ferromagnetic Domain Crystal. H. J. WILLIAMS AND W. SHOCKLEY, *Bell Telephone Laboratories.*—Studies of hysteresis loops have been made for a simple "picture frame" crystal of silicon iron.* The force $2\times$(Saturation Magnetization)$\times$(Applied Field)$\times$(Wall Area), required to move the domain wall is found to be a function not only of the wall position but of the previous wall motion, the wall remembering its past positions up to nearly 0.1 cm of motion. The proposed explanation is that secondary domains,* "Néel Spikes," form around crystal inclusions or cavities and tend to cling to the wall as it moves past. These exert a force on the wall as they are stretched (actually observed) up to their breaking point and furnish a force varying up to ~0.02 oersted. A local force without memory of 0.003 oersted is also found. This probably corresponds to local strain and smaller inclusions that do not form secondary domains but otherwise impede the motion of the wall. Integrated expressions for the theoretical hysteresis loop, obtained for a simplified form of the force of a single secondary domain, are generally consistent with experiment.

* Williams, Bozorth, and Shockley, Phys. Rev. **75**, 155, 178 (1949).

R8. Dynamic Experiments with a Simple Domain Boundary in a Ferromagnetic Crystal. W. SHOCKLEY, H. J. WILLIAMS, AND C. KITTEL, *Bell Telephone Laboratories.*—Studies have been made of the Bloch wall velocities under applied magnetic fields in the ferromagnetic single crystal discussed in the preceding abstract. The wall velocity appears to be a linear function of the applied field and of the resistivity, as determined by varying the temperature. The behavior is accounted for in a quantitative way by the eddy currents induced in the crystal by the motion of the wall. The wall appears to move so that the energy input from magnetization reversal is equal to the eddy current losses. It appears that in large magnetic fields the domain wall becomes distorted and perhaps may tend to close on itself. For the case of self-closure in

large fields the radial wall velocity at radius r is given by $v=[H\rho c^2/32\pi^2 M_s r \ln(R/r)]$, where ρ is the resistivity in e.s.u., and R is the equivalent radius of the crystal cross section. For our crystal the wall velocity is roughly of the order of 3 cm/sec./oersted.

R9. Magnetic Resonance Absorption in Magnetite at Low Temperatures.* L. R. BICKFORD, JR., *M. I. T.*—The microwave resonance absorption technique, at both 1.25- and 3.3-cm wave-lengths was used to study the ferromagnetic crystalline anisotropy characteristics of magnetite, Fe_3O_4, in the vicinity of its low-temperature transition. The experiments were performed on synthetic single crystals at temperatures down to −195°C. The transition in magnetite, which occurs at ca. −160°C, is characterized by anomalous effects in specific heat, magnetization, and electrical conductivity. At temperatures above the transition, the crystalline and magnetic symmetry is cubic. The behavior of magnetite in the resonance experiments below the transition seems to indicate that the magnetic symmetry is uniaxial in this temperature region. This conclusion is consistent with the findings of other investigators. Below the transition the magnetic axis is the [100] direction most nearly parallel to a strong magnetic field which was applied to the crystal as it cooled through the transition. At temperatures not far below the transition it is possible to change the magnetic axis from one [100] direction to another by means of a strong magnetic field.

*Sponsored by the ONR, the Army Signal Corps, and the Air Force.

R10. Specific Heat Determination on Non-Metallic Ferrites.* T. R. MCGUIRE AND LOUIS N. HOWARD,** *Naval Ordnance Laboratory.*—Following a method developed by Sykes[1] the specific heat (C_H) of Ferroxcube III was determined in the temperature range from room temperature through the Curie temperature (ca 150°C) to 300°C. C_H remained constant at approximately 0.20 ± 0.01 calories/°C g. The expected change in specific heat at the Curie temperature is 0.05 calorie/°C g based upon the reported composition of this material.[2] The sensitivity of the apparatus was such that changes of 0.02 calorie/°C g could have been detected. Specific heat data are correlated with measurements taken of the temperature variation of the intensity of magnetization and the magnetic susceptibility.

* This work was supported in part by the ONR.
** Now at Swarthmore College, Swarthmore, Pennsylvania.
[1] C. Sykes, Proc. Roy. Soc. **148A**, 422 (1935).
[2] J. L. Snoek, *New Developments in Ferromagnetic Materials* (Elsevier Publishing Company, Inc., 1947), p. 91.

R11. The "Heterocharge" of Carnauba Wax Electrets. A. D. FRANKLIN, *Franklin Institute* (Introduced by C. T. Chase).—By insulating the electret material from the electrodes with sulfur disks during polarization of the electret, it has been possible to produce the "heterocharge" without the "homocharge." The decay characteristics of the "heterocharge" so produced have been studied as a function of time and temperature of polarization.

R12. Thermal Conductivity of Copper and Tin at Liquid Helium Temperatures. F. A. ANDREWS, D. A. SPOHR, AND R. T. WEBBER, *Naval Research Laboratory.*—The thermal conductivity of rods of highly pure copper (polycrystalline) and tin (single crystal) has been measured at temperatures available with liquid helium. The temperature gradient along the rods was determined by means of helium gas thermometers employed differentially. The thermal conductivity of the copper was found to increase linearly with the temperature over most of the range measured, reaching a value of 2.32 watt/cm °K at 4.0°K. This is in excellent agreement with the results of Allen and Mendoza,[1] and in accord with the theory of Makinson.[2] The temperature dependence of thermal conductivity of the tin crystal was similar to the results found by Hulum[3] for polycrystalline tin.

[1] J. F. Allen and E. Mendoza, Proc. Camb. Phil. Soc. **44**(2), 280 (1948).
[2] R. E. B. Makinson, Proc. Camb. Phil. Soc. **34**, 474 (1938).
[3] J. K. Hulm, Nature **163**, 368 (1949).

R13. The Theory of Superconductivity.* L. TISZA, *M. I. T.*—The standard electronic theory of metals operates with a definite sequence of steps in building up the crystal. First a single electron is coupled with a periodic field, then the inter-electronic coupling is taken into account only by Fermi statistics. The addition of further coupling terms has failed to account for superconductivity. The theory to be presented uses from the outset many-electron wave functions corresponding to bond structures extending over the entire crystal. The condition of superconductivity is essentially the occurrence of quantum resonance of at least three bond structures equivalent under the translation group of the crystal. The formalism leads in a reasonable approximation to the London relation. On the basis of an empirical classification one distinguishes between hard and soft superconductors. It is noteworthy that these are located in regions of the periodic table in which the importance of covalent binding has been postulated by Hume-Rothery[1] and Pauling[2] on the basis of empirical evidence other than superconductivity.

* This work has been supported in part by the Signal Corps, the Air Materiel Command and the ONR.
[1] W. Hume-Rothery, *The Structure of Metals and Alloys* (London, 1936), p. 21ff.
[2] L. Pauling, Phys. Rev. **54**, 899 (1938).

R14. Magnetic Field Penetration in Superconducting Lead. M. C. STEELE, *Naval Research Laboratory.*—The magnetic susceptibility of small superconducting lead spheres (radius $\sim10^{-3}$ cm) has been determined by a self-inductance method. Using relations derived from the London[1] theory for reducing the data, the penetration depth, λ, is calculated for three different lead samples at 4.22°K. Results indicate that λ is $1.3\pm0.3\times10^{-5}$ cm at this temperature. It is also found that within experimental error λ is not a function of the size of the sphere. The importance of using smaller sized particles and accounting for interaction effects is emphasized if future colloid investigations are to give reliable results for testing the London theory.

[1] F. London, Physica **3**, 450 (1936).

R15. Lambda-Points of Solutions of He^3 in He^4 below 1°K. J. G. DAUNT AND C. V. HEER, *Ohio State University.*—Measurements have been made of the transition (lambda) temperatures at which solutions of He^3 in He^4 first show superfluidity by observation of the thermal isolation of a vessel which contained the solutions and which was cooled to low temperature by a paramagnetic salt. The incidence of superfluidity was accompanied by a high heat influx to the solution produced by a convection of film flow to the high temperature together with return flow in the vapor phase. The solution with the highest concentration, namely 89 percent He^3, had a lambda-temperature of 0.38°K; solutions with smaller He^3 content (concentrations down to 40 percent He^3 were investigated) show higher lambda-temperatures ranging up to 1.1°K. It was concluded that pure He^3 could not be superfluid above 0.25°K and most probably is not superfluid down to 0°K. The He^3 mixture was kindly supplied by the Isotopes Division of the AEC.

R16. Superconducting Temperature of Lead. D. B. Cook, H. A. Boorse, and M. W. Zemansky, *Columbia University.**— The superconducting temperature of lead in the absence of an applied magnetic field has been observed in many laboratories by measurements of electrical resistance. In the present experiments the transition temperature was measured by an a.c. induction method which reflects changes in the permeability of a cylindrical specimen of lead used as the core of a secondary coil surrounded by a primary coil carrying an alternating current of 1000 c.p.s. Specimens were cooled from 10.3°K to their transition temperature in a cryostat utilizing desorption of helium gas from charcoal. A helium gas thermometer with large room temperature volume was used to measure temperatures to an accuracy estimated as 0.04 deg. with a sensitivity of 0.01 deg. Using lead of maximum purity obtainable the transition temperature was found to be 7.22 ± 0.04°K in good agreement with the average of the results obtained by resistance measurements. The variation of transition temperature with the intensity of an applied longitudinal magnetic field was observed and found to be in agreement with the values of Daunt.[1]

* Research sponsored by ONR.
[1] J. G. Daunt, Phil. Mag. **28**, 24 (1939).

Atomic Spectra; General Optics

S1. Isotope Shift in the Lines of Pb I.* W. W. Watson and C. E. Anderson, *Yale University.*—We have extended the investigation begun by Manning[1] on the isotope shifts in the lead spectrum, using material enriched in the 204 isotope. Nine of the strongest Pb I lines in the violet and ultraviolet showing isotope structure and Pb 207 h.f.s. have been measured. For all lines with measurable structure the 204–206 interval is less than the 206–208 interval. The resonance line $\lambda2833\ [6p^2(\frac{1}{2}\frac{1}{2})_0-6p7s(\frac{1}{2}\frac{1}{2})_1]$ and $\lambda3639\ [6p^2(\frac{3}{2}\frac{1}{2})_1-6p7s(\frac{1}{2}\frac{1}{2})_1]$ both yield measurements unaffected by superposed 207 h.f.s. For these the ratio of the 204–206 and 206–208 intervals is 0.89 and 0.82, and the ratio of the 206–207 to the 207–208 interval is 0.69 and 0.60, respectively. Most of this splitting is attributable to the interaction with the $7S$ electron in the upper state. Splittings in the $6p6d$ levels (~0.050 cm^{-1}) indicate perturbations by $6p7s$ and $6p8s$. These Pb isotope shifts give further evidence of increasing nuclear stability in the progression 204 to 208. Some inconsistencies in the classification of certain Pb I lines also will be discussed.

* Assisted by the AEC.
[1] T. E. Manning, Phys. Rev. **76**, 464(A) (1949).

S2. The Oscillator Strength for the $4s-4p$ Transition in Ca II.* L. C. Green and N. E. Weber, *Haverford College.*— A number of computations have been made of the oscillator strength or f-value for the $4s-4p$ transition in Ca II. Three fields were used to obtain the necessary wave functions: a self-consistent field, both with and without exchange, and a field of the Kramer's type. With each field, the radial integrals for the dipole moment, for two forms of the dipole momentum, and for the dipole acceleration were evaluated. Each of these radial integrals was then used to calculate two values of the oscillator strength. One value was obtained using the observed energy difference, and a second using the difference of the eigenvalues of the particular wave functions employed in computing the radial integrals. Values from the same field and values from different fields were found to be in closer agreement when the calculated, rather than the observed, energies were employed. Comparison of the various results suggests that the true value of the oscillator strength for this transition probably lies within ±0.10 of the value 1.08.

* The major part of this work was supported by the ONR, Contract No. N8 onr-570, Project No. NR 010–016.

S3. Configuration Interactions in the Pb III Spectrum. J. N. P. Hume and M. F. Crawford, *University of Toronto.*— Although the theory of configuration interactions is formulated in Condon and Shortley's *Theory of Atomic Spectra*, little has been done in the way of definite and detailed calculations of these effects. The Slater parameters were evaluated for the perturbed configurations of the two-electron spectrum, Pb III and the wave functions of 32 levels were calculated in terms of the L-S functions. The wave functions for many of these levels were found to be linear combinations of the L-S functions of two or more configurations, and precise configuration assignments were made for these levels. Using these functions excellent agreement was obtained between the calculated and observed g-values, hyperfine structure interval factors and isotope shifts. The isotope shift and the hyperfine structure interval factor for the $6S$ electron were determined as 0.50 cm^{-1} and 2.60 cm^{-1}, respectively. The isotope shifts can be accounted for on the basis of the field theory alone. The calculations indicate that the wave functions for two of the levels are slightly in error, but confirm the correctness of all the others. It is thus established that the theory is capable of an internally consistent explanation of all the spectroscopic properties.

S4. The First Spark Spectrum of Manganese. C. W. Curtis, *Lehigh University.*—The classification of approximately 700 lines of the Mn II spectrum has previously been reported.[1] These classifications include only quintet-quintet, septet-septet, and a few intersystem transitions. Recently the analysis has been extended[2] to include over 450 additional lines, most of which arise from terms of the triplet system. This system has been placed relative to the normal state, $3d^5(^6S)4s\ ^7S_3$, by numerous combinations between triplet and quintet levels. The lowest lying terms of this spectrum should arise from the $3d^6$ and $3d^54s$ configurations, and in the case of the latter be based on sextet and quartet limit structures. Of 18 septet, quinet, and triplet terms, which could result from these structures, all but the three highest have been located.

[1] Curtis, Phys. Rev. **53**, 474 (1938).
[2] We are indebted to Professor M. Catalan, Ciudad Universitaria, Madrid, Spain, for furnishing unpublished data on the Zeeman patterns of certain lines critical to the analysis.

S5. Electronic Excitation of L_{III} States.* George L. Rogosa and Guenter Schwarz, *Florida State University.*— The electronic excitation of the L_{III} state of $5d$ transition elements has been measured as a function of the energy of the bombarding monoenergetic electrons. Data were taken for an energy region extending from about 30 ev below the excitation potential to 30 ev above. A double-crystal x-ray spectrometer was used as a monochromator, set to pass the peak of the $L\alpha_1$ line into a Geiger counter. The highly stabilized x-ray tube voltage was changed in steps of 2 v, and the intensity, recorded in the Geiger counter, measured at a function of the voltage. This intensity is a measure of the electronic excitation of the L_{III} state. The resulting curves show a very pronounced structure. For tantalum, for example, the intensity-energy curve shows a plateau of about 10 ev width, starting at a position of 6 ev above the excitation potential.

* This work was begun by one of us (G. S.) in 1941; interrupted by the war; and additional data obtained later at the Johns Hopkins University by G. L. R.

S6. Improved Wadsworth Mounting for a Concave Grating Spectrometer.* W. J. Taylor, G. P. Koch, and H. L. Johnston, *Ohio State University.*—A concave grating spectrometer (21 ft. radius, 15,000 lines per in.) of the Wadsworth type suitable for both photographic and photoelectric recording has been constructed. The grating which is illuminated with parallel light, is mounted on a moving beam, directly over the

main bearing about which the beam pivots. The plate, or exit slit (for photoelectric recording), is mounted on the other end of the beam, and is maintained in focus by a cam and reciprocating mechanism as the beam moves. The main component of the wave-length drive is a 10-ft. lathe bed and screw. As the screw rotates it advances a plate mounted on the lathe parallel to the incident beam of light. The plate in turn engages a roller fixed to the beam, and thus drives the latter. This mechanism produces an accurately linear wave-length scale such that one revolution of the screw represents (approx.) 23A (11.5A in the second order) over the entire range of 1800–12,000A; 1/500 revolution is significant. This design makes possible an improved method of photoelectric scanning, in which the exit slit is maintained on the normal to the grating as the beam is driven (as opposed to the use of several fixed settings of the beam).

* This work was supported in part by the ONR under contract with The Ohio State University Research Foundation.

S7. Variable Thickness Low Temperature Infra-Red Absorption Cell.* R. B. HOLDEN, W. J. TAYLOR, AND H. L. JOHNSTON, *Ohio State University.*—An infra-red absorption cell of unique design has been constructed and has proved very convenient for the study of the spectra of liquids and solids at low temperatures. The metal members on which the windows are mounted are joined by a short metal bellows, so that the separation of the windows, and therefore the sample thickness, can be varied continuously within certain limits. This motion is controlled by three micrometer screws spaced at 120° intervals around the bellows, and turned in unison by an annular gear. The windows are of AgCl, 11.5 mm thick, with a deep recess cut in the rim to allow a gasket seal and at the same time permit the flat inner faces of the windows to be brought into contact. An excellent vacuum-tight seal is obtained with Teflon gaskets and spring loading. Gases or volatile liquids are condensed into the cell through a fine metal tube soldered to the cell, and may then be frozen. The cell is suspended in an evacuated cryostat in the optical path of a Perkin-Elmer spectrometer. The sample thickness may be varied without removing the cell from the cryostate by means of a shaft which emerges through a Wilson seal.

* This work was supported in part by the ONR under contract with The Ohio State University Research Foundation.

S8. Optical Alignment of a Recording Near Infra-Red Spectrophotometer. JAMES L. LAUER, *Sun Oil Company.*—Refractive indices of an EDF-3 glass prism suitable for a Littrow-type instrument covering the region from 0.6 to 2.0μ were obtained and a cam designed for continuous scanning at a rate constant with respect to wavenumber. With mirrors and slits aligned and the prism oriented for a visible Hg emission line at which its refractive index was known, the Littrow mirror was turned through angles determined by an optical lever and the relative intensities and corresponding mirror positions of the infra-red Hg lines were found by observing the current of a PbS photo-conductive cell placed behind the exit slit. The lines were identified by comparison with benzene absorption bands. The angle of incidence on the prism was measured as the angle between a transit's telescope aligned above the prism for sighting the entrance slit through the collimating mirror and a telescope provided with a Gaussian eyepiece, rigidly mounted parallel to and below the former, lined up with the normal to a prism face. Data thus obtained yielded all the required information.

S9. A Ratio-Recording Double Beam Infra-Red Spectrophotometer Using Phase Discrimination and a Single Detector. ABRAHAM SAVITZKY AND RALPH S. HALFORD, *Columbia University.*—A simple modification will be described for converting a Perkin-Elmer infra-red spectrophotometer to double beam operation for direct recording of percent transmission *versus* wave-length. A phase discrimination system is used, requiring no changes in the optical system, and no sacrifice of versatility or ease of prism interchange. A complete spectrum over the rocksalt region may be obtained in 25 min. with good resolution, and with no attention from an operator. Samples as small as 1×6 mm can be studied. The system is readily adaptable to other spectrophotometers, including those in the visual and ultraviolet range, the only limitation being sufficiently rapid response by the detector. A Golay pneumatic detector was employed in the present application.

S10. The Diffraction Pattern in the Plane of a Circular Aperture. C. L. ANDREWS, *General Electric Research Laboratory.*—The diffraction patterns in the planes of circular apertures from one to eight wave-lengths in diameter have been measured when a plane-polarized electromagnetic wave was incident normally on the aperture. A circuital integral based on Thomas Young's theory of diffraction yields the distribution of intensity over the aperture quantitatively. A demonstration of diffraction by an aperture four wave-lengths in diameter will be given employing microwaves of 2500 Mc.

S11. Combination Two-Circle Goniometer and X-Ray Spectrometer. M. L. BARON AND A. DEBRETTEVILLE, JR., *Signal Corps Engineering Laboratories.*—A combination instrument consisting of a two-circle goniometer and x-ray spectrometer suitable for the study of crystals was designed and fabricated in Squier Signal Laboratory. A crystal can be oriented optically by using the instrument as a goniometer. X-ray techniques can then be used to study the crystal by replacing the collimator and telescope with a monochromatic x-ray beam and a Geiger counter. Absolute intensity measurements can be made by fixing the Geiger counter at twice the Bragg angle and rotating the crystal at 8° per hour from $\theta_{\text{Bragg}}-\Delta\theta$ to $\theta_{\text{Bragg}}+\Delta\theta$. Back-reflection angles of up to 160° are obtainable. The result of a test on synthetic halite (400) reflection, gave a structure factor of 12.7 compared with Max Renniger's value of 12.67.

Reactions of Transmutation; Theories of Elementary Particles

U1. Studies of Disintegrations by 14-Mev Deuterons.* M. S. LIVINGSTON, K. BOYER, H. E. GOVE, J. A. HARVEY, AND M. DEUTSCH, *M. I. T.*—The following three papers describe experimental results obtained by bombarding thin targets of many elements with 14-Mev deuterons produced in the M.I.T. cyclotron. A magnet focuses the emergent beam on a target in an observation chamber behind a 4-ft. concrete wall. Detection instruments mounted on two movable arms are used to observe angular distributions and coincidences between nuclear radiations. A triple-coincidence proportional ionization chamber with variable aluminum absorber gives differential number-range curves for charged particle products. Protons and alphas are identified uniquely and with zero background even for ranges shorter than scattered deuterons. Group structure is observed for all targets. Amplifiers, coincidence circuits, and recording instruments are arranged to record the data rapidly and automatically. Crystal counters for gamma-rays and chambers to detect recoil nuclei are used in coincidence with the proton counter. Studies are in progress of nuclear excitation levels indicated by the proton and alpha-groups, of the variation in angular distribution of individual groups, of coincidences between proton groups and gamma-rays and on the protons of low energy which have anomalously high intensities.

* Assisted by the Joint Program of the AEC and ONR.

U2. The Energy Spectrum of Protons from (d, p) Reactions.* KEITH BOYER, *M. I. T.*—The proton energy spectra resulting from 14-Mev deuteron bombardment of thin targets have been determined for many elements randing from Be^{9} to Be^{209}. Considerable group structure is evident for most of the elements studied in energy regions corresponding to both bound and virtual levels. In the heavier elements the energy resolution is not sufficient to determine whether most of the groups are due to one or two individual levels, or to fluctuations in level density. However, where checks could be made against levels known from γ-ray transitions induced by slow neutron capture, the higher energy proton groups were found to correspond to no more than three levels. In the lighter elements the groups were well resolved and could be identified with individual levels. Eight levels were found in $Be^{9}(d, p)Be^{10}$ having an average separation of about 1.2 Mev. The two lowest levels had excitation thresholds of about 7 Mev explaining why they have not been found previously. A level at 1 Mev was definitely established in $C^{12}(d, p)C^{13}$. An unexpectedly large number of low energy protons was found especially in the heavy elements. For elements in the region of gold the distribution had a broad maximum at about 5 Mev when viewed at 90°.

* Assisted by the Joint Program of the AEC and ONR.

U3. Angular Distributions of Protons Emitted in Reactions Induced by 14-Mev Deuterons.* HARRY E. GOVE, *M. I. T.*—Protons are found to be concentrated in the forward direction in all elements studied. The ratio of intensity at 20° to that at 135° varies from 10 to 50. This is interpreted as being associated with the stripping process. In addition for light elements such as C, Al, and Ni in which individual groups can be resolved, the number of protons in a given group, in some cases, shows maxima at various angles. It is assumed that these sharp angular maxima are associated with the unique nuclear energy state in which the neutron was left initially. Present theory of the stripping process is inadequate to explain such maxima. In heavier elements in which the proton spectrum is continuous, the angular variation of segments of the spectra was measured. It is observed in general that the distribution is more strongly forward for higher energy protons. The reaction $Au^{197}(d, p)$ shows the number of protons rising from 30° to a rather broad peak about 60° and dropping off toward back angles independent of proton energy.

* Assisted by the Joint Program of the ONR and AEC.

U4. Neutron Binding Energies from (d, p) Reactions.* J. A. HARVEY, *M. I. T.*—Q-values have been determined for the maximum energy proton group from (d, p) reactions in many elements. The targets in general were 0.5 mil thick. The energy loss for deuterons was obtained by inserting the target in the deuteron beam; the target thickness for protons by the range reduction of a known high energy proton group. Accepting the aluminum ground state group Q-value as 5.50 Mev, tentative Q-values (in Mev) for a few target elements where the highest energy proton group is well resolved are: Pb^{206}(4.48), Pb^{207}(5.14), Pb^{208}(1.70), Bi^{209}(1.95), Fe_{5}^{4}(7.1), Fe^{56}(5.4), Ni^{58}(6.8), Zr^{90}(5.0), Zr^{91}(6.5). In order to identify the highest energy group observed with the ground state of the residual nucleus, coincidence studies were made between protons and γ-rays for the lighter elements. Also the bismuth and lead Q-values correspond to ground state groups, since their sum agrees with the value (13.6 Mev) calculated from radioactive decay energies. Neutron binding energies computed from the Q-values are compared to previous experimental results and theoretical predictions.

* Assisted by the Joint Program of the AEC and ONR.

U5. On the Self-Stress of the Electron. S. BOROWITZ, W. KOHN, AND J. SCHWINGER, *Harvard University.*—It is known that the vanishing divergence of the stress tensor of an electron interacting with the vacuum electromagnetic field implies formally a vanishing self-stress. Nevertheless, previous calculations[1] have led to a finite value for this quantity. This result arises as a consequence of the ambiguities which accompany the divergences of quantum electrodynamics. It has been possible to resolve the difficulty in the following way: The divergence of the second-order correction of the stress-tensor can be written as the difference of two similar non-convergent momentum integrals, which are related by a translation in the momentum variable. To retain a divergenceless stress tensor it is necessary to impose the rule that such integrals shall be invariant under a momentum translation. This rule is simply an expression of gauge invariance. On calculating the self-stress one encounters the integral of a gradient in momentum space. This may be regarded as the difference of two integrals, of the same nature as those above and differing by an infinitesimal translation. According to our rule, therefore, the self-stress vanishes. It may be noted that any theory compatible with gauge invariance which makes the integrals convergent will automatically lead to a null result for the self-stress.

[1] A. Pais and S. T. Epstein, Rev. Mod. Phys. **21**, 445 (1949).

U6. On the Dirac Theory of Spin ½ Particles and Its Non-Relativistic Limit. L. L. FOLDY, *Case Institute of Technology*, AND S. A. WOUTHUYSEN,* *University of Rochester.*—By a canonical transformation a representation of the free-particle Dirac theory is obtained in which positive and negative energy states are separately described by two-component wave functions. Playing an important role in this representation are new operators for position and spin of the particle. The components of the time derivative of the new position operator all commute and have for eigenvalues all values between c and $-c$. The new spin operator is a constant of the motion unlike the conventional spin operator. By a comparison of the new Hamiltonian with the non-relativistic Pauli Hamiltonian for spin ½ particles, one finds that the new rather than the conventional operators pass over into the position and spin operators in the Pauli theory in the non-relativistic limit. The transformation to the new representation is also made in the case of interaction with an external electromagnetic field, and yields essentially the Pauli Hamiltonian in the non-relativistic limit. An examination of the relationship between the new and conventional position operator casts some light on the question of why a Dirac electron shows electromagnetic properties characteristic of a particle of finite extension. This work was supported at Case by the AEC and at the University of Rochester by the Joint Program of ONR and AEC.

* Now at University of Amsterdam, Amsterdam, Netherlands.

U7. Relativistic Model of a Finite-Sized Electron. G. J. YEVICK, *Stevens Institute of Technology.*—The Lagrangian formulation of quantum mechanics developed by Feynman[1] not only furnishes a basis for the Feynman prescription for calculating electron-photon processes but also constitutes one possible framework from which future theories may arise. This framework is more general than the Hamiltonian formalism. As an illustration we have considered a new model of a finite-sized electron suggested to us by some recent work of Yukawa's (unpublished) on non-local fields. (We have been unable as yet to obtain a connection between Feynman's methods as applied to this model and Yukawa's theories.) For our model, the basic idea is that the classical charge-current density of the electron exists only along its velocity four-vector. Unlike the Feynman and Mc Manus model, the charge-current density is localized in a small region of space-time. It also differs from the model recently proposed by

Bohm and his collaborators[2] in that there are no internal degrees of freedom. This makes it much simpler to handle. Quantization is achieved by formally using the Lagrangian method of Feynman.

[1] See Ann Arbor Summer Symposia Notes (1949).
[2] Bohm, Weinstein, and Kouts, Phys. Rev. **76**, 867 (1949).

U8. Interaction between Elementary Particles. ALFRED LANDÉ, *Ohio State University.*—A finite self-field for classical particles was obtained[1] from $c^2t^2-r^2=a^2$ as the basic communication law through which the point center surrounds itself by a Maxwell or meson potential. The same communication law leads to equations of motion for a system of particles, derivable from a least action principle which is a generalization of that described by Feynman.[2] However, instead of a more or less arbitrary smoothed out δ-function representing the "structure" of the particle, the variation principle involves an exact δ-function with shift of origin. The vacuum Maxwell or meson field equations are thereby secured everywhere without exception, and the result is a consistent *unitary theory* of interaction at a distance between particles including finite self-reaction; the field plays the role of an auxiliary scheme only. Translation into quantum theory involves a ψ-function dependent on the individual time coordinates of the various particles as well as on their space and spin coordinates.

[1] A. Landé, Phys. Rev. **76**, 1176 (1949).
[2] R. P. Feynman, Phys. Rev. **74**, 939 (1948).

U9. The Self-Energies of Electrons and Photons. HARTLAND S. SNYDER,* *Brookhaven National Laboratory.*—It has generally been supposed that the self-energy of an electron as determined by the application of perturbation theory to the interaction of the electron-positron field with the electromagnetic field is necessarily infinite. However, by the use of appropriate limiting procedures one can make both the electron and photon self-energies vanish in order α. The procedure used is relativistically invariant. A paper concerning these matters is being prepared for publication.

* Work performed at Brookhaven National Laboratory under the auspices of the AEC.

U10. Covariant Description of Extended Charges. D. BOHM, M. WEINSTEIN, AND H. KOUTS, *Princeton University.*—A simple relativistic description of an extended charged particle can be obtained by specifying the charge-current distribution in the rest system as a function of the proper time. If one requires the distribution to be spherically symmetric in the rest system, charge-current is not conserved. To obtain conservation one must add a spinlike term which takes into account the Lorentz transformation which the rest system undergoes when the particle is accelerated.* The equations of motion have been investigated and it was found that self-acceleration does not take place provided that the non-electromagnetic mass is greater than $\frac{1}{3}$ the electromagnetic mass. In the linear approximation one finds the same self-oscillations that occur in the non-relativistic theory.** The theory is not causal in the most restricted sense, but all features of causality required to provide a consistent description of the relation between past and future are retained if the acceleration in the rest system is limited to be less than C^2 divided by the radius of the particle.

* Bohm, Weinstein, and Kouts. Phys. Rev. **76**, 867 (1949).
** D. Bohm and M. Weinstein, Phys. Rev. **74**, 1789 (1948).

U11. Isobaric State of Nucleon. R. E. MARSHAK, *University of Rochester.*—Recent evidence for highly multiple meson and gamma-production in a large star[1] (*R*-star) favors the pseudoscalar field for the π-meson. When this evidence is coupled with the low cross section found for the scattering of π-mesons by nucleons,[2] one is tempted to return to the strong coupling formulation as an explanation of both phenomena.[3] Using symmetric pseudoscalar strong coupling theory,[4] one obtains a unique nucleonic scource size $a\sim 0.3\ \hbar/Mc$ (M is the nucleon mass) from the scattering data. Using the same theory for the multiplicity of meson production,[5] one obtains $g^2/\hbar c\sim 0.1$ from the data on the *R*-star.[1] These numbers lead to an excitation energy of $2\mu c^2$ (μ is the π-meson mass) for the lowest isobaric state of the nucleon. The isobaric excitation energy is very sensitive to the multiplicity N ($\sim N^{-3}$) but even a value greater than μc^2 need not exclude observation of an isobaric state.[6]

[1] Kaplon, Peters, and Bradt, Phys. Rev. **76**, 1735 (1949); Marshak, Phys. Rev. **76**, 1736 (1949).
[2] Fretter, Phys. Rev. **76**, 511 (1949).
[3] Oppenheimer and Schwinger, Phys. Rev. **60**, 150 (1941).
[4] Pauli and Dancoff, Phys. Rev. **62**, 85 (1942).
[5] Lewis, Oppenheimer, and Wouthuysen, Phys. Rev. **73**, 127 (1948).
[6] Tomonaga, Prog. Theor. Phys. **1**, 109 (1946).

U12. On the Electromagnetic Interaction of Mesons of Zero Spin. F. ROHRLICH, *Cornell University.*—The convergence of the interaction of a scalar (pseudoscalar) meson field with the electromagnetic field has been investigated. A sufficient condition for the convergence of the nth order term in the scattering matrix is: $E\geqslant 5$ (if $n\geqslant E$) or $2E-n\geqslant 5$ (if $n\leqslant E$). E and n are the number of external lines and corners of the corresponding Feynman diagram. It follows that there are at most seven primitive divergent diagrams. One of them, the scattering of light by an external field to third order, vanishes identically due to an obvious extension of Furry's theorem to bosons. The remaining six diagrams are: the meson self-energy, vacuum polarization, the Lamb-shift, Compton-effect and Møller-interaction both to fourth order, and the scattering of light by light. The last process is found to be finite due to cancellations. The other processes can be shown to be finite when mass and charge are properly renormalized, *except for the fourth order Møller-interaction which remains logarithmically divergent.* Similar to the scattering of mesons by mesons via virtual nucleons this divergence can only be removed if a fourth order direct interaction is added to the Hamiltonian.

U13. Quantization of Wheeler-Feynman's Electrodynamics. F. J. BELINFANTE AND J. S. LOMONT, *Purdue University.*—Even if W.-F.'s electrodynamics does not directly describe photons, one might perhaps hope to describe nature by mere quantization of the *electronic* field in it, treating for instance a Compton effect as an initial transition of an excited atom to its ground state, subsequent acceleration of a free electron and final exciting of an "absorber" atom. A quantized W.-F. electrodynamics does not seem possible simultaneously in Heisenberg *and* in interaction representation. One might formulate a variational principle equivalent to W.-F.'s assumptions, for a quantized field $\psi(x, y, z, t)$, in *Heisenberg* representation, using anticommutativity and arrangement of factors for excluding self-interactions. This leads to a Dirac equation for ψ with interaction terms instead of a potential four-vector in it. However, it probably cannot be consistent with the canonical anticommutation relations in more than one Lorentz frame, so that we drop this theory for lack of relativistic covariance. As positon theory requires use of $\psi=\psi^{(+)}+\psi^{(-)}$, while this splitting of ψ is invariant in interaction representation only, one might perhaps hope better results in interaction representation. The generalized Schrödinger equation for $\Psi[\sigma]$ describing such quantized W.-F. theory, however, cannot be expected to be integrable.

Molecular Spectroscopy, Microwave and Infra-Red

V1. Nuclear Quadrupole Coupling and Ionic Character of Molecules.* C. H. TOWNES AND B. P. DAILEY, *Columbia University.*—The nuclear quadrupole coupling of Cl^{35} in a

TABLE I.

Molecule	Electronegativity difference Cl−X	Cl^{35} Quadrupole coupling constant (megacycles)	Percent ionic character
ICl	0.6	−82.5	9
FCl	−1.0	−146.0	25
TlCl	1.7	−15.79	82
NaCl	2.1	0±1	≥97

molecule can be shown to be rather directly related to its coupling in the atomic state and to the nature of its molecular bond. If the Cl is negatively ionic, the quadrupole coupling is small because the charge around the Cl nucleus is essentially spherical; if the Cl is positively ionic, the coupling is large because two electrons rather than only one are missing from a complete shell. Quadrupole coupling constants for the four diatomic molecules in Table I allow determination of the importance of ionic structures and hence a fairly complete curve of ionic character *versus* electronegativity difference for this type of molecule. Values of ionic character are consistently higher than those usually derived from dipole moments. Since quadrupole coupling is more simply related to ionic character than are dipole moments, these values are probably more reliable.

* Work supported jointly by the Signal Corps and ONR.

V2. Determination of Double-Bond Character from the Microwave Spectrum of Planar Asymmetric Top Molecules with a Quadrupolar Nucleus. J. H. GOLDSTEIN, *Emory University*, AND J. K. BRAGG, *Cornell University*.—Under certain simplifying assumptions there may be derived, from the pure rotational spectrum of an asymmetric top molecule containing a nuclear electric quadrupole, the quantity $\Delta = eQ(\partial^2 V/\partial\xi^2 - \partial^2 V/\partial\eta^2)$, where ξ and η are axes perpendicular to the bond to the quadrupolar nucleus and V is the electrostatic potential at this nucleus. If the molecule is planar and ξ lies in the plane, deviations of Δ from zero give a quantitative measure of the double-bond character of the bond to the nucleus, as formulated in atomic orbital theory. This measure is independent of other properties of the bond. For the two molecules for which Δ has so far been obtained, CH_2CHCl[1] and CH_2CFCl[2], the results are 4 and 5 percent double-bond character, respectively.

[1] J. H. Goldstein and J. K. Bragg, Phys. Rev. **75**, 1453 (1949).
[2] Bragg, Madison, and Sharbaugh (to be published).

V3. Centrifugal Distortion in the Formaldehyde Molecule.* RICHARD B. LAWRANCE, *M. I. T.*—The theory of rotation-vibration interaction and centrifugal distortion in non-rigid molecules[1] has been in existence for nearly 14 years but has not heretofore been successfully subjected to experimental verification. The pure rotation spectrum of formaldehyde H_2CO contains within the easily accessible microwave region a large number of lines (30) and participating J-values (zero through 30). We have looked for and observed 17 of these transitions, as well as six lines in the $H_2C^{13}O$ spectrum. We have developed a simple distortion-correction formula for the special case of $\Delta J=0$, $\Delta K=0$ transitions in molecules of small asymmetry parameter δ, and obtain a very good fit. Our distortion corrections and rotational constants thus constitute an independent experimental determination which can be critically compared with the values obtained from the Wilson-Howard theory using infra-red force constants. The agreement is quite satisfactory.

* This work has been supported in part by the Signal Corps, the Air Materiel Command and ONR.
[1] E. B. Wilson, Jr. and J. B. Howard, J. Chem. Phys. **4**, 260 (1936).

V4. The Rotational Spectrum and Molecular Structure of PCl_3.* P. KISLIUK AND C. H. TOWNES, *Columbia University*.—The $J=4\rightarrow5$ transition has been observed in PCl_3 for all four of the isotopic combinations of chlorine. Theory shows that each line is split into several hundred hyperfine components by the chlorine quadrupole coupling.[1] Complete solution of the resulting pattern would be very time consuming, but the observed structure of three broad lines in PCl_3^{35} can nevertheless be qualitatively understood. The center of the patterns for PCl_3^{35} and PCl_3^{37} are at 26,171 and 24,875 megacycles respectively. Even without solving the hyperfine structure the molecular parameters can be calculated with reasonable accuracy. For the P–Cl distance one obtains 2.044±0.01 A and for the Cl–P–Cl angle 99° 56′±1°.

* Work supported jointly by the Signal Corps and the ONR.
[1] R. Bersohn, Thesis, Harvard University, 1949.

V5. The Microwave Spectrum of CH_3SiF_3. H. T. MINDEN, J. M. MAYS,* AND B. P. DAILEY, *Columbia University*.—H. S. Booth and R. W. Morrow have kindly prepared for us a sample of CH_3SiF_3, the microwave spectrum of which we have investigated. The $J=2-3$ and the $J=3-4$ pure rotational transitions of this symmetric top molecule have been observed at 22,295 mc and at 29,727 mc, respectively. The spectrum is very similar to that of CH_3CF_3.[1] In the $J=2\rightarrow3$ transition three lines about 10 mc apart are detectable, a fourth very weak line was observed about 20 mc higher than the strongest line. Five lines about 20 mc apart were observed for the $J=3\rightarrow4$ transition. All lines showed the typical Stark effect for a $\Delta J=1$, $\Delta K=0$ symmetric rotor transition. The most intense lines in each group is assigned to the ground state of torsional vibration. The succeeding lines decreasing regularly in intensity and frequency are assigned to excited torsional levels. The intensity ratios for the various lines give the energy separations through the relationship $I_1/I_2=\exp(h\nu/kT)$. The increase in the degenerate moment of inertia in the excited torsional states is tentatively explained by the repulsion of the C−H and Si−F bonds as the molecule twists away from the torsional equilibrium position.

* Eastman Kodak Fellow.
[1] Dailey, Shulman, and Minden, Phys. Rev. **75**, 1319 (1949).

V6. Microwave Transitions between *l*-Type Doublets of HCN.* R. G. SHULMAN** AND C. H. TOWNES, *Columbia University*.—A new type of transition involving l-type doubling has been observed in the linear molecule HCN. A search of the HCN spectrum was made in an attempt to find the rotational spectrum of the dimer $(HCN)_2$. No lines caused by the dimer appeared, but five lines were found between 9000 and 36,000 Mc. The frequencies, Stark effects and intensities are those to be expected from transitions between the split l-type doublet levels of quantum numbers $v_2=1$, $J=6$, 8, 10, 11 and 12 and $\Delta J=0$. Frequencies are given by $\nu=q(1+\epsilon J)J(J+1)$ where the ordinary l-type doubling constant $q=223.549$ Mc and ϵ, which is of the order B/ω_2, represents a small deviation from the form hitherto assumed for l-type doubling. The HCN dipole moment for this vibrational state, $v_2=1$, was found to be 2.957±0.025 Debye units from the Stark splitting.

* Work sponsored jointly by the Signal Corps and ONR.
** Present address: Chemistry Dept., California Institute of Technology.

V7. Pressure Shift and Broadening in Micro-Wave Spectra. A. G. ROUSE, A. V. BUSHKOVITCH, L. C. JONES, C. A. POTTER, AND W. F. SULLIVAN, *Saint Louis University*.—The microwave spectrograph employed has two absorption cells, and the absorption line for each cell is displayed alternately on an oscilloscope by means of an electronic switch. The pressure in one cell is maintained at a low constant value, the pressure in the other cell is varied or a foreign gas added. Half widths and shifts were measured by superimposing pips on the trace corresponding to a known frequency difference. Effects of polar and non-polar foreign gases have been studied.

V8. Absorption of Millimeter Waves in ND_3.* J. H. N. LOUBSER** AND J. A. KLEIN, *Columbia University.*—The inversion spectrum of ND_3 has been examined at pressures near one atmosphere in the frequency range 24,000–145,000 mc. The first excited vibrational state ($v_2=1$) produces a resonance at 117,000 mc compared with the infra-red value of 102,000 mc and a theoretically calculated value of 83,000 mc. Measurements of the shape of the absorption curve caused by inversion in the excited state show that the fine structure is considerably more widely spaced than in the case of the NH_3 ground state inversion. At 24,000 mc almost the entire absorption of 3.4×10^{-3} cm^{-1} at atmospheric pressure is due to the tail of the ND_3 ground state inversion which (theoretically) occurs near 4000 mc. The ratio of the line breadth parameter of ND_3 to that of NH_3 is 0.88 which is close to the expected ratio of collision frequencies assuming identical cross sections. The millimeter waves were obtained from magnetron harmonics and measurements made essentially as previously described,[1] except that silicon crystals were found to give satisfactory detection down to wavelengths as short as 1.6 mm and were used to some extent.

* Work supported jointly by the Signal Corps and the ONR.
** Carbide and Carbon Post-Doctoral fellow in physics.
[1] J. H. N. Loubser and C. H. Townes, Phys. Rev. 76, 178 (1949).

V9. The Infra-Red Spectra of Crystalline Ammonia and Deutero-Ammonia. D. F. HORNIG AND F. P. REDING, *Brown University.*—The infra-red spectra of thin sublimed films of crystalline NH_3 and ND_3 were studied at −190°C. Sharp bands for NH_3 were observed at 528 (medium), 1059 (strong), 1642 (m) 3223 (m) and 3380 (s) cm^{-1}. The regions 1360–1670; 3100–3360 cm^{-1} contain broad superimposed bands with maxima at 1410, 1500, 1590, and 3297 cm^{-1}. Further broad bands were found at 1840, 2120 and 3536 cm^{-1}. Sharp bands for ND_3 were observed at 819 (s), 1196 (m), 2318 (m), and 2502 (s) cm^{-1}. Since the films of ND_3 were very thin, there was only slight evidence of broad bands. In crystals fundamentals are sharp while combinations and overtones may be broad; if the sharp lines in both spectra are assigned in the previous order to ν_5 (the torsional oscillation perpendicular to the figure axis), ν_2, ν_4, ν_1, and ν_3, the fundamental frequencies are close to those of the gas and the frequency ratios between NH_3 and ND_3 are reasonable. The more diffuse bands require detailed consideration of crystalline interaction, but it seems likely that the spectrum is consistent with a crystal composed of simple molecules, contrary to suggested interpretations of the Raman spectrum.[1]

[1] G. B. B. M. Sutherland, Proc. Roy. Soc. (London) 141A, 546 (1933).

V10. Infra-Red Spectra for Single Crystals of Ammonium Nitrate and Thallous Nitrate in Polarized Radiation. RALPH S. HALFORD AND ROGER NEWMAN, *Columbia University.*—Infra-red spectra have been obtained for thin sections from single crystals of NH_4NO_3(IV), NH_4NO_3(III) and $TlNO_3(\gamma)$ in radiation polarized successively along different crystal axes. Spectra for the first two crystals show (1) that absorptions attributable to molecular modes of nitrate ion are strongly polarized in directions predicted by the general theory[1] of crystal spectra; (2) that envelope structure resulting from combinations between lattice modes and molecular modes is present but not uniquely polarized, again in agreement with general theory;[1] (3) that absorptions attributable to ammonium ions appear to be unpolarized, indicating that these ions are disordered from rotation or other causes. Spectra for the third substance can be used to complete the determination of its crystal structure. One band for this substance has a remarkable envelope structure consisting of a strongly polarized central branch and, at room temperature, three pairs of symmetrically distributed, virtually unpolarized satellites. At −160°C there are no less than seven distinct satellites on the high frequency side with damped out counterparts on the low frequency side.

[1] H. Winston and R. S. Halford, J. Chem. Phys. 17, 607 (1949).

V11. Intermolecular Forces in Benzene, VERNON MYERS, *Pennsylvania State College.*—The long range attractive forces between benzene molecules are computed from optical dispersion data, and the short range repulsive forces are estimated from the known deviations from the perfect gas law.[1] If the repulsive forces are approximated by a hard sphere model with a molecular diameter of 4.52A, the difference between the experimental and calculated second virial coefficient is approximately −3 percent at 318°K and 3 percent at 358°K. When the repulsive forces are represented by $C\exp(-R/0.28\text{A})$ with the potential minimum at 4.45A, the discrepancy is reduced to about −2 percent at 318°K and 0.5 percent at 358°K. The depth of the potential minimum for the hard sphere assumption is −0.11 ev while the depth for the exponential repulsion is −0.078 ev.

[1] Lambert, Roberts, Rowlinson, and Wilkinson, Proc. Roy. Soc. 196A, 113 (1949).

Semi-Conductors; Phosphors; Miscellany in Solid-State Physics

W1. Recovery of Selenium Rectifiers after Passing of Short Current Pulses. K. LEHOVEC, *Signal Corps Engineering Laboratories.*—The impedance of a selenium rectifier is changed after a current pulse in the blocking direction has passed through it. The pulses discussed in this paper were kept so small that the change in impedance was fully reversible. The dependence of this change on recovery time was studied for pulses of various lengths (0.05–300 sec.) and of various heights (0.05–0.5 mA/cm^2) at different temperatures. It was found that the change in impedance was nearly independent of pulse length for a given pulse height if a certain threshold length was exceeded. The product, threshold length times pulse height is found to correspond to 3×10^{14} electrons per cm^2. The recovery time decreases rapidly with increased temperature. Possible alternate explanations of the discussed observations are mentioned based on trapping of carriers in the barrier layer, and on the migration of ions.

W2. Microwave Conductivity of Semiconductors.* RICHARD F. GREENE** AND SOL E. HARRISON, *University of Pennsylvania.*—A method has been devised for measurement of the dielectric constant and conductivity, ($10^{-4}<\sigma<10$ ohm^{-1} cm^{-1}, at 3 cm wave-length), of semiconductors. A thin cylinder of semiconducting material is inserted into the center of a rectangular wave guide parallel the electric field of the TE_{10} mode, and the input impedance of the guide is measured. The measurement is made by a balanced bridge method using magic tees, and the calculation of impedance involves only measurements of plunger displacements. Using a method of Schwinger's the relation between the input impedance and the dielectric constant and conductivity has been calculated for the above geometry. In semiconductors at this frequency the displacement current may be comparable to the conduction current, rendering conventional treatments of the problem inapplicable. It was also necessary to examine critically the bearing of relaxation time, surface conductivity, sample thickness, and skin effect.

* Supported in part by the Bureau of Ships.
** John F. Frazer Fellow.

W3. Conductivity and Hall Coefficient of Zinc Oxide Semiconductor.* E. E. HAHN** AND P. H. MILLER, JR., *University of Pennsylvania.*—The dark electrical conductivity, σ, and Hall coefficient, R, of sintered spectroscopically pure zinc

oxide powder samples are measured over a temperature range from 83°K to 625°K using both the usual d.c. potentiometer probe method and an a.c. (4000 c.p.s.) set; the circuit and advantages of the a.c. set are described. In this reproducible range, $\ln \sigma$ is not linear with $1/T$ but exhibits a maximum occurring at higher T and σ-values the higher the sintering temperature. R is negative and the Hall data can be fitted by $R=(1/\rho)\exp(E/kT)$ where ρ and E increase with sintering temperature. Analysis of the electronic carrier concentration, calculated from Hall data, indicates non-degenerate extrinsic conduction due to thermal excitation of donators lying about 0.04 ev below the conduction band. The donators are believed to be interstitial zinc atoms formed during the sintering process and whose concentration increases with higher sintering temperatures; the lattice spacing increases after sintering.

* Work supported by Bureau of Ships.
** Now at RCA Laboratories, Princeton, New Jersey.

W4. Some Electrical Properties of Zinc Oxide Semiconductor.* P. H. MILLER, JR. AND E. E. HAHN,** *University of Pennsylvania.*—Impedance measurements of sintered zinc oxide samples as a function of frequency show that the conductivity is frequency dependent ($\nu \sim 10^7$ c.p.s.); it is shown that the conductivity is determined by grain boundary layers while the Hall coefficient is determined by the grains,[1] leading to spurious low conductivity and carrier mobility values when measured and calculated by the usual methods. Conductivity measurements are made from room temperature to 1040°K using the a.c. voltmeter-ammeter method. Above 650°K the logarithm of conductivity *versus* inverse temperature is linear and is similar to the results of previous workers; the frequency effect in this range is considered negligible since the conductivity is believed to be intrinsic, arising from thermal excitation of electrons from the filled to the conduction band. This thermal gap is about 2 ev and corresponds to the ultraviolet optical absorption edge at 3.2 ev; the yellow coloring of worked or good conducting samples is attributed to a shift, caused by strains, of this absorption edge into the visible.

* Work supported by Bureau of Ships.
** Now at RCA Laboratories, Princeton, New Jersey.
[1] Hahn, Russell, and Miller, Phys. Rev. **75**, 1631 (1949).

W5. Low Temperature Instability of Germanium. G. T. JACOBI AND W. C. DUNLAP, JR., *General Electric Company.*—Certain samples of germanium, when heated from 0°C to 200°C and then quenched to 0°C, do not revert to their original conductivity, but assume a higher value, followed by exponential decay to the original value. Hall effect measurements indicate a thermal excitation of electronic carriers at the higher temperatures. These carriers return to the normal state only after a period of time. The "excess" conductivity is in some cases two or three times the equilibrium conductivity at 0°C. Time constants for six samples showing this effect ranged from 44 to 93 hr. at 0°C. One finds that the density of active carriers is roughly $n_a = A\exp(-\Delta E/kT)$, where $A \sim 10^{21}/\text{cm}^3$, $\Delta E \sim 0.5$ ev. The time constant τ for the relaxation process was found to obey a similar relation $\tau = \tau_0 \exp(+\Delta F/kT)$ with $\tau_0 \sim 10^{-5}$ sec., $\Delta F \sim 0.5$ ev. The effect apparently can be produced by cooling N-type ingots from the melting point to room temperature in about an hour. A discussion is given of the source of these effects, especially the hypothesis that there are adjacent states of impurity atoms that are easily convertible into each other. One of these states may be active, the other inactive, or one may lead to donor, the other to acceptor action.

W6. The Optical Band Width of *F* Centers at Liquid Helium Temperatures. E. BURSTEIN AND J. J. OBERLY, *Naval Research Laboratory.*—Theory[1] suggests that the width of the absorption bands of F centers, electrons trapped in negative ion vacancies, should be proportional to the square root of the absolute temperature. Previous measurements by Mollwo[2] down to liquid hydrogen temperatures indicated, however, a finite residual band width at low temperatures. Measurements have now been repeated and extended to liquid helium temperatures confirming Mollwo's observations. For example, a band width of 0.17 ev is observed in both annealed and unannealed KCl at liquid helium temperatures. It is suggested that the finite width of the F center bands at low temperatures is due to the existence of a distribution of frequencies which results from variations in the configuration about the F center brought about by the random distribution of vacancies, aggregates of vacancies and impurities in the crystal.

[1] N. F. Mott and R. W. Gurney, *Electron Processes in Ionic Crystals* (Oxford, 1940), p. 116.
[2] E. Mollwo, Zeit. f. Physik **85**, 56 (1933).

W7. Trapping in Zinc-Sulfide-Type Phosphors.* RICHARD H. BUBE, *Radio Corporation of America and Princeton University.*—The phenomena of luminescence have been used to investigate the nature of trapping in ZnS-type phosphors. Measurements of thermostimulated emission (glow curves) and of the decay of phosphorescence emission were obtained for temperatures between −196° and 200°C for samples of cubic and hexagonal ZnS:Cu(0.0–0.3), [NaCl(2)], specially prepared from pure ZnS with no spectroscopically detectable impurities, and for other samples of ZnS-type phosphors. Traps of 16 different depths from 0.20 to 0.75 ev were identified from the glow peaks found for temperatures above −160°C. Comparison of the glow curves shows that if traps of a given depth are present, they are present with the *same* depth in *all* ZnS-type phosphors, regardless of activator, presence or absence of NaCl in the preparation, or the crystal form. It is concluded that traps are located at substitutional sites, principally omission defects, in ZnS-type phosphors, because a study of the nature of crystal defects in ZnS-type phosphors shows that only substitutional sites have the required invariance to account for the experimental results. An hypothesis concerning the correlation between trap depth and type of omission defect is advanced. Other effects of trapping, including retrapping of electrons, have been studied.

* Work done on Contract between ONR and RCA.

W8. Determination of Stresses in Evaporated Metal Films.* R. W. HOFFMAN AND E. C. CRITTENDEN, JR., *Case Institute of Technology.*—The internal macrostress in evaporated metal films has been measured directly by observing the change in curvature of a thin substrate strip. The "beam constants" of the substrate strip were determined by loading with a known force. Deposition at elevated surface temperature introduces a stress, in addition to the intrinsic film stress, through differential expansion of the film and the substrate. These two stress types were separated by observation of the substrate deflection as a function of temperature for small temperature changes. Stress relief due to curvature of the substrate and effects of cross curvature have been evaluated. Fe, Co, and Ni films have been prepared using soft glass approximately 0.002 in. thick as a substrate material. Film thicknesses were determined from the saturation magnetization of the specimens. The intrinsic stress observed for cobalt deposited at 200°C at a rate of 0.01 mg/cm²/min. is 3×10^9 dynes/cm² tension and is independent of thickness in the range studied (1000–4000A). The differential expansion stress is 1.5×10^9 dynes/cm² tension. The stresses for iron and nickel under these conditions are the same order of magnitude.

* This work supported by the ONR.

W9. The Relation of Stress and Rupture in Evaporated Metal Films to Distortion Decay.* E. C. CRITTENDEN, JR. AND R. W. HOFFMAN, *Case Institute of Technology.*—The

intrinsic tensile stress in evaporated films of Fe, Co, and Ni, determined by the method of the preceding abstract, is found to undergo irreversible increase by as much as 100 percent when films deposited in the range of 80°C to 200°C are aged at temperatures above their deposition temperatures. The electrical conductivity also increases irreversibly during such an aging. This indicates that distortions of the type described by Vand[1] decay with a decrease in volume for these metals. The density of distortions indicated by stress and electrical resistance increases both with decreased surface temperature during deposition and with increased rate of deposition. This is consistent with a temperature sensitive surface mobility of arriving metal atoms. Application of these principles makes it possible to control the film tension within certain limits. Rupture has been observed during aging at elevated temperatures of films deposited below 100°C. Long delayed rupture has been observed for similar films aged at room temperature. It seems likely that the commonly observed limiting thickness for rupture results from the tensile force generated by this mechanism.

* This work supported by the ONR.
[1] V. Vand, Proc. Phys. Soc. **55**, 222 (1943).

W10. Quantitative Prediction of Grain Boundary Energies by Anisotropic Dislocation Theory. W. T. Read (*Introduced by W. Shockley*), *Bell Telephone Laboratories.*—Dislocation models of grain boundaries between crystallites having a small angle of misfit, θ, have been proposed and the grain boundary energy calculated from two-dimensional isotropic elasticity.[1] This paper illustrates methods of joining two cubic crystals by appropriate dislocation arrays and presents the results of calculations based on anisotropic elasticity. The energy is $E_0\theta[1-\ln\theta/\theta_m]$ where the angle, θ_m, of maximum energy depends on the inelastic energy near the dislocation and must be determined from experimental data and E_0 is uniquely determined by the dislocation model in terms of the three elastic constants c_{11}, c_{12}, c_{44}. For a symmetrical boundary with relative rotation of the adjoining grains about the [100] axis E_0 is $[(c_{11}+c_{12})a/4\pi][(c_{11}-c_{12})c_{44}/(c_{11}+c_{12}+2c_{44})c_{11}]^{\frac{1}{2}}$ where a is the slip vector. Assuming E *vs.* θ has Dunn's shape,[2] $\theta_m \doteq 25°$; and for copper the relatively constant, large θ, energy is 400–600 ergs/cm^2. Models for grain boundaries and energy formulas have been obtained also for body centered cubic crystals, for relative rotation about the normal to the boundary, and for various orientations of the boundary.

[1] W. Shockley and W. T. Read, Phys. Rev. **75**, 692 (1949).
[2] C. G. Dunn and F. Lionetti, Metals Trans., February, 1949, p. 132.

W11. Interfacial Energies *vs.* Tensions in Polycrystalline Matter. John P. Nielsen, *New York University.*—In fluid films tension and energy are interchangeable in reference to the driving force toward equilibrium configuration, while for grain boundaries the interchangeability is not permissible because for crystals interface tension is undoubtedly anisotropic. A definitive experiment may be used to determine which postulate is the correct one for grain boundaries. Consider three hexagonal grains (e.g. zinc), after extended anneal, in a triangular prism, with sides A, B, and C, and A and $B\alpha°$ to each other, such that the (010) planes of the three grains are all parallel to the bisecting plane of α. Two grains meet at a plane parallel to the prism base and have random [001] direction, while the third grain has this direction perpendicular to the prism base. The three grains meet so that the junction line s connects A and B. Corresponding interfacial energies at s on A and B will be equal. Equivalent sets of angles at s on A and B excludes the tension postulate, while non-equivalency excludes the energy postulate.

W12. Field Electron Emission from Dielectrics. R. T. K. Murray and Alexander Mackenzie, *Long Island University.*—The emission of field electrons from sulphur has been investigated employing a counter. The cathode consisting of a 2-mm polished layer of sulphur on a steel sphere was placed over an aluminum window and the gap distance varied with a micrometer head working through a metallic bellows. Potentials up to 30 kv were applied to the cathode. The behavior of the observed currents was similar to that for a metallic cathode namely an initial erratic emission at low fields with a gradual stabilization at higher fields to give currents of the order of 10 electrons per second at fields of 150 kv/cm. The electron emission results from the superposition of two fields that arising from the surface polarization charges and that arising from the field in the dielectric their ratio being given by $K-1$. From a conditioned cathode the currents increase exponentially with the field according to the Fowler-Nordheim relation and to give no evidence of a gradual accumulation of a positive surface charge. It appears that the similarity in behavior of dielectric and metallic cathodes is to be explained by the electronic conductivity of the dielectric at the emitting points resulting from the high local fields.

W13. Measurement of Thermal Conductivity of Metals at High Temperature.* C. L. Hogan and R. B. Sawyer, *Lehigh University.*—The Forbes bar method has been used in determining the thermal conductivity of steel alloys, nickel, and inconel in the temperature range 0°–900°C. The method has been modified so that it is no longer necessary to know the specific heat as a function of temperature of the sample under test. Further improvements in technique include the measurement of rate of heat loss under steady state conditions thus eliminating a graphical analysis from cooling curve. An analysis of the heat flow problem is included to show that the mutually incompatible assumptions of plane isotherms in the sample and simultaneous radial heat loss leads to an error much less than the usual experimental error of the determination and can thus be neglected. Electrical conductivities have been simultaneously measured in order to check the range of validity of the Wiedemann-Franz-Lorentz law.

* Sponsored by Bell Aircraft Corporation.

W14. Experimental and Theoretical Transient Heat Propagation in a One-Dimensional Composite Material. Herbert A. Elion, *M. W. Kellogg Company.*—The importance of the effect of thermal conductivity was noted while conducting experiments involving molten lead near its solidification point, and solid carbon steel. A theoretical treatment gave the transient temperatures to be expected in either material. The case treated was for two semi-infinite flat plates of finite thickness. The hot plate is held at a constant temperature at one boundary and the cold plate insulated.* Transient temperatures were measured experimentally. The experimental results indicate the importance of the conductivity effect over the smaller natural convection effect for the case treated. The primary errors introduced in the empirical results are those of estimating physical properties (thermal conductivity, specific heat, and density), and equipment accuracy. (Heat perturbations introduced by the temperature sensing device in the steel were kept to a minimum by a special physical construction.)

* Theoretical analysis and curves by M. Yachter and H. A. Elion.

Chemical Physics

Y1. An Interionic Attraction Theory for Regions of Solutions near High Potential Surfaces. Arthur L. Loeb, *M. I. T.*—Langmuir[1] discussed the forces between lyophobic colloid particles on the assumption that ions of charge opposite to that on the colloid particle move only in the field of the colloid charge, without interacting with each other. With the colloid particles highly charged, the concentration of gegenions is sufficiently high to warrant analysis of interionic forces, but

the Debye-Hückel theory is insufficient here because it assumes low potentials and spherical symmetry. An extended interionic attraction theory was developed to avoid these two limitations, and checked in special cases against known results. First the Debye-Hückel equation was solved for regions of solutions near phase boundaries, and secondly a differential equation was developed for the Langmuir case of two parallel, highly charged planes. A correction was then made for Langmuir's expression of the average potential between the walls, the osmotic pressure was calculated including interionic forces, and a new interpretation given to the average potential as distinct from the potential used in the Boltzmann distribution law in determining concentration distribution between the walls.

[1] Langmuir, J. Chem. Phys. 6, 873 (1938).

Y2. On the Specific Heat of Liquid-Vapor Mixtures. LOUIS GOLDSTEIN, *Los Alamos Scientific Laboratory.*—The experimental verification of general thermodynamical relations connected with phase changes is of interest inasmuch as it may yield information both on the macroscopic and, indirectly, elementary properties of such transformations. The general formulas derived by Ehrenfest for phase changes of higher order are of particular importance in this respect. In view of current experimental work on liquid-vapor mixtures it seemed appropriate to call attention to the following result. One group of these general formulas determines also the discontinuities of the constant volume specific heat, as well as of those of other thermodynamical quantities, of liquid-vapor mixtures at the crossing of the saturation line of the fluid in its pressure-volume diagram. Using the abundant data available for water, we have verified the important relations connecting the discontinuities of the constant volume specific heat with those of $(\partial p/\partial v)_T$ and $(\partial p/\partial T)_v$. One may thus look upon the transformations of such mixtures into pure phases as apparent higher order phase changes accompanied by discontinuous variations of the derivatives of several thermodynamical variables.

Y3. Measurements of Gas Adsorption on Metals Using a Radioactive Tracer Method.* ALBERT D. CROWELL** AND H. E. FARNSWORTH, *Brown University.*—Copper and nickel sheets with total surface areas of one to two square centimeters have been exposed to CO_2 containing C^{14} at pressures of less than 1 mm Hg and temperatures below 500°C. Activated adsorption is measured with a counter method after removing the specimen from the gas chamber. The metal is outgassed at high temperatures in a high vacuum before exposure to the gas. Measurements as a function of temperature and pressure are being obtained for polycrystalline samples before extending the observations to a study of metal single crystal surfaces.

* Assisted by ONR and Research Corporation of New York.
** AEC predoctoral fellow.

Y4. Application of A Mass Spectrometer to the Study of Surface Reactions at Low Pressures.* STANLEY A. LANDEEN, H. E. FARNSWORTH, AND RUSSELL K. SHERBURNE, *Brown University.*—A Nier-type mass spectrometer has been used for the investigation of a surface catalytic reaction, the hydrogenation of ethylene over nickel. First attempts at observing the reaction with constant gas flow past the catalyst showed that the percentage yield of ethane by this method was too small to be observed. A change was then made to a static system, first using nickel prepared from Ni $(NO_3)_2$, and finally using a piece of nickel sheet 8 cm^2 in total surface area, electrolytically polished until it was found to appear smooth under 400× magnification. Preceding each set of observations the nickel surface was cleaned by alternate oxidation and reduction at 400°C. The measurements were made by sampling the gas at regular intervals as the reaction proceeded. Easily measurable catalytic activity was obtained at 140°C for gas pressures as low as 1 mm Hg and the variation of reaction rate with pressure was obtained in the pressure range of 1 to 12 mm Hg. It is planned to use the instrument to investigate the variation of catalytic activity for the different faces of metal single crystals.

* Assisted by ONR and Research Corporation of New York.

Y5. Pressures in Hydrogen-Oxygen Detonations.* W. E. GORDON, *University of Missouri.*—Previous measurements[1] of the pressures in $2H_2-O_2$ with tourmaline piezoelectric gauges, have given values in essential agreement with the Chapman-Jouget theory. With greater refinement in the calibration of the gauges, and somewhat different experimental conditions, the pressures are found often to be much lower than theoretical, even though the velocities are very close to the theoretical value. Also, although the velocities indicate a steady-state, the pressures vary widely at different points in the tube. A re-examination of the von Neumann-Chapman-Jouget theory[2] is indicated. The gauges were calibrated with shock waves in air, produced in a tube by a hydrogen-oxygen detonation behind a cellophane diaphragm, the pressures being obtained from the measured velocities through the Hugoniot relation. The decay of such shock waves was found to follow a very simple law, and it was possible to obtain quite precise calibrations with shock waves of comparable shape and amplitude to detonation waves.

* This work supported by ONR.
[1] W. E. Gordon, Third Symposium on Combustion, Flame and Explosion Phenomena (Williams and Wilkins, 1949), p. 579.
[2] J. v. Neumann—OSRD Report No. 1140.

Y6. Zero-Point Equation of State at Extreme Pressures. W. M. ELSASSER, *University of Pennsylvania.*—Bridgman[1] has measured densities of many metals and alkalihalides up to 1.10^5 atmos. The results of Jensen[2] indicate that a Thomas-Fermi model (with exchange correction) gives a good approximation for the density of simple substances from about 10^7 atm. on up. It is possible to introduce thermodynamical and structural criteria which, although not rigorous, help in interpolating densities through the remaining gap. We endeavor to show that in many instances densities of relatively simple substances can be predicted for the gap region with fair reliability without going through elaborate Hartree calculations. The results have significant applications to the interpretation of seismic data from deep layers and to the analysis of the constitution of these layers.

[1] Proc. Am. Acad. 76, No. 1 (1945), No. 3 (1948).
[2] Zeits. f. Physik 111, 373 (1938).

Y7. Entropy of Non-Equilibrium Systems. RICHARD C. RAYMOND, *The Pennsylvania State College.*—In some cases the entropy of a non-equilibrium system may be defined as the thermodynamic entropy which the system components would have at equilibrium minus the information entropy required to construct the actual system from its equilibrium components. The generalized entropy so defined is consistent with the second law of thermodynamics in all the cases so far investigated, and together with a strict interpretation of thermodynamic equilibrium it helps to reconcile some of the discrepancies between the thermodynamic definition of entropy and that derived from statistical mechanics.