with orbital neutron and proton. Using this model calculations of the cross sections for the reactions $Li^6(\gamma,n)Li^5$ and $Li^6(\gamma,p)$ $\times He^5$ have been made. It is assumed that the residual Li^5 or He^5 nucleus may be treated as stable for purposes of this calculation. The contributions of the electric and magnetic dipole matrix elements to the cross sections have been calculated using suitable approximate wave functions for initial and final states. The alpha particle is assumed unchanged in the energy range of interest, that is from threshold to about 30 Mev. It is hoped that comparison of experimental results with the predictions based on the deuteron-alpha model and the present model will yield some information about the actual Li^6 ground state.

* Work supported by U. S. Atomic Energy Commission.

Half-Life Determinations of Radium-223 and Thorium-227. G. R. HAGEE, M. L. CURTIS, AND G. R. GROVE, *Mound Laboratory,* Monsanto Chemical Company.*—Half-life values for radium-223 and thorium-227 have been determined by analyzing data obtained from samples of each element by alpha counting in a proportional counter over a period of 116 days. The samples contained small amounts of other members of the actinium chain. The growth and decay equation of the principal activity and its daughters plus contaminants was derived in terms of the decay constants of radium-223 and thorium-227 and the amounts of each activity present. The decay constants and the disintegration rates of the activities were each set equal to an approximate value plus a correction term. Taylor's expansion was applied to the general equation to yield an expression which was linear in the correction terms. A least-squares treatment was used to derive the correction terms most representative of the data. The half-life values obtained from these analyses were 18.169 ± 0.084 days for thorium-227 and 11.685 ± 0.056 days for radium-223.

* Operated under U. S. Atomic Energy Commission contract.

Half-Lives of Al^{25} and Al^{26}.* D. W. GREEN, J. C. HARRIS, AND J. N. COOPER, *Ohio State University.*—The half-lives of Al^{25} and Al^{26} have been determined by a method previously reported.[1] The Al^{25} was produced by exciting the $Mg^{24}(p,\gamma)Al^{25}$ reaction with 825-kev protons from a Van de Graaff generator in targets of isotopic Mg^{24}, which was obtained from Carbide and Carbon Chemicals Corporation, Oak Ridge, Tennessee. The value measured for Al^{25} was 7.20 seconds, which is in good agreement with the 7.3 seconds reported by Bradner and Gow.[2] The half-life of Al^{26} was measured both at the 563- and the 720-kev resonances in the $Mg^{25}(p,\gamma)Al^{26}$ reaction. The values obtained were 6.47 and 6.40 seconds, respectively, which agree well with the 6.3 seconds of Bradner and Gow[2] and with the 6.5 seconds found by Katz and Cameron.[3]

* Supported in part by the U. S. Atomic Energy Commission through a contract with The Ohio State University Research Foundation.

[1] Green, Harris, and Cooper, Phys. Rev. **90**, 1132 (1953).
[2] H. Bradner and J. D. Gow, Phys. Rev. **74**, 1559 (1948).
[3] L. Katz and A. G. W. Cameron, Phys. Rev. **84**, 1115 (1951).

X-Ray Absorption in a Curved Crystal at the Bragg Angle. ROBERT G. SAUER AND JOHN E. EDWARDS, *Ohio University.*—Primary extinction generally decreases the transmitted x-ray beam intensity when Laue type diffraction occurs in a single crystal. However, Borrmann[1] and others[2] have observed an increase in the transmitted intensity in "thick" crystals at the Bragg angle. An attempt has been made to observe this absorption anomaly in a curved crystal. A double Gauchois type spectrograph was used, the first crystal serving as a monochromator with the speciman crystal placed back of the focal circle. Thus, only x-rays from a very small point on the target were diffracted from the specimen crystal giving sharp lines slightly greater than the natural width. Characteristic lines and the transmitted beams were photographed with a 0.2-mm quartz crystal for wavelengths ranging from 0.469 A to 2.289 A. A 0.81-mm quartz crystal and a 0.56-mm mica crystal were used with 1.54 A lines. A pronounced decrease in intensity of the transmitted beam was observed in every case. The "deficiency" lines were nearly the same width as the diffracted lines.

[1] G. Borrmann, Physik. Z. **42**, 157 (1941).
[2] N. Campbell. J. Appl. Phys. **22**, 1139 (1951); R. L. Rogosa and G. Schwarz, Phys. Rev. **87**, 995 (1952).

Collective Model in the Analysis of Gamma Rays. D. N. KUNDU, *The Ohio State University.*—Nuclear gamma energies are studied from a combined point of view of the independent particle model and the collective model. The former provides the broad pattern of the nuclear energy states on which is superimposed additional states arising from the collective motion of the nucleons within the nucleus. The Coulomb excitation data, whenever available, have been utilized to identify rotational lines near the ground state. The success and also the limitations of the models are examined, among others, with Se^{75}, Lu^{176}, Hf^{181}, Au^{195}, and Hg^{197}, as examples. The gamma rays of Np^{238} have been used to illustrate the possibility of rotational levels associated with the ground state and also the particle-excited state of Pu^{238}. Some tentative decay schemes involving the collective model will be suggested.

MINUTES OF THE 1954 JUNE MEETING HELD AT MINNEAPOLIS, MINNESOTA, JUNE 28–30, 1954

(Corresponding to *Bulletin of the American Physical Society*, Volume 29, No. 5)

THE 1954 June meeting of the American Physical Society was held at Minneapolis on Monday, Tuesday, and Wednesday, June 28, 29, and 30. The unusual choice of days of the week was dictated by the fact that a total eclipse of the sun occurred at 5:07 A.M. on June 30, although preliminary announcements of the meeting stated that the local committee had kindly arranged for the eclipse as an added attraction to the meeting. Be that as it may, the local committee certainly provided ideal weather for the eclipse. After several hot and high-humidity days, interspersed with thunderstorms, the sun rose on Wednesday in a clear and cloudless sky, which remained that way during the entire duration of the eclipse. But within an hour after the eclipse the sky was again half covered with clouds. The great bulk of our members saw the eclipse, as well as the "Skyhook" balloon launching, from the Old University airport, under perfect seeing conditions. A very few were so fortunate as to see it from one of the two special planes provided by the airplane companies.

The American Association of Physics Teachers held concurrent sessions with the American Physical

Society, and there was a common registration and much intermingling of attendance. The total registration was 484, considerably below that (741) at the March Detroit-Ann Arbor meeting. But over 240 attended the banquet on Tuesday evening, a slightly larger number than at the Detroit-Ann Arbor banquet. If half the registrants should attend the banquet at one of the large Atlantic Coast meetings, it would certainly create a problem. The after-dinner speakers were E. W. Davis of the University of Minnesota, speaking on the processing of taconite iron ore, and R. M. Sutton of Haverford College, who by personally devised slides and actual demonstrations illustrated clearly the theory and detailed features of the impending total eclipse. The banquet ended at 10:00 P.M., giving opportunity for a full three to four hours of sleep for those who later viewed the eclipse.

The four lecture rooms of the Physics Building, plus one lecture room in the closely adjacent Murphy Hall, provided more than adequate accommodations for the sessions of both organizations. The largest single attendance, some 350, occurred at the joint session on Monday afternoon, when four invited papers on astronomical subjects were presented. During the middle of Tuesday morning the total attendance at the three physics sections was about 240 and that at the AAPT section was 165. Strange to relate, the total attendance Wednesday morning, in spite of the early morning exertions incident to the eclipse, was equally large, with 160 at the session of invited papers on nuclear accelerators. There were 32 invited papers and 112 contributed papers (plus three post-deadline papers), although how many were read by title only is not known to the undersigned.

The local arrangements were ably handled by a local committee headed by John Winckler, and the ladies were royally entertained by a committee, headed by Mrs. C. N. Wall, which also arranged an enjoyable tea for Monday afternoon. The entire meeting proceeded with great smoothness in spite of the highly unusual but unavoidable absence of Dr. Darrow.

RAYMOND T. BIRGE, *Vice-President*
American Physical Society

Council Meeting of June 18, 1954

The Council of the American Physical Society met in New York City on June 18, 1954, for the purpose of acting on candidates to Fellowship and to Membership. It elected four candidates to Fellowship and 151 to Membership: the names follow.

Elected to Fellowship: W. L. Brown, D. N. Kundu, J. D. Kurbatov, R. D. Spence.

Elected to Membership: [s]Roger Harris Anderson, Frank Asaro, [s]John Joseph Bartulovich, Edward Arthur Baum, Richard Charles Beitz, Paul Belgodere, [s]William Ralph Bennett, Jr., Harold Berger, [s]Eugene M. Bernstein, Eugene P. Bertin, Avadh Behari Bhatia, [s]David Theobald Blackstock, John Dieterle Blades, Eliot Z. Block, [s]Charles R. Bruce, Harry Bryant, [s]James Warland Burgess, [s]Jay Burns, III, [s]Nina Byers, Robert Swain Caird, Jr., Willie Russell Callahan, George Weirich Callendine, Jr., [s]Richard Andrew Campbell, [s]Murray Cantwell, [s]Joan Robinson Clark, Kenneth Leon Clum, James W. Cobble, Royal Eugene Collins, Joseph M. Conley, Frederick Pitkin Cranston, Jr., Robert Wallace Crowe, [s]Robert Emil Danielson, John Edmund Davey, Jefferson Deveaux Davis, Jr., Robert Benjamin Davis, Donald Paul Devor, [s]Bertram Gale Dick, Jr., Pierre Donzelot, Gloria Lee Dority, E. Doser, Albert Charles Doskocil, Jr., [s]Ross Alan Douglas, [s]George C. Dousmanis, [s]James Holahan Doyle, [s]Gene F. Dresselhaus, Richard John Eden, Nicholas E. Efremov, [s]Stanton Lea Eilenberg, John Robert Eklund, Winfield W. Evans, Norman J. Field, Val L. Fitch, [s]Joseph Newton Fritz, Edward Joseph Furno, Wolfgang Gärtner, Andre Gauvenet, [s]Joseph Giordano, Harvey Louis Glick, [s]Irwin Goldberg, [s]James Power Gordon, [s]Kazuo Gotow, [s]Alexander Louis Harvey, Russell LaVerne Heath, Carl Christian Hein, [s]Leon Heller, [s]Charles D. Hendricks, Jr., David Franklin Herring, Casselman Ben Hess, [s]John Harold Hoffman, [s]John P. Hurley, Merle M. Irvine, John Edward Ivory, Jay Andrew Horton Jacobs, Richard Victor Jones, Walter E. Jordan, [s]Robert Michael Kalbach, Shu-koo Kao, Robert Franklin Keith, Donald W. Kent, Yutaka Kohasi, [s]Earl Leonard Koller, John Nelson Kriebel, [s]Robert Krotkov, [s]Theodore Jugo Kruse, Donald Lee Lafferty, W. Laskar, Kent D. Lawson, Robert Briggs Leachman, Graham Edward Lee-Whiting, Lutz Leopold, [s]Alfred U. MacRae, Lawrence Bersell Magnusson, [s]Willard Edward Matheson, Sanford Aaron Meltzer, [s]Bruce Howard McCormick, Forrest S. Mozer, Raj Pratap Misra, Akira Miyahara, Joseph Jackson Murray, Jr., Edward S. Naidus, [s]Edward Hagi Nicollian, Tetsuji Nishikawa, John Torrey Norton, Felix E. Obenshain, Reinhard Oehme, Thomas Otten Paine, James Henry Parker, Jr., [s]William J. Pervin, [s]Richard J. Plock, Kenneth Stanley Preschel, [s]Allen Bishop Robbins, [s]Paul C. Robison, Donald Stanley Rodbell, James Edward Roderick, Roop Chand Sahns, [s]Alvin Martin Saperstein, Muneo Sasaki, Seibun Sasaki, Cameron B. Satterwaite, [s]Heinz Scharfstein, [s]Leon Joseph Schkolnick, [s]Stanley Schneider, Robert T. Schumacher, Herman P. Schwan, [s]Bernice G. Segal, William Eno Semple, [s]Rodman Alton Sharp, [s]James Leonard Shilts, Rachel Stahl, Clare Perry Stanford, Alden Stevenson, [s]James Carr Suits, George K. Tajima, Phrixos J. Theodorides, John Wright Thomas, Ho Yet Tom, Jay Todd, Jr., [s]Arnold Martin Toxen, Robert Allen Tracy, Henry Snowden Valk, Johann Siegfried Wagener, [s]Richard John Wagner, Stephen Waldron, William Charles Walker, Jack Dussel Warthman, [s]Donald Arthur Wiegand, David Jean Winslow, [s]Robert William Wright, Michael Koichi Yonemitsu, John Sheldon Youtcheff, John Southey Wise, and Solomon Zwerdling.

[s] Student.

KARL K. DARROW, *Secretary*
American Physical Society

Errata Pertaining to Papers B1, D1, and H11

B1, by Richard Schlegel. In line 10, the comma between $S=S'$ and $\beta=1/kT$ should be a semicolon.

D1, by Milan D. Fiske. The following should be added to the by-line: Metallurgy Research Department, General Electric Research Laboratory, Schenectady, New York.

H11, by B. E. Simmons, D. M. Van Patter, D. F. Famularo, and R. V. Stuart. In line 5, 136 kev should read 131 kev.

PROGRAMME

MONDAY MORNING AT 10:00

Murphy 105

(D. ALPERT presiding)

Surface Physics and Domain Formation

Invited Papers

(A1 and A2 after A5, and A3 after A7)

A1. Recent Results in Sputtering by Ion Bombardment. G. K. WEHNER, *Wright-Patterson Air Force Base.* (25 min.)

A2. Domains and Their Formation in Barium Titanate Single Crystals. W. J. MERZ, *Bell Telephone Laboratories.* (25 min.)

A3. Surface-Barrier Determination by Periodic Deviations from the Schottky Effect. E. A. COOMES, *University of Notre Dame.* (35 min.)

Contributed Papers

A4. Low-Frequency Dielectric Loss Peaks in KCl Containing Divalent Cation Impurities. E. BURSTEIN, J. W. DAVISSON, AND N. SCLAR, *Naval Research Laboratory.*—Low-frequency dielectric loss measurements have been carried out as a function of temperature, over the range from 25°C to 200°C, for KCl containing divalent cation impurities. KCl containing Sr^{++} exhibits a single peak at 117°C in the dielectric loss *vs* temperature curve for 10 000 cps. On going to lower frequencies, the peak shifts to lower temperatures. A plot of the log of the frequency against the reciprocal temperature at which the peak occurs yields a straight line curve so that the data can be represented by the equation $\nu=\nu_0\exp(-U/kT)$; with $\nu_0=1.9\times10^{12}$/sec and $U=0.64$ ev. Similar peaks are also observed in KCl crystals containing Pb^{++}. The data for these crystals are, however, still incomplete. The low-frequency loss peaks, first pointed out by Breckenridge, are presumably due to relaxation processes involving "ghost" dipoles in the form of divalent cation—positive ion vacancy pairs. The inability to observe loss peaks due to positive ion vacancy—negative ion vacancy pairs in pure alkali halides is attributed to the fact that the concentration of the ion vacancy pairs is very low.

A5. Thin Films of $BaTiO_3$. CHARLES FELDMAN, *Naval Research Laboratory.*—Ferroelectric films of $BaTiO_3$, about 1–2 microns thick, have been formed on platinum substrates by evaporation in a vacuum and a subsequent heat treatment in air. X-ray diffraction examination of the films shows that the structure is mainly perovskite with the hexagonal phase as a minor constituent. Dielectric and hysteresis measurements show the Curie temperature at about 120°C. The room temperature dielectric constant is of the order of 100. Because of their small thickness, the films are almost completely polarized by the voltages used in the dielectric measurements. The measured value accordingly compares favorably with the dielectric constant bulk ceramic.

A6. A Simple Interpretation of Wehner's Sputtering Law. WALTER WESSEL, *Wright-Patterson Air Force Base.*—The law, which states[1] that for the threshold of low voltage sputtering the momentum M, transferred upon a metal atom by the impinging ion, multiplied by the bulk velocity of sound v_s, is proportional to the heat of sublimation S of the metal:

$$Mv_s=C\cdot S \qquad (1)$$

seems to demand an explanation on very general terms, because the constant C (≈11.2) in (1) is so markedly the same for a great number of metals. We have tried to do this, assuming the propagation of a real sound wave along the surface of the metal and applying only the theorems of conservation of momentum and energy. As a result we find the above formula replaced by

$$Mv_t=S(2+2(R/S)^{\frac{1}{2}}+4R/S), \qquad (2)$$

where $R=mv_t^2/2$, m = mass of the metal ions and v_t = surface velocity of sound. The agreement with the experiments is not as good as in the empirical formula (1), being the bracket in (2) variable between 9.3 and 15.9; but its average value 12.2 for 26 metals comes rather close to the value of C in (1).

[1] G. K. Wehner, Phys. Rev. **93**, 633 (1954).

A7. Gettering of a Vacuum Vessel by Titanium Metal. VIRGIL L. STOUT AND MARTIN D. GIBBONS, *General Electric Research Laboratory.*—Data has been obtained for the gettering of gases by titanium metal. The getter was formed of an iodide titanium ring which was heated by a radio-frequency induction heater. Gases that were gettered included oxygen, nitrogen, carbon dioxide, hydrogen, water vapor, methane, and room air. Gettering information was obtained using the closed vessel sorption technique, which has yielded values of gettering rates and quantities of gas that can be sorbed. Residual gases have been identified using the mass spectrometer and reaction products have been analyzed by x-ray diffraction.

A8. Contact Electrification Effects in a Metal-Metal System. I. General Theory. ARTHUR PASKIN, *Sylvania Electric Products, Inc.**—When two dissimilar metals are placed in contact and subsequently separated, an electrostatic charge develops on the two metals. It is found that an application of current ideas on what happens at a metal-metal contact will adequately explain the sign of the charge and give an upper limit to the magnitude of the charge observed in contact electrification. A quantitative understanding of contact charging can be obtained by examining the reduction of charge through field emission as the two metals are separated. Calculations have been carried out which take into account the effect of field emission. The details of these calculations depend on the particular geometry of the metal contacts.

A formula has been developed for the charge to be expected when the two metals are of spherical and planar geometry, respectively. This relationship is found to be in good agreement with preliminary contact electrification experiments carried out in this laboratory.

* Work supported by the U. S. Naval Ordnance Laboratory.

A9. Contact Electrification in a Metal-Metal System. II. Results for Mercury-Steel. PAUL E. CARROLL, *Sylvania Electric Products, Inc.**—Contact electrification measurements have been performed with mercury and steel being used as the contact metals. The measurements were performed in such a way that both contact potential difference and contact electrification could be determined with the same physical arrangement. The two measurements on the same contact surfaces were needed to correlate these measurements with the theory presented in the preceding paper. The use of a liquid metal for one of the contacts reduced the effects of any frictional electrification to the point where they were not detected. The measurements were in agreement with the theory within experimental error.

* Work supported by the U. S. Naval Ordnance Laboratory.

MONDAY MORNING AT 10:30

Physics 170

(E. L. HILL presiding)

Theoretical Physics

B1. Relativistic Statistical Mechanics of an Ideal Gas. RICHARD SCHLEGEL, *Michigan State College.*—For an ideal monatomic gas at equilibrium in system K, $n_i=\exp(-\alpha-\beta\epsilon_i)$; α and β are constants, n_i and ϵ_i are, respectively, the number of atoms and relativistic kinetic energy per atom in the ith phase-space cell. In system K', with velocity $v=v_x$ relative to K, $n_i'=\exp(-\alpha'-\beta'\epsilon_i')$. $n_i=n_i'$. Relativistic transformations on x and momentum p_x lead to $\Delta\tau=\Delta\tau'$, where $\Delta\tau$ is phase-space cell volume. Association of entropy S with statistical probability gives $S=S'$, $\beta=1/kT$ and $\beta'=1/kT'$, where k is Boltzmann's constant and T is temperature, are obtained from customary thermodynamic arguments; $\alpha=\alpha'$ follows from $T=T'$ for $v=0$. The use of the relativistic energy transformation, $\epsilon_i'=[\epsilon_i-vp_x(i)]/\gamma$, where $\gamma=(1-v^2/c^2)^{-\frac{1}{2}}$, gives $T_i'=(T/\gamma)/[1-vp_x(i)/\epsilon_i]$, and, on averaging, $T'=T/\gamma$. Radiation from the gas is found by the energy transformation to have frequency $\nu'=\nu\gamma/(1-v/c\cos\theta')$, the usual relativistic Doppler equation, where θ' is the angle in K' between the observed radiation path and velocity vector of K. Relation to thermodynamic results for transformation of T and possible physical meaning of relativistic transformation of thermodynamic quantities will be discussed.

B2. Virial Expansion of the Ideal Bose-Einstein Gas.* B. WIDOM, *University of North Carolina.*—The ideal Bose-Einstein gas can be looked upon as an imperfect gas, imperfection being due to quantum effects and giving rise to a condensation phenomenon. The virial expansion is obtained in terms of the dimensionless density $x_1=h^3(2\pi mkT)^{-\frac{3}{2}}\rho$ and the dimensionless pressure $x_2=(h^3/kT)(2\pi mkT)^{-\frac{3}{2}}p$, by eliminating y from the equations $x_1=\Sigma_1^\infty n^{-\frac{3}{2}}y^n$ and $x_2=\Sigma_1^\infty n^{-5/2}y^n$. The result is

$$x_2=x_1\left\{1+\sum_1^\infty(-1)^n\frac{D_n}{(n+1)!}x_1^n\right\}, \qquad (1)$$

where D_n is a determinant of order n, the elements a_{ij} of which are given by $[(i-j+1)n+j-1](i-j+2)^{-1}$ when $j\leqslant i+1$, and by 0 when $j>i+1$. The Einstein condensation occurs at $x_1=\zeta(3/2)=2.612\cdots$. The radius of convergence, R, of (1), can be estimated in several ways. Starting with the series in y, and applying a theorem of Landau, gives $R\geqslant\zeta(3/2)\{\zeta(3/2)-[\zeta(3/2)^2-1]^{\frac{1}{2}}\}^2=0.103\cdots$. A rough estimate of the magnitude of D_n yields $R\geqslant 1/2e=0.184\cdots$. A better estimate of D_n yields $R\geqslant 1/2e^{\frac{3}{2}}=0.257\cdots$.

* Work supported by U. S. Office of Naval Research.

B3. Universal Curves for Dispersion and Scattering of X-Rays.* L. G. PARRATT AND C. F. HEMPSTEAD, *Cornell University.*—The theoretical expression for the dispersion (or atomic scattering factor) of x-rays has been integrated for any value of p_q in a λ^{p_q} term in the distribution of dispersion-oscillators for each q shell of electrons. The dispersion-oscillator distribution may be written generally as the sum of n terms $\Sigma_n C_{qn}\lambda^{p_{qn}}$ or, as is commonly done, as a single $C_q\lambda^{p_q}$ term. Damping has been retained, its effect evaluated and shown to be negligible except for λ extremely close to the wavelength of an absorption discontinuity. Universal dispersion curves (with damping neglected) are presented. From the universal curves, if p_q and g_q (the oscillator strength) are known, the refractive index (or the atomic scattering factor) for each q shell of any atom, and hence the sum of all q shells, can be readily and very conveniently deduced. Comparison of these more exact theoretical values with experiment shows less satisfactory agreement than before.

* This research was supported by the United States Air Force through the Office of Scientific Research of the Air Research and Development Command.

B4. Comparison of Several Approximations to Scattering of High-Energy Electrons. J. MAYO GREENBERG, *Rensselaer Polytechnic Institute.*—Several exact calculations of the scattering of high-energy electrons by nuclei have been completed[1] or are in the process of being computed. It is, therefore, now possible to determine the suitability of the various available approximations with the view to finding more convenient methods of analyzing the experimental data.[2] At the least it seems probable that accurate extrapolations from exact calculations can be obtained. Calculations using the soft sphere[3] method show good agreement with those of Yennie *et al.* in the positions of the minima of the diffraction pattern but are in poor agreement otherwise. Further calculations are being made using a method[4] based on the W. K. B. treatment of the incident plane wave.

[1] Yennie, Wilson, and Ravenhall (to be published).
[2] Hofstadter, Fechter and McIntyre, Phys. Rev. **92**, 978 (1953).
[3] E. W. Montroll and J. M. Greenberg, Phys. Rev. **86**, 889 (1952).
[4] R. J. Glauber, Phys. Rev. **91**, 459 (1953); G. Moliere, Z. Naturforsch. **2a**, 133 (1947).

B5. Numerical Solution of the Diffusion Equation in Cylindrical Geometrics, G. M. ROE AND R. H. STARK. *Knolls Atomic Power Laboratory.**—The equation, $\nabla\cdot D\nabla\psi+A\psi=S$, with D, A, and S functions of position in (r,z) space, was

replaced by a set of simultaneous second order difference equations applicable to an NxM mesh. The difference equivalents of the gradient, divergence, and integral operators were chosen to be consistent in the sense that Green's theorem holds exactly. The difference equations were set up for solution on the UNIVAC, using an extrapolated Liebmann iteration scheme. Young's formula[1] for the extrapolation factor, valid for symmetric matrix operators, can be shown to hold also for the nonsymmetric matrix in this problem; and the optimum extrapolation factor can be estimated by a variational method. The convergence rate can frequently be improved by renormalizing the approximate solution at each stage of the iteration.

* Operated by the General Electric Company for the United States Atomic Energy Commission.

[1] D. M. Young, Jr., "Iterative Methods for Solving Partial Differential Equations of Elliptic Type," Ph.D. thesis, Harvard University, 1950.

B6. Classical Field Theory in the Hamilton-Jacobi Formalism. HANS FREISTADT, *Newark College of Engineering.*—The Hamilton-Jacobi formalism referred to[1] in connection with an attempt to describe quantum effects by a classical relativistic field theory is developed further. Both "time-independent" and "time-dependent" formulations are given, and the relation between them is discussed. In the former, the constants of the motion are identified with the "new" field variables, whereas in the latter they are the values of the fields on a suitable space-like surface. As an illustration of the respective procedures, the classical Dirac and Klein-Gordon free fields are solved explicitly. A perturbation method is formulated for the case of fields in interaction. The metric tensor is not treated as a field quantity.

[1] H. Freistadt, Phys. Rev. **B94**, 746 (1954).

B7. On the Correlation Function in Burgers' Model of Turbulence.* MORTON A. HYMAN, *Westinghouse Electric Corporation* (introduced by F. N. FRENKIEL).—Burgers has derived[1] from his well-known model the following equation for the 2nd-order velocity correlation function $R(\eta,t)$ in homogeneous turbulence (η is distance between points correlated, t is time):

$$\frac{\partial^2 R}{\partial t^2}-(2+\beta)\frac{\partial^3 R}{\partial t\partial\eta^2}+2\beta\nu^2\frac{\partial^4 R}{\partial\eta^4}=-\frac{\partial^2}{\partial\eta^2}(\bar{R}-R)^2; \qquad (1)$$

ν is the kinematic viscosity, β is an unspecified pure number, and $\bar{R}(t)\equiv R(0,t)$. It is shown here that $\beta=0$. The resulting 3rd-order differential equation is integrated first qualitatively and then by an accurate numerical scheme. The calculated results are consistent with experiment, indicating that the assumptions made by Burgers in his derivation of (1) are reasonable and that this new approach might be profitably pursued. The problem simplifies if one restricts attention to the cases $\eta\to 0$ and $|\eta|\to\infty$.

* This research was carried out while the author was a Fulbright Scholar at the Technical University, Delft, Holland.

[1] J. M. Burgers, *Proc. 7th Intern. Congr. Theoret. Appl. Mech.*, Istanbul, 1952 (to appear).

MONDAY MORNING AT 10:30

Physics 150

(J. M. BLAIR presiding)

Invited Papers on Nuclear Radii

C1. Determination of Nuclear Radii by Electron Scattering. R. W. PIDD, *University of Michigan.* (30 min.)

C2. Nuclear Radii from Beta Transition-Energies between Mirror Pairs. D. J. ZAFFARANO, *Iowa State College.* (30 min.)

MONDAY MORNING AT 10:30

Physics 133

(E. P. T. TYNDALL presiding)

Solid-State Physics

D1. Effects of Elastic Dilatation and Shear on the Superconducting Transition of Tin. MILAN D. FISKE.—The earlier[1] measurements on the depression of the superconducting magnetic threshold of tin by hydrostatic pressure have been improved by new apparatus using the same differential technique as previously. The isothermal difference between the critical field of one crystal under pressure and that of a similar one under atmospheric pressure has been measured to a precision of $\pm 1\times 10^{-4}$ gauss/atmosphere above 3.4°K. The critical field dependence on pressure varies from -6.8×10^{-3} gauss atmos^{-1} at 3.65°K to -6.5×10^{-3} gauss atmos^{-1} at 3.0°K. These values are in good agreement with those of previous investigators and with the recent results (in press) of Garber and Mapother near 3.6°K. The speculation that shear stresses have a negligible effect on the superconducting transition in tin has been checked by a method analogous to that of the hydrostatic experiment. A thin-walled tubular polycrystal of tin was strained in torsion to provide a nearly uniform pure shear. No effect whatsoever was detectable within the elastic range. From the constants of the apparatus it follows that the effect of shear stress on the magnetic transition is less than 4×10^{-5} gauss/atmos. A similar result with a solid tin cylinder has been obtained by Maxwell and Lutes.

[1] M. D. Fiske, Phys. Rev. (to be published). This contains a summary of results of previous studies.

D2. Temperature Dependence of the Periodic Hall Effect in Bismuth.* J. M. REYNOLDS AND D. D. TRIANTOS, *Louisiana State University.*—At 1.4°K the Hall effect in bismuth shows oscillations which are periodic in $1/H$, and whose amplitude increases with increasing magnetic field.[1] We have measured the Hall effect in a single crystal of bismuth in fields up to 8 kilogauss and at seven temperatures ranging from 1.38°K to 4.21°K. The magnetic field was parallel to the trigonal axis of the crystal and the current was along one of the binary axes. The period and phase of the oscillations were found to be independent of temperature while the amplitude decreased rapidly with increasing temperature. From these data estimates are made of the values of the effective Bohr magneton and of the Fermi energy of the electrons responsible for the effect. For this orientation β^* is 2.2×10^{-19} erg/gauss and E_0 is 1.5×10^{-14} erg $=0.009$ ev.

* Supported by the National Science Foundation.
[1] Reynolds, Leinhardt, and Hemstreet, Phys. Rev. **93**, 247 (1954).

D3. Oscillatory Thermal Conductivity of Bismuth in Magnetic Fields at Liquid Helium Temperatures. J. BABISKIN AND M. C. STEELE, *United States Naval Research Laboratory.*—An oscillatory dependence of the thermal conductivity upon magnetic fields has been observed in a bismuth single crystal at 1.60°K in fields up to 12 600 gauss. The magnetic field was perpendicular to the trigonal axis and parallel to a binary axis, while the heat current was parallel to the trigonal axis. For this orientation the thermal conductivity oscillations were periodic in H^{-1} with β/E_0 equal to 7.2×10^{-5} gauss^{-1}. This value is in good agreement with the results of the measurements of the magnetothermoelectric oscillations[1] and the calculated value from the de Haas-van Alphen effect[2] for the same orientation. The amplitude of the oscillating component amounted to 0.83 percent of the total thermal conductivity at 8300 gauss. The mean value of the thermal conductivity decreased 3.7 percent in going from zero field to 12 600 gauss.

[1] M. C. Steele and J. Babiskin, Phys. Rev. (to be published).
[2] D. Shoenberg, Trans. Roy. Soc. (London) **A245**, 1 (1952).

D4. Order-Disorder Problem for a Cubic Lattice. F. J. MURRAY, *Department of Mathematics, Columbia University.*—A new formulation for the van der Waerden probability approach to the statistics of a cubic lattice is based mathematically on the principle that the order in which flaws are introduced is immaterial. Also a precise treatment of the interference relations between polyhedra is given. This leads to a summation problem involving the matrix A previously considered by the author. For the three-dimensional case, methods are developed for evaluating the A sum which yield the internal energy and specific heat over the full temperature range without mathematical singularity. In two dimensions, A does not have the completely continuous character (when regarded as an infinite matrix) upon which these methods are based. The three-dimensional computation does require large-scale automatic sequence calculation even when certain judicious approximations are made. Agreement with other theoretical evaluations is as good as one could expect in the range over which these are valid, but comparison with the experimental results of Sykes shows definite qualitative differences. However, it may be worth noting that if interference is ignored, good agreement over a specified range is possible. Funds were provided by the Office of Naval Research for this investigation and the Florida Automatic Digital Computer was made available at Patrick Air Force Base.

D5. Effect of Surface Friction on High-Speed Penetration. JOSEPH M. KRAFFT, *Naval Research Laboratory.*—The frictional adhesion between projectile and target during a ballistic penetration has been measured with a torsional Hopkinson bar. The apparatus allows measurement of the torsional adhesion of a spinning projectile during its penetration of the bar end. Both the axial and torsional forces are measured as strain waves in a long bar, separation of the two occurring by virtue of the lower propagation velocity of the torsional wave. By assuming the friction resisting rotation to be equal to that resisting axial penetration, the energy loss due to friction was computed. It was found that friction accounts for at most three percent of the striking energy of the projectile; common surface contaminants, not necessarily special lubricants, reduce this loss to less than one percent. The torque-time pattern during penetration can be closely predicted with the assumption of a frictional energy loss just sufficient to keep the sliding surfaces at the melting temperature of the metal.

D6. Diffusion of Impurities in Silicon. W. C. DUNLAP, JR., H. V. BOHM, AND H. P. MAHON, JR., *General Electric Research Laboratory.*—Measurements of the diffusion of several impurities into silicon have been made using the following methods: (a) the *p-n* junction method,[1] for antimony and boron; (b) the radioactive tracer method, for antimony and gold; and (c) capacity measurements, for gold. The capacity method is based upon the high ionization energy of gold in silicon;[2] when gold diffuses into *p*-type silicon, there is created a layer which becomes highly insulating at liquid nitrogen temperature. By measurement of the capacity of the sample, coated with aluminum-gallium electrodes, the thickness of the insulating layer was measured. Measurements were made on the aforementioned impurities between 900°C and 1300°C. Antimony and boron diffuse relatively slowly. Their diffusion coefficients at 1100°C are about 10^{-13} and 10^{-12} cm^2/sec, respectively. The activation energy for diffusion is about 3.5 ev. Both these elements are probably substitutional in silicon. Gold, on the other hand, diffuses relatively rapidly and has a diffusion coefficient at 1100°C of about 10^{-7} cm^2/sec. The apparent temperature dependence of diffusion is, however, greater than for antimony and boron. Because of the donor action of gold in silicon and the large diffusion coefficient at 1100°C, it is postulated that gold is interstitial in silicon.

[1] W. C. Dunlap, Jr., Phys. Rev. **87**, 615 (1952).
[2] E. A. Taft and F. H. Horn, Phys. Rev. **93**, 64 (1954).

D7. Oxidation of Thin Films of Ge and Si. W. C. DASH, *General Electric Research Laboratory.*—A thin film of varying thickness of amorphous Ge or Si is evaporated onto one wall of a glass tube. Optical transmission studies are made as a function of position along the film using 5461A light for Ge and 3650A for Si. Exposure to silver-diffused oxygen or to room air immediately increases the transmission, and it continues to increase over a period of several days. Using absorption constants reported in the literature, an "apparent" oxide thickness can be computed. This apparent oxide thickness is found to vary approximately linearly with thickness of the film, consistent with the idea that the film is porous or granular. A Ge film which has been recrystallized by annealing for an hour at 400°C[1] oxidizes much more slowly than an unannealed film. It is not possible to decide from these results how thick an oxide layer is formed, but the experiments do establish that at least a monolayer of oxide and probably more is formed very quickly on an amorphous or crystalline film of Ge and on an amorphous film of Si upon exposure to pure silver-diffused oxygen as well as to the atmosphere.

[1] G. H. Haas and N. W. Scott, J. phys. radium **11**, 394–402 (1950).

MONDAY AFTERNOON AT 2:00

Murphy 105

(W. G. SHEPHERD presiding)

Ion and Electron Dynamics, Luminescence

Invited Papers

(F1 at beginning, F2 after F4, and F3 after F8)

F1. Low-Energy-Loss Interaction of Electrons with Solids. L. B. LEDER, *National Bureau of Standards.* (25 min.)

F2. Recent Developments in the Design of High-Energy Synchrotrons. J. P. BLEWETT, *Brookhaven National Laboratory.* (25 min.)

F3. Post-War Developments in Amplifiers Involving Energy-Exchange Processes between Electron Beams and Microwave Electric Fields. L. M. FIELD, *California Institute of Technology.* (25 min.)

Contributed Papers

F4. Investigations of Intensity Anomalies in Electron Diffraction from Crystals.* HENRY E. BREED AND J. MAYO GREENBERG, *Rensselaer Polytechnic Institute.*—The expected intensities of reflections occurring in electron diffraction are generally calculated using the first Born approximation. Errors in this approximation may appear in interpretation of molecular gas diffraction (where atomic numbers differ greatly) and in crystals (where atomic numbers differ by a smaller amount).[1] This experimental investigation has been designed to evaluate anomalous intensities in diffraction of crystals of medium atomic weights, in terms of errors inherent in the approximation. Experimental results on cubic AgBr and hexagonal AgI show that for the former the 111 and 311, and for the latter the 004 reflections are considerably stronger than the Born approximation predicts. Geometrically, destructive interference occurs between silver and halide atoms in these reflections. Incomplete interference is attributed to relative internal phase shift between atoms of different atomic number. A small phase difference is sufficient to account for the anomalies. Approximate calculations of the phase difference, based on the Thomas Fermi model, are in qualitative agreement with the experimental observations.

* Supported in part by the Research Grants Committee of Rensselaer Polytechnic Institute.

[1] Glauber and Shomaker, Phys. Rev. **89**, 667–671 (1953).

F5. Mass Doublet Measurements Using a Modulated Magnetic Field.* CLAYTON F. GIESE AND T. L. COLLINS, *University of Minnesota.*—A double-focusing mass spectrometer previously described[1] now employs a modulated magnetic field for sweeping of mass peaks. A supplementary coil wound directly on the spectrometer tube within the magnet gap supplies the modulating field and permits, in conjunction with an electron multiplier and fast electrometer amplifier, the display of a portion of the mass spectrum on the oscilloscope. A system of high-speed commercially available (millisec) relays provides for incremental changes in the ion accelerating voltage and electrostatic analyzer deflection voltage on alternate sweeps. Adjustment of this increment until the two peaks of a mass doublet are superimposed on the oscilloscope screen is then equivalent to finding the relative change in energy required to give the two ions of different mass the same trajectory. Calculation of the mass difference follows from this relative change in energy, measured in terms of resistance by a precision voltage divider. The advantages of this technique are: (1) instantaneous observation of the mass peaks facilitates adjustment of the spectrometer, and (2) the fast sweeping eliminates the problem of drifts.

* This research sponsored in part by the joint programme of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.

[1] A. O. Nier and T. R. Roberts, Phys. Rev. **81**, 507 (1951).

F6. Applications of Rapid Sweeping to a Single-Focusing Mass Spectrometer. C. ROBERT LAGERGREN, *University of Minnesota.*—A method of rapid sweeping and alternate selecting of ion beams in an ordinary 60° mass spectrometer permits the investigation of initial kinetic energy distributions of fragment ions formed by electron impact. A deflection coil placed in the gap of the analyzer magnet sweeps the ion beam over a single mass peak. Two ion accelerating voltages, accurately determined by the ratio of the masses of the ions involved, are alternately applied by means of a high-speed commercially available (millisec) relay and a precision voltage divider network. The relative positions and shapes of the two ion peaks appearing simultaneously on an oscilloscope reflect their relative initial kinetic energy distributions. Choosing for one of the peaks that of a molecular ion whose shape is assumed to represent the "zero" initial kinetic energy distribution; one can obtain information about the initial energy distribution of the other. The superposition of ion peaks also facilitates the rapid measurement of the relative abundances of ions. This is accomplished by a selective attenuation of the input signals to the oscilloscope so that the alternate peaks are matched in height.

F7. Stabilization of Potentials in a Precision Double-Focusing Mass Spectrometer.* K. S. QUISENBERRY, T. T. SCOLMAN AND T. L. COLLINS, *University of Minnesota.*—Preliminary tests and measurements have been completed on a large double-focusing mass spectrometer.[1] To realize the advantages of the high resolution, which is approximately 1 in 40 000, extreme stability is required. This is accomplished by using two sensing and stabilizing circuits. The first of these, which stabilizes the potential supplied to the electrostatic analyzer and compensates for any changes in the magnetic field, employs a second smaller spectrometer with a modulated ion beam. This system utilizes a synchronous detection technique. The second circuit regulates the accelerating potential in the large spectrometer tube by sensing the position of the ion beam after leaving the 90° electrostatic analyzer. These systems employ both electronic feedback and

mechanical servomechanisms so that the error signals are maintained essentially zero.

* Supported by a grant from the National Science Foundation.
[1] Collins, Scolman, and Nier, Bull. Am. Phys. Soc. **29**, No. 4, 27 (1954).

F8. A Model of Solar Proton Streams. WILLARD H. BENNETT, *Naval Research Laboratory.*—A laboratory tube has been developed which provides a true scale model of the paths of solar proton streams in the earth's magnetic field. This model shows that proton streams approaching the earth in a stream whose diameter is of the order of 1000 kilometers is mostly turned back by the earth's field before reaching the earth, while only a small part of the stream reaches the earth at the auroral zone of magnetic latitude in a spiral which tightens as the stream nears the earth. Streams can also pass the earth and be turned back towards the earth forming a ring current about the earth near the equatorial plane. The magnetic effects of the ring currents and of the tight spirals between them account at least qualitatively for magnetic storms, and the patterns in the laboratory model agree at least qualitatively with the timing of the sequence of events in sun spots, first auroral displays and magnetic disturbances.

F9. Luminescence from NaCl.* W. E. SPICER, *University of Missouri.*—The low intensity, x-ray induced luminescence from single NaCl crystals has been studied in the range 240 mμ to 580 mμ using photon-counting techniques. The spectra obtained depend strongly on the past history of the sample. With no heat treatment and small x-ray dosages, bands centering about 550, 400, and 250 mμ were observed. Heating the crystals to temperatures between 200°C and 550°C for a few minutes causes new, more intense bands at 350 mμ and 505 mμ to replace (or mask) the two long wavelength bands. The 250 mμ band is increased by a factor of about 20. This spectrum changes with time under constant x-ray irradiation. After 5½ hours of irradiation, the 350 mμ band becomes rudimentary, the 250 band is greatly reduced, the band at 505 mμ disappears, leaving the 550 mμ band and a new band at 430 mμ. Repeating the heat treatment restores the high intensity of the 505, 350, and 250 mμ bands. The luminescence was also studied as a function of time after stopping the irradiation. It was found that after a decay in intensity of three orders of magnitude had taken place, almost all of the original intensity could be regained by shining white light on the crystal.

* Supported in part by the United States Office of Naval Research.

F10. Long Life Luminescence and Diffusion in Magnesium Oxide.* B. GOODMAN, *University of Missouri.*—An ionic (vacancy) diffusion model is considered for the very long life phosphorescence ($\sim 10^7$ seconds) observed by Eisenstein[1] in x-ray irradiated MgO crystals. It is assumed that: (1) the x-rays release vacancies at dislocation lines,[2] some of which diffuse away from the region of influence of the stress field of dislocation; (2) the vacancy mobility is enhanced during the irradiation;[3] (3) luminescence results in some unspecified way when the vacancies reunite with dislocations. Calculated decay curves are similar to those observed which follow t^{-n} ($n \sim 0.3$–0.7) for a number of decades and then fall off rapidly but the theoretical curves do not fall off as rapidly. If the diffusion coefficient is written as $D = D_I + (T)$ where D_I is the x-ray induced part (assumed proportional to the x-ray intensity) and $D(T) \alpha e^{-E/kT}$ is the normal coefficient, the ratio $D_I/D(T)$ can be estimated by using different x-ray intensities and different temperatures. Both estimates give $D_I/D(T) \sim 40$ for the room temperature irradiations. A rather low activation energy, $E \sim 0.6$ ev, is obtained from a fit of the decay curves at different temperatures to the calculated curves.

* Supported by the U. S. Office of Naval Research.
[1] A. S. Eisenstein, Bull. Am. Phys. Soc. **29**, No. 1, 39 (1954).
[2] J. J. Markham, Phys. Rev. **77**, 500 (1952).
[3] F. Seitz, Phys. Rev. **89**, 1299 (1953).

F11. Optical Absorption Spectra of Stoichiometric Single Crystals of MgO.* W. T. PERIA, *University of Minnesota.*—Magnesium oxide single crystals, believed to be of stoichiometric composition, have in the ultraviolet region of the spectrum an absorption commonly believed to be the tail of the fundamental absorption band. However, in experiments on the coloration of these crystals with excess magnesium, changes in this "background" absorption have been observed quite apart from the large absorption changes caused by the addition of the excess magnesium. This has led to attempts to correlate the background absorption with the densities of the various types of lattice defects present in the crystal. To this end background absorption spectra are being studied as a function of the time and temperature of heat treatment in vacuum.

* Supported by United States Signal Corps.

F12. Excitation of Zinc Oxide Phosphors by Low-Energy Electrons. ROSS E. SHRADER, *RCA Laboratories Division.*—The phenomenon of excitation of ZnO phosphors by electrons when the applied voltages are equal to or less than the equivalent ev of the observed photons has been investigated. The results suggest that in ZnO phosphors the energy level distribution is such that any electron accepted by the crystal lattice, regardless of how small was its velocity in vacuum, has the ability to produce luminescence.

MONDAY AFTERNOON AT 2:00

Physics 150

(R. T. BIRGE presiding)

Joint Session of American Physical Society and AAPT

Invited Papers on Astronomical Subjects

G1. Galactic Magnetic Fields. W. A. HILTNER, *Yerkes Observatory.* (30 min.)
G2. White Dwarfs and Degenerate Stars. W. J. LUYTEN, *University of Minnesota.* (30 min.)
G3. The Probable Age of the Earth. T. L. COLLINS, *University of Minnesota.* (30 min.)
G4. Galactic and Extra-Galactic Sources of Radio Waves. F. GRAHAM SMITH, *Cambridge University.* (30 min.)

MONDAY AFTERNOON AT 2:00

Physics 170

(G. FREIER presiding)

Mainly Reactions of Transmutation

H1. Gamma Rays from Proton Capture in Li^7 and F^{19}.* E. B. NELSON, W. LAWRENCE, AND R. R. CARLSON, *State University of Iowa.*—Sodium iodide scintillation detectors and a 10-channel pulse-height analyzer were used to search for cascade gamma-ray transitions following the capture of 440-kev protons by Li^7. The number of coincidences between a gamma ray of energy greater than 6 mev and one of energy greater than 2.6 Mev is less than 1 percent of the total gamma transitions. A three-crystal scintillation pair spectrometer was used to search for gammas in the energy region of 10–12 Mev. Their intensity is less than 10 percent of the 17.6-Mev intensity. The 13.08-Mev state in Ne^{20}, formed by the capture of 224-kev protons by F^{19}, was found to decay by alpha emission to the 6.13-Mev state in O^{16}. The angular distribution of the 6-Mev radiation is strongly anisotropic. Alpha emission to the ground state of O^{16} is inhibited by at least a factor 2 compared to the short-range alpha. These results limit the l value of the captured proton and the spin and parity of the capture state.

* Supported in part by the U. S. Atomic Energy Commission.

H2. Gamma Rays from (p,γ) Reactions in B^{11} and Mg^{24}. D. S. CRAIG, W. G. CROSS, AND R. G. JARVIS, *Chalk River Laboratories.*—The yield of 16-Mev radiation from $B^{11}(p,\gamma)C^{12}$ has been found to exhibit a resonance at 163 kev with an intensity 1/40 that of the 12-Mev radiation in agreement with Moak and Robinson.[1] The angular distribution of the 16-Mev radiation at this resonance has been determined from measurements at 0, 60, 90, and 120° to be of the form $1-A\cos\theta+B\cos^2\theta$ with $B=A\pm0.03$ and $A=0.22\pm0.06$. The presence of the odd power cosine term can be interpreted as interference with a level of opposite parity. The gamma spectrum from the 222-kev resonance in $Mg^{24}(p,\gamma)Al^{25}$ shows a line of 2.03 ± 0.02 Mev coincident with one of 0.47 ± 0.02. In disagreement with measurements of Casson[2] no 2.5-Mev transitions to the ground state with an intensity greater than 2 percent of the 2.03 component has been fund. The angular distribution of the 2.03-Mev radiation is isotropic to within a few percent. Assuming this transition is to the first excited state then the spin and parity of the 2.5-Mev level in Al^{25} is $1/2\pm$, or possibly $3/2+$.

[1] Oak Ridge National Laboratory 1005 (unpublished).
[2] H. Casson, Phys. Rev. **89**, 809 (1953).

H3. The Reaction $C^{14}(p\gamma)N^{15}$ Above the (pn) Threshold. H. E. GOVE, G. A. BARTHOLOMEW, E. B. PAUL, AND A. E. LITHERLAND, *Chalk River Laboratories.*—The yield of the proton capture gamma ray leading to the ground state of N^{15} has been measured at three angles 0°, 90°, and 142° from $Ep=0.90$ to 2.2 Mev. The angular distribution and partial width of this gamma ray were measured at resonances at 1.17 and 1.32 Mev and, in addition, the partial width was measured at 1.46 Mev. The results are summarized in the table. The values for Γn and Γp will be discussed in the following abstract. The spin and parity assignments are based on angular distributions, interference effects, and single particle limit arguments. The previously unreported broad s-wave state at 1.46 Mev whose total width and partial width for ground-state gamma emission are both about 0.2 of the single particle limit may account for the thermal neutron-capture cross section and gamma-ray spectrum. Some previous measurements have been reported.[1]

Ep	Γkev	Γnkev	Γpkev	$\omega\gamma$ev	J	$\Gamma\gamma$ev	Radiation
1.17	7.5	1.3	6.2	0.17	$\frac{1}{2}-$	0.21	$M1$
1.32	43	34	9.4	0.48	$\frac{1}{2}+$	2.2	$E1$
1.46	500	~5	~500	29	$\frac{1}{2}+$	29	$E1$

[1] Spearman, Hudspeth, and Morgan, Bull. Am. Phys. Soc. **29**, 10 (1954).

H4. Neutrons from the Reaction $C^{14}(pn)N^{14}$. A. E. LITHERLAND, E. B. PAUL, G. A. BARTHOLOMEW, AND H. E. GOVE, *Chalk River Laboratories.*—The $C^{14}(pn)N^{14}$ reaction has been studied with protons in the energy range from the threshold to 2.2 Mev. The angular distribution of the neutrons has been measured at the resonances previously reported[1] using a long BF_3 counter as detector. All distributions but one showed odd terms in $\cos\theta$ indicating interference between states of opposite parity. The 1.17 and 1.32-Mev resonances seem to interfere with the broad level at 1.46 which is more clearly seen in the γ-ray yield curve. The angular distributions are consistent with assignments of $\frac{1}{2}-$ and $\frac{1}{2}+$ respectively for the former resonances and $\frac{1}{2}+$ for the broad state. The neutron and proton partial widths have been calculated using the known $(np)^2$ and $(nn)^3$ cross sections and our (pn) yield measurements. The assignments of higher resonances from width and angular distribution measurements will be discussed.

[1] Roseborough, McCue, Preston, and Goodman, Phys. Rev. **83**, 1133 (1951).
[2] C. H. Johnson and H. H. Barschall, Phys. Rev. **70**, 818 (1950).
[3] Hinchey, Stelson, and Preston, Phys. Rev. **86**, 483 (1952).

H5. An Excited State of Oxygen-19.* T. F. STRATTON, K. F. FAMULARO, H. D. HOLMGREN, AND R. V. STUART, *University of Minnesota.*—Foils of 0.04-mil nickel were oxidized with oxygen enriched to 23 percent O^{18} [1] to form self-supporting NiO targets containing approximately 10^{19} oxygen atoms per square centimeter. Comparison of the yield of reaction products with deuterons incident on normal and enriched targets showed one new proton group due to the O^{18} target. The experimentally determined Q for the reaction was 0.3 ± 0.3 Mev. Assuming a mass defect of 8.65 Mev[2] for O^{19} places the excited state in O^{19} at about 1.6 Mev. The differential cross section for the reaction was measured for 3.01 Mev deuterons at twenty center-of-mass angles ranging from 5° to 161°. The distribution was of the character of a typical $1_n=0$ type stripping distribution with a cross section of 213 mb at 5° falling to a minimum of 11 mb at 48° and rising to a secondary maximum of 27 mb at 84°. Attempts to resolve the ground-state protons from $O^{18}(d,p)O^{19}$ and $O^{16}(d,p)O^{17}$ failed, indicating that the Q's for these reactions are the same within the resolution of our detectors, 0.4 Mev.

* Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Courtesy of Professor A. O. Nier.
[2] E. Bleuler and W. Zünti, Helv. Phys. Acta **20**, 195A (1947).

H6. Angular Distribution of the $O^{16}(d,p)O^{17}$ Reaction.* D. M. VAN PATTER, B. E. SIMMONS, T. F. STRATTON, AND D. M. ZIPOY, *University of Minnesota.*—Nickelous oxide foil targets as described in the preceding abstract were bombarded with incident deuterons of laboratory energies 2.3 Mev to 3.9 Mev. The absolute yield of the $O^{16}(d,p)O^{17}$ ground-state

reaction was measured at $\theta_{cm}=53°$ in 35-kv steps over the indicated energy range. A resonant type yield was obtained with differential cross sections at $\theta_{cm}=53°$ of 17 mb at 2.65 Mev, 33 mb at 3.01 Mev, 19 mb at 3.25 Mev, and 31 mb at 3.43 Mev. Angular distributions[1] obtained over twenty-two center-of-mass angles from 5° to 161° at these four deuteron energies showed a forward maximum at 53° falling to a minimum of 13 mb in the neighborhood of 90° and rising gradually to 16 mb in the back angles. Fluctuations of intensity at the forward maximum provided the major contribution to maxima in the total yield at 3.0 Mev and 3.4 Mev. The differential cross section for the $O^{16}(d,p)O^{17*}$ reaction (0.875-Mev level) was measured at 3.01 Mev and 3.43 Mev. The distribution obtained was of the typical stripping type with $l_n=0$.

* Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] N. P. Heydenburg and D. R. Inglis, Phys. Rev. **73**, 230 (1948).

H7. Angular Distributions in (d,p) Reactions with Ti^{47} and Ti^{48}.* F. B. SHULL AND M. M. BRETSCHER, *Washington University.*—Thin targets of TiO_2 (one with Ti^{47} enriched to 82 percent, another with Ti^{48} enriched to 99 percent) were bombarded with 10.2-Mev deuterons. Proton angular distributions were determined by a photographic method. Aluminum foils in front of nuclear emulsion plates served as energy selectors, so that proton groups from various excited states could be studied separately. Comparison with Butler's[1] theoretical curves establishes the angular momentum $l_n\hbar$ for the captured neutron, from which spin and parity of the final nuclear level may be determined. Our results are tabulated:

Reaction	Q value (Mev)[a]	l_n	Final Spin	Final Parity
$Ti^{47}(d,p)Ti^{48}$	8.14	3	0	even
	6.81	1,(3?)	1,2,3,4	even
	5.83	1	1,2,3,4	even
	4.83	1	1,2,3,4	even
$Ti^{48}(d,p)Ti^{49}$	5.81	3	5/2,7/2	odd
	4.46	1	1/2,3/2	odd
	4.11	1	1/2,3/2	odd

[a] G. F. Pieper, Phys. Rev. **88**, 1299 (1952).
* Supported by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.
[1] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).

H8. Phase-Shift Analysis of the Elastic Scattering of Protons by He^3. R. W. LOWEN, *University of Minnesota* (introduced by C. Critchfield).—A phase-shift analysis of the differential cross sections for the elastic scattering of protons by He^3 in the region from 1.01 to 3.52 Mev[1] has been made. It is found that the data can be fitted within the probable errors of approximately 5 percent by a single S-wave and a single P-wave phase shift, without any spin dependence. The S-wave phase shift is very nearly that of a charged hard sphere of radius 3.6×10^{-13} cm, while the P-wave phase shift is positive and increases from about 4° at 1.01 Mev to 25° at 3.52 Mev. The best value for the D-wave phase shift at the highest energy is zero.

[1] Famularo, Brown, Holmgren, and Stratton, reported at the Thanksgiving meeting of the American Physical Society, 1953 (to be published).

H9. Energy Levels of Li^6.* A. GALONSKY AND M. T. MCELLISTREM, *University of Wisconsin.*—A phase-shift analysis of deuteron-helium elastic scattering[1] has been performed. The single-particle level at 2.187 Mev in Li^6 has been verified at 3^+. The broad anomaly extending from 3 Mev to the limit of observation, 4.62 Mev, cannot be analyzed in terms of a single level. Instead, it has been fitted with two single-particle levels, a 2^+ level at $E_R=4.53$-Mev excitation in Li^6 and a 1^+ level at 5.4 ± 0.5 Mev. The 1^+ level cannot be located more accurately because only the tail is visible at the bombarding energies available. Of all the other two-level combinations only (3^+, 1^+) has not yet been ruled out. The assignments (3^+, 2^+, 1^+) and locations of the levels agree with an intermediate coupling[2] which is close to the $L-S$ extreme. In fitting the 3^+ resonance, it was necessary to use a small positive P-wave phase shift, whereas the usual hard-sphere phases are negative. Neither inclusion of G-wave excitation of the 3^+ level nor variation of the interaction distance can change the sign of the P-wave phase shift.

* Work supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
[1] Galonsky, Douglas, Haeberli, McEllistrem, and Richards, Phys. Rev. **93**, 928 (1954).
[2] D. R. Inglis, Revs. Modern Phys. **25**, 390 (1953).

H10. Cloud-Chamber Investigation of High-Energy Photonuclear Reactions.* W. E. MATHESON,† C. R. CARLSON,‡ F. S. MATHEWS, R. O. HAXBY, AND R. M. WHALEY, *Purdue University.*—A 14-inch Wilson cloud chamber with associated timing and control equipment designed for use with the Purdue 300-Mev electron synchrotron has been constructed and put into operation with the accelerator. While the 13 000-gauss magnetic-field equipment is being completed, experiments have been carried out by irradiating internal and external chamber targets with a 285-Mev photon beam. Photodisintegrations in carbon, argon, and helium have been observed inside the chamber. Photoprotons from carbon with energies ranging from 45 Mev to 105 Mev have been observed at 90° to the photon beam. The proton differential spectrum as determined from 236 protons recorded in approximately 6800 photographs compares well with the results obtained by other workers using scintillation-counter techniques. Nuclear cross sections obtained in units of $d\sigma/Qd\Omega$ microbarn-effective quantum^{-1}-steradian^{-1} are: 37.5 ± 4.5 in the proton-energy interval 45 Mev–80 Mev and 13.0 ± 1.5 in the interval 80 Mev–105 Mev.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Linde Air Products Company.
‡ Now at Sandia Corporation.

H11. Coulomb Excitation of Neodymium.* B. E. SIMMONS, D. M. VAN PATTER, K. F. FAMULARO, AND R. V. STUART, *University of Minnesota.*—A NaI-Tl scintillation spectrometer with 9° angular resolution was employed in conjunction with the Minnesota electrostatic generator to study the 136-kev gamma[1] resulting from the proton bombardment of neodymium metal.[2] A target "thick" to protons and "thin" to the gammas was prepared by evaporating Nd onto a 0.1-mil nickel backing. Electronic circuits designed to prevent overloading and a 10-channel pulse analyzer provided stable operation for obtaining an angular distribution of this gamma ray, of the form $1+0.2\cos^2\theta$ for a proton energy of 2.25 Mev. At this energy the yield at 90° is 0.20 that of the Ta 137-kev gamma ray, whose angular distribution was measured, as a check, to be isotropic to ±2 per cent. Measurements of the excitation function and the absolute cross section for production of the Nd gamma ray, as well as theoretical calculations concerning its angular distribution, are in progress.

* Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] This gamma has been previously reported by N. P. Heydenburg and G. M. Temmer, Phys. Rev. **93**, 906 (1954).
[2] We are indebted to Professor F. H. Spedding for making available the neodymium.

H12. Comparative Study of Gamma Spectrum of I^{131} with Scintillation and Thick Lens Spectrometer. M. SAKAI, B. MURRAY, AND J. D. KURBATOV, *The Ohio State University.*—Gamma-ray spectrum of highly chemically pure I^{131}* was first obtained with an ordinary single-channel scintillation spectrometer. This spectrum was resolved for the well-known 364-kev, 634-kev, and the 720-kev gamma rays by comparison with the gamma rays emitted by Hg^{203} and Be^7 using a procedure which will be described. A new "peak" of 514 ± 25 kev ap-

peared in the spectrum of I^{131}. The Compton spectrum was also measured independently with a pure aluminum radiator. In addition to the three previously noted gamma rays, analysis of the Compton spectrum produced evidence for a new gamma ray of approximately 514 kev. The intensity of the gamma ray is estimated at 1.2 to 2.0 percent of the intensity of the 364-kev gamma ray. Since disintegration of the 514-kev gamma ray in all observations followed the eight day half-life, it is conditionally assigned to I^{131}.

* I^{131} was obtained from Oak Ridge National Laboratory and further purified chemically.

H13. Radiations of Pa^{232}.* C. I. BROWNE, D. C. HOFFMAN, H. L. SMITH, M. E. BUNKER, J. P. MIZE, J. W. STARNER, R. L. MOORE, AND J. P. BALAGNA, *Los Alamos Scientific Laboratory.*—The nuclide Pa^{232} has been prepared by thermal neutron irradiation of Pa^{231} in the Materials Testing Reactor and the Los Alamos "water boiler" and its radiations have been studied with a magnetic lens beta-ray spectrometer and several types of NaI(Tl) scintillation spectrometers. Coincidence and delayed coincidence techniques were utilized in the scintillation studies. The beta-ray spectrometer data indicate three negatron groups of end-point energies 1.27, 0.502, and 0.304 Mev with relative abundance of 2, 8, and 90 percent, respectively. At least fifteen gamma rays have been found to accompany the decay of this isotope. The decay of Pa^{232} was followed over eight half-lives, giving a value of 1.31 days for the half-life. This is in good agreement with the value of 1.32 days previously reported.[1] Gamma-ray energies, K/L ratios, and conversion coefficients will be given and a decay scheme presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] A. H. Jaffey and E. K. Hyde, Phys. Rev. **79**, 280 (1950).

TUESDAY MORNING AT 9:30

Murphy 105

(G. WANNIER presiding)

Electronic Conduction in Solids

Invited Papers

(K1 at beginning of session and K2 after K5)

K1. Photoelectric Emission and the Electronic Energy Structure of Some Amorphous Semiconductors. L. APKER, *General Electric Company.* (25 min.)

K2. The Role of Crystal Imperfections in Photoconductivity. R. H. BUBE, *Radio Corporation of America.* (25 min.)

Contributed Papers

K3. On the Fermi Level in Semiconducting Amorphous Antimony Films. E. TAFT AND L. APKER, *General Electric Research Laboratory.*—Thin layers of Sb were evaporated onto substrates of single-crystal Ge held slightly above 300°K. They were included as interchangeable emitters in a concentric-sphere retarding-potential phototube in the usual way.[1] Results showed that the Sb had the electronic energy structure of a semiconductor. The Fermi level lay about 0.1 ev above the top of an occupied band. When the films were heated to 100 or 200°C, they converted irreversibly to ordinary crystalline semimetallic Sb.[1] One concludes that the semiconducting layers were amorphous, a form of Sb previously observed only at considerably lower temperatures.[2] The Fermi level as determined here is consistent with resistivity-temperature data of Moss and of Suhrmann and Berndt.[2] The behavior of evaporated Sb is thus analogous in character to that of As,[1] and the electronic energy structure changes in the same general way when the amorphous material is crystallized.

[1] E. Taft and L. Apker, Phys. Rev. **75**, 1181 (1949); **76**, 270 (1949).
[2] F. S. Moss, Proc. Phys. Soc. (London) **A65**, 147 (1952) and cited references.

K4. Photoelectric Emission from BaO.† H. R. PHILIPP,* *University of Missouri.*—The energy distribution of photoelectrons from sprayed coatings of BaO indicates two sets of energy levels located photoelectrically about 2.0 and 2.7 ev below the vacuum level as well as an exciton-induced distribution appearing for wavelengths below 3500 A. Yield curves from two deactivated cathodes showed no exciton-induced emission nor any yield in the 2-ev region indicating that exciton-induced photoelectrons probably have their origin in the 2-ev level. Measurements were made of the temperature dependence of photoelectric emission. The yield was found to increase with temperature in the region of the threshold and decrease with temperature for wavelengths below 4000 A. Semilog plots of exciton-induced emission *vs* $1/T$ give straight lines corresponding to an activation energy of 0.15 ev for the thermal destruction of excitons. Irradiating the cathode with red light had no effect on the exciton-induced emission. Measurements were made of the photoelectric enhancement of thermionic emission. The enhancement increases rapidly for enhancing wavelengths below 4500 A. Photoelectric emission was found to saturate with voltage for all incident wavelengths.

† Supported in part by the U. S. Office of Naval Research.
* Minneapolis-Honeywell Research Fellow.

K5. Surface "Channel" Detection Method for Semiconductors. H. CHRISTENSEN, *Bell Telephone Laboratories, Inc.*—Electrical "channel" conduction phenomena[1,2] occurring on germanium and silicon surfaces have been advantageously studied for a considerable time by a chopped light spot method similar to that used for minority carrier diffusion and lifetime measurements.[3] The observed phenomena can be illustrated by consideration of the photoresponse that is obtained for a reverse biased *n-p* grown junction bar of germanium when the chopped light spot is moved parallel to the axis of the bar.

If no channel is present, the ac photocurrent through the bar drops off approximately logarithmically with distance from the *n-p* junction. When a "channel" is present on the surface, the photoresponse to chopped light remains the same as at the *n-p* junction when the chopped light spot is moved a considerable distance away from the junction into the channel region. This constant response distance is a function of reverse bias voltage and specific conductivity of the channel conduction skin. The method can separate "channel" conduction and surface ionic leakage effects.

[1] W. H. Brattain and J. Bardeen, Phys. Rev. **75**, 1208 (1949); Bul. System Tech. J. **32**, 1 (1953).
[2] W. L. Brown, Phys. Rev. **91**, 518 (1953).
[3] F. S. Goucher, Phys. Rev. **81**, 475 (1951).

K6. Computation of the Mobility Ratio in Pure *p*-Type Semiconductors.* ALLEN NUSSBAUM, *Honeywell Research Center.*—Pure *p*-type semiconductors will show a reversal in the Hall coefficient as their temperature rises into the intrinsic range. The ratio c of electron to hole mobility for such materials can be computed from resistivity *vs* temperature and Hall coefficient *vs* temperature data by the formula $(10^3/T_x) - (10^3/T_r) = (0.397/E_G)\log\{c/c-1\}$, where E_G is the forbidden band width in ev, T_r is the Hall reversal temperature, and T_x is the temperature at which the extrapolated intrinsic and impurity sections of the resistivity curve intersect. In the case of pure Te, where it is impossible to determine c by direct measurement, the formula gives a value which agrees fairly well with that obtained by indirect measurement.[1,2] Similarly, for Te–Se alloys, the computed values increase with Se concentration, agreeing with the predicted theoretical trend.[3] Direct verification has been obtained for one sample of single-crystal Ge, with a measured value[4] of 1.47 and a computed value of 1.41.

* Work supported by U. S. Air Force while at the University of Pennsylvania.
[1] Fukoroi, Tanuma, and Tobisawa, Science Repts. Research Insts., Tôhoku Univ. Ser. **A1**, 373 (1949).
[2] A. Nussbaum, Phys. Rev. (to be published).
[3] H. B. Callen, J. Chem. Phys. **22**, 518 (1954).
[4] R. M. Baum and D. C. Eckhardt, Sylvania Electric Products, Inc. (unpublished).

K7. Grain Boundary Conduction in Gold-Doped Ge. A. G. TWEET, *General Electric Research Laboratory.*—Bicrystals of *n* and *p*-type gold-doped germanium have been drawn from the melt using (100) seeds bound symmetrically on either side of a Mo wedge. The wedge angle β was 5° to 15° and lay in a (110) plane common to the two seeds. Wafers were cut from the bicrystals perpendicular to the axis of growth and ohmic contacts fused to either face. The resistance at 80°K between these contacts was in the megohm range for bulk germanium,[1] but was found to be from 2×10^3 to 10^5 ohm if the contacts were on the grain boundary. Hall effect measurements show that the grain boundary current is *p* type for the case of either *n* or *p*-type bulk germanium. Measurements of the conductivity between 20°K and 80°K show that it varies approximately as $\exp(-\varphi/kT)$, with φ between 0.01 and 0.07 ev. φ seems to be dependent upon β and γ, where γ is the angle which the perpendicular to the plane of the grain boundary makes with the common (110) planes of the bicrystal halves. Twin boundaries do not conduct.

[1] W. C. Dunlap, Jr., Phys. Rev. **91**, 1282 (1953).

K8. Ultraviolet Transmission and Alpha Bombardment Conduction Inhomogeneities in Diamond. A. J. AHEARN, *Bell Telephone Laboratories.*—Most diamonds showed some alpha-particle bombardment conduction but its magnitude varied widely. Experiments with a beam of alpha particles revealed extensive inhomogeneities[1] within given specimens. Contradictory results were obtained in tests with gamma rays[2] *vs* alpha particles[1] to see if this counting property could be related to the optical transmission in the ultraviolet. This suggested that the diamonds were mixtures of opaque and transparent types. Contact print transmission photographs were taken at 2540–2570 A.U. which showed that many specimens were mixtures of opaque and transparent regions. With certain diamonds in the form of thin slabs, the same variations in alpha counting were observed on both sides, and the opaque and transparent regions were larger than the alpha beam. On a given diamond meeting these two qualifications, the high alpha-count regions agreed well with the transparent areas and the low alpha-count regions agreed well with the opaque areas. This confirms the conclusion[3] drawn from similar comparisons between small diamonds under beta- and alpha-particle bombardment.

[1] A. J. Ahearn, Phys. Rev. **73**, 1113 (1948); **84**, 798 (1951).
[2] Friedman, Birks, and Ganvin, Phys. Rev. **73**, 186 (1948).
[3] F. C. Champion, Proc. Phys. Soc. (London) **B65**, 465, (1952).

TUESDAY MORNING AT 10:00

Physics 150

(PHYLLIS FREIER presiding)

Cosmic Rays and Mesons

L1. Search for Departures of Cosmic Rays from Poisson's Law at Low Counting Rates. I. T. E. BAKER, JR.,* N. C. BLAIS,† C. L. HEMENWAY, V. ROJANSKY, M. S. WEBSTER,‡ AND M. S. WERMAN,§ *Union College.*—A small GM tube was triggered by cosmic rays on the average about once per second. Each pulse originating in this tube was counted by a scaler A, and every 64th pulse was recorded by an Esterline-Angus recorder. A pulse separated from the preceding pulse by more than about 20 milliseconds opened after a short delay a 20-millsecond electronic gate. A pulse that arrived while the gate was open triggered not only A but also a second scaler A', and moved a second pen of the recorder. We found that the number of pulses passing through the gate was about 3 percent larger than that computed on the basis of Poisson's law from the readings of A. The probability that this discrepancy occurred in our experiment by chance was about one in twenty.

* Now at the University of Illinois.
† Now at Yale University.
‡ Now at Washington University.
§ Now at New York University.

L2. Search for Departures of Cosmic Rays from Poisson's Law at Low Counting Rates. II. W. M. CEGELSKI, A. T. GOBLE, C. L. HEMENWAY, K. REINITZ, V. ROJANSKY, AND F. A. RUSHWORTH,* *Union College.*—Our apparatus is a modification of that described in the preceding abstract. A pulse originating in the GM tube is counted by the scaler A, as before, and also by a scaler B, which is reset 50 times

per minute by a synchronous motor. The "on" time of B is about 0.7 second, the "off" time about 0.5 second. If (and only if) B accumulates four or more counts during an "on" interval, it triggers, when reset, a second pen of the recorder. We find that the number of sets of four or more pulses occurring during the "on" intervals of B is somewhat larger than that computed on the basis of Poisson's law from the readings of the scaler A; numerical results will be presented at the meeting. Measurements were also made with B modified to count sets of eight or more pulses. A two-tube coincidence circuit, activated by a radon source, is being constructed in order to permit us to feed random pulses into the apparatus and thus to obtain a comparison with cosmic rays.

* On leave from St. Andrews University, Scotland.

L3. Heavy Cosmic-Ray Nuclei.* JOHN LINSLEY, *University of Minnesota.*—Analysis has been completed of data obtained with a Čerenkov counter-cloud chamber apparatus during two balloon flights at 40° geomagnetic latitude and atmospheric depths 15 and 19 g/cm². Pulses from the Čerenkov counter, gated by a Geiger counter telescope, were recorded continuously during the 13 hours at high altitude, and cloud-chamber photographs were obtained of 394 of the events that caused pulses. The primary purpose of the experiment was to measure the flux of fast alpha-particles, and 175 photographs show the track of such an object, but in addition some 40 show the track of a heavier nucleus. The pulse height record, which exhibits peaks corresponding to charge 6, 7, 8, and a group of pulses ($Z \geqslant 9$) that saturated the amplifier, served to identify the nuclei whose tracks were photographed. On the other hand, the cloud-chamber data made it possible to evaluate the counter background, which proves to be small, especially in the region $Z \geqslant 6$. Values will be reported for the flux of helium; that of Li, Be, B; that of C, N, O; and that of nuclei with $Z \geqslant 9$.

* The research was supported in part by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

L4. Cosmic-Ray Studies with a Čerenkov Detector at $\lambda = 10°$ and 55°.* K. A. ANDERSON, *University of Minnesota.*—Absolute flux measurements of the cosmic-ray albedo obtained at balloon altitude by means of a Čerenkov detector have now been made at $\lambda = 10°$ and 55°N, supplementing the data already reported for 40°.[1] The apparatus incidentally performs a simultaneous range and velocity determination on the cosmic-ray particle.[2] The slow portion intensities thus obtained are in agreement with those from other methods. Using the experimental value of the splash albedo flux and also taking into account the dependence of multiple meson production on energy, an approximate calculation shows that the E−W asymmetry predicted by geomagnetic theory on the basis of all positive primaries can be brought into agreement with the measured value[3] at $\lambda = 10°$. This would indicate (1) that the "distant" albedo is not large compared with the splash flux, at least for $\lambda = 10°$, and (2) it is not necessary to require that 20 percent of the primaries are negatively charged as Bhowmik[4] has done.

* This research was supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. R. Winckler and K. Anderson, Phys. Rev. **93**, 596 (1954).
[2] J. R. Winckler, Phys. Rev. **85**, 1053 (1952).
[3] J. R. Winckler *et al.*, Phys. Rev. **79**, 656 (1950).
[4] B. Bhowmik, Phys. Rev. **89**, 327 (1953).

L5. Flux and Azimuthal Asymmetry of Primary Cosmic-Ray Nuclei at the Equator.* R. E. DANIELSON, P. S. FREIER, J. S. NAUGLE, AND E. P. NEY, *University of Minnesota.*—Nuclear emulsions were flown for a period of six hours at an average atmospheric depth of 15.2 g/cm² and at a geomagnetic lattitude of 9–10°. This flight was part of Project Churchy, sponsored by the U. S. Office of Naval Research. Six 4 in.×10 in. stacks were exposed, each stack consisting of two 600 μ Ilford G-5 emulsions and one 600 μ Ilford G0–G5 emulsion. The stacks were flown horizontally and were oriented with respect to the earth's magnetic field for approximately 70 percent of the time at altitude. A preliminary value† of the flux for $z \geqslant 10$ has already been given as 0.36 ± 0.05/m² sec sterad. A better value for the flux based on about 1000 particles will be reported as well as the azimuthal asymmetries of these particles.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Reported at Duke Conference on Cosmic Rays.

L6. Densitometric Measurement of Emulsion Tracks.* E. P. NEY, JOHN NAUGLE, PHYLLIS FREIER, *University of Minnesota.*—A track densitometer of the general type described by von Friesen† has been designed and used to measure the area of developed grains on tracks of heavy particles as a function of their residual range. The method is useful for determining the charges of stopping particles. It has been found that the method is more reproducible than δ-ray counting. The uses and limitations of the device will be discussed and compared with the results obtained by δ-ray counting.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Sten von Friesen, Arkiv Fysik **4** (1952).

L7. An Example of an Unstable Nuclear Fragment Being Emitted from a Heavy Meson Induced Star.* J. E. NAUGLE, P. S. FREIER, AND E. P. NEY, *University of Minnesota.*—A very unusual event has been observed in an emulsion exposed at 15.2 g/cm² at the equator during the Churchy expedition sponsored by the U. S. Office of Naval Research. A charged particle travels 1.6 cm in a G-5 emulsion before coming to rest. At the end of its range is a star, similar to an ordinary sigma star. However, one of the fragments of this star travels 78 microns before coming to rest in the emulsion. At the end of its range is a second star consisting of a short nuclear fragment, a 9.0 ± 0.2 Mev proton and 23.5 ± 0.5 Mev pion, which travels 1.1 cm before coming to rest. The tentative explanation of this event is that a negative heavy meson is captured by a nucleus of the emulsion, this nucleus disintegrates into several fragments, one of which contains a "bound V^0 particle" and which suffers a mesonic decay after coming to rest in the emulsion. The energetics, masses of the particles involved, and possible decay schemes will be discussed.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

L8. Nuclear Collisions at Extreme Relativistic Energies.* MARCEL SCHEIN, D. M. HASKIN, AND R. G. GLASSER, *University of Chicago.*—Two unusually large stars have been observed which may further contribute to our understanding of the processes which occur in nucleon-nucleus collisions at very high energies. The N star is of type 32+137 (n) and the P star is of type 25+76 (p). The stars are practically identical in laboratory angular distribution showing a strong forward collimation. The total charge of the outgoing slow fragments in the N star is estimated at 40–45, so that the target nucleus must have been silver. Of the 137 shower particles in the N star, at least 130 must be created particles; π mesons, K mesons, proton-antiproton pairs, and hyperons. Thus, counting neutral radiation a total of about 200 particles are being created in a collision of one nucleon with only a few nucleons. It is most difficult indeed to see how any modification of an

essentially plural theory can explain this fact. Preliminary estimates indicate that the primary energy for both these stars should be over 10^{13} ev. The N star and the P star represent conclusive evidence that in interactions with a heavy nucleus multiple meson production must occur in processes involving more than one nucleon.

* Supported in part by a joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

L9. Comparison of Proton and Meson Produced Stars of Comparable Excitation Energy.* A. D. SPRAGUE, *DePauw University*, AND D. M. HASKIN, R. G. GLASSER, AND MARCEL SCHEIN, *University of Chicago.*—An analysis is carried out of star formation in nuclear photoplates of 405-Mev protons and 222-Mev negative pions produced in the University of Chicago 250-Mev synchrocyclotron. A comparison of the angular distribution of the charged particles in proton stars with a Monte Carlo calculation is made. The results show that the cascade mechanism is an important factor in proton produced stars at these energies. In addition, the number of charged particles arising from excitation and subsequent evaporation of the heavy nucleus were determined and found to be in disagreement by a factor of 5 with predictions of evaporation theory. Pion produced stars yield an angular distribution of charged particles which is much flatter than that of proton produced stars.

* Supported in part by a joint program of The U. S. Office of Naval Research and The U. S. Atomic Energy Commission.

L10. Studies of Penetrating and Cascade Showers of Cosmic Rays with Plastic Scintillators at an Elevation of 11 500 Feet.* C. N. CHOU, *University of Chicago.*—An apparatus consisting of G-M counters and four $18\times18\times1$ cm^3 plastic scintillation counters interposed with lead plates of various thicknesses was used to investigate the penetrating showers produced in carbon by cosmic rays at an altitude of 11 500 feet. The frequency *versus* energy relation of γ rays produced from the decay of neutral pions in penetrating showers and also the multiplicity spectrum of the charged pions were obtained. In addition, the frequency *versus* energy relation of cascade showers produced by the bremsstrahlung accompanying high-energy μ mesons was determined. The same apparatus was also used to measure the energy spectra of high-energy photons and electrons of cosmic rays at 11 500 feet.

* Supported in part by a joint program of The U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

L11. Coulomb Effect on the Photoproduction of Low-Energy Charged Mesons.* J. R. VOSS, T. R. PALFREY, AND R. O. HAXBY, *Purdue University.*—Following the method of White,[1] the Purdue 300-Mev electron synchrotron has been used to expose some Ilford 600 micron G-5 plates. Thin targets were placed in the γ-ray beam and reaction products at 120° from the beam were captured in the emulsion. The π^- and π^+ mesons that stopped in the emulsion were counted. The Coulomb field of the nucleus might be expected to shift the energy of charged mesons as they leave the vicinity of the nucleus. Since the photoproduction cross section of π mesons strongly increases with energy at low energies, the Coulomb shift would manifest itself in an increase in the π^-/π^+ ratio as the energy decreases. Experimentally this change has been found in the energy range 0–20 Mev for the elements C, Cu, Sn, and Pb. The effect is strong, especially for the higher Z materials.

* Work supported in part by contract with U. S. Atomic Energy Commission.
[1] R. H. White, University of California Radiation Laboratory Report 1319 (1951).

L12. Ionization Energy Loss of Mesons in a Sodium Iodide Scintillation Crystal.* THEODORE BOWEN, *University of Chicago.*—The response of a thallium activated sodium iodide crystal to high-energy charged particles passing through the scintillator has been investigated. π and μ mesons produced by the Chicago 450 Mev cyclotron have been used to cover energies ranging from 61 Mev π mesons to 245 Mev μ mesons. Sea level cosmic ray μ mesons have been used to cover energies from 200 Mev to greater than 2 Bev. At each energy, the most probable energy loss is determined from the pulse height distribution, making use of Po—Be 4.44 Mev γ rays for an energy calibration. The distributions from cyclotron data are found from the density variations on photographs of the superposition of many pulses appearing on an oscilloscope. Because the cosmic ray counting rate is low, each pulse is individually photographed and measured. The results for energies below the occurrence of the minimum in ionization indicate good agreement with the probable energy loss as given by the Bethe-Bloch formula. Beyond the minimum the probable loss is in fair agreement with Sternheimer's calculations[1] for sodium iodide, rising slightly more rapidly than predicted to the Fermi plateau.

* Supported in part by a joint program of The U. S. Office of Naval Research and The U. S. Atomic Energy Commission.
[1] R. M. Sternheimer, Phys. Rev. **88**, 851 (1952); **91**, 256 (1953).

TUESDAY MORNING AT 10:00

Physics 170

(C. L. CRITCHFIELD presiding)

Invited Papers in Theoretical Physics

M1. Various Comments on Deuteron-Induced Reactions. W. B. CHESTON, *University of Minnesota.* (30 min.)

M2. The *S*-Operator in Quantum Electrodynamics. J. M. JAUCH, *State University of Iowa.* (30 min.)

M3. Formal and Methodological Aspects of Present Quantum Electrodynamics. F. ROHRLICH, *State University of Iowa.* (30 min.)

TUESDAY AFTERNOON AT 1:45

Murphy 105

(H. REISS presiding)

Gaseous Electronics

Invited Papers

(Q1 at beginning of session, Q2 after Q6, Q3 after Q8)

Q1. Drift Velocities and Mobilities. R. N. VARNEY, *Washington University.* (25 min.)

Q2. Microwave Discharges. W. P. ALLIS, *M.I.T.* (25 min.)

Q3. Atomic Collision Processes in Ionized Gases. M. A. BIONDI, *Westinghouse Research Laboratories.* (25 min.)

Contributed Papers

Q4. Drift Velocities of Argon Ions in Argon at Various Temperatures.* E. BEATY AND R. VARNEY, *Washington University.*—A microsecond pulsed Townsend type of parallel-plate discharge tube has been designed and constructed for submerged operation in a regulated temperature bath. The leads to the electrodes and a quartz window for admission of ultraviolet radiation remain out of the bath during operation but are mounted to provide a tube surface area which is not at the equilibrium temperature. Limited results have been obtained fitting qualitatively with theoretical predictions. Extension to a greater range of temperature and of E/p, the field-strength-to-pressure ratio will be described.

* Supported in part by the U. S. Office of Naval Research and by a grant from Research Corporation.

Q5. Mobilities of Various Ions in the Noble Gases. LORNE M. CHANIN AND MANFRED A. BIONDI, *Westinghouse Research Laboratories.*—The recently developed techniques[1] for measuring the mobilities of near-thermal ions in gases have been extended to studies of ions moving in gas mixtures. The measurements provide an experimental test of the validity of Blanc's Law, which states that the mobility μ_{AB} of an ion moving in a mixture of gases A and B is given by $1/\mu_{AB} = (f_A/\mu_A) + (f_B/\mu_B)$, where μ_A and μ_B are the mobilities of the ion in the pure gases, and f_A and f_B are the fractional concentrations of the gases. Systematic deviations from Blanc's Law have been observed for Ne^+ moving in helium and neon. In addition, measurements have been made of the mobility as a function of E/p of such systems as He^+ in neon and Ne^+ in helium. In these cases the resonance interaction of charge transfer between ion and atom is absent, and the polarization interaction is of importance. It is found that in some cases, e.g., He^+ in neon, the experimental values differ widely from the predictions of Langevin's theory.[2]

[1] M. A. Biondi and L. M. Chanin, Phys. Rev. **94**, 910 (1954).
[2] P. Langevin, Ann. Chim. phys. **5**, 245 (1905); H. R. Hasse and W. R. Cook, Phil. Mag. **12**, 554 (1931).

Q6. Corrected Values for the Charge Transfer Cross Section in the Noble Gases. GREGORY H. WANNIER, *Bell Telephone Laboratories.*—Ziegler published recently[1] values for the ion-atom charge transfer cross section which he had obtained by direct measurement. Such cross sections were also published by some of us at Bell Laboratories as deduced from ion mobility studies. These latter appear high by about 50 percent. An even bigger discrepancy appears in the predictions of Sena.[2] However, Ziegler's observations show that the physical assumption of Sena's theory is closer to the truth than the one of the author: namely little or no momentum is transferred in most charge transfer collisions. Perusal of Sena's work and correction of an error in the derivation yields the usual square root law for the drift velocity with a factor $(2/\pi)^{\frac{1}{2}}$ instead of 1.147 as published previously by the author.[3] This yields the following values for the charge transfer cross sections of helium, neon, argon, krypton, xenon: 38, 45, 93, 109, 134×10^{-16} cm^2. The new values are in close numerical agreement with the ones of Ziegler in three out of five cases. The cause for the remaining discrepancies is not clear.

[1] B. Ziegler, Z. Physik. **136**, 108 (1953).
[2] L. Sena, J. Phys. U.S.S.R. **10**, 179 (1946).
[3] G. H. Wannier, Bell System Tech. J. **32**, 170 (1953), Eq. (100).

Q7. Mechanism of the Termination of the Geiger-Plateau Region.* HERBERT L. WISER AND A. D. KRUMBEIN, *University of Maryland.*—Experimental investigation of counting rate and number of positive ions per pulse *versus* voltage for Geiger counters at the high-voltage end of the plateau leads to the belief that spurious counts, and therefore the termination of the plateau, can be accounted for by secondary electrons created by positive ion bombardment of the cathode and metastable atom collisions in the gas. Studies were made on counters of different cathode diameters and partial pressures of the main gas and of the quenching vapor. The rate of spurious counts caused by positive ion bombardment is found to be proportional to the rate of positive ions striking the cathode, and therefore, to the voltage. The rate of spurious counts caused by metastable collisions depends on the number of metastables existing after the deadtime of the Geiger tube, and therefore is an exponential function of the ratio of the deadtime to the metastable half life. Since the deadtime decreases with increasing voltage, the rate of spurious counts caused by metastable collisions is an exponential function of voltage.

* This work is supported by the Bureau of Ships, U. S. Navy Department.

Q8. Corona Discharge Current from Aircraft.* SEVILLE CHAPMAN, *Cornell Aeronautical Laboratory.*—In a system for maintaining zero electrostatic charge on aircraft where electric field meters on the surfaces of the wings control a high-voltage corona discharge point behind the tail of the aircraft, the primary factors influencing the magnitude of blow-away discharge current i are point potential V, aircraft speed v, point geometry, and space charge from the already discharged current. The fundamental physical effects are that V must be large enough to create an electric field vector toward the rear to drive the discharge current into the space charge behind the point, but since this same V creates a field vector forward toward the aircraft skin, the point must be disposed so that the wind past the point prevents return current to the aircraft. The problem is approached mathematically from several points of view, to evaluate constants F, G, and H in $i=\epsilon_0(FkV^2/l+GvV+Hlv^2/k)$ where k is the mobility and l a length. Currents of a few hundred micro-

amperes can be expected when $V=100$ kilovolts and $v=200$ knots. Some data are presented.

* Supported by the Air Force Cambridge Research Center.

Q9. Absorption Studies of the Helium Metastable Molecule. A. V. PHELPS, *Westinghouse Research Laboratories.*—Measurements of the lifetime of helium atoms in the triplet metastable state (2^3S) as a function of the pressure of the helium gas[1] have shown that these metastable atoms are destroyed as a result of collisions with the wall of the absorption cell and by three-body collisions with neutral helium atoms. In order to test the proposal[1] that these three-body collisions result in the formation of a helium molecule in the metastable state ($2s^3\Sigma_u^+$), arrangements were made to measure absorption of the 4650A band during the afterglow of a pulsed discharge.[2] The observed absorption shows that metastable molecules are formed as predicted and that the natural lifetime of the $2^3\Sigma_u^+$ state is at least 0.005 second. These experiments also show that the lifetime of the triplet metastable molecule is very sensitive to small concentrations of neon (~one part in 10^5) present in commercial reagent grade helium.

[1] A. V. Phelps and J. P. Molnar, Phys. Rev. **89**, 1202 (1953).
[2] The 4650 A band is the O→O band of the $3p^3\Pi \rightarrow 2s^3\Sigma$ system; see e.g., G. H. Dieke and E. S. Robinson, Phys. Rev. **80**, 1 (1950).

Q10. Diffusion of Metastable Mercury Molecules. A. O. MCCOUBREY AND C. G. MATLAND, *Westinghouse Research Laboratories.*—In studies on the band fluorescence of mercury vapor,[1] diffusion data obtained for metastable diatomic mercury molecules, $Hg_2(^3O_u^-)$, suggested that the molecules may be partially reflected by glass walls; this circumstance complicated the evaluation of the diffusion coefficient. In the present work, metal walls were substituted for the glass walls. The experimental method is that used in previous work, in which $Hg_2(^3O_u^-)$ molecules are created as a consequence of the absorption of 2537A resonance radiation. The time variation of the concentration of the molecules is obtained during the afterglow by measuring the intensity of band radiation. The data obtained with a vessel having nickel walls is consistent with the hypothesis that the $Hg_2(^3O_u^-)$ molecules are completely destroyed upon diffusing to the boundaries. The product of the diffusion coefficient and the mercury vapor density obtained from this work is $ND=63\times10^{-16}$(atoms cm²/cc sec). These experiments, which extend over a wider density range than heretofore, have also yielded a more accurate value for the three-body collision induced radiation rate for the $Hg_2(^3O_u^-)$ molecules, i.e., $29\times10^{-32}\times(\text{atom/cc})^{-2}$ sec^{-1}. Further work is in progress to more accurately determine the reflection coefficient of the molecules at a glass surface.

[1] A. O. McCoubrey, Phys. Rev. **93**, 1249 (1954).

Q11. Excitation by Electron Impact of the Optically Forbidden Transition $1^1S\rightarrow2^1S$ in Helium.* E. N. LASSETTRE, M. E. KRASNOW, AND S. SILVERMAN, *The Ohio State University.*—The electron spectrometer described previously[1] has been used for the study of the transitions $1^1S\rightarrow2^1P$ and $1^1S\rightarrow2^1S$ in helium. These transitions are separated in energy (0.6 ev) by slightly more than the resolution of the apparatus. Incident electrons with kinetic energies of about 500 volts were used. Electron impact energy spectra have been obtained for scattering angles from 3.8 to 15.3 degrees. Over this angular range the relative electronic collision cross sections of the two transitions vary in such a way that the optically forbidden transition $1^1S\rightarrow2^1S$, which is undetectable at the smallest angle, becomes almost equal in intensity to the $1^1S\rightarrow2^1P$ transition at 15.3 degrees. Electron impact energy spectra showing this variation will be presented. Electronic collision cross sections have also been calculated from the data over this angular range. At the smaller angles these cross sections are subject to considerable error because of the indirect method which must be used to separate the contribution of the $1^1S\rightarrow2^1S$ transition from the $1^1S\rightarrow2^1P$ transition.

* The research reported in this paper has been sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command.
[1] Lassettre, Berman, Silverman, and Krasnow, Bull. Am. Phys. Soc. **29** No. 4, 47 (1954).

Q12. The Quenching of Sodium Iodide Fluorescence by Various Gases and Vapors.* HOWARD G. HANSON, *University of Minnesota, Duluth Branch.*—Experimental data has been taken on the quenching of the sodium D line arising from the optical dissociation of NaI molecules by ultraviolet light in the 2000A to 2500A range. The gases and vapors used were hydrogen, carbon dioxide, hydrogen chloride, and water vapor. Water vapor shows little quenching action. The quenching action of hydrogen and cargon dioxide show slight experimental dependence on the velocity of the excited sodium atoms. The quenching action of hydrogen chloride is the greatest and shows an experimental dependence on the relative velocity of the excited sodium atoms and the HCl molecules. The intensity of the sodium D line as a function of wavelength of exciting ultraviolet light has been measured. The wavelength for maximum excitation of the sodium D line shifts to higher ultraviolet wavelengths with increasing temperature of the NaI salt. A grating monochromator was used to isolate narrow regions of ultraviolet light from a hydrogen discharge lamp. A photomultiplier tube circuit measured the intensity of fluorescence. A device to record intensity of fluorescence as a function of exciting wavelength is described together with other experimental detail.

* Supported by the U. S. Office of Ordnance Research.

TUESDAY AFTERNOON AT 2:00

Physics 170

(A. VAN DER ZIEL presiding)

Mainly Semiconductors

R1. Magnetic Susceptibility of Residual Bisulfate Compounds of Carbon. H. T. PINNICK, *University of Buffalo.*—The introduction of bisulfate ions between the graphitic layers in carbons and graphite results in the formation of excess holes in the π band. The magnetic susceptibility of a series of bisulfate residue compounds of carbons has been studied at room temperature. Compounds with residual ion concentrations varying from 5×10^{-4} ion/atom to 15×10^{-4} ion/atom were prepared from rods of soft carbon heat-treated (H.T.) to temperatures ranging from 1600°C to 2800°C. The decrease in susceptibility with increasing ion concentration was found to be greater for carbons heat-treated to higher temperatures. The decrease per 1×10^{-3} ion/atom is about 23 percent for 2800°C H.T., 18 percent for 2400°C H.T., 14 percent for

2000°C H.T., and approximately zero for 1700°C H.T. Since the susceptibility of pure carbons reaches the maximum value at heat-treatment temperatures of about 2000°C and remains constant for higher H.T.[1] the susceptibility of the bisulfate compounds with a given ion concentration reaches a maximum at about 2000°C heat-treatment and decreases for higher heat-treatment temperatures, leading to the rather unexpected result above 2000°C H.T. of a decreasing diamagnetic susceptibility for carbon compounds with increase of crystallite diameters.

[1] H. T. Pinnick, Phys. Rev. **94**, 319 (1954).

R2. Magnetoresistance and Planar Hall Effects in *N*-Type Germanium. R. E. DAVIS AND COLMAN GOLDBERG, *Westinghouse Research Laboratories.*—The magnetoresistance and planar Hall[1] effects have been measured from 77°K to 300°K for oriented samples of 13 ohm-cm *n*-type germanium. The magnetoresistance measurements permit calculation of the planar Hall effect, and this calculation agrees with actual measurement of the latter effect. The data are in qualitative agreement with calculations[2] based upon the assumption that the energy surfaces are ellipsoids of revolution about the (111) directions in *k* space.[3]

[1] C. Goldberg, Phys. Rev. **93**, 913 (1954); R. E. Davis and C. Goldberg, Phys. Rev. **93**, 913 (1954); C. Goldberg and R. E. Davis, Phys. Rev. **94**, 1121 (1954).
[2] S. Meiboom and B. Abeles, Phys. Rev. **93**, 1121 (1954).
[3] Lax, Zeiger, Dexter, and Rosenblum, Phys. Rev. **93**, 1418 (1954).

R3. Resistivity Changes in Silicon Induced by Heat Treatment. C. S. FULLER, J. A. DITZENBERGER, N. B. HANNAY, AND E. BUEHLER, *Bell Telephone Laboratories.*—Room temperature resistivity measurements on a variety of single crystals of silicon grown by the Teal-Little method show that large changes in resistivity may be induced by heat treatment. These appear to be independent of surface impurities and occur throughout the volume of the material. At temperatures between about 300–700°C many crystal show an increase in electron content with time. The rate and magnitude of these changes are a maximum at 430–450°C and require between 1–48 hours for completion. Changes as great as 5×10^{16} electrons cm^{-3} are observed. Smaller increases occur above and below this temperature. By heating to temperatures above about 500°C these changes are reversed, the original resistivity being rapidly obtained above 800°C. The changes in carrier content are intimately associated with the crystal growing variables. A discussion of these and possible origins of the observed effects will be given.

R4. The Interaction of Traps and Heat Treatments in Silicon. N. B. HANNAY, J. R. HAYNES, AND R. G. SHULMAN, *Bell Telephone Laboratories.*—Shallow and deep trapping levels in both *n*- and *p*-type silicon have previously been observed[1] at room temperature. Densities of these four traps have been measured in crystalline regions which had been pulled from the melt under different growth conditions. Reproducible measurements of many crystals indicate that the trap concentrations after growth are related to the crystal growing variables. Trap densities are high in those crystals which change resistivity upon heat treatment as discussed in the preceding paper. They are one to two orders of magnitude lower in crystals whose resistivities are not affected by heat treatments. Typical values of effective trap concentrations are 10^{13}/cc in the former regions and 10^{11}/cc in the latter. After the crystals have been grown different time-temperature cycles drastically alter trap densities. As a result of the measurements it is seen that the same conditions which give high trap concentrations also give large resistivity changes at 450°C. In order to identify the traps the effects of different temperature cycles, high-energy electron bombardment, dislocations and chemical impurities have been studied.

[1] J. R. Haynes and J. A. Hornbeck, Phys. Rev. **90**, 152 (1953).

R5. Impurity Levels in Silicon. F. J. MORIN, J. P. MAITA, R. G. SHULMAN, AND N. B. HANNAY, *Bell Telephone Laboratories.*—Electron energy levels associated with nine different impurities and several annealing conditions have been found in the forbidden gap of silicon. The levels were located with respect to the conduction band edge in *n*-type silicon and the valence band edge in *p*-type silicon by analysis of carrier concentration data determined from measurement of the Hall coefficient as a function of temperature. Energies measured in electron volts are as follows: *p*-type silicon; B, 0.045[1]; Al, 0.057; Ga[1], 0.065; In, 0.16; Au[2], 0.39. For *n*-type silicon; P, 0.039; As[1], 0.049; Sb, 0.039; Li, 0.033; annealed at 475°C 100 hours,[3] 0.033; annealed at 475°C 10 minutes,[3] 0.133 and 0.3. The differences in ionization energies of the Group III elements were not expected on the basis of the hole on a neutral acceptor moving in a hydrogen-like orbit. Changes of lifetime due to these and other chemical impurities will be discussed.

[1] E. Burstein *et al.*, J. Phys. Chem. **57**, 849 (1953) and private communication report similar values from optical absorption.
[2] E. A. Taft and F. H. Horn, Phys. Rev. **93**, 64 (1954).
[3] Prepared by C. S. Fuller (see preceding paper).

R6. Hole Trapping Due to Lattice Defects in Germanium. R. G. SHULMAN, W. L. BROWN, AND R. C. FLETCHER, *Bell Telephone Laboratories.*—An investigation of *n*-type germanium indicates that hole traps are created by high-energy electron bombardment at room temperature. Using a technique similar to that of Haynes and Hornbeck,[1] one observes the rise and fall of photoconductivity associated with chopped light falling on the sample. Trap concentrations were studied in several samples having different bombardments. The measured concentrations ($\sim10^{13}$/cc) agreed with the density of bombardment centers to ±25 percent. Decay times did not change when the surfaces were alternately etched and sandblasted. In control samples trap densities were negligible. Measurements made from 160°K to 240°K were consistent with a capture cross section of $\sim2\times10^{-15}$ cm^2. Decay curves were simple exponentials with time constants of 300 μsec at 200°K. The energy of the traps above the valence band can be determined from both the temperature dependence and the absolute value at any temperature of the decay time constants.

[1] J. R. Haynes and J. A. Hornbeck, Phys. Rev. **90**, 152 (1953).

R7. The Absence of Bombardment Annealing in the Electron Bombardment of Germanium. R. C. FLETCHER AND W. L. BROWN, *Bell Telephone Laboratories*, AND K. A. WRIGHT, *M.I.T.*—In the bombardment of *n*-type germanium with electrons the rate of change in conductivity with bombardment has been found to decrease as the bombardment proceeds. Investigation indicates that this nonlinearity cannot be caused entirely by thermal annealing nor by the proximity of the Fermi level to a bombardment induced energy level. Two other possible causes are (1) annealing induced by the presence of the high-energy electrons and (2) a nonuniform distribution of impurities. We have been able to show experimentally that the former is an unlikely explanation. First, if, as we would suppose, the rate of annealing is much less dependent on the bombardment energy than the rate of creating damage, damage created at 3 Mev should anneal out by bombardment at 1.5 Mev. No such annealing was observed. Second, with enough bombardment a steady state should be reached, limiting the maximum amount of damage possible. No such saturation was found; nonlinearity was observed at densities of bombardment centers as low as 10^{15} cm^{-3} in a 1 ohm-cm sample, but densities as high as 10^{18} cm^{-3} were achieved

without saturation in a 0.003 ohm-cm sample. The most plausible source of this nonlinearity seems to be a microscopically nonuniform distribution of impurities.

R8. Traps Produced by Electron Bombardment of Germanium at Low Temperature. W. L. BROWN AND R. C. FLETCHER, *Bell Telephone Laboratories*, AND K. A. WRIGHT, *M.I.T.*—Minority carrier traps[1] have been produced in both *n*- and *p*-type germanium by electron bombardment at 78°K. Hole traps are responsible for approximately 3 percent of the total change in conductivity produced by 1.5- and 3-Mev bombardments of *n*-type samples (1.4 mho/cm at 300°K). At 1.5 Mev in *p*-type samples (1.6 mho/cm at 300°K) the conductivity changes are very small and no traps have been observed, but at 2.5 and 3 Mev when the equilibrium conductivity changes are comparable to those in *n*-type, 70–80 percent of the change is associated with two classes of electron traps characterized by different electron capture cross sections. The larger cross section is $\sim 10^{-19}$ cm^2 at 78°K. The release time for electrons for this class of traps is about a minute at 140°K. A preliminary investigation of its temperature dependence indicates a trap depth of about 0.2 ev below the conduction band. While minority carrier lifetime is not limited by recombination in these traps, the lifetime is markedly reduced as the traps are filled with electrons. The defects responsible for both classes of electron traps anneal out at about 185°K or below. The hole traps in *n*-type disappear with annealing at about 140°K.

[1] J. R. Haynes and J. A. Hornbeck, Phys. Rev. **90**, 152 (1953).

R9. Plastic Deformation of Gold-Doped Germanium. C. J. GALLAGHER AND A. G. TWEET, *General Electric Research Laboratory.*—The center sections of $\frac{1}{16}$ in.$\times\frac{1}{16}$ in.$\times$2 in. rods of Ge doped with 2×10^{14} gold atoms/cm^3 have been bent[1] to a prescribed radius of curvature on a quartz form at temperatures between 400°C and 700°C. The rods, which were etched and then rinsed in KCN to remove Cu, were supported at the ends in an atmosphere of forming gas during bending. The resistance at 80°K of the unbent section of a typical rod was in the megohm range,[2] while the average resistance in the bent portion was found to be from 10 to 10^4 times smaller. Higher conductivity was associated with sharper bending. The resistivity of all samples showed considerable variation with position, as did the density of slip lines on the surface. Since the unbent gold-doped Ge was *p*-type, the data suggest that bending introduces an acceptor level somewhere between the valence band and the lower gold level, which lies 0.15 ev above the valence band.

[1] C. J. Gallagher, Phys. Rev. **88**, 721 (1952).
[2] W. C. Dunlap, Jr., Phys. Rev. **91**, 1282 (1953).

R10. Action Spectra for the Photoconductivity of Dye Films. JOHN W. WEIGL, *The Ohio State University.**—Electrons or holes responsible for photoconduction in films of basic dyes[1,2] may be optically excited by visible light,[3] absorbed at any wavelength in the main absorption bands of the dyes. Since the bands in the solid films appear to correspond to the normal singlet-singlet bands of the "isolated" molecules in solution, one may identify the optical transitions leading to carrier excitation with those of the component molecules—a situation peculiar to organic photoconductors. This makes it possible to apply existing information concerning the spectroscopy and photochemistry of the "isolated" dye molecules to phenomena characteristic of the solid state. Action spectra of examples of xanthene, acridine, cyanine, and triphenylmethane dyes will be presented.

* Work supported by the Charles F. Kettering Foundation.
[1] A. Vartanian, Acta Physicochimica U.R.S.S. **22**, 201 (1947).
[2] R. C. Nelson, J. Chem. Phys. **19**, 798 (1951); **20**, 1327 (1952).
[3] A. Vartanian, J. Phys. Chem. U.R.S.S. **24**, 1361 (1950).

R11. Electron Energy Levels in Ionic Crystals.* E. L. JOSSEM AND L. G. PARRATT, *Cornell University.*—Information on the electron energy levels in solids is provided by the energy positions, intensities, and shapes of component lines in x-ray emission and absorption spectra. The x-ray $K\beta$ emission spectra of chlorine in the alkali chlorides and in cuprous chloride have been recorded with a curved crystal focusing vacuum spectrometer using a proportional counter detector. These lines involve transitions from levels in or near the valence band to an inner (K shell) vacancy. The principal features of the spectra are: (a) the chlorine $K\beta_1$ line, commonly ascribed to the transition valence-band-to-K-vacancy, is uniformly too narrow to permit such assignment; (b) the intensity of the chlorine β_x and β_5 lines relative to the β_1 line varies with the compound. Interpretation of these features in terms of the band structure of the crystal and the sharp "impurity-type" levels[1] introduced by the inner shell vacancy will be discussed.

* This research was supported by the United States Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] L. G. Parratt and E. L. Jossem, Phys. Rev. **84**, 362 (1951) and **85**, 729 (1952).

TUESDAY AFTERNOON AT 2:00

Physics 150

(E. P. NEY presiding)

Invited Papers in Cosmic-Ray Physics

S1. High-Energy Nuclear and Electromagnetic Interactions. PHYLLIS FREIER, *University of Minnesota.* (30 min.)

S2. Alpha-Particles in Primary Cosmic Rays. NAHMIN HORWITZ, *University of Minnesota.* (30 min.)

S3. The Light Elements in Cosmic Rays. LELAND BOHL, *University of Minnesota.* 30 min.)

S4. Recent Results with S-Particles. H. S. BRIDGE, *MIT.* (30 min.)

TUESDAY AFTERNOON AT 2:00

Physics 133

(R. G. HERB presiding)

Various Topics in Nuclear Physics

T1. Measurement of Phase Noise in a Pre-Excited Oscillator System.* LAWRENCE H. JOHNSTON, NORTON M. HINTZ, AND HARRY J. SCHULTE, *University of Minnesota.*—If multiple, independent linear accelerator cavities are driven by free-running oscillators, can they be phased within a few degrees by a small, coherent pre-exciting signal? This case is of interest for linacs designed for 100 Mev and higher energy. Slater† reports ±10° probable phase fluctuations from pulse to pulse for the MIT electron linac, due to magnetron noise. A unique opportunity was recently afforded for such a measurement when the first cavity of the Minnesota Linac was driven by an interim system of oscillators to give 10-Mev protons. (Two more cavities will eventually give 68 Mev.) Phase of rf in the cavity was compared to that of a crystal CW pre-exciting source (5 percent voltage), the relative phase being displayed on an oscilloscope. While relative phase drifts (~30°) were observed during a 450-microsecond rf pulse, these repeated on 100 successive pulses within ±5°, and this "jitter" was found to be largely instrumental. We conclude that the oscillators built up in constant phase relationship to the pre-exciter within less than ±5°.

* Partially supported by the U. S. Atomic Energy Commission.
† Demos, Kip, and Slater, J. Appl. Phys. **23**, 53–65 (1952).

T2. A 200 Mc Phase Detector.* EDMUND B. TUCKER, LAWRENCE H. JOHNSTON, AND DONALD E. YOUNG,† *University of Minnesota.*—The inter-cavity phasing problem for an accelerator consisting of a number of independent high Q cavities requires accurate tuning of the individual cavities even when amplifiers are used to power the machine. For the case of a cavity with a Q of 70 000 a phasing tolerance of ±8° requires a tuning accuracy of 1 part in 10^6. The automatic frequency control designed for use with the Minnesota linear accelerator is similar in principle to that used by Rideout,[1] Pound,[2] and others for stabilization of microwave oscillators. The phase detector used in this system operates at the accelerator frequency of 202.5 Ms and consists of distributed constant circuits. During stability tests the phase detector has shown a drift of less than 1° over a period of 10 hours. The complete system including integrators, amplifiers, servos, and tuners has been tested at low power in the first cavity of the accelerator with a resulting tuning accuracy of 1 part in 4×10^6.

* Partially supported by the U. S. Atomic Energy Commission.
† Now at General Mills Research Laboratories, Minneapolis, Minnesota.
[1] V. C. Rideout, Proc. Inst. Radio Engrs. **35**, 767 (1947).
[2] R. V. Pound, Proc. Inst. Radio Engrs. **35**, 1405 (1947).

T3. A "Zipper" Scattering Chamber.* C. J. COOK, *University of Nebraska.*—A continuously variable vacuum port has been developed. This apparatus is similar to a zipper in that it consists of two rubber diaphragms under pressure that form a vacuum tight seal along a slot in the wall of a vacuum chamber, and a port, or "zipper foot," that slides between the rubber diaphragms without destroying the vacuum inside the chamber. By utilizing this vacuum "zipper" it was possible to construct a plane scattering chamber suitable for studying the energy and angular spectrum of the secondary electrons resulting from ionizing collision of a 20- to 400-kev proton and a gas molecule. With this type of scattering chamber it is possible to observe the scattered beam continuously through a laboratory angle of 0 to 150 degrees symmetrically about the incident beam. Another major advantage of this type of scattering chamber is that all of the necessary detecting apparatus for the scattered particles is conveniently placed outside of the small active portion of the scattering cell. A detailed description will be given, with slides, of the construction and operation of this specific "zipper" scattering chamber.

* This work is being carried out under contract with the U. S. Atomic Energy Commission.

T4. Mass Measurement by Multiple Coulomb Scattering on Stopped Particles.* R. G. GLASSER, *University of Chicago.*—Measurements have been made on 100 stopping protons and on 20 positive pions produced in the 450-Mev synchro-cyclotron of the University of Chicago in order to determine the relation between range and scattering. The particles could be unambiguously identified. The relationship can be represented by a power law

$$\langle|N|\rangle_{Av}=(18.9\pm0.1)R^{-(0.607\pm0.005)}\left(\frac{M}{M_P}\right)^{-(0.393\pm0.005)}\left(\frac{t}{50}\right)^{\frac{1}{2}}$$

where $\langle|N|\rangle_{Av}$ is the absolute average sagitta of successive chords, R is the range at the midpoint, M and M_P are, respectively, the mass of the particle and of the proton, and t is the cell length; all lengths are in microns. The formula given enables one to compute a constant sagitta (varying cell length) measurement scheme for any particle. The use of this method allows dependable scattering measurements of mass to be made. The mass of an artificially produced negative K meson, which Dr. Salant and Dr. Hornbostel of Brookhaven National Laboratories kindly provided, was measured as 1300±150 times the electron mass.

* Supported in part by a joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

T5. Comparison of Proton Energy Loss by Integral and Differential Experiments. THEODORE JORGENSEN, JR., *University of Nebraska.*—The apparatus for range determinations of protons in gases[1] has been modified to determine the ratio of $(\Delta E/\Delta X)_D$ (differential experiment) to $(\Delta E/\Delta X)_R$ (obtained from range measurements) by inserting an additional diaphragm at about 10 percent of the range from the entrance diaphragm. The two diaphragms act to form a differential stopping cell and the range measurements serve to determine the energy lost in the cell. The result of this experiment shows that $(\Delta E/\Delta X)_D$ and $(\Delta E/\Delta X)_R$ are essentially equal. This checks the agreement between our results and those of the differential experiments.[2] Results for protons in argon show that $(\Delta E/\Delta X)_D<(\Delta E/\Delta X)_R$ and that $\Delta E/\Delta X$ by the two methods cannot be expected to agree for gases in which proton scattering is excessive. Details of the experiment and results will be presented.

[1] Cook, Jones, and Jorgensen, Phys. Rev. **91**, 1417 (1953).
[2] S. K. Allison and S. D. Harshaw, Revs. Modern Phys. **25**, 798 (1953)

T6. Low-Energy Pair Production Cross Sections in Scintillators. HARRY I. WEST, JR.,* *Stanford University.*—Using the center crystal of a three-crystal scintillation pair spectrometer[1] as the pair convertor, we have measured both absolute and relative pair cross sections in NaI(Tl) and anthracene for Co^{60} γ rays (1.173 Mev and 1.333 Mev) and relative pair cross sections in NaI(Tl) for the γ rays of Na^{24} (1.38 Mev and 2.76 Mev). The detection efficiency of the spectrometer for pairs was measured by coincidence methods using the decay properties of Na^{22} (β^+ followed by a single γ ray). The cross

sections obtained for carbon (from anthracene) are $\sigma p(1.33)/\sigma p(1.17)=5.20\pm0.17$ and $\sigma p(1.33)=6.03\pm0.17\times10^{-28}$ cm². From the Born approximation theory of Hough[2] we find 6.16 and 5.97×10^{-28} cm², respectively. The cross sections obtained for iodine (from NaI(Tl)) are $\sigma p(2.76/\sigma p(1.38)=15.0\pm0.8$, $\sigma p(1.33)/\sigma p(1.17)=5.00\pm0.15$ and $\sigma p(1.33)=6.82\pm0.15\times10^{-26}$ cm². From the Born approximation theory of Hough, we get 18.7, 6.16, and 4.68×10^{-26} cm², respectively. Experimental techniques, treatment of data including the bremsstrahlung and electron escape problem from the pair convertor, and comparison of results with theory will be discussed.

* Now at the Army Chemical Center.
[1] Harry I. West, Jr., and L. G. Mann, Rev. Sci Instr. **25**, 129 (1954).
[2] P. V. C. Hough, Phys. Rev. **73**, 266 (1948).

T7. Neutron Cross Sections of Light Nuclei.* CHARLES E. PORTER, *Brookhaven National Laboratory.*—Examination of data[1,2] on the neutron total cross sections of light nuclei indicates that much of the variation of these cross sections can be accounted for by the complex-potential model[3] proposed for heavy nuclei. An attempt is being made to see to what extent this is so and will be reported on.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] N. Nereson (private communication).
[2] Neutron Cross-Section Compilation, U. S. Atomic Energy Commission Report AECU-2040, 1952 and three supplements (unpublished).
[3] Feshbach, Porter, and Weisskopf, Phys. Rev. **90**, 166 (1953).

T8. (Abstract withdrawn.)

T9. Small Angle Scattering of 1-Mev Neutrons by Intermediate and Heavy Nuclei. S. E. DARDEN, W. HAEBERLI, AND R. B. WALTON, *University of Wisconsin.**—Previous measurements[1] on the angular distributions of elastically scattered neutrons show qualitative agreement with the complex-well scattering model,[2] but suggest that the predicted values are too large at small scattering angles. In an attempt to provide a more sensitive check, the previous measurements have been extended to smaller angles. Using a ring geometry, differential scattering cross sections for 1-Mev neutrons were measured at five angles between 8° and 30° for ten elements. The observed cross sections are about ten percent higher than values found by extrapolating the previous measurements[1] to smaller angles, but appreciably lower than the predicted values[3] for heavy elements.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] M. Walt and H. H. Barschall, Phys. Rev. **93**, 1062 (1954).
[2] Feshbach, Porter, and Weisskopf, Phys. Rev. **90**, 166 (1953).
[3] Feshbach, Porter, and Weisskopf, Massachusetts Institute of Technology Technical Report No. 62 (1953).

T10. Scattering of Polarized Neutrons from Heavy Nuclei. A. OKAZAKI, R. L. BECKER, AND H. H. BARSCHALL, *University of Wisconsin.**—Experiments to determine the polarization of neutrons scattered by intermediate and heavy elements have been continued. As in previous measurements[1] 380-kev neutrons from the $Li^7(p,n)$ reaction emitted at 50° in the laboratory system were scattered through 90° from cylindrical samples, and the left-right asymmetry was observed. Seventeen elements from Cu to U were investigated. Elements between Nb and Sn showed appreciable asymmetries in one direction, while a slight asymmetry in the opposite direction was found for the heaviest elements in qualitative agreement with previous measurements.[1] An attempt was made to deduce the polarizations produced in the scattering from the intermediate and heavy elements by measuring the polarization of the incident $Li(p,n)$ neutrons. For this purpose the 435-kev neutron resonance in oxygen was used. The results are so far not entirely consistent with the assumed parameters of the O^{17} level so that polarizations cannot be deduced with certainty.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] Darden, Fields, and Adair, Phys. Rev. **93**, 931 (1954).

T11. Gas Recoil Fast Neutron Spectrometer.* R. E. BENENSON, M. B. SHURMAN, AND W. HAEBERLI, *University of Wisconsin.*—A gas recoil neutron spectrometer similar in operation and geometry to that described by Giles[1] has been constructed and tested with monoenergetic neutrons from 0.68 to 5.1 Mev, using fillings of palladium-filtered H_2 and 99.9 percent pure tank propane. The number of wires in the transparent cathode and anticoincidence anodes has been increased over the number used by Giles; end effect anticoincidences are employed; and clean vacuum techniques to eliminate electron capture by electronegative impurities have been used. The width of the peak and peak-to-background ratio are markedly dependent on the proton recoil range chosen. Widths of the peak at half-maximum of 10 percent have been attained. Efficiencies of the order of 10^{-4} are obtained for the pressures and ranges employed. In the most favorable case the average background was reduced to 5 percent of the peak height; 10 percent is considered to be compatible with good efficiency. The anticoincidence voltage is independently variable; multiplications of the order of 10^4 are required in the anticoincidence counters for good gating. Nuclear reactions are being studied.

* Work supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
[1] R. Giles, Rev. Sci. Instr. **24**, 986 (1953).

TUESDAY EVENING AT 7:00

Junior Ballroom, Coffman Memorial Union

(MARSH W. WHITE presiding)

Banquet of the AAPT and the American Physical Society

After-dinner speakers: R. M. SUTTON and E. W. DAVIS.

WEDNESDAY MORNING COMMENCING AT 4:30

Total Eclipse of the Sun

WEDNESDAY MORNING AT 10:30

Murphy 105

(R. L. SPROULL presiding)

Electron Emission and Ejection Phenomena, I.

Invited Paper

U1. On the Escape Mechanism for Secondary Electrons. A. J. DEKKER, *University of Minnesota.* (25 min.)

Contributed Papers

U2. Methods of Preparing Thin Film MgO Secondary Emission Surfaces on Ag-Mg Alloys.* PETER WARGO, *University of Minnesota.*—Many procedures have been described for the preparation of thin film secondary emission surfaces of MgO. Variations in these procedures give rise to widely varying results. Two simple procedures will be described which result in consistent maximum values of δ of approximately 12 at a primary energy near 500 volts. The simpler method using a low pressure of oxygen is particularly suited to cases where the targets are prepared in one vessel and transferred to a second for application. Some of the problems encountered in this transfer process will be discussed. The second method using a CO_2 atmosphere is particularly suited to situations where the targets can be processed in the final site.

* Supported by the U. S. Signal Corps.

U3. Inelastic Scattering of Medium-Fast Electrons in Alkali Metals.* E. M. BAROODY, *Battelle Memorial Institute.*—Earlier calculations[1] concerning the excitation of valence electrons to the next Brillouin zone by medium-fast primaries have been extended. Using the approximation of nearly free electrons, explicit expressions for the number of interzonal transitions per unit primary path and for the distribution in energy of the transitions have been obtained and applied to several alkalis. For these metals, a similar method has been used in the past to account for the absorption of visible and ultraviolet light; and for sodium, potassium, and rubidium, Butcher[2] has chosen Fourier coefficients of the lattice potential which give adequate agreement with the limited experimental data. When Butcher's coefficients are introduced into our equations, interzonal transitions are found to be infrequent, only two or three being predicted per 1000A when the primary energy is 1000 ev. This supports the view that the interzonal transitions emphasized in the Fröhlich-Wooldridge theory of secondary emission from metals are actually of minor importance.

* Sponsored by the U. S. Army Signal Corps and the U. S. Air Force.
[1] E. M. Baroody, Phys. Rev. **89**, 910 (1953).
[2] P. N. Butcher, Proc. Phys. Soc. (London) **A64**, 765 (1951).

U4. Work Functions of Tungsten Single Crystal Planes.* ERWIN W. MÜLLER, *Pennsylvania State University.*—Electron emission from the 110 plane has been measured as a spurious effect only.[1,2] The method of a field emission microscope with a probe hole in the screen and behind it a suppressor and a collector[3] has been improved. The current density in the 110 plane was found to be 4 to 5 orders of magnitude smaller than in the strongly emitting planes. Applying the Fowler-Nordheim theory and assuming $\phi_{111}=4.38$ ev according to,[1] one finds ϕ_{110} between 5.80 and 6.15 ev, depending on the temperature at which the crystal has been annealed previously (2500°K and 1200°K, respectively, vacuum 10^{-12} mm). The same effect at the 112 plane yields work functions between 4.80 and 5.05 ev. It is caused by freezing in the thermal imperfections. The data of all strongly emitting planes agree with those obtained by thermionic methods.

* Work supported by U. S. Office of Scientific Research, U. S. Air Research and Development Command, Baltimore, Maryland.
[1] M. H. Nichols and G. F. Smith: U. S. Office of Naval Research Report No. 24433 (1952).
[2] W. P. Dyke and co-workers: J. Appl. Phys. **25**, 106 (1954).
[3] E. W. Müller, Z. Physik **120**, 261 (1943).

U5. Noise Mechanisms in Oxide-Coated Cathodes.* A. VAN DER ZIEL, *University of Minnesota.*—Order of magnitude considerations will be applied to discriminate between various noise mechanisms that might be proposed to explain flicker noise in vacuum tubes. It will be shown that noise due to fluctuations in number of adsorbed atoms or noise due to fluctuations in the number of donor atoms in the coating cannot account for the observed noise, but that either Schottky's emission center theory or the spontaneous fluctuations in the number of carriers in the surface layer may explain the experimental results.

* Work supported by the U. S. Signal Corps.

U6. Influence of Different Activating Agents on Flicker Noise in Oxide-Coated Cathodes.* W. W. LINDEMANN, *University of Minnesota.*—A series of experiments to determine the differences in the flicker noise characteristics of tubes with different types of cathode nickel alloys will be discussed. Of the alloys used (Inco 220, Inco 225, 0.1 percent Al, 0.4 percent W, and 499 nickel). 0.1 percent Al nickel consistently gave the least noisy tubes. Some observations of other characteristics of the various cathode nickel alloys which might suggest an explanation of these results will also be given.

* Supported by U. S. Signal Corps Contract.

U7. Influence of Tube Structure and Tube Operating Conditions Upon Flicker Noise.* H. J. HANNAM, *University of Minnesota.*—To show how the amount of flicker noise generated in vacuum tubes depends upon the tube structure, a comparison will be made of the noise generated in a triode and the noise generated in the same tube in diode connection. To show the influence of operating conditions, measurement will be presented of flicker noise in triodes and pentodes as a function of the applied voltages. A discussion of possible causes of effects will be given.

* Work supported by the U. S. Signal Corps.

WEDNESDAY MORNING AT 10:00

Physics 150

(J. H. WILLIAMS presiding)

Invited Papers on Nuclear Accelerators

V1. Recent Cyclotron Experiments at Harvard University. N. F. RAMSEY, *Harvard University.* (30 min.)

V2. Recent Progress in Electrostatic-Generator Techniques. R. G. HERB, *University of Wisconsin.* (30 min.)

V3. Preliminary Operation of the Bevatron. E. J. LOFGREN, *University of California, Berkeley.* (30 min.)

V4. Research with the Cosmotron. LYLE W. SMITH, *Brookhaven National Laboratory.* (30 min.)

WEDNESDAY MORNING AT 10:00

Physics 170

(J. VALASEK presiding)

General Physics

W1. Preliminary Description and Analysis of the Spectrum of Polonium. G. W. CHARLES, D. J. HUNT, G. PISH, AND D. L. TIMMA, *Mound Laboratory.**—Purified polonium has been excited by both high-frequency electrodeless discharges of 10, 30, and 400 megacycles/sec at temperatures ranging from 200° to 800°C, and in an enclosed spark source. One hundred forty-seven lines have been found in the spectrum from the electrodeless discharge and thirteen additional lines have been observed in the spectrum of the spark discharge. Forty-eight lines have been classified as transitions involving twenty-four energy levels of PoI. Four levels of the fundamental configuration $6p^4$ have been identified. The observations have been compared with theoretical predictions for this configuration. Separations are well represented by theory with the parameter $F_2=1112$ cm^{-1} and $\zeta=12393$ cm^{-1}. The absolute value of the lowest level $6p^4\,{}^3P_2{}^1$ has been estimated from the first two members of the series $6p^3({}^4S^0)$ ns using the method of Russell. An estimate of 67 990 cm^{-1} is obtained. This corresponds to an ionization potential of 8.43 volts.

* Operated by Monsanto Chemical Company for the United States Atomic Energy Commission.

W2. Thomas-Fermi Calculation of the C−H Bond Moment in Methane.* H. GLAZER AND H. REISS,† *Boston University.*—The pyramids formed by the planes bisecting the H−C−H bond angles were taken as elements of symmetry. Each pyramid encloses a carbon-hydrogen bond and the four close pack to form the methane molecule. To simplify the problem, the pyramid was replaced by a cone of equal volume. The Fermi-Thomas equation was solved for the potential within this cone subject to the appropriate boundary conditions, on the IBM 701 Electronic Data Processing Machines, using the extrapolated Liebmann method. Boundaries were chosen about each nucleus on which the superposition solution was used. The equation was solved for carbon alone and then for carbon-hydrogen within the cone. The dipole moment was taken as the difference[1] between the two and found to be 2.8 D C$^+$H$^-$. The large magnitude is attributed to the poor description of hydrogen by the statistical theory.

* Supported by the Geophysics Research Directorate, Air Force Cambridge Research Center.
† Present address: Bell Telephone Laboratories.
[1] C. A. Coulson, Conference on Quantum Mechanical Methods in Valence Theory, Long Island, New York, September, 1951, p. 19.

W3. The Shape of the Coexistence Curve of Two-Phase Systems Near the Critical Point.* O. K. RICE, *University of North Carolina.*—The data of Atack and Rice[1] on the coexistence curve of the cyclohexane-aniline system and on the densities of the coexisting phases have been correlated, and the conclusion confirmed that the coexistence curve has a flat top (i.e., a *range* of critical compositions). The data on the liquid-vapor equilibrium in two one-component systems, xenon[2] and carbon dioxide,[3] have also been examined. Although the authors of these papers believe that the coexistence curves are rounded on top, it is shown that the data are not conclusive on this point. In the case of carbon dioxide, in particular, the evidence may indicate a flat horizontal portion at the top of the coexistence curve. Certain thermodynamic relations between the shape of the coexistence curve and the shape of the critical isotherm have been worked out and applied to the available data.

* Supported by U. S. Office of Naval Research.
[1] D. Attack and O. K. Rice, J. Chem. Phys. **22**, 382 (1954).
[2] H. W. Habgood and W. G. Schneider, Can. J. Chem. **32**, 98 (1954).
[3] H. L. Lorentzen, Acta Chem. Scand. **7**, 1335 (1953).

W4. Kinetics of Phase Transitions for Systems Undergoing Association: Monomer-Dimer Equilibrium. HOWARD SALTSBURG, *Air Force Cambridge Research Center,* AND HOWARD REISS, *Bell Telephone Laboratories.*—The kinetics of nucleation of a system in which the metastable phase contains an equilibrium mixture of monomer and dimer has been formulated in terms of the vector model of Reiss.[1] The results will be contrasted with the result of the recent formulation of Frisch and Willis[2] and, in particular, the distinction between the perturbing effects of collisions between embryos of size two and nucleation in a system in which dimers are present will be made. Numerical results will be presented for ethanol vapor nucleation assuming various ratios of

monomer to dimer in the vapor phase. In contrast to the result predicted by Frisch and Willis, the nucleation rate falls off quite sharply with increasing amounts of dimer. The failure of the simple Becker-Doring theory to predict the observed critical supersaturation for methanol vapor will be considered in the light of this analysis.

[1] H. Reiss, J. Chem. Phys. **18**, 840 (1950).
[2] H. Frisch and C. Willis, J. Chem. Phys. **22**, 243 (1954).

W5. The Excitation of Molecular Vibrations in Halogen-Substituted Methanes. THOMAS ROSSING AND SAM LEGVOLD, *Iowa State College.**—The relaxation times for the excitation of molecular vibrations in CH_2ClF, $CHCl_2F$, $CHClF_2$, CBr_2F_2, $CBrClF_2$, CCl_3F, CCl_2F_2, $CClF_3$, CH_2F_2, CH_3Br, and CH_3Cl have been measured with an acoustic interferometer. All the gases studied were found to have a single relaxation time, indicating that intermodal coupling in these gases is strong. The average probabilities for the excitation of molecular vibrations have been calculated from the relaxation data and examined on the basis of existing theory. Preliminary calculations show that an energy barrier type of theory recently suggested[1] describes the probability better than the theory of Bethe and Teller.[2] The height of the barrier is found to depend upon the energy of the lowest mode and upon the number of hydrogen atoms replaced.

* Work supported by the National Advisory Committee for Aeronautics.
[1] Fogg, Hanks, and Lambert, Proc. Roy. Soc. (London) **A210**, 490 (1953)
[2] Bethe and Teller, Report X-117, Aberdeen Proving Grounds.

W6. Evaporation of Small Drops at Low Pressures. LOUIS MONCHICK, *Boston University*, AND HOWARD REISS, *Bell Telephone Laboratories.*—The rates of evaporation of small drops of diamyl sebacate (average radius, approximately one micron) were measured in a Millikan oil-drop chamber and observed to obey a law of the form $dR/dt=a/(1+bRp)$ which has been predicted by the theories of Fuchs and Frisch and Collins. Using a nonequilibrium distribution function of velocities, the relation has been rederived in a more rigorous fashion (over a limited range of conditions). Certain corrections in the constants a and b are introduced, and the validity of the Fuchs theory in this range of conditions is demonstrated. Using the formulation of Frisch and Collins, the law may be derived in the same form, subject to certain conditions.

Post-Deadline Papers, if Any

WEDNESDAY AFTERNOON AT 1:30

Murphy 105

(G. E. MOORE presiding)

Electron Emission and Ejection Phenomena, II

Invited Papers

X1. Experiments Bearing on the Mobile-Donor Hypothesis in Oxide Cathodes. L. S. NERGAARD, *Radio Corporation of America.* (25 min.)

X2. Elementary Processes in Semiconductor Emitters. J. A. KRUMHANSL, JR., *Cornell University.* (25 min.)

Contributed Papers

X3. Electronic Structure of Magnesium Oxide.* J. R. STEVENSON,† *University of Missouri.*—Measurements are reported on the thermionic emission, photoelectric emission, and optical absorption of MgO in different physical forms. Samples include single crystals, powders, and thin films. For six powdered samples studied in the temperature range 1300°K to 900°K the true work function ϕ was 3.3 ± 0.2 ev and $d\phi/dT$ was about 10^{-4} ev/°K. For a single crystal the value of ϕ of 3.5 ev was obtained in the same temperature range. $d\phi/dT$ was also about 10^{-4} ev/°K. The thresholds for photoelectric emission, as determined by linear extrapolation to zero current, were approximately 3.5 ev for powdered samples and single crystals. However, the quantum efficiencies of the powdered samples at 4.9 ev were a factor of 10^6 larger than for the single crystal. Photoelectric emission from metals into single crystals of MgO indicate an electron affinity for MgO of 1.8 ± 0.5 ev. Two new optical absorption bands have been detected at 1.2 and 1.8 ev. These bands are enhanced by oxygen doping and x-ray irradiation.

* Supported in part by the U. S. Office of Naval Research.
† Sylvania Fellow (1951–1953).

X4. Measurement and Theoretical Study of the Conductivity and Hall Effect in the Oxide Cathode. R. FORMAN, *National Bureau of Standards, University of Maryland.*—Conductivity, Hall effect, and magnetoresistive measurements have been made on oxide cathodes having varying degrees of porosity. Anomalous effects at high temperatures, previously reported,[1,2] have been confirmed. These are (1) large Hall coefficients, (2) large values for mobility, and (3) large magnetoresistive effects. The temperature at which these measurements were made has been extended down to 500°K by the use of an electrometer instead of the usual potentiometric techniques. In the temperature range below 700°K the mobility was found to decrease rapidly with decreasing temperature. The variation of resistance with magnetic field was found to be dependent on the degree of porosity of the cathodes. These experimental results and others, which will be discussed, are consistent with the model originally suggested by Loosjes and Vink[3] to explain the electrical properties of the oxide cathode. A theory has been developed, based on the high-temperature pore conductivity model, which is in qualitative and quantitative agreement with the data.

[1] D. A. Wright, Brit. J. Appl. Phys. **1**, 150 (1950).
[2] Ishikawa, Sats, Okumura, and Sasaki, Phys. Rev. **84**, 371 (1951).
[3] R. Loosjes, and H. J. Vink, Philips Research Repts. **4**, 449 (1949).

X5. Reaction between BaO and C and BaO and Si. MICHAEL HOCH, ANTHONY J. LAMANTIA, AND HERRICK L. JOHNSTON, *The Ohio State University.*—The reactions $BaO+C\rightarrow Ba$

$+CO$(1) and $4BaO+Si \rightarrow BaSiO_4+2Ba$(2) were studied by the Knudsen effusion method between 1290°–1390°K and 1280°–1600°K, respectively. In reaction (1) the measured partial pressure of CO agrees well with calculated values, whereas the Ba pressure is much lower. In reaction (2), the partial pressure of Ba corresponded to the calculated value. These measurements indicate a strong adsorption of Ba on BaO, which, however, is not enough to explain the long life of the oxide cathode.

X6. Measurement of Excess Ba in Emitting Oxide-Coated Cathodes. L. A. WOOTEN,* GEORGE E. MOORE, AND W. G. GULDNER.—More than 300 cathodes of various structures were tested thermionically throughout lifetimes up to 50 000 hr and submitted to a destructive chemical analysis which exposed the cathode to water vapor and measured the H_2 liberated by reoxidation of excess Ba. Measurable sensitivity was 0.02 microgram. We discuss typical tests illustrating potentialities and limitations of the analytical method. Relatively large quantities of readily available Ba (as on glass surfaces) react completely within 15 min at ambient. Because nearly all Ba produced leaves the oxide coating in practical cathodes, measurements significant for correlation with thermionic emission require isolation of the cathode. Both nickel itself and its impurities can, under suitable circumstances, react with water to produce H_2, but the rates of these side reactions become insignificant through interfaces formed in the processing of practical cathodes. For an isolated cathode, H_2 forms in amounts approximately linear in the logarithm of exposure time. To avoid side reactions, the H_2 evolved upon 16 hours' exposure to water vapor is taken to measure Ba content; relative Ba content of different cathodes is usually not altered significantly by using any exposure time from 1 min to 65 hr.

* Deceased.

X7. Excess Ba Content of Emitting Oxide-Coated Cathodes. GEORGE E. MOORE, L. A. WOOTEN,* AND JAMES MORRISON.—Measurements were made of excess Ba content and emission for 125 coated equipotential cathodes, and 15 coated filaments, each isolated from its experimental tube. Similar measurements of equivalent Ba were made for 19 uncoated cathode sleeves. Support metals were grade A nickel, relatively pure Ni, and purified platinum. Coating composition was usually 35 mole percent BaO, 65 mole percent SrO, but pure BaO and pure SrO were also examined. Results cover 5 orders of magnitude in both Ba content and emission. Throughout this range, there was no indication of increased emission with increase in Ba content. Deposited Ba in excess of 0.05 layer decreased emission and re-evaporated above 600°K within 5 min; production of Ba by exposure to methane usually decreased emission but such Ba was stable even above 1100°K. Median Ba content for demounted filaments prepared commercially was 0.90×10^{17} atoms per cc, equivalent to only 0.005 monolayer on the true oxide surface but sufficient for emission according to the semiconductor model for oxide cathodes. However, absence of correlation between emission and Ba content indicates that other factors are decisive. For example, emission observed from coated platinum was significantly less than from coated nickel, regardless of Ba content.

* Deceased.

X8. Applications of Radioactive Tracer Techniques to the Study of Thermionic Emission of Oxide-Coated Cathodes.* R. W. PETERSON, D. E. ANDERSON, AND W. G. SHEPHERD, *University of Minnesota.*—Studies of the evolution of Sr and Ba from oxide-coated cathodes using radioactive isotopes have indicated that for the normal range of operating temperatures the rate of Ba evolution differs only slightly from that to be expected from the evaporation of BaO. On the other hand, the evolution of Sr is orders of magnitude larger than would be expected from the simple evaporation of SrO, suggesting that the Sr is evolved principally by the reduction of SrO. This suggests that the evolution of Sr should serve as a measure of the reduction rate of the oxide coating. Studies will be reported which have been concerned with determining whether a correlation exists between the thermionic emission and the rate of reduction of the oxide coating.

* Supported by the U. S. Navy.

X9. Solute Diffusion in Nickel.* R. A. SWALIN AND A. E. MARTIN, *University of Minnesota.*—Diffusion studies of manganese, aluminum, and titanium in nickel have been made as part of a general program of investigation of solute diffusion in nickel. A diffusion couple method embodying low concentration changes was used and diffusion coefficients were calculated by the Grube method. Special spectrophotometric methods of analysis were adapted for each element. Diffusion coefficient measurements were made in the temperature range of 1100 to 1300°C with the following results:

Solute	D_0(cm²/sec)	ΔH(kcal/g-atom)
Mn	7.50	67.1
Al	1.87	64.0
Ti	0.86	61.4

The values of the activation enthalpies approximate that for self-diffusion of nickel in agreement with Nowick's hypothesis.[1]

* Supported by U. S. Navy.
[1] A. S. Nowick, J. Appl. Phys. **22**, 1182 (1951).

X10. Diffusion of Tungsten in Nickel. H. W. ALLISON AND GEORGE E. MOORE, *Bell Telephone Laboratories, Inc.*—Diffusion of radioactive tungsten in nickel has been measured over a temperature range 1100°C to 1400°C by using a sectioning technique. The couples used were of three types, (1) radioactive tungsten powder in contact with nickel, (2) tungsten deposited by evaporation onto nickel, (3) 4.9 percent W−Ni alloy in contact with nickel. Values of D, computed assuming D independent of concentration, agree within experimental error for all three types of couples. These D values fit an equation $D=Ae^{-Q/RT}$, and are representative of combined volume and grain boundary diffusion through nickel with grain size ranging from 0.2 mm to 7 mm. Radioautographs indicate that grain boundary diffusion may be appreciable in polycrystalline nickel. Rates of reaction of SrO coating with tungsten diffusion to the surface of a 4.9 percent W−Ni alloy were determined for a temperature range 1200°–1540°K by use of the hydrogen evolution technique. The measured rates indicate that the reaction of the initial 10 percent of the coating is not limited by diffusion of the tungsten through the nickel.

X11. An Oxide Impregnated Nickel Matrix Cathode. W. BALAS, J. DEMPSEY, AND E. F. REXER, *Honeywell Research Center.*—A new cathode is described consisting of an oxide-impregnated nickel matrix. A sintered nickel matrix of controllable porosity is prepared and impregnated with solutions, which precipitates a mixed carbonate within the matrix. The resulting cathode is a dispenser type with a minimum of surface coating. The cathodes can be activated by schedules which approximate those of a normal oxide-coated. Pulse-emission tests of these cathodes show properties intermediate between the oxide-coated cathode and the L cathode, and of the same order as the molded cathode described by McNair, Lynch, and Hannay.

Author Index to Papers Presented at the Minneapolis Meeting